Selin Ortenburger, Timo Hartmann

Supporting the Last Planner System with 4D BIM

Supporting the Last Planner System with 4D BIM

Selin Ortenburger [1] and Timo Hartmann[2]

[1]M.Sc. Civil Engineering, Technical University Berlin, Construction Manager, Ed. Züblin AG, Stralauer Platz 35, 10243 Berlin, Germany; email: selinortenburger@gmail.com

[2]Professor, Civil Systems Engineering Department, Technical University Berlin; Gustav-Meyer-Allee 25, 13156 Berlin, Germany; email: timo.hartmann@tu-berlin.de

ABSTRACT

Both Building Information Modeling (BIM) and Lean Construction are able to optimize the scheduling efficiency of a project by using a BIM 4D model or the Last Planner® System (LPS) which is a scheduling tool for Lean Construction. So far both methods have mainly been implemented separately, even though both share many similar aspects. This paper reports on a retrospective study of a recent project in Berlin, Germany, during which only the LPS was applied to plan the construction work. By using the real schedules from the LPS and creating a retrospective 4D BIM model of the building by using data and plans from the project, it was possible to evaluate how 4D models could have helped planners to circumvent problems that occurred during the LPS process in retrospect. The retrospective case study shows that there is a high likelihood that planners could have been able to mitigate most of the problems that were observed during the project if they would have combined their LPS effort with a 4D BIM implementation.

INTRODUCTION

One of the major parts of a successful project is the completion of the project in time. Remaining on schedule leads to a higher chance of keeping the costs of the project low and ensuring that project clients are satisfied. For that reason, it is crucial to have an accurate and up to date construction schedule. But since construction projects are highly complex endeavors, estimating and designing an accurate schedule and maintaining it throughout the project is an extremely hard task. The fact that many construction projects fail to deliver the product on time, shows that there is still a lot of room for improvement in the efficiencies of the schedules.

To achieve the goal of a project delivery on schedule various new management methods and Information Technologies have surfaced recently. Two of those methods, which have gained popularity, are Building Information Modelling (BIM) (Eastman et al. 2011) and Lean Construction (Jørgensen & Emmit, 2009; Alarcón 1997). Both concepts have shown to improve the efficiency of construction projects in the past. Lean Construction focuses on creating a reliable and predictable workflow on a construction site through aligning the entire supply chain which is necessary for creating a project structure that maximizes value and minimizes waste. Because of this promise, Lean methods have found wide documented application in the international construction industry (see for example Bajjou & Chafi, 2018 or

Ogunbiyi, 2014). One of the major scheduling tools of Lean Construction is the Last Planner System (LPS) which "is based on a Should-Can-Will-Do system of project planning" (Bhatla & Leite, 2012). It focuses on creating detailed weekly plans in discussion with the subcontractors and other people who are responsible for delivering the work (the Last Planners). The LPS is considered to coordinate the flow of the various tasks during the entire construction process (Onyango, 2016).

BIM, on the other hand, is an intelligent 3D computer-aided design technology to create digital 3D models of physical and functional characteristics of a structure, which compared to earlier 2D or 3D CAD models, contains specific information about the objects inside the model. BIM helps to create a clear understanding of the building and all the various requirements of the structure through visualization and therefore identifies the best and most efficient solutions. This results in technical superiority, early building information capture, use throughout the building lifecycle, improved cost and scheduling control mechanisms, clash detection, reduced conflict and project team benefits (Ghaffarianhoseinia et al., 2016). Those aspects, which drastically increase the productivity and enhance the collaboration between all members of a project, while at the same time, decrease risks, are formulated in seven dimensions of BIM. Besides the three dimensions of the 3D model there were four more dimensions added. While the 4D BIM is about time, temporal planning precisely linked to each of the modeled elements, 5D BIM deals with the project's economy, 6D BIM with the sustainability aspects of the project and 7D BIM with the maintenance of built facilities. The purpose of 4D BIM is to visualize the erection of the construction projects by using a BIM model and linking its geometry to the single tasks inside a construction schedule. This procedure enables the analysis of the project activities and helpsproject communication. Improved communication, in turn, leads to a reduction of delays and errors inside the schedule and the sequencing of the various tasks (Hartmann et al. 2008).

So far both Lean Construction and BIM have generally been applied independently from each other, even though both share common features, especially in areas of improving the schedule related aspects of a project. Therefore, to advance their individual efficiencies, a combination of both approaches through their similarities and overlapping characteristics, could form a new and more effective method of construction management (Onyango, 2016). Many sources suggest, that using a combination of both methods would in theory lead to an optimization of construction processes (Bhatla & Leite, 2012; Sacks & Koskela, 2009). Currently, however, few combined approaches have been developed and sufficiently tested during practical projects. This study aims to fill this gap, by describing the implementation of a combined usage of BIM and Lean Construction as a retrospective study on a high-rise project in Berlin, Germany. During this project, only the LPS was applied. For this case we analyzed the possible efficiency improvement, if in addition to Lean Construction also a 4D BIM model would have been used. Our results show that 4D would have most likely have helped the planners on the project to circumvent a number of problems that they encountered in their LPS effort.

The paper is structured as follow: We first report on our initial analysis of the theoretical potential to support LPS with 4D models and introduce a simple guiding framework that supported the retrospective study. Afterwards the research method is presented of how we implemented the framework on a retrospective case study of a construction project in Berlin, Germany. We will then discuss the results of this retrospective study illustrating a couple of potential examples of beneficial 4D model applications. We then discuss our findings and conclude the paper.

LAST PLANNER SYSTEM AND 4D BIM

As discussed in the previous section, combining LPS and BIM potentially yields significant value. The LPS at its core is based on a pull planning process, during which all disciplines responsible for delivering a building together, brainstorm the construction tasks that need to be executed and develop a sequence of how this process can be physically executed in the field without causing conflicts between the disciplines. The pull planning process usually yields a work flow for the work of all disciplines that can be repeated for each level of a building which is integrated in a Master schedule as a next step of the LPS. Pull planning meetings are usually conducted before the start of construction to determine an initial planning sequence and then in regular intervals during the construction phase to update this initial sequence based upon current developments in the field (Alarcón, 1997). In current practice, planners support this pull planning practice usually with 2D drawings of the construction site to understand which construction tasks need to be conducted. The planners then use post-it notes to plan construction sequences together (Figure 1).

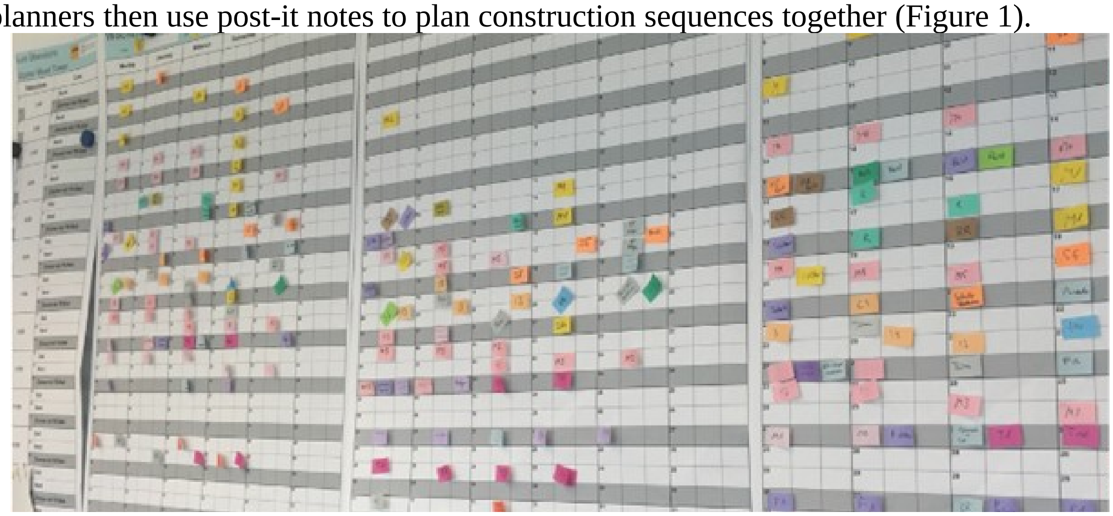

Figure 1: Example of a pull planning sequence developed in a last planner meeting using post-it notes.

Ideally, of course, sequence updates during the construction times are few and are only caused by unforeseen and uncontrollable circumstances, such as possible labor or material shortages or delays caused by weather conditions. At the same time, ideal LPS efforts start construction with a pull plan that accounts for all the construction activities within a feasible sequence that are entirely in the control of the planning team.

Part of the research question that we try to explore in this paper is whether the currently used supporting devices to support LPS efforts – 2D drawings and post-it notes – are a sufficient means to avoid omissions and sequencing mistakes. We further hypothesize that many omissions and sequencing mistakes that occur in in pull plans within today's practice, can be avoided if planners would make use of the capabilities of 4D models. 4D models provide detailed animations of complex construction projects by linking schedule tasks of the work flow with detailed 3D models of a building. In the past, empirical studies have reported that 4D models have been successfully applied, for example, to support constructability reviews (Hartmann and Fischer, 2007), the impact of construction work on the public (Zanen et al. 2013), or during the project shaping phases (Mahalingam et al., 2010). Most importantly, however, researchers have also shown that 4D models can be beneficially used to support the coordination of activities between contractors (Trebbe et al., 2015; olde Scholtenhuis et al. 2016). Therefore, we hypothesize that 4D models potentially can also support pull planning efforts. We assume that the visualizations 4D models can provide information that allows the different disciplines involved in the LPS process to quickly understand the feasibility of their sequences and schedules. To provide empirical evidence for this hypothesis we conducted a retrospective case study. The method we used for the case study is discussed in the next section.

RESEARCH METHOD

To be able to analyze the application of the framework and determine the potential of supporting LPS efforts with BIM we conducted a retrospective case study. To this end, we used a high-rise construction project in Berlin, Germany that was built between May 2014 and March 2017. Today, the 118-meter office and hotel tower with 33 floors and a gross floor area of 53,000 m² is one of the tallest buildings in Berlin. The tower contains various offices, a sky bar in the 33rd floor and a hotel chain. During that project the construction management team applied the LPS for planning the construction of the 18 stories high hotel section inside the tower, however, BIM was not used during this effort.

Table 1. Project drawings (2D) used to reconstruct the BIM model.

Type		Description
Elevation views	4	North, South, East, West
Section plans	32	
Floor plans	18	Floors 1-18 of the hotel
Ceiling plans	18	Floors 2-18 of the hotel
Details	40	Plumbing, HVAC, Bathrooms, Accomodation shafts, Drywalls, Electricity, Floor structure, Facade
Component Catalog	1	Details for structure and materials of all walls and ceilings

To understand the positive aspects the application of BIM could have had, we modeled the project using Autodesk Revit. We obtained all ground floor and ceiling drawings and all other relevant architectural data (Table 1). Based on the plans, we modeled all major given aspects of the hotel, such as the architectural, structural, and

MEP systems. The final BIM model included all items, such as light switches, pipes, bathroom equipment, which were relevant for the scheduling with the LPS. The entire modeling effort took around 320 hours.

We then analyzed the data and schedules of the LPS effort and linked the BIM model to detailed the sequences depicted in the look ahead plans and the Master plan using the 4D software Navisworks. Overall, we generated 38 4D models for each of the look ahead schedules established during all the pull planning meetings that were conducted on the project. After modeling, we then retrospectively analyzed problems and omissions that occurred during the weekly look ahead meetings and during executing the construction work. In a final step, of our retrospective case study we then used the BIM and the 4D models to understand whether their use could have helped to solve the problems identified. The next section describes the results of this retrospective analysis.

SUPPORTING THE LAST PLANNER SYSTEM WITH 4D BIM

During our retrospective analysis we were able to discover seven major issues that significantly impacted the project and that most likely could have been avoided or mitigated if the planners would have used a 4D model to support their process. Due to space limitations, the following sub-sections will provide a detailed description of three examples of the above problems.

Sequence planning for hallways

Our retrospective analysis shows that during the pull planning process, the planners omitted a number of important work tasks within the sequence that they developed. The planners only realized these omissions in the later pull planning meetings, and the sequence that was developed in the initial meetings had to be revised after construction had started. These changes had ramifications on the Master schedule and delayed the project. Our retrospective analysis shows that there is a high likelihood that the planners would have identified the missing tasks already during the initial pull planning meetings if they would have supported their efforts with dedicated 4D models.

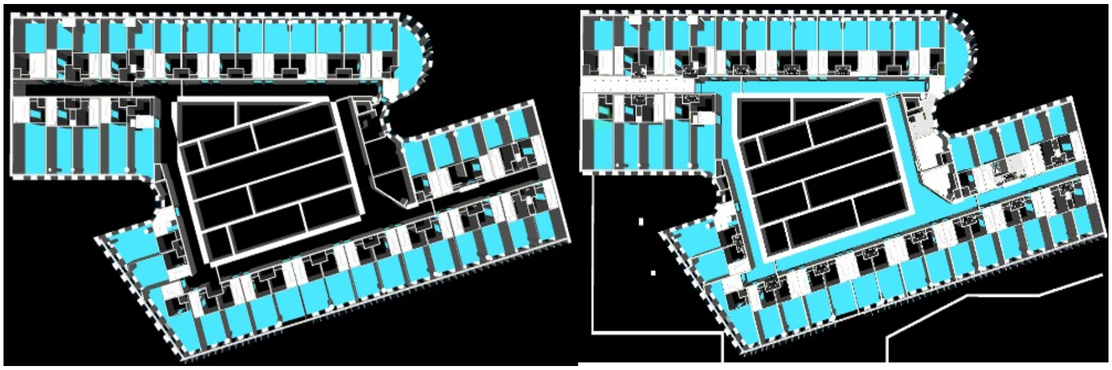

Figure 2. 4D models of the overall floor plan depicting the end of construction. Left: 4D model of the initial sequence developed in the pull planning stage. Right: 4D model of the revised sequence after the third weekly look-ahead meeting.

For example, one of the major tasks that the initial pull planning sequence did not account for were the construction of the ceilings of the hallways of each floor. Figure 2 shows an overview of the 4D model that would have represented the final stage of the construction work with the initially developed pull plan. On this figure the omission of the hallways is visible and would have most likely been picked up by the planners in the meeting.

Accomodation shafts

Another major area which wasn't considered in the early last planning sessions were the accommodation shafts for the buildings systems. Those shafts were designed to accommodate the pipes and ducts for the water, wastewater and air supply of the entire building. Different types of pipes and ducts need different types of insulation and fitting. The pipes and ducts are also built by different subcontractors for heating, ventilation, and air-conditioning (HVAC), as well as, plumbing. Every shaft segment also required fire insulation between the separate stories of the building to prevent fire to reach the next story through the shaft. Finally, after installation all pipes also need to thoroughly pressure checked before the commissioning of the building. Hence, the accommodation shafts were one of the most complex systems to schedule, but were also forgotten in the first three pull planning meetings.

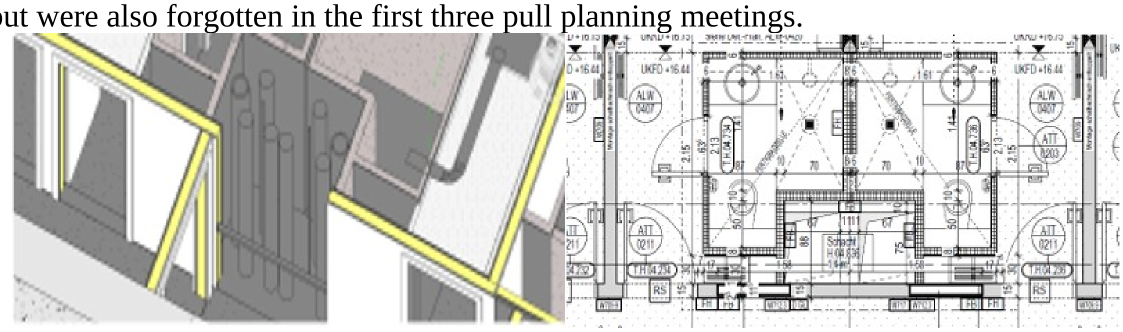

Figure 3. BIM view of the accommodation shafts (left side) in comparison with the 2D drawings used during the last planning meetings (right side).

Not considering the accommodation shafts during the early last planning sessions, in which all the planners with the detailed knowledge of the construction of those shafts are present, resulted in lack of important information to inform the site work. The reason why the shafts weren't considered in those meetings was that 2D drawings were used to determine the scope of the construction process. In those drawings the piping systems were not included (Figure 3). The building systems were explained in detail in a different set of 2D drawings that the planners overlooked during the meetings. Our BIM model contains all the major information of the building including the MEP system, so planners would have most likely realized the omission of the accommodation shafts in their sequence plans. Having a BIM model would have additionally allowed the participants of the meeting to understand the complex details of the accommodation shafts better and would have allowed them to plan the sequence better.

Planning the door installation

Another problem that occurred because of a problem within the initial sequence led to a problem in the field which led to disruptions of the initial flow of sequences depicted in the sequence from the pull planning efforts. In the end, some important delivery dates were missed.

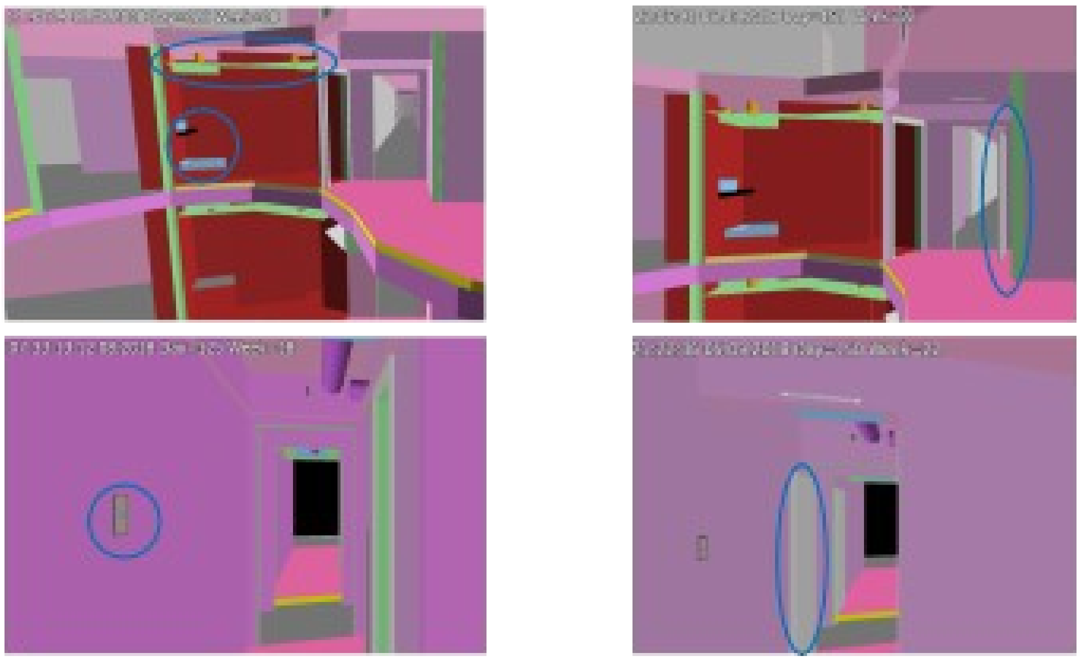

Figure 4. 4D snapshots visualizing the door and fixture installation sequence. Upper row: 4D of the initial sequence - the bathroom fixtures are installed, but the door is not in place. To the right, the new sequence with installed door. Lower row: 4D of the initial sequence - the lighting fixtures are installed, but the door is not in place. To the right, the new sequence with installed door.

One of the most important issue that we discovered in our retrospective analysis, was related to the planning of the supply chain with respect to door and lock delivery, as well, as the installation of the plumbing and electrical items. In the initial sequence, it was planned to install the bathroom equipment of the rooms across different levels of the building first, before installing the doors of the rooms. In practice, this sequence that was spread across different levels was not ideal, as bathroom fixtures are expensive items that are prone to theft. To protect the fixtures, it is necessary to install the room doors first which was not accounted for within the Master schedule. Figure 4 shows detailed snapshots from the retrospective 4D model that we believe could have helped planners to determine an adequate sequence before the start of construction.

DISCUSSION

Our retrospective analysis provides evidence that planners can support LPS efforts well with 4D models. We show that a number of quite complex construction related sequencing issues, such as the installation of the ceilings, the requirement to install doors before bathroom fixtures are easily detectable in a 4D model and therefore, would have been most likely also been picked up by the planners on the project.

Of course, the effort to implement 4D models to support LPS efforts needs to be carefully evaluated against the expected benefits. For one, implementing 4D models will require a different technological infrastructure. In the initial process on the projects, the planners mainly supported their meetings with printed 2D drawings, post-it notes, and other non-electronic equipment. The use of a 4D model would at a minimum require the provision of a projector and screen to display the models and it would also require the provision of a high-end graphics work station to display the at times large 4D models. Additionally, it will be important to account for the time it is required to develop the necessary 4D models. In our retrospective analysis, it took the first author of the paper approximately 320 hours to model the required 3D model from the project documents available. Another 320 hours were required to link the model to the different versions of the construction sequence. Hence, a significant investment is required to generate the necessary 4D models. Considering, however, that more and more BIM models become readily available for projects, this initial modeling effort will most likely be significantly reduced in the future. Additionally, the first author of the paper did not have any prior experience with BIM or 4D modeling. Nevertheless, the effort to generate the 4D models need to be accounted for when evaluating the business potential of supporting LPS with 4D.

Of course, our study is not free of limitations. Our results are based upon a retrospective case study of one single construction project. How well these results can be generalized for other projects is not clear from this study. Different project characteristics, such as size or system complexity could have influence on the benefits of applying 4D to support LPS. Moreover, the expertise and the collaborative ability of the planners can have significant influence on the potential benefits of 4D. Future research should reproduce this study on projects with different characteristics to further add evidence to our findings. Additionally, the retrospective character of the study could have influenced the results. In particular, we as authors of the paper could not always free ourselves from the bias that 4D will have a positive effect. How much this bias unconsciously influenced our analysis of the results is unclear. Again, future studies should provide additional accounts, maybe using action research-based studies that can follow the support of LPS with 4D in real time on a project.

Nevertheless, despite these shortcomings, our results provide evidence for the potential benefits that might help practitioners to improve their LPS meeting significantly. After all our examples show that 4D most likely would have helped the project. The examples with their detail might also help practitioners to discuss possible benefits of 4D on their projects.

CONCLUSION

We introduced the results of a retrospective study to evaluate the potential to support LPS efforts with 4D models. Based on schedules, drawings, and first-hand experience of a LPS implementation on a large construction project in Germany, we were able to create a detailed 4D model of the project and then evaluate how the model could have helped to overcome some of the problems that occurred during the project. We provide examples of a number of problems on the project that could have most likely be avoided using 4D models.

If nothing more, the paper provides first empirical evidence for the potential of supporting LPS with BIM. The results can support planners with their decisions to implement 4D and LPS on their project and to communicate the reasons behind this decision. The results of the study further draw attention to the general field of inquiry that focuses on the integration of Lean and BIM methods, probably the two mostly explored innovations in the construction industry today.

REFERENCES

Alarcón, L. (1997). Lean construction. CRC Press.

Bajjou, M. S., & Chafi, A. (2018). Lean construction implementation in the Moroccan construction industry: Awareness, benefits and barriers. Journal of Engineering, Design and Technology, 16(4), 533-556.

Bhatla, A., & Leite, F. (2012). Integration framework of BIM with the last planner system. In IGLC 2012-20th Conference of the International Group for Lean Construction.

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

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O., & Raahemifar, K. (2017). Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. Renewable and Sustainable Energy Reviews, 75, 1046-1053.

Hartmann, T., & Fischer, M. (2007). Supporting the constructability review with 3D/ 4D models. Building Research & Information, 35(1), 70-80.

Hartmann, T., Gao, J., & Fischer, M. (2008). Areas of application for 3D and 4D models on construction projects. Journal of Construction Engineering and management, 134(10), 776-785.

Jørgensen, B., & Emmitt, S. (2009). Investigating the integration of design and construction from a “lean” perspective. Construction innovation, 9(2), 225-240.

Mahalingam, A., Kashyap, R., & Mahajan, C. (2010). An evaluation of the applicability of 4D CAD on construction projects. Automation in Construction, 19(2), 148-159.

olde Scholtenhuis, L. L., Hartmann, T., & Dorée, A. G. (2016). 4D CAD based method for supporting coordination of urban subsurface utility projects. Automation in construction, 62, 66-77.

Ogunbiyi, O., Goulding, J. S., & Oladapo, A. (2014). An empirical study of the impact of lean construction techniques on sustainable construction in the UK. Construction innovation, 14(1), 88-107.

Onyango, A. F. (2016). Interaction between Lean Construction and BIM: How effectiveness in production can be improved if lean and BIM are combined in the design phase A literature review.

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

Trebbe, M., Hartmann, T., & Dorée, A. (2015). 4D CAD models to support the coordination of construction activities between contractors. Automation in construction, 49, 83-91.

Zanen, P. P. A., Hartmann, T., Al-Jibouri, S. H., & Heijmans, H. W. N. (2013). Using 4D CAD to visualize the impacts of highway construction on the public. Automation in construction, 32, 136-144.