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DEVELOPMENT OF AN EXPERIMENTAL WASTE FRAMEWORK BASED ON BIM/LEAN CONCEPT IN CONSTRUCTION DESIGN

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ABSTRACT

The construction industry faces many problems and challenges especially with the construction of housing which are due to the high level of non-value-adding activities (waste) that reduce the overall construction performance and productivity. In recent years, there have been investigations and research on improving the performance of construction. Lean construction is widely known as an effective process which aims to maximise customer value and the efficiency of the project by eliminating non-value-adding activities or waste. Moreover, the Building Information modelling (BIM) concept has been recognised as a collaborative process which aims to improve the overall project performance through its tools' capabilities. This paper intends to study the potential effects of integrating these two concepts in order to reduce construction waste.

This paper presents a framework, named an Experimental Waste Framework based on the findings of this paper to explore how an integrated BIM and Lean concept can contribute to the practicable reduction of construction waste in the design process of construction.

KEYWORDS

Lean construction, Building Information Modelling (BIM), Waste.

INTRODUCTION

The construction process can be found as an inefficient process in which a very high level of waste (non-value added) activities exist. Horman & Kenley (2005) conducted a meta-analysis of time that is wasted in construction activities which revealed that over the past 30 years, an average of 49.6% of construction time was wasted in activities that add no value. Non-value-adding activities will have negative impacts on the construction industry in terms of inefficiency and low productivity. Moreover, technological adaptation is another major issue as the construction industry is lagging far behind other industries when

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it comes to adopt new technology (Flanagan, Ingram & Marsh 1998; Hewage et al. 2008; Government Construction Strategy 2011). Lack of modern technological implementation will result in dissatisfaction of workers which will accordingly contribute to inefficiency of projects in terms of communication and information transfer (Hewage et al. 2008; Bowden et al. 2006).

Despite the fact that the construction industry faces major problems, the industry is still likely to overcome some of these major key challenges by implementing effective approaches and processes such as Lean Construction and Building Information Modelling (BIM). In order to achieve effective change as well as improving efficiency of the construction process Egan (1998) recommended adoption of Lean principles. However, in construction projects there are some difficulties to implement Lean because of the complication of construction tasks and factors in its different stages especially in the design stage. It is widely believed that using a 3D modelling software and process (BIM), which will help all project participants to visualise the whole construction process early in the design phase, will enable Lean principles to be used in construction projects (Eastman et al. 2011, 297-300). Also, implementation of BIM can have significant benefits to the construction industry in terms of increasing productivity and quality and reducing cost as well as project delivery time which will result in better project performance improvement (Eastman et al. 2011, 297-300; Azhar 2011).

As stated by Sacks et al. (2010) “there is a lack of systematic exploration between BIM and Lean construction” to discuss the benefits of these two collectively. Also, the existing literature on the integration of BIM and Lean construction are more focused on the ‘theoretical framework’ which explores the “degree of validity of the interactions” (Sacks et al. 2010) and not their practical applicability to eliminate waste. Therefore, there is a need for research to bridge this gap in knowledge by using existing evidence on both BIM and Lean construction principles and explore some practicable solutions to reduce waste in the design process through an integrated Lean/BIM concept to rethink the internal construction processes.

INTERACTION OF LEAN AND BUILDING INFORMATION MODELLING (BIM)

SYNERGY BETWEEN LEAN AND BIM

Lean principles can better contribute to eliminate waste if they are adopted with another concept which facilitates waste reduction. BIM can be recognised as the beneficial concept which will help reduce construction waste by the different features that it provides (Sacks et al. 2010). Dave, Boddy & Koskela (2013) stated that “Lean construction and BIM have significant synergies, and can bring benefits if implemented together”. Likewise, according to Eastman et al. (2011, 298) “There is a strong synergy between lean construction and BIM” as some of the principles of lean construction can be fulfilled by using BIM and it will also enable achievement of other principles (Eastman et al. 2011, 298; Sacks et al. 2010). Also, BIM “improves workflow in the construction process” which helps in the reduction of construction waste (Eastman et al. 2011, 298).

The integration of Lean construction principles with BIM can benefit the construction industry by the support and good understanding of the theory of production in construction (Sacks et al. 2010).

BIM is about people, processes and technology (Arayici et al. 2011). However, there is a lack of theoretical evidence on the BIM concept which could support and ensure its implementation. On the other hand, the foundation of Lean construction is based on the theory of production (Koskela 2000) and it is people and process focused.

Therefore, BIM with its technology capability and Lean with its theoretical foundation can complement each other for a better project efficiency. This integration of Lean and BIM is shown in Figure 11.

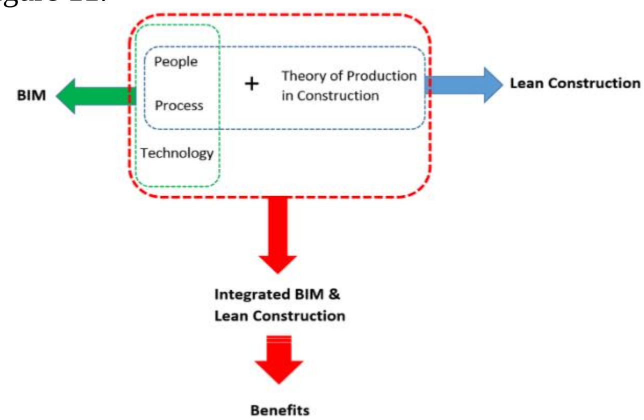

Figure 11- Integration of BIM and Lean Construction

IMPACT OF LEAN/BIM CONCEPT ON WASTE REDUCTION IN THE DESIGN PROCESS

Even though all stages of construction contribute to produce waste (Osmani, Glass & Price 2008), the most significant cause of waste is related to design changes (Faniran & Caban 1998) which occurs in the design process. Therefore, it is important to understand the benefits of Lean/BIM integration in the design stage in terms of reducing waste.

Some of the benefits of using an integrated BIM and Lean approach in the design stage of construction were summarised by Dave et al. (2013): reducing the design development life cycle, reducing rework, increasing the number of iterations for value improvement, improving predictability of investment and lifecycle costs (4D scheduling), and enhancing the ability to engage with stakeholders. One of the main beneficial features of BIM is the ability to provide 4D models and simulation, which includes not only the 3D model but also time and cost scheduling, throughout the design process (Eastman et al. 2011). Therefore, if there is any conflict, error or confusion, these issues can be resolved in the design process which will help to eliminate the waste of processing, correction and waiting (Sacks et al. 2010).

Moreover, Formoso et al. (1998) listed three principles for waste elimination in the design process:

Reduce uncertainty, which can be found as one of the main causes of rework. This can be done by increasing the effort in terms of clearly defining the project restrictions and the requirements of internal and external clients;

Reduce waiting time by decomposing adequately the design tasks so that they can be properly planned, and also allow the transfer of information to be made in smaller batches;

Reduce the effort needed for information transfer through team work, and by rearranging the design tasks.

All these three principles can be achieved through the Lean/BIM concept. As all the information is available in a BIM model which can be collaboratively shared between all projects teams, the effort for data transformation will be reduced and this in result will contribute to reduce waste of waiting, unnecessary movement, defects and excess inventory.

METHODOLOGY

The research strategy that is chosen for this paper is Design Science Research (DSR) approach. The research question is certainly important in order to find an appropriate research strategy (Yin 1994, 2013). In this paper the main question is "how an integrated BIM and Lean approach can contribute to waste reduction?". This research question is related to the field of production management and Information Science; it is also a practice oriented question in nature. DSR is not only used in the field of information science research, but also it is increasingly applied in the realm of construction management (Rocha et al. 2012). In this research method, the key task is to construct an artefact that will be used to develop applicable solutions which address the real-world problems (Hevner et al., 2004; Hevner & Chatterjee 2010). Therefore, DSR can be found as a relevant research strategy for development of a 3D model which aims to find solutions to solve the construction's problems that are recognized as 'waste' in this context.

The research techniques, which have been used in this paper are adopted from '*the general methodology of design science research*' developed by Vaishnavi & Kuechler (2008). The implementation of DSR comprises of five steps in relation to the objectives of this research.

The first two steps of the research process include collecting secondary data through literature reviews on the identification of existing waste in construction and identification of waste through the integration of BIM/Lean. The step three of the process plan includes conducting semi-structured interviews, questionnaires and also developing a 3D model in which the proposed methods of waste reduction, identified in the literature review, interviews, and questionnaires will be applied. Interviews are chosen as another research technique at step three because theories (or suggestions) can be tested through interviews as well as identifying variables and their relations (Cohen & Manion, 1997 cited in Gray, 2004) to collect qualitative data. Six interviews have been conducted in this research. Participants were divided into three groups of: Construction managers, Lean and BIM experts, and Construction Academics. The data that has been gathered from step three was analyzed and evaluated from a BIM/Lean perspective by utilizing the created 3D model. Finally, at step five all the results and data from the previous steps are collected to propose a practical framework which is validated through a set of questionnaires.

FINDINGS

BIM MODEL

The findings of this paper indicate that there are four main BIM features that have the most positive interactions with lean construction and particularly to the waste reduction approach. These following features of BIM are also in line with the BIM features that were highlighted by Sacks et al. (2010): visualisation, Clash detection, 4D scheduling, and construction sequence planning and collaboration and communication.

The four potential benefits of BIM which were also recognised in the interviews and questionnaires, were analysed through a BIM model as part of data collection to demonstrate their potential benefits in terms of reducing four particular types of waste in an experimental practice.

The results indicated that all of the mentioned BIM features will have positive influences on reducing construction waste. For example, visualisation as a key feature of BIM enables the project owner to obtain a better understanding of what the final building will look like early in the design process. Therefore, if the client decides to make any changes to the building design, these changes can be applied in the initial stage of the design process which will have a significant impact in reducing all four types of waste. Visualisation also helps to realise and identify any missing information or elements as well as identifying any design error in the designed building as shown in Figure 12. This will allow the project participants to take necessary actions in order to resolve any identified issues early in the design process which as a result will help to reduce major types of waste (such as defects, waiting, and unnecessary movement).

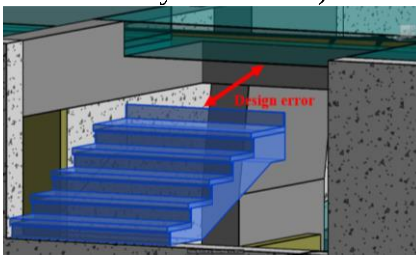

Figure 12 - Design error detection

Also, clash detection as another effective BIM feature contributes to significant waste reduction. Any conflicts can be identified and detected within the clash detection early in the design stage which will help to reduce the amount of time and money that would be spent on discovering and resolving these issues late on construction site.

4D scheduling and construction sequence planning bring design and construction together. Planning the whole construction and design process activities with their approximated duration time will have many benefits to the project in terms of reducing waste. The 4D model provides a construction sequence that will simulate the whole process of construction of the BIM model which facilitates the project team to visualise any specific and critical part of the BIM model at any certain time and date as shown in Figure 13. This function helps to reduce nearly all four types of waste; waiting, unnecessary movement, defects, and excess inventory. Possible failure in the construction sequence can be visually identified which helps to reduce uncertainty before or even during the construction process that will contribute to produce waste later on the project process.

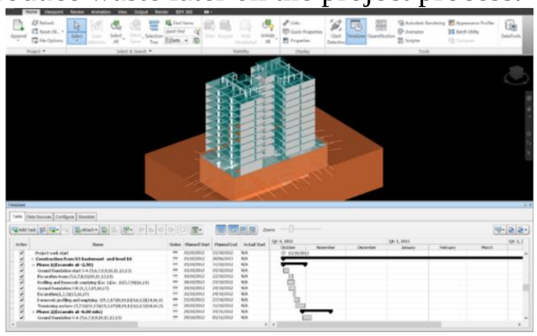

Figure 13 - 4D scheduling and construction sequence planning

Moreover, BIM provides a platform for a better communication through integrated teams in which all project participants including contractors, architects, engineers, and project managers will work collaboratively together. This enables all project participants to visualise and adjust any changes in activities collaboratively together early in the design process which has a significant impact in reducing major types of waste such as waiting, defects, and unnecessary movement.

WASTE IDENTIFICATION AND WASTE REDUCTION APPROACH FROM BIM/LEAN PERSPECTIVE

It was found from all gathered data that even though identifying waste through an integrated BIM/Lean concept is possible, it is also challenging. It was suggested by the interviewees that in order to identify waste in the design process, the root cause of waste needs to be recognised first. It may be possible to recognize the root cause of waste and identify construction waste through both the BIM and Lean concept separately but when these two concepts are integrated, waste reduction approach can be more effective and practical to be achieved particularly in the design process.

There have been different opinions on whether all types of waste can be identified through integrated BIM/Lean concept in the design process. The findings indicate that the four main types of construction waste, which have been considered in this paper, were more likely to be identified through integrated BIM/Lean concept in the design process; waiting, defects, unnecessary movement and excess inventory.

From the findings of all the collected data Table 9 demonstrates the main identified root causes of the four predetermined construction wastes and brief explanations of how they would contribute to producing waste.

The findings of this paper revealed that the waste reduction approach brings many benefits to the design process from Lean and BIM perspective. These benefits are as follows:

- *Improve the workflow*: using the waste reduction approach through an integrated BIM/Lean concept increases the chance of being more reliable and the increase of reliability will accordingly increase the flow of work.
- *Improve the quality of design*: the complexity and uncertainty of tasks will be reduced through the waste reduction approach which will improve the quality of design.

Reduce work load: as all the tasks are clear and the rework is prevented through the waste reduction approach, the overall workload will be reduced.

Value generation: reducing construction wastes which are also known as 'non-value-adding activities' will add value to the whole process.

Saving time: one of the most positive impacts of the waste reduction approach through an integrated BIM/Lean concept in the design process is saving the overall time of the project. The time that would have been wasted on rework, or waiting for one task to be done to start another task, waiting for material arrival or information exchange will be saved.

Moreover, it was argued by both interviews and questionnaires that the waste reduction approach in the design process would overcome some of the construction problems such as cost and time overrun, communication and co-operation, health and safety, and lack of information exchange. However, it was mentioned in the interviews that in order to achieve the benefits of the waste reduction approach in terms of overcoming the construction problems, the BIM model needs to be designed with a high accuracy and the design process must be well-organized as well.

Table 9 - Root cause of waste

Root cause of waste	Construction waste				Comments
	Waiting	Defects	Unnecessary movement	Excess inventory	
Change orders	✓	✓	✓	✓	Change orders would make one task to be done several times. This might have negative impacts on the construction site. Additionally, change orders in the construction would affect the productivity of labour as well as the efficiency of the work.
Decision making	✓	✓	✓	✓	Insufficient design decision making at the wrong time would result in producing major types of waste. Also poor decision making will impact on the construction quality.
Lack of information exchange	✓	✓			Lack of information exchange will make tasks or project team wait for the information to be shared. Also, if information wont be shared at the right time this might result in redoing tasks. Moreover, lack of information exchange might result in receiving wrong information by project team which will result in rework, waiting and reducing the productivity of work and workers.
Poor communication	✓	✓	✓		Poor communication is relatively influence by late involvement of construction management team to give sufficient insight during design stage. This will result in many change orders and poor design decision making which have negative impacts on the project. Additionally, late involvement of project team as a result of poor communication will have many impacts in terms of producing construction waste and reducing productivity and efficiency of work.
Lack of knowledge and the right mind-set	✓	✓			When people who are involved in the project do not have the right mind-set, they would resist to change their working way. This will result in reducing the project efficiency as they would not believe in what they are required to do. Also lack of knowledge will have negative impacts on the outcome of the project.

PROPOSED FRAMEWORK

Based on the findings of this research and the authors' interpretation a waste framework has been designed which comprises five steps as shown in Figure 14. This framework which can be considered as an early attempt to find widely accepted methods, aims to identify waste through integrated BIM/Lean concept in the design process. The framework is developed based on the basis of several aspects of the collected data throughout this paper. Each step of the framework is shown in Figure 15 and Figure 16.

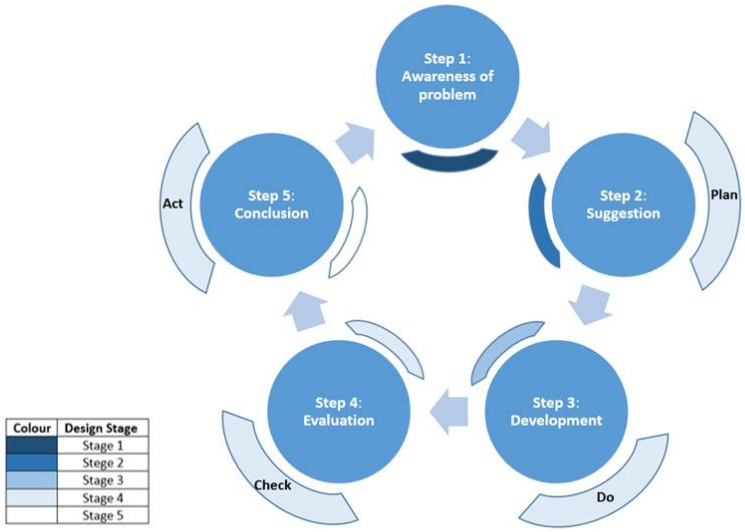

Figure 14 - Proposed Framework

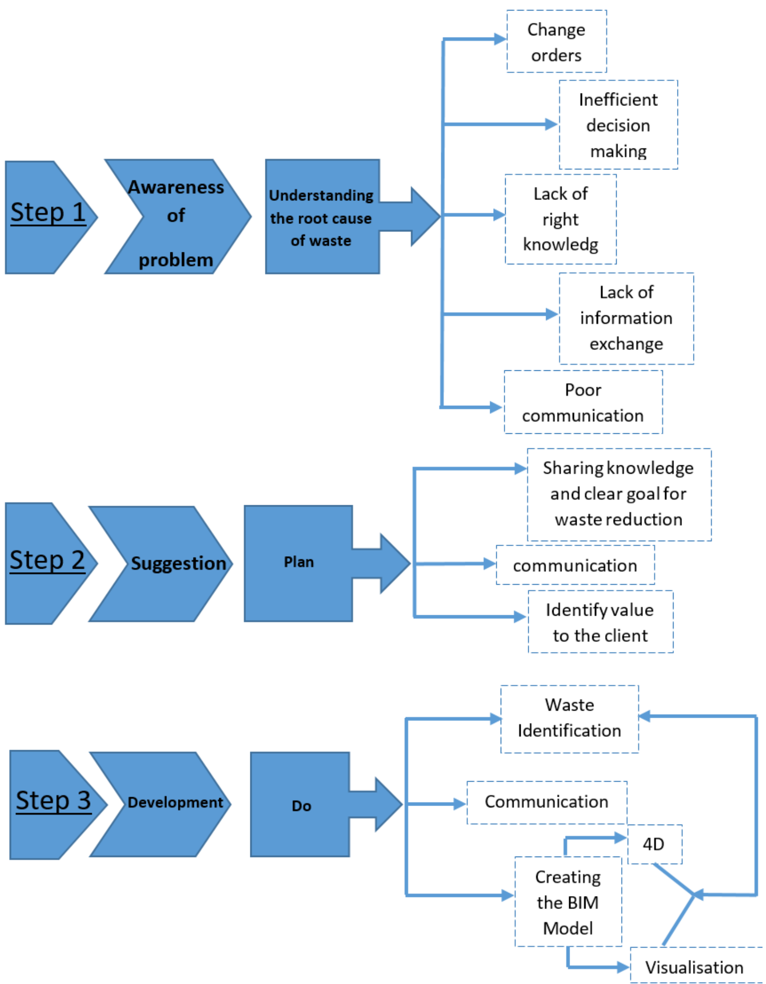

Figure 15 - Step 1,2 and 3 of the framework

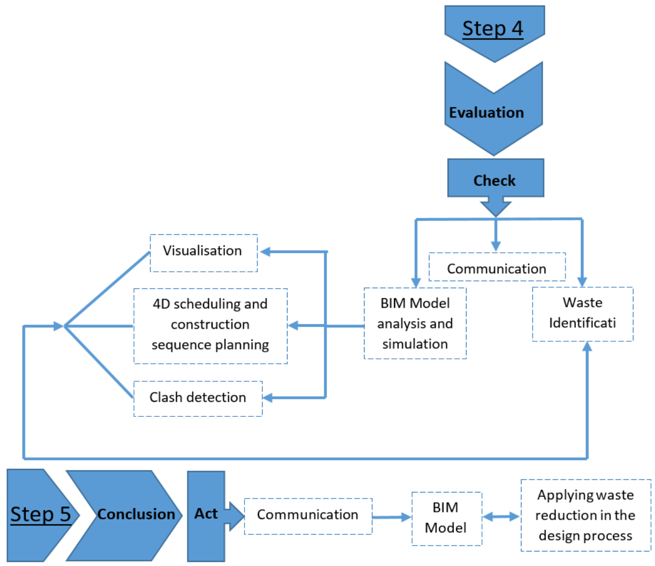

Figure 16 - Step 4 and 5 of the framework

CONCLUSIONS

BIM and Lean concept is widely known in the construction industry and it was found that the integration of these two concepts would bring many benefits to construction in terms of identifying and reducing construction waste. The findings indicated that the waste reduction approach through an integrated BIM and Lean approach would have many potential benefits to overcome some of the construction problems.

This research aimed to develop a practical waste framework, based on the findings of this research from theory (literature review) to practice (interviews, questionnaires, analysing the BIM model), through which waste can be identified and therefore reduced in the design process. The framework was validated through a set of questionnaire that was sent out to the groups of academics, Lean and BIM experts, and construction managers. The 82% of the participants who responded to the questionnaires agreed that the proposed framework will be effective to reduce the waste through an integrated BIM and Lean approach in the design process. The framework should be considered as an initial attempt to find widely accepted methods to identify and reduce waste in the design process.

Further validation of the proposed framework is useful to refine it and make it more effective. Also, testing the framework in a real project and using Delphi technique to know more opinions on it is suggested for the future research. The Experimental Waste Framework still needs to be studied further to propose a long term strategy in which more aspects of waste reduction approach can be addressed not only in the design process but also throughout the whole construction process.

REFERENCES

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., and O'reilly, K. (2011). “Technology adoption in the BIM implementation for lean architectural practice.” *Automation in Construction* 20(2), 189-195.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C., and O'Reilly, K. (2011). “BIM adoption and implementation for architectural practices.” *Structural Survey* 29(1), 7-25.

Azhar, S. (2011). “Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry.” *Leadership and Management in Engineering*.

Bowden, S., Dorr, A., Thorpe, T., and Anumba, C. (2006). “Mobile ICT support for construction process improvement.” *Automation in Construction* 15(5), 664-676.

Dave, B., Boddy, S., and Koskela, L. (2013). Challenges and Opportunities in Implementing Lean and BIM on an Infrastructure Project.

Dave, B., Koskela, L., Kiviniemi, A., Owen, R., and Tzortzopoulos, P. (2013). Implementing Lean in construction: Lean construction and BIM. London: CIRIA.

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers, and contractors (2nd ed.). Hoboken, N.J.: John Wiley & Sons.

Egan, J. (1998). Rethinking Construction. Construction Task Force Report for Department of the Environment, Transport and the Regions. DETR, London.

Flanagan, R., Ingram, I., and Marsh, L. (1998). A Bridge to the Future: Profitable Construction for Tomorrow's Industry and it [ie It's] Customers. Thomas Telford.

Gray, D.E. (2004). *Doing Research in the Real World.* London: Sage Publications.

Hevner, A., and Chatterjee, S. (2010). *Design research in information systems: theory and practice*. USA: Springer Science & Business Media.

Hevner, A., March, S., Park, J., and Ram, S. (2004). Design Science in Information Systems Research. *MIS Quarterly 28*(1), 75-105.

Hewage, K. N., Ruwanpura, J. Y., and Jergeas, G. F. (2008). IT usage in Alberta's building construction projects: Current status and challenges. *Automation in construction* 17(8), 940-947.

Horman, M. J., and Kenley, R. (2005). Quantifying levels of wasted time in construction with meta-analysis. *Journal of Construction Engineering and Management* 131(1), 52-61. DOI: 10.1061/(ASCE)0733-9364(2005)131:1(52)

Koskela, L. J. (2000). *An exploration towards a production theory and its application to construction*, PhD thesis, Technical Research Centre of Finland. Espoo, Helsinki University: 296. <http://laurikoskela.com/papers/>

Rocha, C.G., Formoso, C.T., Tzortzopoulos Fazenda, P., Koskela, L.J., and Tezel, B.A. (2012). Design Science Research in Lean Construction: Process and Outcomes.

Sacks, R., Koskela, L., Dave, B. A., and Owen, R. (2010). Interaction of lean and building information modeling in construction. *Journal of construction engineering and management* 136(9), 968-980.

Vaishnavi, V., and Kuechler, W. (2008). *Design science research methods and patterns innovating information and communication technology*. Boca Raton: Taylor & Francis.

Yin, R. K. (1994). Case study research: Design and methods (2nd ed.). London: Sage.

Yin, R. K. (2013). Case study research: Design and methods (5th ed.). California: Sage publications.