Integration of BIM and Automation in High-Rise Building Construction

*Heikkilä, R.
University of Oulu
Erkki Koiso-Kanttilankatu 1
Oulu, Finland
*(*Corresponding author: rauno.heikkila@oulu.fi)*

Malaska, M.
University of Oulu
Erkki Koiso-Kanttilankatu 1
Oulu, Finland

Törmänen, P.
University of Oulu
Erkki Koiso-Kanttilankatu 1
Oulu, Finland

Chris Keyack
Conxtech
Hayward, CA, United States

ABSTRACT

In this paper the utilisation of building information models (BIM) and construction automation on building sites is discussed. A lot of research has been carried out to develop new applications for using BIM to assist construction site planning, different operations and logistics. The methods of production control and management on site utilize BIM together with machine control and navigation systems. In Finland machine control systems and the automation of construction equipment is widely used in infrastructure construction. Recently similar methods have been introduced also in building construction. This paper describes some latest Finnish examples where BIM-software is used for the planning, execution and control of building construction operations. University of Oulu has studied methods and technologies to capitalize BIM-models. The research has been mainly in infrastructure construction but the activities have recently been extended to building construction. In this paper a BIM-based tower crane operation and control system is discussed as a case study. The aim of this study was to highlight the potential areas were automation can increase the crane productivity and improve site operations and logistics. The construction site managers and tower crane operators interviewed in this study were experienced in using BIM-models on site.

KEYWORDS

BIM, construction automation, robotics, tower crane, crane control.

INTRODUCTION

There are many definitions for BIM (Building Information Modeling). Wikipedia describes BIM as a process involving the generation and management of digital representations of physical and functional characteristics of a facility. The resulting models become shared knowledge resources to support decision-making about the facility throughout its lifecycle including design stages, construction, operational life and eventual demolition. The BIM Handbook (Eastman et al 2011) defines BIM as a modeling technology and associated set of processes to produce, communicate, and analyze building models. As a vision, the book describes BIM as “an improved planning, design, construction, operation and maintenance process using standardized machine readable information model for each facility”. BIM has been widely used in the design phase for communication, co-ordination, cost estimation, structural analysis and for the studies of design variations. A lot of research has also been carried out to develop applications for using BIM in construction. In Finland BIM and construction automation are widely used in infrastructure construction. The exploitation of automation in building construction has been slower, but the potential of integrated BIM and automation has been recognised.

Reiman (2010) studied the possibilities to utilise 3D-machine control systems in earthworks and site excavations on building site. Using the information available from BIM-based design process a special 3D-machine control model (Landnova) was created. The model included the whole construction site and all the earthworks and excavations to be undertaken on site. Based on the results of the study it is feasible to use machine control models for building construction sites. Most sites are complex entireties and it is important that the machine control model covers all the relevant information and details without becoming too large to manage and slow to run. Site managers and operatives are the best professionals to provide this information.

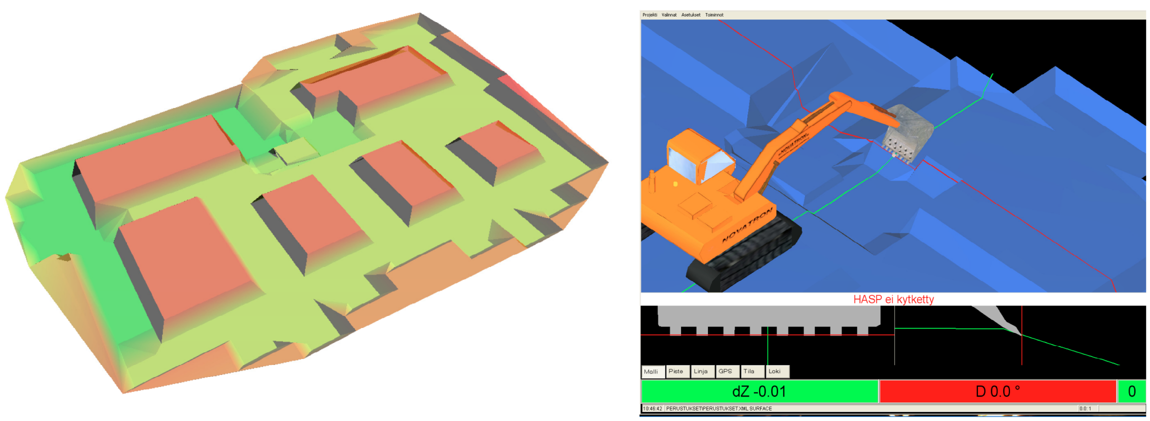

Figure 1. Foundation construction using an excavator and a 3D machine control model, left: the machine control model, right: the model imported to the machine control system (Reiman J.).

University of Oulu has studied the applications of automation in infrastructure construction several years. The research has now been extended to building construction. A tower crane is involved in many different tasks on construction site. It is the most shared resources on site and it controls the site logistics. The crane was therefore found a potential construction plant to be investigated and a case study developing a BIM-based tower crane operation and control system has been carried out in 2012-2013. The findings of the study are presented in this paper. The aim of the study is to highlight the potential areas where automation can increase the crane productivity and improve site operations and logistics. The current uses of BIM on site and the new potential applications of BIM and construction automation are identified by interviewing construction site managers and tower crane operators.

The automation of tower cranes has also been studied by Lee et all (2012, 2009) and Al-Hussein et all (2005). They have developed a BIM- and sensor-based tower crane navigation system for blind shifts in a seven story building case in Korea. In this system, different sensors and video cameras were used to produce accurate information about the crane location and position. The information was transferred to the BIM model, where the operator was able to see the building, surroundings and moving object in real time. One of the results was that 2D representations of the views were considered to be more understandable than 3D representations. The research pointed out that using the navigation system on a site where multiple tower cranes are operating will still require a significant amount of research to make the technology reach practical level. The research also highlighted that the on-site construction management and of-site design process would benefit if the building model could be automatically updated as the construction and erection work proceeds. This however requires a 4D BIM model having the fourth dimension of time via a schedule and sequence of construction activities. Al-Hussein et all (2005) have studied the utilization of different visualization and simulation methods in more accurate task planning for crane operations.

Based on the above observations it was found necessary to investigate how BIM models are currently being used on-site and where do the site operatives see the potential opportunities to develop the process and automation further. A BIM-based tower crane operation and control system was used as a case study. The project, building site and the results are introduced next.

METHOD

A large 23 000 m^2 two-storey educational building (Kastelli Community Centre) in Oulu Finland is used as a case study. The building is of precast concrete construction. In the original research plan the aim was to use a highrise building as a case project, but suitable projects were not available. The main contractor and the BIM coordinator of the project, Lemminkäinen Oyj, is one of the biggest building contractors in Finland. Tekla Structures is used as the BIM-software.

The turning tower crane used in the construction was of type Potain MD365, see figure 2. The crane has a 70 m long boom and it is operated by two tower crane operatives; one in the crane cabin and the other one managing lifting operations from the ground.

Figure 2. The studied tower crane Potain MD365 in operation.

A special tower crane modeling and simulation tool is available in Tekla Stuctures and the main contractor used this tool to add the crane into the structural BIM model. The final location and installation point of the crane was planned using the simulation tool. Figure 3 shows a view from the user-interface of the crane modeling and simulation tool of Tekla Structures. As the site was large the tower crane could not lift in all areas and several mobile vehicle mounted cranes are to be used on site in addition to the tower crane.

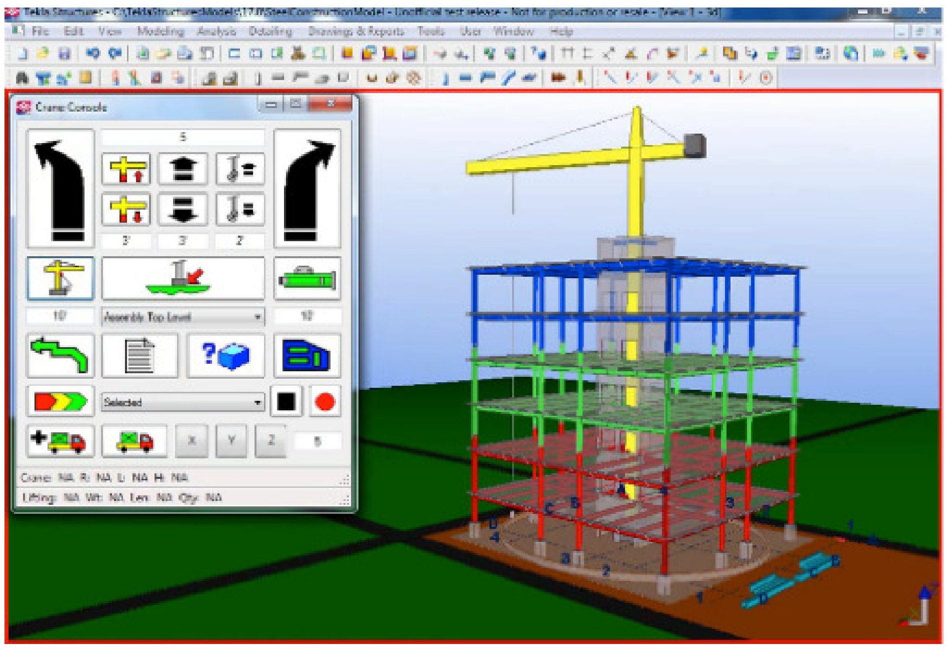

Figure 3. A view from the user-interface of the crane modeling and simulation tool in Tekla Structures software. Picture provided by Tekla Corporation.

In this research two construction site managers and two tower crane operators were interviewed in November 2012. All the interviewed persons were experienced in using BIM-models on site. The interviews of the crane operators were carried out in the crane cabin. The crane was operating during the interviews which made it easier to visualise the problems and potential opportunities.

RESULTS AND OBSERVATIONS

BIM models are in active use on this construction site and they have also been used for designing lifting operations. The precast concrete elements are modelled in different colours. The colour depends on the self weight of an element. For example elements which are heavier than 10 tons are modelled in red. The tower crane is modeled into the BIM model and the lifting capacity curves are visualized on plan in the model. It can be seen from the model if there are elements which are too heavy to be lifted using the tower crane and a mobile crane is required. The colour coding and the capacity curves can be seen in figure 4.

About 10 construction plants were used for earthworks and excavation. Construction automation was however not utilised.

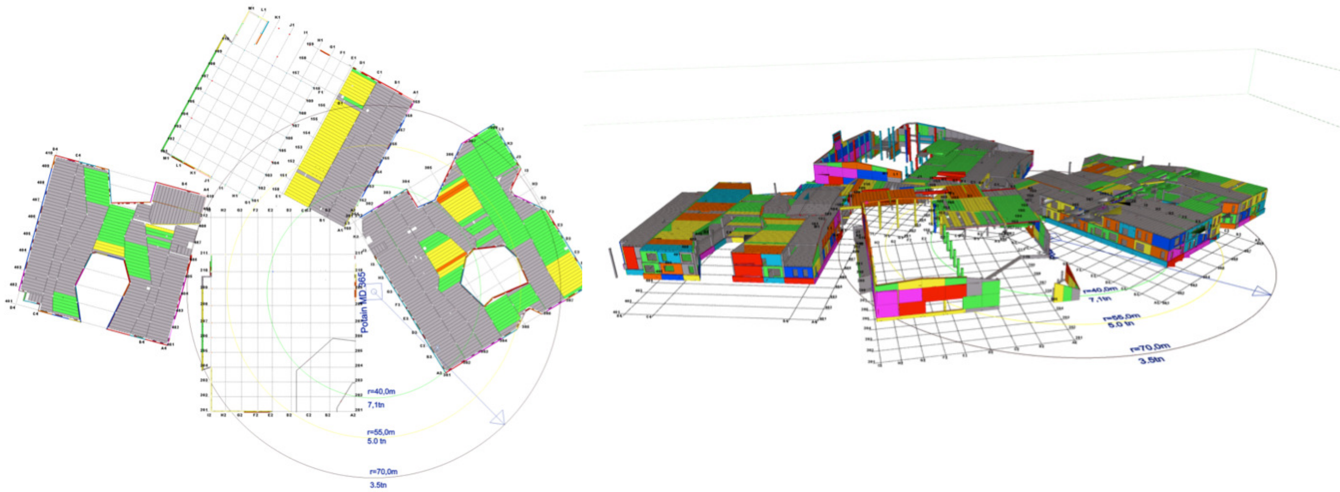

Figure 4. Left: lifting capacity curves in a BIM model, right: element colours based on their self weight (Kastelli Community Centre in Oulu, Tekla Structures, Lemminkäinen Oyj, 2013).

The results of this case study indicate that fully automated lifting process and self lifting cranes are very complicated to arrange for construction sites as the site and environmental conditions vary and the lifting tasks are not similar or repetitive. Systems and technological requirements become even more challenging when multiple cranes are operating at a site. There is very limited amount of research carried out in this area and new technology is required to ensure safe and efficient operations.

However systems where the work of a crane operator is assisted with machine control and navigation systems were found feasible. It is important that the operator knows the locations and the positions of the crane boom, lifted object, surrounding structures and other cranes and construction plants on site. This requires different sensors, GPS coordinates and the accurate location of the BIM model within the site. A real-time 3D geometric representation of the as-built site is important to prevent the potential for the crane and crane hook to hit any potential obstacles. This real-time information is especially important for multi-storey and highrise construction where blind lifts are typical.

Virtual simulation is an effective tool in modeling complex tower crane lifting. 3D simulations assist in crane optimisation, planning lifting operations and construction safety planning. They allow for planning and verification before actually deploying the costly equipment on site. Simulations also show the crane operator virtually how to execute the lifting operation and what are the potential risks during the work.

In this building project the lifted and erected elements are updated into the building model manually. A 4D BIM model would allow automatic updates and real time statistics of time and schedule. A 4D-modelI can show if the crane has being efficiently utilized in order to maintain the planned schedule and production rate. Changes in the planned lifting schedules are typical and a 4D model would make rescheduling easier. It is also possible to use 4D model to make volume measurements for in-situ concrete pours and to assist the pumping operation.

CONCLUSIONS

The utilisation of building information models (BIM) and construction automation on building sites has been studied in the University of Oulu. A case study developing a BIM-based tower crane operation and control system has been carried out in 2012-2013. The aim of the study was to highlight the potential areas where automation can increase the crane productivity and improve site operations and logistics. The results of this case study indicate that fully automated lifting process and self lifting cranes are very complicated to arrange for construction sites. However systems where the work of a crane operator is assisted with machine control and navigation systems were found feasible. A real-time 3D geometric representation of the as-built site can increase the crane productivity and reduce the risk of accidents. This real-time information is especially important for multi-storey and highrise construction where blind lifts are typical. Also the use of 4D models can improve site operations and productivity. Further research is under preparation to develop tower crane operations using the above technology.

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