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BIM-based site layout and safety planning

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Abstract

This paper deals with the opportunities building information modelling (BIM) offers in supporting occupational safety in construction projects. The main focus is in BIM-based site layout planning and visualization. The paper demonstrates BIM-based site layout planning and the usability of the model. The main findings concerning the modelling tools available and the requirements for BIM-based site planning are also described. Additionally, the potential of 4D-simulation in safety planning is presented. The paper is grounded in the research project called SafetyBIM: Building Information Model (BIM) promoting safety in the construction site process. The main objective of the research project was to encourage and develop utilization of BIM technology in construction planning and management from the viewpoint of occupational safety. In the project, the potential of the building information model in safety management was studied, 3D site planning objects were collected and created, and BIM-based building site modelling and visualization tests were carried out using data from an completed building project. Additionally, the object library was tested and developed further in an ongoing BIM-based site planning pilot project. As a result, there is the first version of a site planning object library available for use in building projects. In addition, the needs, ideas and potential of BIM-based safety management were surveyed by workshops with industry representatives.

Utilization of BIM technology connects safety more closely to construction planning, provides more illustrative site layout plans, effectively supports communication, and finally promotes occupational safety on building sites. From the viewpoint of occupational safety, the 4D production model enables visualization of safety arrangements in construction projects at different moments of time. This can be used for example in safety planning, day-to-day safety communications and managing changing situations. However, more experience and knowledge are needed concerning 4D safety simulation as well as further development of modelling tools such as object libraries to broaden the use of the BIM-based safety planning in the design-build process.

Keywords: Site planning, Information management, Building information modelling, BIM, Safety Management, Risk management, Safety Communication, Visualization, 3D objects, 4D

1. Introduction

Over the past ten years, building information model based design has changed from single trials and pilot projects into standard practice in the various design and engineering fields in the Finnish house building sector. There is positive and encouraging experience of utilization of BIM technology in building design and production planning [7], [8], [2]. The use of 4D production planning is now at an early stage in the house building sector, but is increasing all the time. Great potential has been consolidated to 4D, especially regarding its suitability for solving conflicts and preventing problems pro-actively in an effective manner [3]. However, there is still little research and experience considering the use of BIM technology in safety management and its potential for promoting safety.

The high accident frequency is still a real safety challenge in the building industry in Finland. An accident always prejudices the operations of the construction site and incurs both direct and indirect costs. The challenges of accident prevention are effectively organising the construction site, planning the use of the site and the tasks, as well as communication and influencing the safety attitude of personnel. [10], [5]. Also safety planning and management methods can be improved by using BIM-based plans. At the same time, implementation of new technology is a chance to change customary workflow and include a safety viewpoint more fully into production management. Traditionally construction safety management has been based on official demands, which has led to separate planning viewpoints and methods. [9]

This article is based on the TurvaBIM research project, the main target of which was to encourage and develop the utilization of BIM technology in construction planning and management, from the viewpoint of occupational safety. The key questions were the potential of BIM technology to promote occupational safety in the construction sector, the possibilities of a BIM-based site layout plan, and the possibilities of 4D modelling in safety-related activities planning and management. The project was carried out 10/2007-2/2009, and financed by The Finnish Work Environment Fund (TSR), VTT and Skanska. The research work was carried out by VTT in close co-operation with the industry. More information is available at the project web-site ([11]).

2. Method

The utilization, research and the potential of building information modelling in safety planning and management, as well as available model-based software, services, and object libraries were first surveyed by a study of the literature and expert interviews. BIM-based site layout planning was developed by carrying out a site layout modelling test and demonstration, and by developing a component library for use in BIM-based site layout planning. Hands-on modelling was also carried out to test and demonstrate 4D-visualization opportunities regarding safety-related tasks, and in addition, in a BIM-

based site planning pilot project, in which model-based site planning, visualization and the object library were developed further. In addition, ideas concerning building information modelling in safety planning and management were surveyed more widely in the research project in collaboration with industry representatives during workshops.

3. BIM-based site layout planning

3.1 Requirements for BIM-based site layout planning

The project supervisor makes the written site plan. The aim is to plan the site operations and the arrangements required in order for work to proceed as efficiently as possible during all stages of construction. The site plan is used to inform all parties of a construction project about internal and external logistic arrangements and the arrangements concerning work and safety. [4] During the site planning phase there is a need to evaluate and plan things like site exclusion and separation, logistic arrangements, site limitations, dangers and protection, the number and location of office facilities and personnel rooms, working places and areas, site electrification and lightning, lifting arrangements and transportation, intermediate storage arrangements and logistic solutions for materials, fire fighting and prevention of other special risks on site. The site plan needs to be kept up to date. In practice the site plan can be made in a variety of ways. There are site plans made on town plan drawings with the use of a CAD program, plans that are drawn by hand or made with using sticker labels. [9]

The same standards and good design principles apply to BIM-based site layout planning as with current two-dimensional planning. However, building information modelling also offers completely new opportunities for site planning and presentation when passing that information on. For example, different levels and roughness or other comparable risk factors in the site area cannot be appropriately presented in 2D plans, but can be shown in a three-dimensional model. On the other hand, because a BIM-based site plan is visually illustrative, accuracy is even more important than with a traditional site plan. For example, 3D-presentation of site equipment should be illustrative and recognizable, but not misleading. [9]

Today, a static three-dimensional site layout plan can be considered as a basic method for creating a BIM-based site plan, in which case a BIM-based site plan is created for various construction stages. Nevertheless, the target is to use more dynamic 4D site models in the future. [9] The site layout planning and management systems based on 2D drawings can no longer meet planning needs, especially when some resources or facilities are put inside the building under construction. Additionally, in different phases, the site layout will change accordingly to meet the changing demands for materials. So a site layout should never be static and two-dimensional, instead, it should be a dynamic activity across the whole 3D site. [12]

3.2 Site modelling tools

Over the last few decades several computer-based site layout systems have been developed. Research has been carried out and attempts made to optimise site layout solutions for example by means of artificial intelligence and knowledge-based systems. However, to date, no standard tool has gained wide acceptance by the industry [6].

Today, there is the same software available for BIM-based site layout planning as is used in 3D building design and 4D production planning, as well as object technology related to modelling software. The strength of BIM-based software is the opportunity to use building information models created in the design process for BIM-based site layout planning. However, from the viewpoint of site layout planning and BIM-based safety planning, there are strengths and weaknesses in each example of modelling software. No single software has all the suitable features, such as tools for land surface modelling, 3D materials for illustrative and realistic 3D presentation, suitable tools for managing schedule information and offering appropriate 4D simulation, and the ability to handle time in adequate short term periods.

Object and component libraries in various modelling software aims to provide ready-modelled 3D descriptions or structures to facilitate and accelerate modelling of building components that can be installed permanently into a building. In addition, objects and components support product information management and product marketing. However, site equipment such as office containers and other spaces, machinery and material storage in the site area, needed for example during precast unit installation, are temporary parts and circumstances for which the libraries do not offer ready 3D descriptions. In addition, libraries are software-specific, so that for example, GDL-objects used in ArchiCAD software cannot be directly used in other modelling software.

There is hardly any experience considering the suitability of various designers' building information models for safety management. BIM-based site planning can be based on the architectural model and the architectural modelling software can also be used for model-based site layout planning. Alternatively, BIM-based site planning can be started with the structural model, or with a 4D-production model based on the structural model, and use the same software employed to create those models. In addition, a BIM-based site plan can be a combined model, if the separate models of the buildings and the site area, modelled with different software, can be merged in an appropriate manner. Combining can be done with the help of the IFC-format or with specific software. IFC is a neutral data exchange format, the goal of which is to respond to the problems occurring in practice during data transfer and sharing between various computer applications used in AEC and FM. [9]

3.3 Site planning objects

One of the main objectives of the TurvaBIM research project was to demonstrate BIM-based safety planning by carrying out a site layout modelling test using data of a real case building project and study the potential of a BIM-based plan. For the test, 3D representations of temporary structures and equipment occurring in site plans were needed. A 3D site object library was created in the project by searching available ready objects and modifying some of them so as to be more suitable for site layout planning, as well as modelling missing objects needed for the test. As a result, a 3D site component library was developed for research use, including approximately 70 GDL objects found, modified or created in VTT. The so-called TurvaBIM-library was created without any business goals and site planning objects have also been given for use in real building projects.

The main objective was to create three-dimensional and identifiable site planning objects. The development work does not cover constructing object parameters, in other words objects' adaptability concerning materials, dimensions or other properties. Most of the 3D objects look real and are understandable, for example the wood saw, the trash pallet/skip, bundled reinforcing bars, window packages, and polystyrene-insulation bales. A general 3D-object was created to represent storage areas for less frequently occurring materials. When using a general object, the 3D appearance can be improved by selecting a suitable 3D surface material for the case. Examples of site planning objects created in TurvaBIM project are presented in Figure 1. Examples of safety-related objects included in the TurvaBIM library are the pedestrian shield and the precast element stud, and the safety railing found as ready-modelled. Useful ready-modelled objects were found mainly in the Construction Equipment library from Graphisoft Object Depository ([1]). The standard library of the used modelling software (ArchiCAD 11) contained only single usable 3D objects for site planning, such as a truck.



Figure 1. *Examples of site planning objects created in the TurvaBIM-project.*

The TurvaBIM-library was used to create a building information model-based site layout plan for the case project. Additionally, the library was later tested and developed further in an ongoing BIM-based site planning pilot project. The possible future

development of the objects could be related to the creation of parameters or developing usability in other modelling software.

3.4 A BIM-based site plan, a residential building project as a case example

The BIM-based site planning test was carried out using data from a completed residential building project (As Oy Vantaan Ankkahovi). The owner and the contractor of the building project was Skanska, the architectural design and modelling had been done by Arkkitehtitoimisto L-N Oy, and the structural engineering and splitting the architectural model to precast units had been done by Finnmap Consulting Oy. Besides the models, there was the traditional 2D dwg site plan available. The site plan was modelled and visualized in the research project at VTT. The aim was to demonstrate new BIM-based site representation and illustration opportunities, and the potential offered by modelling tools.

The construction site area was modelled according to the traditional site layout planned for the precast unit installation stage. Additionally, the immediate surroundings including streets and buildings were modelled roughly. At the first stage of the testing, modelling was based on the architect's model, modelled with ArchiCAD 9, and the site plan prepared by the contractor (Figure 2). ArchiCAD 11 software and the TurvaBIM-library, created in connection with the modelling test, were used to model the site plan. The land surface was modelled approximately with the mesh-tool included in the modelling software, and corresponds more closely to the designed final finished surface than the real site elevations in the element assembly stage at the construction site.

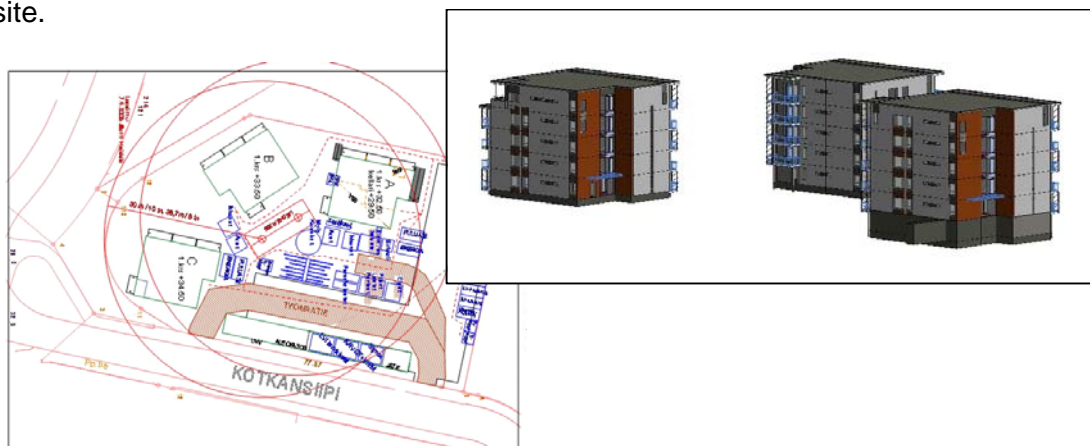


Figure 2. *The original 2D site plan and the architectural model in the case building project.*

The essential contents of a BIM-based site plan are 1) the construction site area and adjoining streets, and other immediate surroundings, that the construction site may impact 2) temporary site facilities, structures and equipment 3) temporary site

situations, such as area reservations for material storage, and 4) visualizations that promote safety, such as illustration of risk zones. There are general views to the case project's site layout model in the following figure (Figure 3). The contents of the demonstration model are precisely the following:

- **Buildings:** three blocks of flats modelled by the architect
- **Site and surroundings:** the construction site area and site road, adjoining streets and street names, opposite city blocks and buildings roughly, parking slots (that are not included in the original site plan)
- **Site facilities and enclosure:** office facilities and storage, site fencing
- **Machinery and equipment:** tower crane, wood saw, concrete-mixer
- **Electrification and lighting:** main distribution board
- **Material storage:** thermal insulation, reinforcing bars, windows, HVAC pipes, trash skips with 3D-text (e.g. wood waste), precast element rack, and storage areas for various concrete precast units and utilities needed for their assembly (modelled with a general material storage object, which can stand for any material and presentation improved by selecting a suitable 3D surface material).
- **Visualizations:** crane reach, site walkways, vehicles



Figure 3. *General views of the model based site plan created in the TurvaBIM research project.*

To be able to demonstrate BIM-based planning of fall protection related to precast unit installation stage of a building project, the BIM-based site model and the structural engineer's ArchiCAD model, that included precast concrete members, were combined. Splitting the walls of the architectural model into precast units had been done using the ElementtiApi-application. Additionally, the 4D simulation test was carried out by using the same combined model, linking schedule information to the site layout objects.

3.5 BIM-based site and safety visualization

BIM-based site plan can be used to produce many kinds of illustrative images and visualizations, both as static views and animations.

Static views: A three-dimensional site layout model can be used to produce various illustrative views of the site plan, from the desired viewpoints and perspectives. Static views can represent general overviews or details of the site plan. Challenging points or solutions can also be highlighted from the plan for example with the use of colours. Additional information can be also added to the 3D view by 3D text, for example adding explanations to the model such as the "site road". Images from desired viewpoints can also be produced as rendered images, which are usually photorealistic images of the model as snapshots, aiming to produce the most understandable and life-like views of the plan.

Animation: The same model can be used to produce animations. Animations can provide a general understanding of the site quickly, and can be used for example as virtual sightseeing when introducing the project to site staff, or when presenting site arrangements to the client. In the pilot project, fire truck route was also illustrated using an animation.

Visualization opportunities regarding site arrangements and risk zones:

- Visualization of temporary site area or space reservations: Temporary site area or space reservations for storing materials or performing a specific work task effectively and safely are visualized.
- Visualization of site walkways: Visualization of temporary site walkways can be used when informing the site staff about the safest walkways at each stage of construction.
- Visualization of risk zones related to cranes: Visualization of crane reach was carried out by making a 3D reach-cylinder object, which was used together with the crane object (Figure 4). 3D visualization can be used to examine the risks in case of load fall, or to evaluate what the crane jib could hit. The significance of this kind of examination increases if there is limited space around the construction site and clashes become possible. In the pilot project risks associated with the fall of the crane were evaluated with the help of 3D visualization. 3D objects were used to show the affected zone, and two different fall cases were examined, using empirical information concerning the behaviour of the crane in a fall situation.



Figure 4. Visualization of crane reach [9].

- Other guard zone visualizations: Taking advantage of visualization when informing site staff about safety hazards, could also mean, for example, warnings about cables, pipe lines, excavations and protection areas related to those, as well as showing location or affected zones of contaminated soil or other hazardous substances, such as asbestos and microbes.

Besides the new kind of 3D visualization material, building information models are also intended to be used to produce drawings, such as the traditional 2D site plan containing text descriptions, and the drawings can be used in parallel to the three-dimensional plan. In addition, the quantities and product data can be produced from the model, concerning for example construction machinery and equipment planned for use on site.

4. The potential of 4D in safety planning

When the schedules are linked with the building parts of a three-dimensional BIM, the result is a 4D-model. In this case, the planned or the actual construction status can be reviewed as, for example, a view corresponding to a specific calendar date. From the viewpoint of occupational safety, the 4D production model enables visualization of safety arrangements in the construction project at different moments of time. [9] There is also a strong need for more effective planning and management of site space and facilities, which can be supported by 4D, combining 4D building and 4D site models [12].

Today, construction simulations are done mainly for the building components that will be assembled to permanent parts of the building. There is most real experience concerning precast element assembly. This is related to schedule planning and simulation, and monitoring the actual construction status at the building site. For safety reasons, it would also be useful to model and simulate temporary situations and arrangements on site, such as fall protection and excavations. In future, the safety aspect should be included in a 4D-production model, so that besides the parts of the building, safety arrangements related to each working phase are shown in the model.

The following figures demonstrate the connection of safety tasks within 4D-production planning. The case example is a model-based fall protection plan related to precast unit construction, which is the first major step towards BIM-based safety management (Figure 5). Additionally, getting fall protection planning into part of 4D-production planning promotes safety, because a concrete fall protection plan is rarely seen on site in practice. Besides guard railing and protective lids shown in the Figures, relevant safety-related components to be modelled include safety nets and safety harness anchor points. [9]

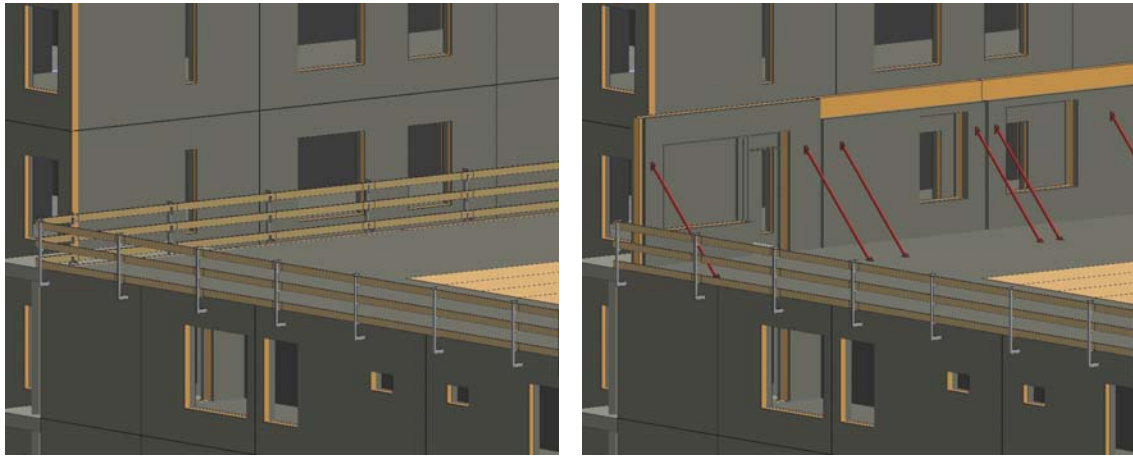


Figure 5. *Model-based fall protection planning related to precast unit construction [9].*

4D-model, and site status views and simulations produced from the model, could be used to support safety especially at the following ways:

- **Safety planning and identifying safety hazards:** Planning and analyzing construction sequencing and related safety arrangements simultaneously supports risk assessment and identification of special safety hazards. At the same time, coordination, clash detection and evaluation of adequacy of space for conducting work tasks safely can be done.
- **Task guidance and instructions:** Briefing work performance and safety issues illustratively.
- **Informing staff about current work, hazards and safety arrangements:** Up to date 4D-model can be used when communicating the progress of the project, future work, current work, and related safety arrangements, as well as issues requiring special attention from staff.
- **Recording and verification of inspections:** Status information concerning various inspections related to safety management could be recorded or linked to the 4D-model, so that in addition to the component status information such as planned and actual erection date of safety railing, there would also be a registered auditor and the date of inspection available in the model.

5. Benefits and challenges for the industry

From the viewpoint of safety, the most important benefits of building information modelling are related to the graphicness of a 3D plan, the potential for using BIM to plan and analyze safety, safety management, communication and promoting motivation of personnel. Additionally, 4D connects safety more closely to production planning, and provides up-to-date safety plans as well as making simulations possible.

The concrete benefits of a BIM-based site plan are related to its visual nature, which encourages more accurate planning concerning site area use, and improves both risk management and communication. BIM-based site planning is a method for managing, connecting and using information. A BIM-based site plan provides different views needed in the same plan, and the information can be used for many purposes. A BIM-based site plan can be used to produce illustrative representations of the site and safety arrangements, and the views can be used for orientation, for informing about risks and for discussions with the client concerning site arrangement, enclosure and temporary roads and walkways. Because of the third dimension it is possible to visualize and evaluate the risks that relate to the crane placement, for example by carrying out clash detections and analyzing collapse situations with help of 3D. In addition, it is possible to see from the BIM-based site plan the site and safety equipment, the quantity that is required, as well as the product information, which is needed in the ordering and selection process.

The three-dimensional BIM-based site plan is an intermediate phase en route to extensive 4D product planning. The most important benefits concerning 4D BIM and the materials produced with help of a 4D BIM instead of a 3D BIM-based site plan are related to the potential for producing real time safety planning and connecting safety plans to product planning.

Full exploitation of the opportunities for improving safety with help of BIM technology requires still further developing of the programs, tools and working methods. There is a need to get more practical experience of safety planning using BIM and more competence in construction projects to use BIM methods and programs.

New methods of preparing BIM-based site plans need to be tested in real construction projects. On the basis of the feedback collected during this research project, the testing will take place in many companies. Furthermore, opportunities for using combined BIM of various design fields in safety planning should be inspected and tested.

6. Conclusions

Experience concerning the use of building information modelling for safety planning, especially concerning BIM-based site planning, was good and encouraging in both the case project test and in a pilot project. The BIM-based site plan proved to be a versatile visualization source and it was also useful in real projects. It seems that in the future the BIM-based site plan will constitute one clear case of building information modelling being used in the construction industry.

The modelling software developed for building design can also be used for BIM-based site planning. Nevertheless, there are certain strengths and weaknesses in the software with relation to this use. For example, suitable tools for land surface modelling can be found today in architectural modelling software, but better tools for an updated site plan and safety planning can be found in structural modelling software and so-called 4D-applications. In addition, the site equipment and safety utilities needed in BIM-based site planning, have received little attention in object libraries included in modelling software. One crucial precondition in regard to BIM-based site planning in real-life projects would be that planner has ready 3D descriptions for repeatedly used site equipment to facilitate and accelerate the site planning.

4D production planning is a breakthrough in construction production management, and at the same time an opportunity to integrate safety management more intensively in the construction process. Connecting safety tasks into the 4D-model opens up entirely new opportunities to review and evaluate safety as part of construction production, to increase cooperation in safety planning, and to enhance safety communication. In early stages, essential safety arrangements to be modelled and included in 4D-modelling are related to protection against falls, such as guard rails, protective lids and safety harness anchor points. Significant potential is also related to BIM-based planning of scaffolding and form work, and modelling other temporary frame supports. Besides 4D safety planning, one significant development area is managing information concerning construction site status with the help of 4D-models. This offers opportunities to identify safety risks caused by changes and interruptions occurring at the building site. BIM-based plans also provide a basis for developing computer-aided analysis aimed at improving safety, for example in relation to crane reach with different loads. In addition, BIM-based safety plans provide illustrative 3D-presentations, which should be used in safety communications all the way to the employee level.

The proposed BIM-based methods support the vision of IDS (Integrated Design Solutions) by providing opportunity to use the same modelling software and the models created in the BIM-based design-build process also for site and safety planning. The methods also increase collaboration in safety management and integrate safety data with other construction data. Nevertheless, significant further development in the research area is needed.

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