Bortolini, R. Shigaki, J.S. and Formoso, C.T., 2015. Site Logistic planning and control using 4D Modeling: A Study in a Lean Car Factory Building Site. *Proc. 23rdAnn. Conf. of the Int'l. Group for Lean Construction*, 28-31 July, Perth, Australia, pp. 361-370, available at www.iglc.net

SITE LOGISTICS PLANNING AND CONTROL USING 4D MODELING: A STUDY IN A LEAN CAR FACTORY BUILDING SITE

Rafaela Bortolini[1], Jeferson Shin-Iti Shigaki[2], and Carlos Torres Formoso[3]

ABSTRACT

A major challenge in most construction projects is the need to coordinate a large number of logistic operations in site installation. Despite the growing use of 4D models for planning and coordinating construction activities, the traditional approach adopted for those models is simply to represent the installation sequence defined in a CPM network, which is limited only to conversion activities, whilst a lean perspective suggests that production should also be seen as a flow. The purpose of this paper is to discuss how to plan and control logistics processes in engineer-to-order prefabricated building systems with the use of 4D BIM modeling. This paper investigates the use of BIM to simulate both value-adding and non value-adding activities, such as waiting, inventory and moving materials, as well as site layout.

An empirical study was developed in an industrial project for a Car Manufacturing Company that is highly advanced in the implementation of lean production. The scope of the research project includes both the simulation of logistic operations and the monitoring of those operations in the construction site. This paper discusses the benefits and limitations of using 4D BIM for planning and controlling logistics operations in construction sites. Moreover, this study highlighted the need to plan and control site logistics processes hierarchically and focus on logistics critical processes.

KEYWORDS

Building information modeling (BIM), logistics, prefabrication, 4D modelling, visual management.

INTRODUCTION

In the context of engineer-to-order prefabricated building systems, the management of construction projects requires a large amount of information and treatment of

[1] M.Sc.,Faculty of Engineering, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul, Porto Alegre, 90035-190, BR, +55 (51) 3308-3518, bortolinirafaela@gmail.com

[2] M.Sc. Student,Faculty of Engineering, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul, Porto Alegre, 90035-190, BR, +55 (51) 3308-3518, js_shigaki@yahoo.com.br

[3] Associate Professor, Faculty of Engineering, Building Innovation Research Unit (NORIE), Engineering School, Federal University of Rio Grande do Sul, Porto Alegre, 90035-190, BR, +55 (51) 3308-3518, formoso@ufrgs.br

inaccurate data. The degree of uncertainty is high due to environmental factors, design errors, late design changes, lack of information, communication failures, delays in materials delivery and other issues (Hajdasz, 2014). Engineer-to-order (ETO) companies usually supply highly customized products to meet individual customer requirements. According to Hicks, McGovern and Earl (2000), the high level of customization in ETO products may lead to increased costs, higher risks and long lead times. The complexity of product structure makes outsourcing more difficult at the same time the variety of ETO projects implies in the involvement of many different types of supplier relationships. Therefore, logistics planning and control is extremely important to achieve the goals of schedule, cost, quality and safety of ETO building projects. Moreover, empirical observation within an ETO company has indicated to need for a site logistic planning in order to reduce wastes stemming from excessive transportation of material and equipment and also duo to the poor organization of components on-site.

The layout of materials and temporary storage facilities areas needs careful planning to minimize costs and moving resources, and comply with the operational and safety constraints (Said and El-Rayes, 2013). Also, the difficulties imposed by on-site work and the complexity and dynamic nature of construction create the need for effective ways to support construction planning and control (Hajdasz, 2014). In fact, several research studies have suggested the potential use of 4D models in planning the construction site.

Most previous studies on the use of 4D models for construction focused on a specific topic, such as site layout planning (Zhang, Ma and Cheng, 2001); analysis of conflicts related to safety (Zhang and Hu, 2011); automatic generation of work spaces (Akinci, Fischer and Kunz, 1998); producing visual logistics and resource schedules (Chau, Anson and Zhang, 2004), and analysing the movement of equipment onsite (Olearczyk, Al-Hussein and Bouferguène**,** 2014). Despite the contributions of those research studies, none of them investigated the interactions between production planning and logistics planning, and how to implement logistics plans in an organizational context. Moreover, most studies do not address details of logistics operations and material inventory. In fact, most studies on 4D models simply a translation of the output of a CPM network that contains only transformation activities, so criticized by the Lean Construction Community. It implies that the so called flow activities are being neglected once more.

This paper investigates the use of 4D BIM modeling to plan and control logistical operations on site for ETO prefabricated building systems, including site layout, main unloading operations, inventories, and critical site assembly operations. This research study is based on an empirical study carried out in and industrial development is placed in a construction project, which the has as a client a car manufacturing company that was very demanding with their suppliers in terms of implementing some core lean production ideas. This investigation was developed in partnership with a steel fabricator company (Company A), but also had a strong interaction with representatives of the client organization, since these were actively involved in the implementation of some innovations in the site assembly process.

LITERATURE REVIEW

LOGISTICS PLANNING AND CONTROL AND 4D MODELING

Site logistics planning and control involves site layout planning activities (Said and El-Rayes, 2013), which imply the definition of the space needed for the movement of materials (Tommelein and Zouein, 1993), and decisions about what to do in conflicts situation of space and time (Akinci, Fischer and Zabelle, 1998), and the size, shape and location of fixed and temporary facilities, as well as vehicle routes necessary for the development of operations, during each phase of the site. In addition, logistics planning and control should aim to eliminate or reduce material transportation operations, and to avoid congestion of flows in the construction site (Tommelein and Zouein, 1993) by controlling operations involved in the unloading of materials (Agapiou, et al., 1998). Agapiou, et al. (1998) state that logistics planning can have a highly positive impact on the productivity of construction operations.

The aim of 4D BIM models in production planning is provide a virtual environment for simulating and viewing production processes and operations (Davies and Harty, 2013).Those models offer the opportunity of identifying resource conflicts in time, with the aim of improving efficiency and safety, and improving the flow through the identification of bottlenecks (Davies and Harty, 2013). For instance, Olearczyk, Al-Hussein and Bouferguène (2014) investigated the use of 4D models to analyse the vehicles trajectory on construction sites. Akinci, Fischer and Kunz (2002) explored the use of 4D models to detect possible conflicts of space and time. Wang, et al. (2014) investigated the modeling construction operations and analysis of the materials inventory, which in this research is called critical operations. Also, some research studies used 4D models for planning and testing construction sequence alternatives (Chau, Anson and Zhang, 2004) and predict potential logistical problems (Hartmann, Gao and Fischer, 2008).

RESEARCH METHOD

Designed Science Research, also known as Constructive Research was the methodological approach adopted in this investigation. According to Kasanen, Lukka and Siitonen (1993), constructive research aims to develop innovative solutions that solve practical problems and at the same time allow a theoretical contribution. Figure 1 presents schematically the research design, which was divided into the following stages: (a) a literature review; (b) understanding the problem; (c) development phase, based on an empirical study; (d) analysis and reflection phase. This paper reports some of the results of broader research project, which aimed to devise a logistics planning and control model to be detailed in a further publication.

As in most design science research projects, the development of the solution involved several cycles of planning, execution, data collection, and analysis. At each cycle, the plans were revised and detailed, based on feedback from site operations and also due to additional demands of information by site managers. The main sources of evidence are presented in Table 1.

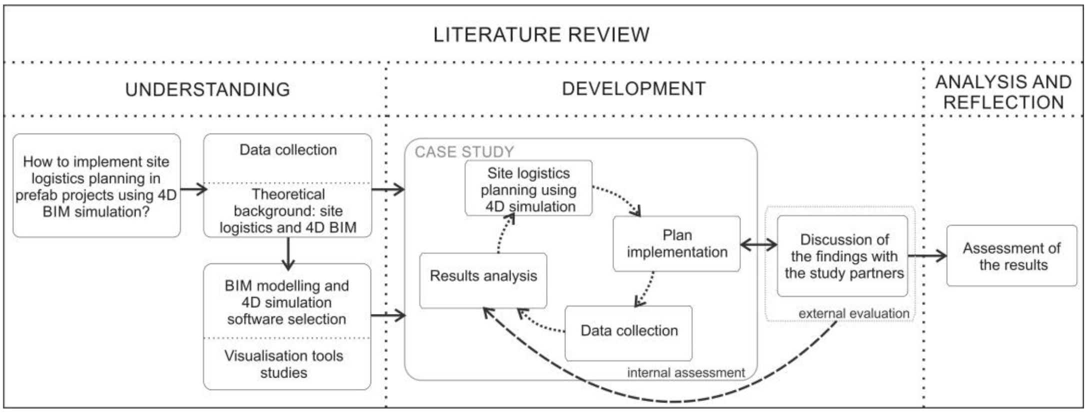

Figure 1: Research design

Table 1: Sources of evidence

Goals	Sources of evidence
Understand the site characteristics, the construction and logistics process and possible challenges on site	Interviews with both site engineer and project coordinator Site visit to identify its main features and implications for site planning
Understand the client requirements	One hour meeting with the client and the site engineer to discuss the first version of the proposed logistics plan
Logistics planning	4 one-hour meetings with the site engineer and a client representative to define the site layout and a solution for logistics operations
Implementation of the logistics plan	Participation in 4 planning and control meetings involving company managers and client representatives, with an average duration of 30 minutes, to discuss the construction progress
Assessment of the implementation	15 site visits focused in analysing the proposed logistics plan

In terms of software, this study has used ArchiCAD® to model the building product, using 2D drawings provided by the design team as a starting point. Synchro Pro® was used to develop 4D models. It was initially developed with its components at scheme design level of development, considering that for this macro site planning it did not require a very high level of detail. The model was divided into nine building stages, which were identified with the same colours of labels made for the components identification. It was used to support collaborative decision-making related to logistic planning.

EMPIRICAL STUDY

Company A is a steel fabricator that design, fabricates and assembly on site steel structures mostly for industrial buildings, warehouses, supermarkets, and high rise buildings. It is considered the largest steel structure fabricator in Brazil, with more than 2000 employees, 3 manufacturing plants, and around 200 simultaneous contracts.

Short delivery times and design flexibility are the main competitive advantages of this company.

The development process of the company’s product begins with the division of the building into stages with the aim of reducing the batch size. The separation in stages also helps to achieve similar production batches, which should make it easier the detection of errors, as well to establish a stable pace of work. Each stage of the project is divided into sub stages, which are assembly units that can be erected independently.

Company A did not used to perform systematically layout planning and logistics operations studies. In fact, the company did not have standard operations for the unloading of components on site. Therefore, there were several problems in site logistics, such as inadequate location of inventories, the mixing of components from different stages, and time consuming transportation operations. This was particularly common when the logistics department mixed components from different stages in the same load, with the aim of minimizing freight costs.

The project for this empirical study was suggested by Company A, because it was considered as an opportunity to implement improvements in the company's logistics processes due to the fact that the client organization was very demanding in terms of schedule, safety and organization of the construction site. For that reason, Company A decided to implement several improvements in logistics with the aim of improving the performance of the site assembly process.

The project consisted of the assembly of steel components for a 20 thousand square meter single floor industrial building, including steel beams, spatial trusses, sheet metal cladding, sheet metal roofing.

One of the main challenges for the logistics planning in this project was to not mix sub stage components on site. There was a relative large storage area for the projects, due to the fact that the client had an additional area for future expansion of the plant. However, this area had to be shared with preassembly operations without compromising safety and productivity as a well as avoiding conflicting flows with other suppliers.

RESULTS

Company A decided not only to implement logistics planning and control but also to introduce some visual management practices on site. One of the initial decisions regarding visual management was to adopt colour labels to identify the component batches for each stage. In addition, all loads for that project were planned at a very detailed level, based on weight and size constraints. The main assumption made in developing those plans was that each load should only contain components of the same building stage. Furthermore, the components distribution in each load should be positioned in the best possible way for the assembly sequence. Meetings were held to define the loads with the participation of representatives from the logistics department and the site engineer. The loads were delivered according to the assembly sequence defined by the assembly on site.

For the development of the logistic plans, 5 meetings with the participation of site engineers, project coordinator and client were held. In those meetings, 4D simulations were used to refine the sequence of stages, and to define the positioning of storage areas, vehicle routes and pedestrian routes (Figure 2). The storage location was designed as close to the assembling area as possible, to reduce unnecessary transportation activities, and increase productivity.

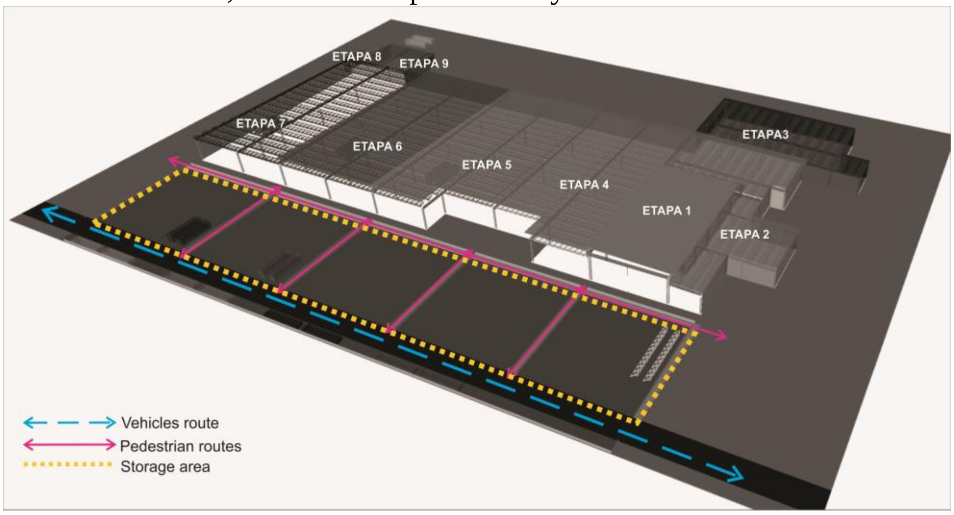

Figure 2: Batch sequencing definition

A line of balance (LOB) was used to generate a long term plan. The LOB was useful to explore alternative execution sequences in combination to the 4D model (Figure 3). Each planned activity occupied a workspace in the construction site and a material storage area. The site layout was divided into bays to prevent mixing of materials and to seek better organization of inventories. Simulation included the indication of pre-assembled trusses areas and logistics processes.

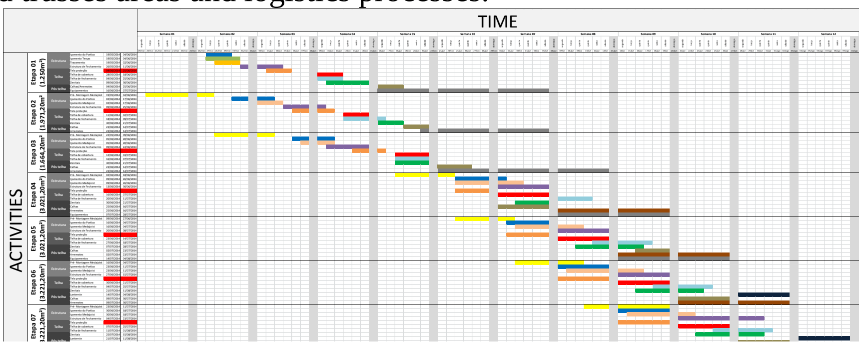

Figure 3: Line of Balance

The importance of client engagement in this work became evident with a change request for the product design. As the Company A seeks maximum reduction in the use of steel for cost reasons, their solutions usually provide a wide variety of components. This variety of parts occurs in the primary structure (beams, frames) and also in the secondary structure (space trusses). Due to customer request for a leaner work, product design was modified in order to decrease to less than a half the number of different space trusses (50 types to 17 types). This action resulted in an increase in the total weight of the project. By contrast, it made simple handling the components and the assembly process, by decreasing the variety of products to be assembled.

The logistic plan developed with the 4D model was implemented on site with the support of visual devices. They were made with screenshots taken from the 4D model in correspondence to time flow. One of the boards that were produced had one screenshot of the building and inventories per week (Figure 4). These boards aim to facilitate the exchange of information in the construction site, being used by different stakeholders including the site engineer, client representatives, and assembling subcontractors. That visual board were used to monitor the assembly process and deviations in inventories.

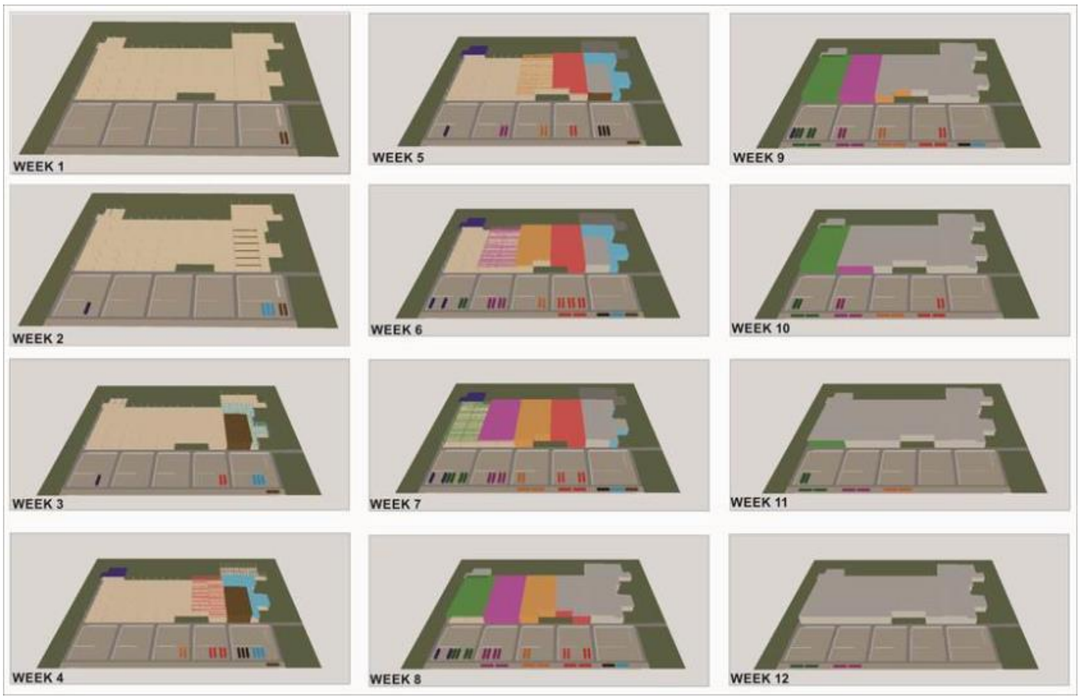

Figure 4: Visual device produced from screenshots of a 4D model

Different visual devices were placed near the assembly area, and in both Company A and client's site offices (Figure 5). Direct observation indicated that the boards were useful to support discussions about production plans and layout.

The implementation process had a control phase about the planned logistics activities. The control phase included the analyses of component unloading operations on site, access routes and pedestrian routes. This control was important to identify the causes of deviations and, when necessary, to revise or detail the logistics plans.

Figure 5: Visual management in the construction site

One critical process was chosen to be planned at a fine level of detail, with the aim of improving productivity in site assembly. The pre-assembly and the lifting of space trusses were the process chosen by Company A. The stage 6 of the building was selected due to the fact that the previous stages were in process and they could be used as a source of data to produce the 4D model.

Firstly, the existing schedule for the pre-assembly activities was analysed. That plan was problematic since a large amount of work in progress was going to be created. Then, the study was conducted with the aim of improving the logistic plan for this particular process. A specific BIM model was developed to a higher level of development, modelling the space truss components at a fine level of development. The storage area and the assembling area were also modelled, and the schedule of the activities involved was analysed in the 4D model. The simulation highlighted the possibility to configure a more continuous process with a minimal inventory of trussesto be lifted. This investigation had the participation of the site engineer and assembly subcontractors, so that their tacit knowledge could be used to build the best possible scenario for this process. Client representatives also participated in the discussions. Figure 6 illustrates this process and the screenshots images taken from the 4D model. Another visual device was produced using screenshots from that model. The virtual prototype was implemented and refined along the process, considering suggestions of improvements made by client representatives, site engineer and assembly subcontractors.

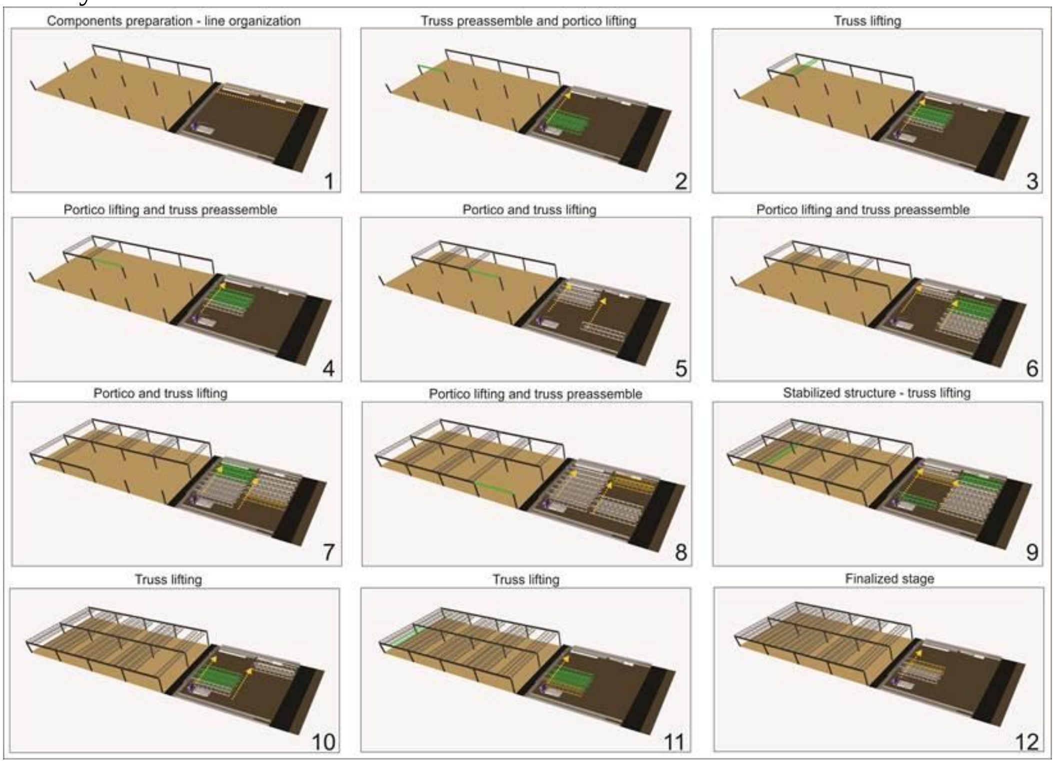

Figure 6: Screenshots of 4D simulation (critical stage detailing)

The control of this process was also part of this investigation. The productivity of this process was monitored and compared with the productivity of the initial stages of the assembly. The amount of trusses stored decreased 60% and the process productivity increased 15%. These results were relevant due to the study of the components position for pre-assembly trusses that was placed as close as possible to avoid transport operations, and to the study of lifting operations. Figure 7 illustrates a comparison between the erection plans in 4D modeling and the real construction site performed. Figure 7 (a and b) presents the assembly and pre-assembly areas near from each other to avoid transport waste. Figure 7 (c and d) show the components organization to the pre-assembly trusses near for the operation process. This comparison shows the similarities of 4D simulation model with the executed work. However, it must be pointed out that this was only possible due to the refinement of the 4D model along the process with the participation of site engineer and subcontractors.

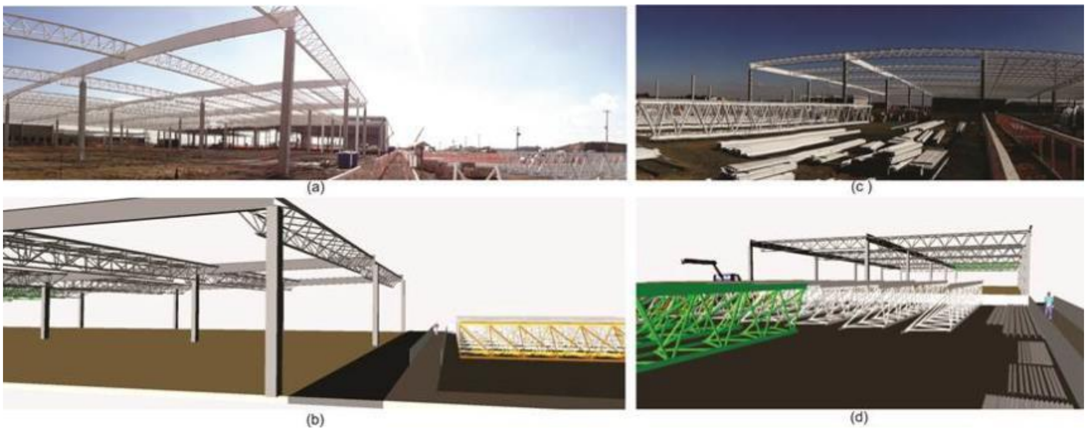

Figure 7: Comparison between as designed and as erected on site

CONCLUSIONS

In the context of engineer-to-order prefabricated building systems, it was identified the need for improvement in site logistics processes. This research brought as a result the development of logistics plan with the use of 4D BIM tools. This study highlighted the need to plan and control logistics operations in construction sites by using hierarchical approach. The initial decisions do not require a detailed BIM model, while the modelling of critical logistics operations requires a fine level of detail. Through 4D simulation, it could be analysed in detail the times of each process involved and thereby increase assembly productivity, reducing inventories and work in progress and seeking a continuous flow of production.

The combination of 4D BIM models with visual management brought an interactive process which included the participation of various stakeholders (researcher, coordinator, site engineer, assembly subcontractors and client). The board with screenshots from 4D modeling became a useful tool to implement in the construction site. The site engineer, the assembly subcontractors and the client could participate in the planning sessions in an easier way, given that they did not know how to operate the 4D modeling software. Those boards were useful for the implementation of layout and also for monitoring the work progress.

The 4D-based visual boards in combination with the LOB facilitated logistic planning by enabling the simulation of individual sequences of lifting-assembly operations duo to critical conditions. It also allowed the visualization of what-if scenario in critical process which incorporated a number of non-value adding activities. Therefore, the 4D simulation played a key-role in encouraging collaboration between the planning-assembly-erection teams in the logistic management process.

REFERENCES

Agapiou, A., Clausen, L.E., Flanagan, R., Norman, G. And Notman, D., 1998. The role of log logistics in the materials flow control process. *Construction Management and Economics*, 16(2), pp.131-137.

Akinci, B., Fischer, M. and Kunz, J., 2002. Automated generation of work spaces required by construction activities. *Journal of Construction Engineering and Management*, 128(4), pp. 306-315.

Akinci, B., Fischer, M. and Zabelle, T., 1998. Proactive approach for reducing non-value adding activities due to time-space conflicts. In: *Proc. 9thAnn. Conf. of the Int'l. Group for Lean Construction*. São Paulo, Brazil, Aug.13-15.

Chau, K.W., Anson, M. and Zhang, J.P., 2004. Four-dimensional visualization of construction scheduling and site utilization. *Journal of Construction Engineering and Management*, 130(4), pp.598-606.

Davies, R. And Harty, C. (2013). Implementing 'Site BIM': a case study of ICT innovation on a large hospital project. *Automation in Construction*, 30, pp. 15-24.

Hajdasz, M., 2014. Flexible management of repetitive construction processes by an intelligent support system. *Expert Systems with Applications*, 41(4), pp. 962-973

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

Hicks, C., McGovern, T. and Earl, C.F., 2000. Supply chain management: A strategic issue in engineer to order manufacturing. *International Journal of Production Economics*, 65, pp.179-190.

Kasanen, E., Lukka, K. and Siitonen, A., 1993. The constructive approach in management accounting research. *Journal of Management Accounting Research*, 5, pp. 243-264.

Olearczyk, J., Al-Hussein, M. And Bouferguène, A., 2014. Evolution of the crane selection and on-site utilization process for modular construction multilifts. *Automation in Construction*, 43, pp. 59-72.

Said, H. and El-Rayes, K., 2013. Optimal utilization of interior building spaces for material procurement and storage in congested construction sites. *Automation in Construction*, 31, pp.292-306.

Wang, W., Weng., S., Wang., S. and Chen, C., 2014. Integrating building information models with construction process simulations for project scheduling support. *Automation in Construction*, 37, pp.68-80.

Zhang, J.P. and Hu, Z., 2011. BIM-and 4D-based integrated solution of analysis and management for conflicts and structural safety problems during construction: 1. Principles and methodologies. *Automation in construction*, 20(2), pp. 155-166.

Zhang, J.P., Ma, Z.Y. and Cheng, P., 2001. 4D visualization of construction site management. In: *Proc. 5th Int'l. Conf. on IEEE*, 2001. London,UK, Jul. 25-27

Tommelein, I.D. and Zouein, P.P., 1993. Interactive dynamic layout planning. *Journal of Construction Engineering and Management*, 119(2), pp. 266-287.