
This is an electronic reprint of the original article.
This reprint may differ from the original in pagination and typographic detail.

Tauriainen, Matti; Marttinen, Pasi; Dave, Bhargav; Koskela, Lauri
The effects of BIM and lean construction on design management practices

Published in:
Creative Construction Conference 2016, CCC 2016, 25-28 June 2016

DOI:
[10.1016/j.proeng.2016.11.659](https://doi.org/10.1016/j.proeng.2016.11.659)

Published: 01/01/2016

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Tauriainen, M., Marttinen, P., Dave, B., & Koskela, L. (2016). The effects of BIM and lean construction on design management practices. In Creative Construction Conference 2016, CCC 2016, 25-28 June 2016: Selected papers (pp. 567-574). (Procedia Engineering; Vol. 164). Elsevier. <https://doi.org/10.1016/j.proeng.2016.11.659>

This material is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the repository collections is not permitted, except that material may be duplicated by you for your research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered, whether for sale or otherwise to anyone who is not an authorised user.



Creative Construction Conference 2016, CCC 2016, 25-28 June 2016

The effects of BIM and lean construction on design management practices

Matti Tauriainen^{a,b,*}, Pasi Marttinen^c, Bhargav Dave^a, Lauri Koskela^{a,d}

^a*Aalto University, Department of Civil Engineering, Rakentajanaukio 4A, FI-02150 ESPOO, Finland*

^b*Lujatalo Oy, Sokerilinnatie 11 B, FI-02600 ESPOO, Finland*

^c*Sweco Structures, Ilmalanportti 2, FI-00240 HELSINKI, Finland*

^d*University of Huddersfield, School of Art, Design and Architecture, Queensgate, Huddersfield HD1 3DH, UK*

Abstract

Arguably, Design Management can be improved by utilizing new tools and methods introduced by building information modeling (BIM) and lean construction. However, in the projects that use BIM, roles of personnel, design methods and the practice of communication between designers often derive from the era of document based design management and can only be partially adapted to a new way of working. In managing building design, the use of lean management tools can be seen a driver increasing value to the customer, improving operations and removing activities that do not add value.

In the research described, typical structural and building services design management problems in the context of BIM implementation were identified and improvement methods and tools were suggested. Designers and design managers were interviewed in three case projects. The interviews were analyzed dividing problems in six categories, and the seriousness of problems was decoded. Recommendations for improvements were given to design teams.

In the end, 13 major and 6 average serious level problems were identified. Important causes for the problems were: an unclear sharing of responsibilities between designers in teams, inadequate BIM instructions, an insufficient BIM experience and knowledge of the design manager and the lack of communication between design team. Besides better BIM implementation management lean tools, especially big room, knotworking, last planner and set based design, were recommended for problem solution.

© 2016 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the organizing committee of the Creative Construction Conference 2016

Keywords: building information modeling; collaboration; design management; design team; lean construction

* Corresponding author. Tel.: +358 44 5852 752.

E-mail address: matti.tauriainen@aalto.fi, matti.tauriainen@luja.fi

1. Introduction

Projects that have several parties involved are typical for construction industry. There is a big challenge in the industry of how to make employees from different companies to work towards a mutual goal. The contract types used and the mutual relationship of participants make it possible for individual project parties to practice opportunistic behavior. In construction projects, there are several design disciplines involved that have to work effectively together in order to fulfill customers' expectations and requirements, and to avoid errors and conflicts in design. These challenges together with unsystematic design management and different design practices make it prone to design errors and conflicts to occur.

Design managers have used different management practices to manage projects and no standard for collaboration between different design disciplines has been made. Additional challenge has been the introduction of BIM and the changes it has introduced. BIM can be thought as one of the biggest changes in design industry after the use of CAD and it has a potential to enhance the whole construction industry. However, the current practices of design management have prevented these improvements from fully realizing. Partially this is caused by the fact that weak project management makes it difficult to stay on schedule and there is not enough time to optimize design solutions. Final design solutions may contain errors and different designers may have conflicts between their models.

One of the reasons for these problems is that design process is conceptualized as a series of different tasks and their internal relations are not taken into account. An alternative approach, which is used in lean design management, is that design process is seen as flow and value generation. Lean management includes a wide list of tools that can be used to enhance the management process.

The researchers hypothesized that the design of a construction project can be significantly improved by implementing lean construction management practices and by intensifying the use of BIM. However, improvement requires that current problems that affect design process are first identified and resolved.

This research focused on design management practices between structural and building services design on an operational level of BIM projects. The first objective of the research was to acquire a thorough understanding about the current design management practices and major challenges and issues in design projects. The second objective was to define suitable and easy to use lean construction methods and tools for the improvement of design management practices on an operational level of projects.

2. Research methodology

The research consists of a literature review and an empirical investigation. In the literature review, previous studies and their results are examined along with the professional journals and text books of the construction industry.

Empirical data was collected from semi-structured interviewees that focused on three separate construction projects. The research followed the frame of the focused interview [1]. The interviews for cases 1 and 2 were performed in 2012-2013 and for the case 3 in 2014-2015. The basic information on cases is presented in Table 1. The questions posed were mainly the same in all three cases, including questions for BIM management and communication practices, design and modeling practices used, important schedule related issues, challenges and problems that have affected the case projects. In case 3, additional questions of lean philosophy and design management were included. All the interviews were recorded, transcribed, categorized and analyzed.

Problems identified were divided into six different categories. For each problem frequency, seriousness and potential tools that could be used to remove these problems were defined. The identified problems are presented in Table 2.

3. Literature review

Use of BIM and lean design management can lead to an increased value realization for the customer. The content of design work can be visualized and design tasks that do not create value can be identified and removed. At the same time, value adding tasks can be improved. Also the number of design cycles and design errors can be decreased which further leads to a faster, smoother and more economical construction process. [1]

BIM greatly reduces design conflicts by relying on one information source and enabling clash checking. It has enabled a better visualization of form and evaluation of function. Other improvements include easier generation of design alternatives, better maintenance of information and design model integrity including reliance on a single source of information and active clash detection. Design requirements are also easier to define and information flows are improved. As a result of reduced cycle time of drawing production, the conceptual design phase can be extended. [3]. BIM has succeeded in changing work processes and removing much of this waste. Sacks et al. [4] have studied the synergies of BIM and lean. In this research, 24 lean principles and 18 BIM functionalities were used and 56 interactions were found between them. From these interactions, 52 were positive. [3].

Lean in its simplest form means eliminating waste from every stage of a work process and at the same time producing added value to the customer by completing value adding functions as effectively and quickly as possible. [5], [6]. The use of last planner system has spread from construction management to design management. The purpose is to maximize the productivity of labor, resources and materials and in addition, improve the managing of issues related to construction project variability and work-flow smoothness. Using last planner system in design and design management can lead to improvement in project transparency through schedules, design structure matrices and percent plan complete [7].

Lean principles are used to generate value for the customer. The essential idea in target value design is to make clients value a driver of design. These can be specific design criteria, cost, schedule or constructability. Choosing this driver of design can lead to the reduction of waste and fulfilling or exceeding of client's expectations. [8]. There is evidence that projects are often completed as much as 19 percent below market costs when using target value design. The value is produced in the cooperation between project parties. [5].

Collaboration between parties could be facilitated using ideas of big room and knotworking. The basic idea of big room is that different designers work side by side in the same location. This enables more effective information sharing between them when compared with working different locations. Big room decreases the latency of decision making. Information can be asked face to face instead of using remote communication tools or waiting for proper meetings. This leads to a shortening of overall design time by decreasing the duration of single design tasks. Big room is best suited for large construction projects where designers can work only on one project at the time. However, construction projects are not typically this large in Finland. For this reason the altered form of big room, which is called knotworking has been created. The basic idea of knotworking is that designers meet at the same location in the planned or spontaneous critical points of the project when cooperation benefits the most. These knotworking points usually last for a few days after, which designers can go back to their own offices and continue to work on their respective projects. [9], [10].

4. Results and analysis

Problem analysis is based on interviews made in three construction projects (Table 1.). Each of these projects was located in Finland.

Table 1. The basic information of projects used in the research.

Project	Case 1	Case 2	Case 3
Time and number of interviews (structural/building service)	2012; 5 (3/2)	2013; 6 (4/2)	2015; 6 (3/3)
Construction type	New office and residential buildings (2); 16000 m ²	New residential buildings (4) office space and parking hall; 36000 m ²	New (58000 m ²) and renovation (30000 m ²) office buildings, parking hall
Type of project	Turnkey contract	Speculative builder	Management contract
Location	Metropolitan area	Central part of Finland	Metropolitan area
BIM instructions	Project specific	Project specific	COBIM 2012 (Finland)
BIM coordinator	Client hired BIM consult	Structural designer	Client hired BIM consult

4.1. Project management and competence related problems

Project managers were not familiar with BIM. When project manager is not familiar with BIM, it is challenging for him/her to correctly evaluate the scope of design and modeling contract and the magnitude or time requirements of modeling processes. The actual modeling skills of project manager are not mandatory even though these would be recommendable. BIM related process instructions have been made that describe project manager's required BIM competence and main responsibilities. Project manager has to be aware of these and they should be prerequisites in working as a project manager in BIM project. If project manager is not familiar with BIM the design discipline-based person in charge of modeling should assist project manager throughout the project. This person participates in meetings where modeling is involved and works closely with project manager. He/she also assists project manager at the beginning of the project when the modeling contract and modeling practices are defined.

Essential aspect in preventing conflicts between different models is that there is a BIM coordinator in the project and design discipline based persons in charge of modeling are defined. The BIM coordinator inspects combination models and creates clash reports, which are presented in modeling meetings. These meetings have to be organized as often as required. However, BIM coordinator and modeling meetings do not eliminate the importance of communication and effective design collaboration between design managers.

Issues with tight design schedules were a common problem and general opinion among interviewees was that it is occurring in most of the projects. However, the severity of it depends largely on the project type and is project specific. Project managers have to comment on the content of the schedule if they think it is impossible to be realized. For this reason, project managers have to be familiar with BIM if it is used in the project. Otherwise, it is challenging to identify schedule related problems early enough.

4.2. Communication related problems

Acquiring required input data on time is an essential prerequisite for an uninterrupted design process. If the required data is missing, the design process is disturbed. This was one of the most essential problems that affected the design process. It partially results from the fact that design disciplines do not understand each other's processes and requirements and thus cannot recognize, if input data required from them is critical for the design process to continue. The problem was also linked to the observation that it takes too long time to receive an answer to an email. Before the answer is received, the design process cannot proceed. The introduction of BIM has not removed the importance of section drawings as building services designs input data. However, it was viewed that as a result of BIM, the number of published section drawings had decreased and currently not enough of them are received.

Collaboration between designers has not worked. This resulted from the fact, that designers were not familiar with each other. Organizing a design group that works effectively together is a challenging task for the design management. Design disciplines worked in separate offices. Therefore, no face-to-face communication was practiced in daily work. Collaboration between parties is needed, especially in coordinating change management situations. Interviews indicated that the architect model is not always updated according to a structural model. This leads to problems because building services design uses the architect model as an input data and geometry of structures is critical for their design. A BIM coordinator and design managers together with a design discipline based person in charge of modeling have to take care of this issue.

4.3. Instruction related problems

In the projects studied, proper modeling instructions were not used. These instructions should be created by the client or the owner of the project in cooperation with design disciplines at the beginning of the project before the modeling process has been initiated and they have to be presented in the project initiating meeting. First, instructions should define how modeling should be done. This includes the software versions, file formats, how often the model is shared, location of origin and other issues related to the actual creation of the model. Second, instructions should define what is to be included in the models. In the projects, only the necessary modeling objects were highlighted in the instructions. Third, special process related instructions should be published and followed carefully. These instructions include, e.g., void provision instructions and a list of critical structures.

Table 2. Identified problems in case projects.

Identified problems	Type of problem					Cases	Seriousness	Lean tools suggested as solution					
	Technology	Communication	Instruction	Project management	Competence			General	Big Room	Knotworking	Target Value Design	Last Planner	Some other
Acquiring required input data on time from other design disciplines was problematic.		x					1, 2, 3	Major	x	x	x	x	x
Collaboration between designers did not work. Problems have rather been solved alone than in cooperation.		x					2	Major	x	x	x	x	
Changes in input data caused redesign in building services design.		x				x	1, 2, 3	Major	x	x			
Modeling instructions were not used in the project.			x				1, 2	Major					x
Proper instructions for void provision phase were not sent or they were not sent on time.			x				1, 2, 3	Major	x	x			
Void provision instructions were not properly examined in the building service design.			x				1	Major					x
Project manager was not familiar with BIM.				x	x		1, 2, 3	Major	x				
Design schedule was too tight and there was little opportunity for designers to affect its creation.				x			1, 2, 3	Major	x	x	x	x	
The modeling scope defined in the contract did not correspond to the reality or designers were not aware of the modeling scope.				x			1, 2	Major	x	x		x	
The BIM coordinator was not defined in a contract.				x	x		2	Major					x
Conflicts between models from different design disciplines.				x			1, 2, 3	Major	x				
There was no practice of collecting internal project feedback.					x		1, 2, 3	Major					x
Response time between design disciplines was too long.		x					1, 2, 3	Average	x	x	x	x	
An architect model changed and caused redesign.		x					2, 3	Average	x	x	x		x
A sufficient number of section drawings were not delivered to the building service designer.		x					2	Average	x	x			
The client was not familiar with BIM.					x		1, 2	Average					x
Client requirements changed and caused redesign.					x		2	Average	x	x	x		x
Model revision documentation has not been done and changes had to be found visually.	x				x		2	Average					x

It is most likely that the use of comprehensive instructions would improve the cooperation and design process. Importance of active project management and design supervision is essential part of successful void provision and this also includes the utilization of instructions. A design manager together with a designer responsible for the void provision phase have to make sure that each designer is aware of the importance of using prearranged work methods, which include the use of instructions. Also structural designers have to publish instructions well in advance so that building services designers can take advantage of them.

4.4. General unsorted and technology related problems

Collecting of project feedback should be an essential part of project closing procedures. For each design disciplines there were guidelines stipulating that this must be done. However, it was not practiced in any of the cases analyzed. The reason for this might be that project managers are not aware of the real importance of feedback as a learning tool or they have an attitude problem towards collecting feedback. The feedback is an essential source of knowledge when working methods are changing. Each designer learns and discovers new working methods and evaluates them during the project. If the feedback is not collected, then the sharing of this information is limited. As a result, these same observations are done several times in different projects and the same mistakes are made repeatedly. A large scale sharing of knowledge would require a systematic feedback system.

A project manager's responsibilities should include the reporting of the internal project feedback. This would consist of the evaluating of the work methods used in the project. Modeling tools and design practices that work and those, which need more development would be reported. Also the methods of collaboration between other design disciplines would be included in this report.

4.5. Recommendation for the use of lean tools

It is proved that the utilization of last planner system increases project efficiency and transparency, and enhances the project collaboration and commitment. It also improves team work. [7], [11] The preparation of the phase pull schedule in the last planner system helps participants to understand each other's processes and requirements. Another potential tool is target value design. It has an overall positive effect on the collaboration of participants. More attention is given to the earlier stages of a project and meetings are held at least on a weekly basis. In target value design, cooperation between participants is much greater than in a typical construction project. However, the utilization of a target value design has to be a client oriented process because the contract and project risk management are the basis of target value design.

Big room improves information sharing and decreases communication latency because it can be practiced face to face. A brief weekly video conference between design managers would improve design cooperation. Video conferences are suggested instead of traditional meetings because time requirements are not as great due to the lack of travel. Big room and knotworking would lower the threshold to practice collaboration because designers would become familiar with each other and conversation would not require the use of phone or email. More importantly, it would enable a work method where the whole design process is done in full collaboration. Benefit of this is greater in big room but it can still be acquired using knotworking even though only certain moments of the design process would be done in full collaboration.

5. Conclusions and summary

In the analysis of the empirical data it was discovered that certain problems typically occurred together. Especially the absence of a BIM coordinator, not defining designers responsible for the modeling, not creating sufficient instructions, and the non-collaboration culture between design disciplines could be affiliated to the occurrence of several problems. Even though both structural and building service design teams were used to BIM, the full potential of modeling could not be reached. Lean tools presented in the literature review were found to be potential in the removal of problems. However, a full scale utilization of these tools would require that the lean culture has been adopted in the strategy of the company.

Big room was found to be the most widely applicable tool for major problems. It was identified as a potential solution for 12 different problems. The second most widely recognized tool was knotworking, which was identified as a solution for ten problems. Big room and knotworking are targeted to facilitate information flow and communication in projects between design teams. Target value design was identified as a solution for six problems, and three of these were rated being of major seriousness. It helps to develop design solutions in teams and get indepth views for managing decision making. Last planner system was identified as a solution for five problems and four of these were problems of major seriousness. The use of Last Planner System helps project managers to develop and keep on time schedules and control the flow of input data in projects.

Remarkably, it was discovered that the removal of several major problems does not necessarily require the use of special tools. Instead, being aware of these problems, using comprehensive instructions and having competent project manager and designers in the team can have a significant effect on the occurrence of these problems. Improving design management practices in BIM projects the guideline for recommendations and activities include:

- The design discipline-specific project managers must be experienced in BIM, if not, BIM consultation should be acquired. The differences between the 2D Cad and BIM projects have to be known.
- The main BIM coordinator responsible for modeling instructions, integrating and clash checking models must be named at the beginning of the projects.
- The design discipline-specific BIM coordinator must be named and serves as the project manager's support.
- The instructions and ways of action which are related to the BIM must be specified at the beginning of the project. Utilizing the national Common BIM Requirements and Level of Details (LODs) as far as possible is recommendable.
- The main structural engineer or modeling coordinator must publish the comprehensive modeling instructions for hole circulation before the hole provision phase.
- The hole circulation should be made strictly according to the schedule avoiding several iteration circuits.
- Keeping on a pre-scheduled design and modeling meetings for controlling activities, BIM contents and communications between design teams. Organizing knotworking sessions to solve difficult design issues.
- Discussion meeting(s) between design teams has to be organized and the project feedback has to be collected when handing-over projects.

When the results of this research are evaluated, it has to be taken into account that each of the case projects used different contract type. In addition, one case project was geographically situated in different location but the effect of geographic location was not taken into account. Finally, the number of executed interviews was small, which contain the possibility of a large margin of error. Therefore, an exact understanding about design management practices used through them is not achieved thoroughly. Better understanding could have been achieved if empirical research would have contained a larger sample of interviews. It was considered if a question list would also have been sent to a larger group of designers and project managers but this was excluded in this research.

Potential lean tools that could be used to improve design management were reviewed in this research. The use of these tools does not necessarily require a lean policy but the benefit acquired can be increased when the company has adopted it. Therefore, methods how lean policy can be achieved in the company should be researched. This research was limited to the collaboration of structural and building services design. However, the interviews proved that there is a demand for improvement to the collaboration between other participants, including an architect or a contractor. Research should be done in a case project where big room or knotworking tool is in use.

Acknowledgements

The research is the part of work package “Use of BIM during property’s life cycle from the owner’s perspective (Model Nova)” at Built Environment Process Re-engineering (PRE) program in Finland (2000-2014). The research was financed by RYM Oy, Tekes and Sweco (former Sweco Finland). In addition to the authors, the research team includes A-K. Mero (Sweco Finland), Antti Sahala (Sweco Finland), Hannele Kerosuo (University of Helsinki) and Sami Paavola (University of Helsinki). Lauri Koskela (formerly at Aalto University) and Bhargav Dave participated in the framework of the BIMforLean project, funded by Tekes and a number of companies.

References

- [1] R.K. Merton, M. Fiske, P.I. Kendall. The Focused Interview. 2nd ed. The Free Press; 1990.
- [2] Y. Arayici, P. Coates, L. Koskela, M. Kagioglou, C. Usher, K. O'reilly. Technology adoption in the BIM implementation for lean architectural practice. *Automation in Construction*. 2011; 20(2):189-195.
- [3] C. Eastman, P. Teicholz, R. Sacks, K. Liston. BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors. 2nd ed., Hoboken, New Jersey, John Wiley & Sons Inc.; 2011.
- [4] R. Sacks, L. Koskela, B. Dave, R. Owen. The Interaction of Lean and Building Information Modeling in Construction. *Journal of Construction Engineering and Management*. 2010; 136(9), 968-980.
- [5] B. Dave, L. Koskela, A. Kiviniemi, P. Tzortzopoulos, R. Owen. Implementing Lean in construction: Lean construction and BIM. CIRIA, London, UK; 2013.
- [6] R. O'Connor, B. Swain. Implementing Lean in construction: Lean tools and techniques - an introduction. CIRIA, London, UK; 2013.
- [7] M. Cremona. (2013). The application of Last Planner System in Construction Design: Enhancing Collaboration and Decision-Making. LAP Lambert Academic Publishing; 2013.
- [8] D. Zimina, G. Ballard, C. Pasquire. Target value design: using collaboration and a lean approach to reduce construction cost. *Construction Management and Economics*. 2012; 30(5), 383-398.
- [9] Kerosuo H. BIM-based collaboration across organizational and disciplinary boundaries through knotworking. 8th Nordic Conference on Construction Economics and Organization. *Procedia Economics and Finance*. 2015; 21(15), 201-208.
- [10] H. Kerosuo, T. Mäki, J. Korpela. Knotworking – a novel BIM-based collaboration practice in building design projects. Proceedings of the 20th Annual Conference of the International Group of Lean Construction. Orange County, California, USA; 2013
- [11] H. Kerosuo, T. Mäki, R. Codinhoto, L. Koskela, R. Miettinen.. In time at last – Adaption of Last Planner tools for the design phase of a building project. 20th Annual Conference of the International Group for Lean Construction - Past The Tipping Point?; 2012.