Editorial

Introduction

Lean construction and building information modelling (BIM) are central means of ongoing transformation in the construction industry. BIM consists of a set of tools, processes and technologies, facilitated by digital machine-readable information about a building, which collectively provide the basis for new construction capabilities and changes in the roles and relationships between project team members (Sacks *et al.*, 2018). Lean production is a managerial philosophy that originated in the automobile industry, with the goals of eliminating waste and improving value generation (Koskela, 2000). This philosophy has been adapted successfully in different sectors, including the construction industry. Lean construction can be defined as the effort to develop and adapt lean production concepts and principles to the context of construction projects.

Both topics have attracted the interest of the construction management academic community, and although these are originally separate approaches, there is much synergy between them. This special issue of *Engineering, Construction and Architectural Management* explores the interactions between BIM functionalities and lean production concepts and principles. Those interactions were initially pointed out in a highly cited paper by Sacks *et al.* (2010). This special issue revisits the theme and reports advances made in the last decade.

In this editorial, we briefly present the papers and their highlights. We then identify new insights that arise from the collection that extend our understanding of the synergies between lean and BIM. We conclude with recommendations for further exploration.

Presentation of the papers

Eight papers have been accepted for this special issue. They present the results of research projects carried out in nine different countries: Australia, Brazil, Canada, China, Finland, India, Israel, UK and USA. With the exception of the last paper, which discusses BIM and lean education, the papers are ordered in the same sequence as the construction project stages that they deal with would occur in a project.

In the first paper, Guo *et al.*, from China, explore the context of integrated project delivery (IPD) and the use of BIM. The main contribution of the paper is development of a fuzzy alliance model for measuring the profit distribution in IPD, which connects the degree of participation with profit distribution.

The second paper, by Baldauf *et al.*, from Brazil and UK, is concerned with value generation in the design of healthcare projects. The main outcome of the paper is a process-based approach for managing client requirements with the use of BIM.

The third one, by Shou *et al.*, from Australia, presents a systematic literature review on the use of simulation in lean construction research. The main contributions of this paper are to identify the state-of-the-art development on this topic and to propose future research directions.

The fourth paper, by Barkokebas *et al.*, from Canada, proposes a framework that provides measures for planning and implementing digitalization in offsite construction by combining BIM and lean principles. This framework is concerned with the initial design and planning

The authors thank the authors of the eight excellent papers in this special issue; their contributions are enlightening and valuable. The authors are also indebted to the editor in chief of the journal, Prof. Chimay Anumba, for his support in compiling the issue.

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phases. Moreover, this investigation provides quantitative evidence of the benefits of data integration through BIM.

The following three papers are mostly concerned with production management. In the study undertaken by Maraqa *et al.*, from Israel, the impacts of the implementation of lean construction principles and BIM functionalities on construction project flows are assessed. A metric, named construction flow index (CFI), is used to provide project managers and planners a view of the smoothness or irregularity of flows.

The aim of the study carried out by Lappalainen *et al.*, from Finland and India, is to identify the requirements of situational awareness system development in construction and to provide recommendations for developing this type of system. This investigation also pointed out gaps in knowledge, as the concept of situational awareness has not been sufficiently investigated in construction.

Perez and Costa, from Brazil, proposed the application of the principle of minimizing or eliminating non-value adding activities combined with 4D BIM simulations, with the aim to reduce transportation waste in construction sites. The main outcome of this investigation is a set of criteria for assessing the utility of 4D-BIM for removing this type of waste.

Finally, the last paper, by Nikolic *et al.*, from the UK and the USA, explores a pedagogical approach for teaching students a collaborative information delivery process in the context of BIM. The aim of this study is to understand how students approach the complex and open-ended problem of planning collaborative processes and then identify strategies for improving their process through a learning cycle.

Developments and insights regarding synergies between BIM and lean construction

Some of the papers published in this special issue have made contributions towards extending the original lean principles/BIM functionalities matrix proposed by Sacks *et al.* (2010).

Baldauf *et al.*'s paper proposed two additional BIM functionalities: (1) structuring and storing client requirements and (2) visualizing interactions between the built environment and business processes. Both these functionalities can serve the lean principle of identifying and enhancing client value. From a practical perspective, the outcomes of that study can be used to establish requirements for BIM-based software solutions for managing client requirements. This is aligned with some applications that have been developed in the industry. For instance, Fira Inc. have developed a process called "Verstas" in which they work with clients not only to define but also to improve their business processes through the process of collecting and analysing requirements for new buildings with BIM tools (Sacks *et al.*, 2017, Ch. 19).

Perez and Costa's paper have explored the synergies between lean and BIM to reduce transportation waste. That investigation provided empirical evidence of the interaction of the BIM functionality "visualization of flow activities and temporary objects" by using 4D-BIM, proposed by Bortolini *et al.* (2019), and the lean principle of elimination of non-value-adding activities.

Barkokebas *et al.*'s paper and Maraqa *et al.*'s papers break new ground in the exploration of Lean and BIM synergies in that they both provide quantitative assessments for the value that arises from synergistic use of Lean and BIM. Barkokebas *et al.*'s contribution is significant because they have explored the preconstruction phase that precedes fabrication in offsite manufacturing of construction components. Maraqa *et al.*, by contrast, examined the impact of BIM and lean interventions in the work of masonry construction crews, identifying and measuring specific aspects of waste reduction. They concluded that "Lean and BIM interventions improved the flow by reducing out of sequence work, reducing interference of

trade crews with one another and increased the degree of work continuity between tasks. Implementing lean without BIM improves the workflow, but not to the same extent as implementing lean and BIM together".

The Last Planner System (LPS) and virtual design and construction (VDC) were among the practices they explored. These are prominent examples of lean and BIM developments that have been the focus of much work in academia and have been adopted in the construction industry (Fischer *et al.*, 2017). Other examples of lean/BIM integration in the construction industry since 2010 are the development of commercial software for planning and control of construction, such as *vPLanner*, *VisiLean*, *TouchPlan* and others (Sacks *et al.*, 2018).

Recommendations for further research

Besides the contribution of each paper to the advancement of knowledge, several relevant recommendations for further research have been made in this special edition.

Lappalainen *et al.*'s paper discusses the notion of *situational awareness* in the context of construction management, which is a common goal among the growing crop of construction tech start-up companies applying monitoring technologies to track production in construction, in the spirit of what some have called "Construction 4.0" (Sawhney *et al.*, 2020). They found that in systems designed to provide situational awareness in construction, "the mere collection and presentation of data are not enough; the system must also include the second and third levels of situational awareness (having an understanding of and projecting situational awareness, respectively)". The same conclusion is apparent in the distinction drawn between raw monitoring data and meaningful construction project status information adopted in the BIM2TWIN project (www.bim2twin.eu), which aims, *inter alia*, to build systems capable of fusing or merging diverse data streams to generate useful process information. The new paradigm of "Digital Twin Construction" (DTC), embodied in that project, provides a business model and a technological framework for extensive future research to explore practical applications of the synergies of BIM functionalities and lean construction principles.

Other areas of research identified as needed across the spectrum of papers in this special issue include

(1) Further analysis of profit distribution impacts on behaviour in IPD projects, specifically how does BIM influence participants' motivation and to what extent can it reduce the info gap between participants?

(2) Development of BIM tools to support comprehensive requirements modelling, covering different types of information (qualitative and quantitative, subjective and objective) and supporting automated and semi-automated checking.

(3) Digitalization in the context of pre-fabrication: new methods and tools for measuring and visualizing production flows and for pulling manufacturing and logistics operations from site assembly; tools for modelling and standardizing logistics operations, including the design of transportation batches; models for improving communication between different production units (e.g. pre-fabrication plants, logistics centres and construction sites); systems that are able to model the status of the system, etc.

(4) Methods to estimate the negative impact of inaccurate data used in pre-manufacturing phases in offsite construction and ways to ensure provision of accurate, reliable information using BIM.

(5) Empirical studies to explore the nuances of different combinations of lean and BIM-related practices in terms of their impacts on production flow.

In conclusion, it appears that the subject of BIM and lean synergies continues to be highly relevant for researchers and practitioners and that both will continue to earn value from this pursuit as digitalization deepens in the construction industry, and we inch forward toward DTC.

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