# 4D-BIM for Construction Safety Planning

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## Abstract

This paper explores the chances for having 4D-BIM (four-dimensional building information modelling) as a central technology for construction site safety related planning activities. The paper is grounded in the on-going research project called BIM Safety (BIM-based Safety management and Communication System). As an intermediate result of the research project, it is presented how four-dimensional site layout and safety related planning activities can be carried out by using the currently available BIM software. Besides of the tools and procedures, findings concerning potential safety related use-cases to be tested in the pilot projects will be presented, as well as expected challenges and benefits of utilization of 4D-BIM. BIM technology can be used as a starting point for safety planning and communication. The utilization of 4D-BIM technology can result in improved occupational safety by connecting the safety issues more closely to the construction planning, providing more illustrative site layout and safety plans, providing methods for managing and visualizing up-to date plans and site status information, as well as by supporting safety communication in various situations, such as informing site staff about coming safety arrangements or warning about risks. The main objective of the BIM Safety research project is to develop procedures and use of BIM technology for safety planning, management, and communications, as part of the 4D-construction planning. Piloting BIM-based procedures in real on-going building projects is an essential development method that will be used in the research project. The project started at April 2009 and will be going on till April 2011.

**Keywords:** construction planning, safety planning, building information modelling, 4d, site planning

# 1. Introduction

BIM-based construction production planning and 4D simulation increases rapidly in Finland on the basis of building information models created in design and engineering phase. Nevertheless, even in the cases of most advanced construction process modelling the main focus is usually merely on the scheduling of parts of the building's frame, as well as planning and visualization of corresponding work tasks. Thus the site processes including safety and logistic aspects are practically ignored although some practical experience on BIM-based site layout or area planning exists.

Safety planning can be seen as a part or dimension of the construction production planning. In several other disciplines it has a key aspect position in the field of production planning. Safety planning has been carried out to a certain extent separately with other production planning and control and for example, a concrete falling protection plan is not created in all projects. Safety management related communication to the level of employee is challenging under the site circumstances. Partly for these reasons the construction accident rate has remained high compared to other industries. In Finland, one in four fatal occupational accidents takes place in the construction field. Several previous studies show that the problem of the high accident rate and hazardous activities on site has been identified in many countries, for example Vacharapoom & Sdhabhon 2009.

BIM Safety project continues the work started within the earlier TurvaBIM- research project (Building Information Model promoting safety in the construction site process, TurvaBIM 10/2007 - 2/2009). The main results of the TurvaBIM project were the three dimensional BIM-based site layout planning procedures and their testing. A static three-dimensional site layout plan was considered as a basic method for creating a BIM based site plan, in which case a site plan is created for various construction stages.

The on-going BIM Safety research project aims to develop and test solutions for the planning and management of construction site safety using more dynamic 4D site models. This means that construction schedules are linked with i) the building parts, ii) the temporary structures, and iii) site production equipment. BIM technology will be applied to safety planning, safety management and safety communications, and these activities will be integrated into the 4D-construction management (more information available at the project web-site http://www.vtt.fi/sites/bimsafety/).

# 2. Method

The BIM Safety research project encompasses action research approach where the piloting of designed BIM-based procedures in real on-going building projects will be the most important experimental task. At the first stage of the project, preparation work for piloting has been carried out including literature study, safety hazard record analysis, pilot planning, hands-on modelling testing, and tool development in co-operation with the research partners. Additionally, work concerning possible technologies for BIM-based or mobile safety communication at site has been started, a practical demonstration using available technology being a target.

Literature study and analysis of records of real safety hazards/accidents has been carried out to find out the major problems of occupational safety at construction. At the next stage the most promising opportunities to progress these safety problems with the help of 4D-BIM are to be tested in pilot-cases.

Generally, two main approaches for improving construction safety and security have been identified and used as starting points for this research:

**1. Proper Collaborative Planning.** Detailed construction site layout planning is perhaps the best practical example of this paradigm where site safety issues are proactively studied and communicated for creating working conditions where chances for accidents are minimised. It is important to take into account the need for incorporating all partners and their knowledge for the facilitation of high level committed safety securing activities.

**2. Sufficient Awareness.** This refers to continuous reviews of working conditions and relating potential hazards. Nowadays experienced site foremen and project managers are carrying out these activities intuitively. However, the advanced BIM technology based solutions encompass potential for reaching new performance level.

The Tekla Structures software package was selected to be the main research platform. Functionality tests concerning 4D-features in the selected modelling software Tekla have been carried out using Tekla structural model of a completed building project. Testing has been carried out to assure that the selected software can be used for safety planning and visualization in the coming pilot projects. This far there is real experience of use of the software related to planning, modelling and visualization of permanent construction assemblies of buildings only. As part of the modelling and visualization tests a set of suitable visualization rules were developed for temporarily used safety equipment. The rule set can be used and developed for different purposes in pilots. Additionally, availability of safety related custom components for the selected modelling software has been surveyed in the project, and needed missing site layout and safety planning components created in cooperation with the contractor.

At the next stage the usability and potential of BIM will be tested and studied in on-going building projects, and feedback collected concerning experience in the use of BIM for safety planning, management and communication. The development work has recently started in the first pilot project by supporting the safety planning. Construction work of the pilot project has started at January 2010 and is scheduled to be completed at January 2012. The second pilot is expected to be started during the second half of the year 2010.

## 3. Recent research and developments on BIM based safety solutions

Occupational health and safety management is a multi-dimensional field. The nature of its research, development and their results has a heterogeneous nature with links to the basic sciences such as psychology and medicine, and, besides of that it has strong links to the applied sciences such as education, engineering and management. Current interest in BIM and more generally in new technology are gradually bringing ICT and its applications to the field of occupational health and safety management. This can result in solutions that can be characterised as *engineering controls* and *health management system as part of business decision making*. The need of such solutions has been discussed by Gibb (2006) and Williams (2006). The overall interest around BIM and its applications have created wide variety of attempts some of which have also addressed occupational safety issues. The identified categories of such research and development are presented on the following.

*Education and training*. Visualization technologies and facilities, interactive learning environments having BIM models as central units (Alshawi et al, 2007; Vries et al, 2004).

*Analysis and anticipation of unsafe conditions*. Rule based hazard identification from 4D CAD Model (Vacharapoom & Sdhabhon, 2009), Dynamics of different site operations causing safety risks to each other (Rozenfeld et al, 2009). Analytical procedures based 4D simulations to reveal potential safety threats (Hu et al, 2008).

*Monitoring of conditions*. Use of RFID, mobile and augmented reality technologies for obtaining real-time data from construction site and for comparing those to the plans (Sørensen et al, 2009; Hakkarainen et al, 2010; Golparvar-Fard & al, 2009)

*Communication and collaboration*. BIM centric practices have been found to have significantly beneficial to the industry (Mahalingam et al, 2009). BIM technologies are generally seen as means to facilitate communication in relation to safety aspects (Eastman et al, 2008; Suermann & Issa, 2007; Heesom & Mahdjoubi, 2002; Khanzode & Staub-French, 2006). Automated system approaches for getting good quality work instructions have been studied by Mourgues and Fischer (2010).

Recent advancements of BIM technologies are providing decent starting points for the development of solutions for pro-active site safety planning and management. This means that the user is not just a passive observer of potential problems but he/she has all necessary functions available as efficient solutions enablers for improving the working conditions. The research effort presented in this paper falls into the category of pro-active site safety planning and management solutions. Compared with the earlier research we consider that the selected research approach having *collaborative safety planning* and *safety awareness building* as starting points can result in novel contributions by combining safety management functions with appropriate BIM solutions.

## 4. Opportunity to promote safety with the help of 4D-BIM

Recent research concerning occupational deaths in Finnish construction concludes that the major safety problems are associated to falls, moving on site from one location to another as a part of work tasks and installations of prefabricated units (Lappalainen et al 2007). Inappropriate work planning and supervising, insufficient communication between different partners and lack of safety training and practices were identified as key contributing factors behind the named accident types. Reasons of disability pensions of retired construction workers indicate that those individuals have suffered from sharp heavy load lifting. At the first stage the BIM Safety research focuses on these special major problems of occupational safety at construction sites in Finland.

BIM solutions include many attributes which offer several interesting opportunities to promote safety at construction sites. The visualization offers a totally new tool for risk assessment, planning, introduction, safety management etc. The use of visual BIM encourages other partners to involve both risk assessment and planning. These partners are designers, other contractors, safety specialists, occupational health care etc. Additionally 4D-BIM means improved chances to make alternative preliminary plans of different construction stages and tasks. It can also produce better safety while safety matters are included in this planning process.

# 5. Approach and tools for 4D-safety in the BIM Safety research project

The main target of the research project is to develop BIM-based solutions for construction site safety planning and management as part of the 4D-construction management. Safety planning procedures and particularly those by the contractors have been studied to find the planning tasks which could be supported by BIM. Construction events/tasks and the related necessary technical solutions including safety are to be modelled into the building's 4D production model, in which the structural model produced by the structural engineer is used to serve as the starting point. Safety planning is part of the whole construction planning, a perspective which will be taken into account in the methods developed. This complies also with the current safety management principles. The strength of using BIM-based tools is the opportunity to use building information models created in the design process as bases for BIM-based production models also. Additionally, use of BIM technology in real construction projects increases all the time and is a possibility to develop safety planning when it is integrated with BIM-based 4D construction planning process. According to Vacharapoom & Sdhabhon (2009), many previous international research studies have also addressed the lack of integration between construction and safety. They see various 4D CAD models as innovative tools to link construction design and planning, as well as incorporate safety related activities into the construction schedule.

In Finland building information modelling started in architectural design, but has become more common also in structural and HVAC engineering. The use of modelling has been characterized by the fact that the models created in the design and engineering process are tried to be advantaged for various purposes. Already in design process an architectural model has been used as a reference for engineering modelling and for quantity takeoff by contractors. Today use of models for construction planning and management including safety purposes is at the early stages. Models created in the design process can be developed to serve site and safety planning by adding the planned temporary site and safety arrangements to the model created in the architectural design or structural engineering stages. In some other countries, e.g. in USA and China, it’s more common that contractors has their own CAD expert to create models, because BIM-based tools are not commonly used during design work and as a result there is no models available for contractors needs.

Several BIM-based software packages have nowadays well established positions and are used by design and construction professionals. Such tools form natural starting points also for BIM-based site layout and safety planning. Tekla Structures and Tekla Construction Management software were selected for testing and piloting tasks of the BIM Safety project. Tekla Structures is a structural engineering and modelling software and Tekla Construction Management is meant for use on site. Modelling software covers tools for steel, concrete and precast element structures modelling to the detailed level. Both software includes rather sophisticated 4D-tools, and especially those features important for site use are being developed further all the time. A special advantage of using Tekla software for safety planning is the opportunity to use the real structural model of the building project as a basis for safety planning. This model corresponds to the construction work at site including the assemblies like the building is designed to be built up. Nevertheless, development work has been needed to find the ways to apply the selected software for the proposed safety related purposes.

Beside Tekla Structures, other available BIM-based tools suitable for site and safety planning have been also studied. Examples of those are ArchiCAD and Revit. From the viewpoint of safety, the strengths of these software include suitable tool for landscape modelling and visually high level plans, and a weakness is lack or limitation of 4D-features. Google SketchUp has achieved a relatively high popularity of professional use, especially in architectural sketching, but in USA some contractors have also been using it for site planning and to support project communication (http://sketchup.google.com). Its popularity seems to be based on low cost, easiness of use, visually high level plans, and support to easily share 3D-components modelled by users with the help of Internet-based 3D Warehouse. Additionally, one special feature is the opportunity to place the 3D-models of buildings to Google Earth. BIM used on site can also be a combined model created e.g. by the help of Navis Works software. Navis Works does not include any modelling tools but can be used to combine models of various design parties to create combined models of rather small file size, to review these combined building designs, for clash checking and for creating 3D or 4D visualizations.

# 6. Piloting 4D-BIM for safety in the BIM Safety project

## 6.1 Developing 4D-BIM for safety purposes

Before the start of the actual piloting, functionality tests concerning 4D-tools in the selected modelling software Tekla Structures were carried out relating to the modelling and visualization of safety tasks and corresponding temporary equipment. The central tools at the software that supports the use of a BIM at construction phase are called model organizer, task manager and project visualization tools. Testing was needed to find out how the temporary safety related structures and equipment can be managed with the help of the selected software. This testing focused on 4D falling protection planning, especially scheduling and visualisation of safety railings. As a result of the testing, a BIM-based 4D safety railing demonstration has been created.

Technical 4D testing was carried out by VTT using Tekla Structures (version 15) modelling software and data from a completed residential building project called Mäntylinna (the developer and the contractor in this case is Skanska). The original Tekla structural model was created by the structural engineer Finnmap Consulting, and it served as a base for modelling safety tasks. Before actual safety planning, the surface of the site area was roughly modelled with the help of architectural modelling software ArchiCAD and combined into Tekla model as a reference model. Next safety railings were modelled to the edges of the intermediate floors and balconies with help of roughly modelled/semantic railing components. To create 4D-BIM, tasks corresponding erection of precast elements and related safety railings was created into a task list in the task manager -tool. After scheduling the tasks and linking them with the corresponding parts in the model, and creating suitable visualization rules, it became possible to visualize project status on any selected review-date on the planned time scale (Figure 1). This view describing current or planned status of the construction project on a specific date can be easily distributed to any project participant as a snapshot produced with one press of a button.

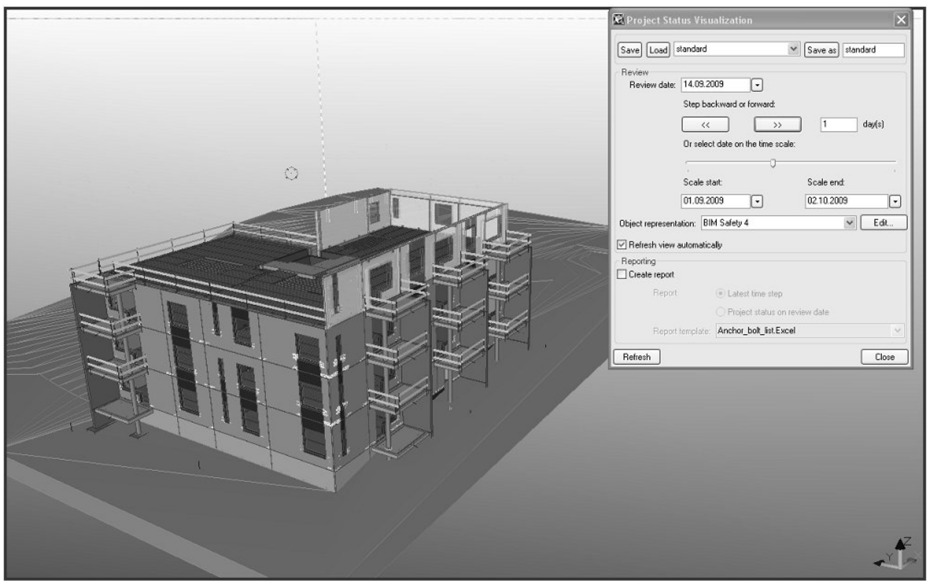


Figure 1: 4D safety railing visualization as part of precast element erection visualization.

4D visualization requires appropriate set of visualization rules, by which the software is told which parts are to be displayed and how. This far there is real experience of use of the software to permanent construction assemblies of a building only, and the new thing in the demonstration is including temporary safety railings in 4D planning and visualization. In the test, the following object groups and representation styles were defined for visualizing status of safety railings on any review date: railings to be assembled today (shown as red), other railings needed today, but installed earlier (colour by class, meaning displayed with the same colour as modelled), and railings taken away (shown as hidden). Parts of the model are filtered to each object group by rules relating to status of the corresponding task on the review date, and rules are set in object group dialog box (Figure 2). The rule set can be used and developed in different purposes in pilots.

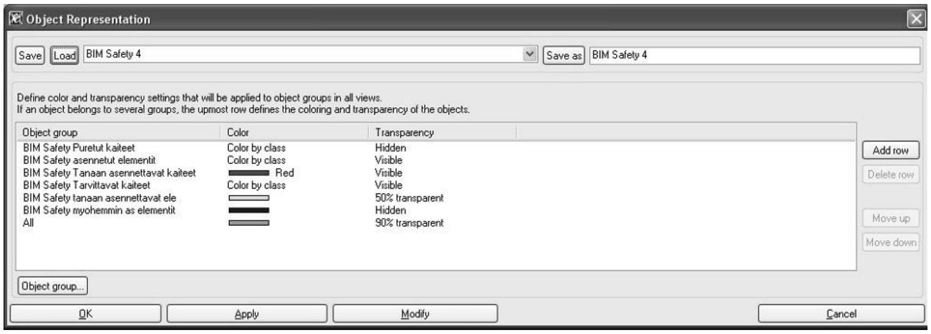


Figure 2: Object representation groups for the precast elements and safety railings in the 4D safety railing visualization test.

Object and component libraries in various modelling software aim to provide ready-modelled 3D descriptions or structures to facilitate and accelerate modelling of building components that can be installed permanently into a building. However, the site equipment 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. (Sulankivi & al 2009)

The software used here has originally been developed for structural engineering and does not include customised components for site safety planning. Availability of safety related custom components for Tekla Structures in other sources was studied in the project, before starting to create needed site layout and safety planning components in cooperation with the contractor. The next figure presents some examples of custom components created for site layout planning (Figure 3). Custom components that correspond to the real safety railings planned to be used in the first pilot project are being developed.

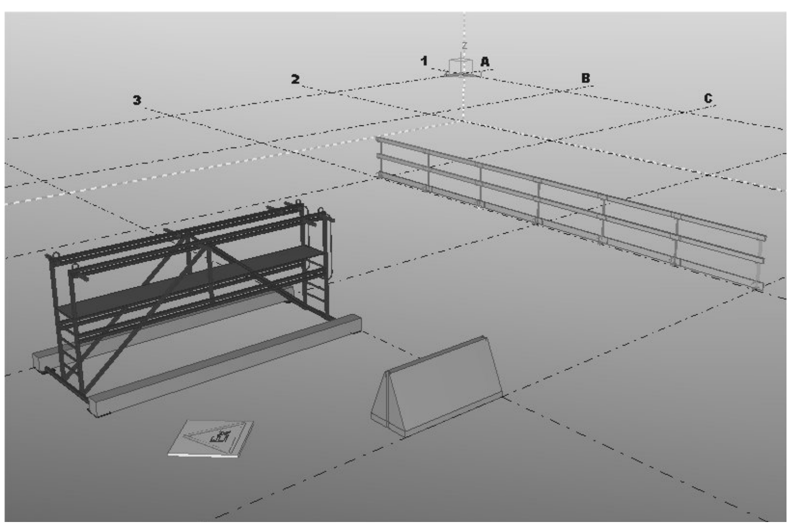


Figure 3: Examples of BIM Safety custom components for site planning**.**

At the next stage of the research project, the experience from 4D visualization test will be used for creating a real 4D falling protection plan for an on-going pilot construction project.

## 6.2 Utilization of 4D-BIM in the first pilot project (planned testing)

New office premises of Skanska corporation have been selected to be the first pilot project in BIM Safety research effort. This construction project is located in Helsinki Finland. BIM-based site layout and falling protection planning, as well as use of BIM for risk assessment, orientation guidance and safety communication are considered to be the development areas related to BIM and safety in this first pilot.

BIM-based site layout planning is under way by the contractor, and the development work related to BIM-based falling prevention planning has recently started. Research team has been carrying out preparation work for conducting 4D site layout and falling prevention plan in cooperation with the site organisation, by attending safety planning and modelling the railings planned to be used in the construction project. At the next stage a real BIM-based falling prevention plan will be created. That will be integrated with the real structural design and the scheduling of safety equipment will be based on the erection schedule of corresponding building assemblies. Consequently the target is to include a BIM-based falling prevention plan as part of the 4D-planning. This 4D model is aimed to be used to support safety planning, risk assessment, and safety communications, as well as for visualizing the project when introducing the project to site staff.

## 6.3 Expected benefits and challenges

Based on the first experiences concerning safety related tasks scheduling and 4D-visualisation using Tekla Structures, it seems that the temporary safety related parts can be included in 4D planning and visualization. Additionally, the user can define object representation and visualization rules quite flexibly to the purpose needed, e.g. by selecting which parts are showed and how (colour and visibility) in the visualization. However, some special features and requirements are related to BIM-based planning and 4D visualization of temporary structures, that have not needed to be taken into account when modelling and visualization has covered permanent building parts only. For example, if permanently installed building elements are modelled and scheduled, they will be visible in status-views of a 4D-visualization from the installation date forward. Temporary parts are to leave their position when they become unnecessary, or a permanent building part is to be installed at the same location.

In the first pilot project the target is e.g. to carry out more comprehensive BIM based falling prevention plan. That is expected to promote quality of planning and risk assessment, as well as support communication related to falling protection arrangements. As the safety railing modelling is implemented on the structural model it is possible to plan and manage also the details e.g. safety railing fixings. While all safety railing items are modelled the needed safety railing quantities can be calculated from the model.

The most significant weakness in tools identified so far is, that the time scale for visualizations is one calendar day (steps between review days), which seems to be too long time for ordinary building projects. That goes for scheduling tasks in task manager also, but possibility to define the assembly order of parts related to one task supports more detailed planning and information of installation sequence. Another identified problem is the lack of specific components for site planning, slowing down remarkable the utilization of the tool for site layout and safety planning in practice. When safety related components are created, it must be considered that they should be easy enough to model (insert to a BIM), and assemblies of parts in a component correspond to real installation and removing units at a construction site, to be able to carry out scheduling and visualization with help of 4D-tools. Additionally, it should be taken into account that pre-modelled components may be used as source of product and quantity information on construction site. Thus, there may be need to save specific product identifying codes or other information into the safety components, to be able to produce suitable quantity-reports.

# 7. Conclusions

BIM Safety project is revealing the special characteristics of safety oriented construction process planning. These special characteristics are requiring new functionalities that do not exist as such in the current BIM software. There are special requirements for modelling, scheduling and visualizing various temporary safety related structures if compared to those parts permanently installed into a building. Development work is needed for having workable and efficient site safety planning that would then fully capitalise the potential of BIM technologies and result in better accident prevention. In particular we see that the following functionalities should be in focus in the research and concerning development efforts by software companies.

- *Object and component libraries for site planning*: structural supports, site facilities (such as huts), large-scale temporary structures, main work equipment including safety equipment

- *Site planning functions:* Site layout planning with necessary spatial modelling functions, modelling land surface and temporary excavations, presence of detailed 4D simulations (time-steps < one day)

- *Safety analysis procedures:* space occupancy/realise by various resources, space usage clashes, analysis of transportation and movement routes, analysis of fixing and installation procedures, analysis of selecting safety equipment

From the process –view, one of the basic findings has been that detailed falling protection planning has traditionally not been carried out. A concrete falling protection plan is not created in all projects, and if it has been done, various safety guardrail types planned to be used, have been marked usually to a 2D-plan only symbolic by different colours. BIM-based safety railing planning requires more detailed falling protection planning, and is closely related to the planning of installation order of the prefabricated or cast in place structures of the building. As a result of more carefully safety planning construction site safety will be improved.

The conclusions above demonstrate the intermediate findings according to the focus and direction of the BIM Safety research project. The empirical work onwards focuses on trials in pilot construction project where 4D BIM based site safety planning procedures are to be applied. Identified further testing and development needs are for example, to facilitate the safety related modelling, producing quantity information for safety equipment directly from BIM, and to test the potential of BIM-based falling protection plan to support construction work at site and to improve site safety.

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