Lean, BIM and Augmented Reality Applied in the Design and Construction Phase: A Literature Review

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***Abstract*—Along with the development of technology, new tools are born which facilitate the workflow in the engineering and construction field. By taking advantage of these tools, like Building Information Modeling (BIM) and Augmented Reality (AR), multiple benefits are obtained such as: (1) reducing time in decision making during the design stage (2) a better understanding of the documents in the planning stage (3) monitoring of the project in real time to ensure the fulfilment of the schedule, amongst others. On the other hand, and since its origins, Lean Construction philosophy promotes the use of these tools to automatize projects according to its principles. The objective of this paper is to present the state of the art regarding the simultaneous use of BIM, AR and Lean Construction, applied to the design and construction phases. For this purpose, the documents published in the last 5 years regarding BIM and AR in the conference of the International Group for Lean Construction and main journals were reviewed. Finally, the paper concludes with the recommendation of assessing a deeper research on the integration of BIM, AR and Lean Construction.**

***Index Terms*—Lean construction, augmented reality, Building Information Modeling (BIM).**

I. Introduction

Since its origins, the Lean Construction philosophy proposes the redefinition of the main development efforts in construction [1], among them: (1) industrialization (2) safety (3) construction integrated by computer (4) and the automatization of construction. It is very important to redefine them in terms of the new conceptual base [1] and highlight the validity of this proposal. Building Information Modeling (BIM) and Augmented Reality (AR) have a direct relationship with what Koskela defined in 1992 as construction integrated by computer and automatization in construction. For example, using a virtual reality environment on workers improved the process flow and eliminated waste [2]. Also, it is possible to use AR for collaborative planning to improve predictability and reduce waste [3]. Lean Construction is constantly being compatibilized and integrated with the tools, techniques and practices of all management systems [4].

II. Building Design and Construction Using BIM

In the latest years, BIM tools have substantially improved design and construction management in projects [5], [6]. The information models integrate reasonably the initial stages of a project development [5]. On the other hand, the industry has been developing systems and software that generates models in 3D, 4D (time) and 5D (budget/cost) which allows the simulation and coordination in the design stage of what is going to be executed and monitored later, allowing a better collaboration between work teams and a better understanding [7]. However, in the construction stage, it is still a frequent practice to have the design information in 2D documents, with manual processes, using templates, excel sheets, etc. [4], [8], [9] or carrying a tablet and seeing the 3D model in a 2D screen [6]. This way, stablishing a relation between the construction project and the technical dossier is a manual task [5]. Finally, construction management and inspections are also done in 2D, making progress monitoring very laborious and error prone, which can have repercussions in the building quality and the value perceived by the users [4].

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III. Augmented Reality

The new tools that are being applied to the construction field have proven a great potential in several stages of the construction process [5], [10]. The automation of the processes that are currently being worked on 2D has been one of the targets for the past few decades. AR can be defined as an application that empowers the user perception over a real situation [5]. There are several prototypes and framework proposals that allow the integration of BIM and AR [5], [11] either through Head Mounted Devices (HMD), smartphones, tablets or computers. This way, an infinity of applications is available for the stages of design and construction in a project. Applying new techniques for visualization like AR integrated with BIM on workflow is recently being analyzed [2], [3].

IV. Workflow and Lean Construction

According to Lauri Koskela (1992), because of the traditional practices, the flow processes had not been controlled or improved in an orderly manner, generating: (1) complex, uncertain and confusing flow processes; (2) an expansion of the activities without added value; and (3) reduction of the production value. For this reason, he proposes the Lean Construction philosophy, whose main goals are: (1) reducing waste (2) generating value for the client [1]

Workflow design still represents a cornerstone in the evolution of the Lean systems [12]. In the year 2000, Glen Ballard proposes the Lean Project Delivery System (LPDS), a system that englobes the whole life cycle of a project,

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essential to understand the needs of the client through an analysis of the different alternatives [13]. In the year 2005, the Target Value Design (TVD), system that adapts the practice Target Costing from the Toyota System and the Integrated Project Delivery (IPD), the structure of collaborative contracts, are beginning to be used along with the BIM tools in the management of more complex projects. The IPD, TVD and BIM are used simultaneously [12].

V. Methodology

Given that AR is a recent technology, the search was narrowed down to the last 5 years. The documents published in this time frame were searched in the IGLC conference papers and Lean Construction Journal webpage. In these sites, the main publications for the Lean Construction network of researchers from practice and academia are found.

From the Web of Science and Scimago links, the journals with the highest Impact Factor (Journal Citation Report JCR) and/or Scimago Journal & Country Rank (SJR) were selected. These journals were chosen from the categories indicated in Table I.

TABLE I: Categories for Journal Selection

Scimago	Web of Science
Building and Construction	Construction & Building Technology
Civil and Structural Engineering	Engineering, Civil
Control and Systems Engineering	Engineering, Multidisciplinary
Information Systems	Computer Science, Interdisciplinary Applications
Computer Science Applications	
Engineering miscellaneous	

After that, three types of searches were done in these publications, according to the following keywords:

A. AR, BIM and Lean Construction

B. Lean and BIM

C. AR and BIM

Finally, Google Scholar search engine was used to verify the obtained results and gather any additional publication (journal, conference, book, guide, etc.) important for its number of cites, relevance of the author, etc.

This methodology is explained in Fig. 1.

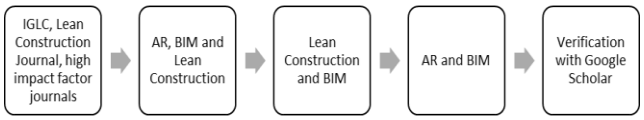

Fig. 1. Search methodology.

VI. Results

After following the explained methodology, a total 116 papers were gathered. The list of selected journals and papers by search type are shown in Table II.

TABLE II: Number of Papers in Main Journals by Search Type

Scimago and Web of Science Selected Journals	Institution	Lean, BIM and AR	Lean and BIM	BIM and AR
Automation in Construction	Elsevier	1	13	20
Advanced Engineering Informatics	Elsevier	0	0	1
ASCE Journal of Computing in Civil Engineering	ASCE	0	0	2
ASCE Journal of Construction Engineering and Management	ASCE	0	8	2
Construction Management and Economics	Taylor and Francis	0	2	1
Computer-Aided Civil and Infrastructure Engineering	Wiley Online Library	0	0	1
IGLC	IGLC	0	27	0
Lean Construction Journal	Lean Construction Institute	0	1	0
Others (Google Scholar)	Others	1	17	19
Total		2	68	46

A. AR, BIM and Lean Construction

Little to no information was found in the literature regarding the integration of AR, BIM and Lean Construction: an exact number of 2 papers. This was mainly because the development of this technology, and how it can be implemented to projects is still being researched. In both publications, the use of these new techniques for visualization is proposed for some stages of the workflow, as it is the design and construction stage, and it is being analyzed to determine its impact in the automation and shortening of the processes [2; 3].

Some Lean specialists are developing systems with BIM software in 4D, 5D, 6D, and other technologies [7] and it is likely that AR will be compatible with these new platforms. The attempt is to work in close relation with the users of the construction industry to try to integrate the technology with the workflow that the Lean Construction philosophy proposes and make them shorter, faster and friendlier.

B. Lean and BIM

The integration between BIM and Lean Construction has been studied in a deeper level since the implementation of BIM in construction projects is becoming a widespread practice. A total of 68 documents were found. A comparison has been made between traditional and BIM-based design projects in the design phase [14] indicating the different benefits that can be obtained like design sharing and communication, improving time in the design generation phase, more involvement from the client, etc. All these benefits can be increased by a well-developed visualization tool like augmented reality. Also, during the construction phase, sequence simulation of workflow through BIM has been researched to generate an automated schedule and results indicate that the simultaneous use of 4D simulation and classical Lean tools has great of potential [15].

C. AR and BIM

As for the research on AR and BIM, a total of 46 papers were selected. The AR tool is being studied for both the design and construction phase. Since the design phase is characterized by being a dynamic process with several iterations, AR can be implemented in this stage during collaborative meetings for decision making to navigate through the design options [17]. As for applying AR during the construction stage, the usefulness of the BIM of the project can be increased. The purpose of this application is to reduce the time in the schedule, minimize costs and ensure the quality of the product through an improvement in the constructive process. This way, the adopted process can be visualized and at the same time a risk analysis can be done to mitigate it beforehand [17].

It is also possible to use AR in 4D to make a comparison between what is being executed and what was programmed in real time [18]. The automatization of progress monitoring is important since early detection of a fallout in schedule represents an opportunity to decrease the impacts [18]. On the other hand, senior researchers are developing integration proposals of techniques of low cost like the use of BIM software in 4D, 5D, drone's systems and the Augmented Reality technique [13], [19].

Since most of the research conducted in the field of AR, addresses the technology involving this application, the classification of this literature is based on it. For a better understanding of the current state of the art of Augmented Reality, the documents were classified based on the phase of the project that was studied (design phase, construction phase or both), the limitations the research presented (social acceptance from the AEC professionals, registration problems, ergonomics of the devices available for display, data intake, occlusion issues, alignment between real and virtual entities, connectivity and the capability of the devices for processing information) and the future work that was proposed (wearable devices, progress monitoring in the construction phase, implementation, localization speed, including remote servers and improving visualization). Fig. 2, illustrates how most of the research has been conducted towards the construction phase of the project.

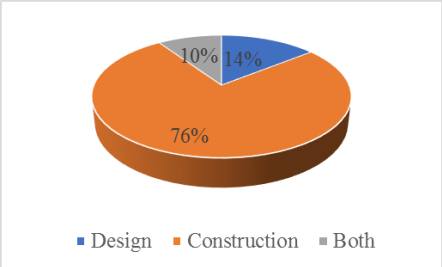

Fig. 2. AR and BIM research according to the project phase.

The AR application has been studied mainly for monitoring, inspection, training and as-built data intake. As for the design phase of the project, even though it has the greatest potential to increase quality and reduce cost in the long term [16], it has not been addressed as exhaustively.

This application still faces several challenges, one of them is to determine the position of the user and to align the virtual data with the real data correctly [5]. This depends on how precisely the position and visual orientation of the user is determined [6]. As any automated process, the importance of its implementation lies in the time, effort and cost savings it represents, as well as that the information generated allows the detection of discrepancies and the implementation of corrective actions. The main limitations found are described in Fig. 3, being hardware capabilities and occlusion issues the main ones. The occlusion problem seems to be solved with depth buffering testing, which allows the invisible part of a virtual object to be correctly occluded [20].

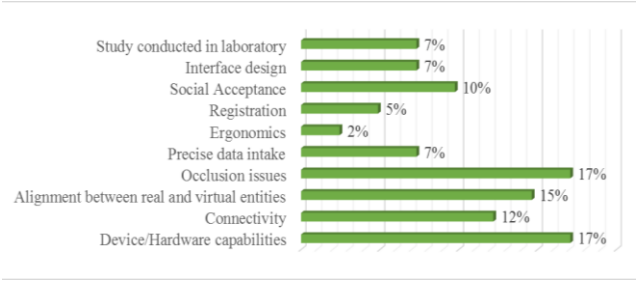

Fig. 3. Limitations/Challenges in AR-BIM.

Future research work proposed involves implementing and testing the systems in a real construction environment, automatization of the data intake for construction progress and developing devices that are safe and wearable onsite. Fig. 4 shows what future research is going to be leaning towards. It is also very important to investigate a method to help the construction industry accept and adopt AR technology by realizing the benefits it includes [21].

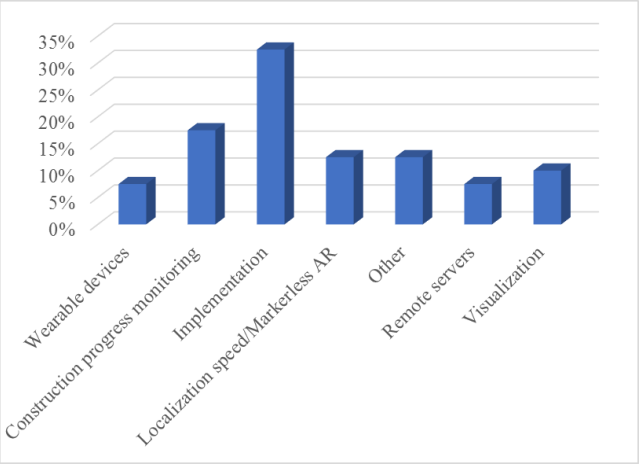

Fig. 4. Future work proposed for AR and BIM.

In the future, it is expected that the limitations of the AR technology are solved by IT professionals and software and hardware developers.

VII. Conclusion

A very limited amount of evidence was found on the integration of Lean Construction with BIM and AR in terms of the automatization of the workflow proposed by Koskela.

It could be suggested that AR is an extension or a supplement of BIM. Also, these applications have a lot of potential during the design and construction stages of a project and its integrated use must be researched on a deeper

level. The flow processes must be designed, controlled and/or improved in an orderly manner, generating activities with added value and reduction of waste. Future work must involve an integration proposal of AR, BIM and Lean Construction.

It is the authors desire that this literature review helps others in identifying the limitations and challenges Lean and BIM with AR face in the present, so that they can be addressed.

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