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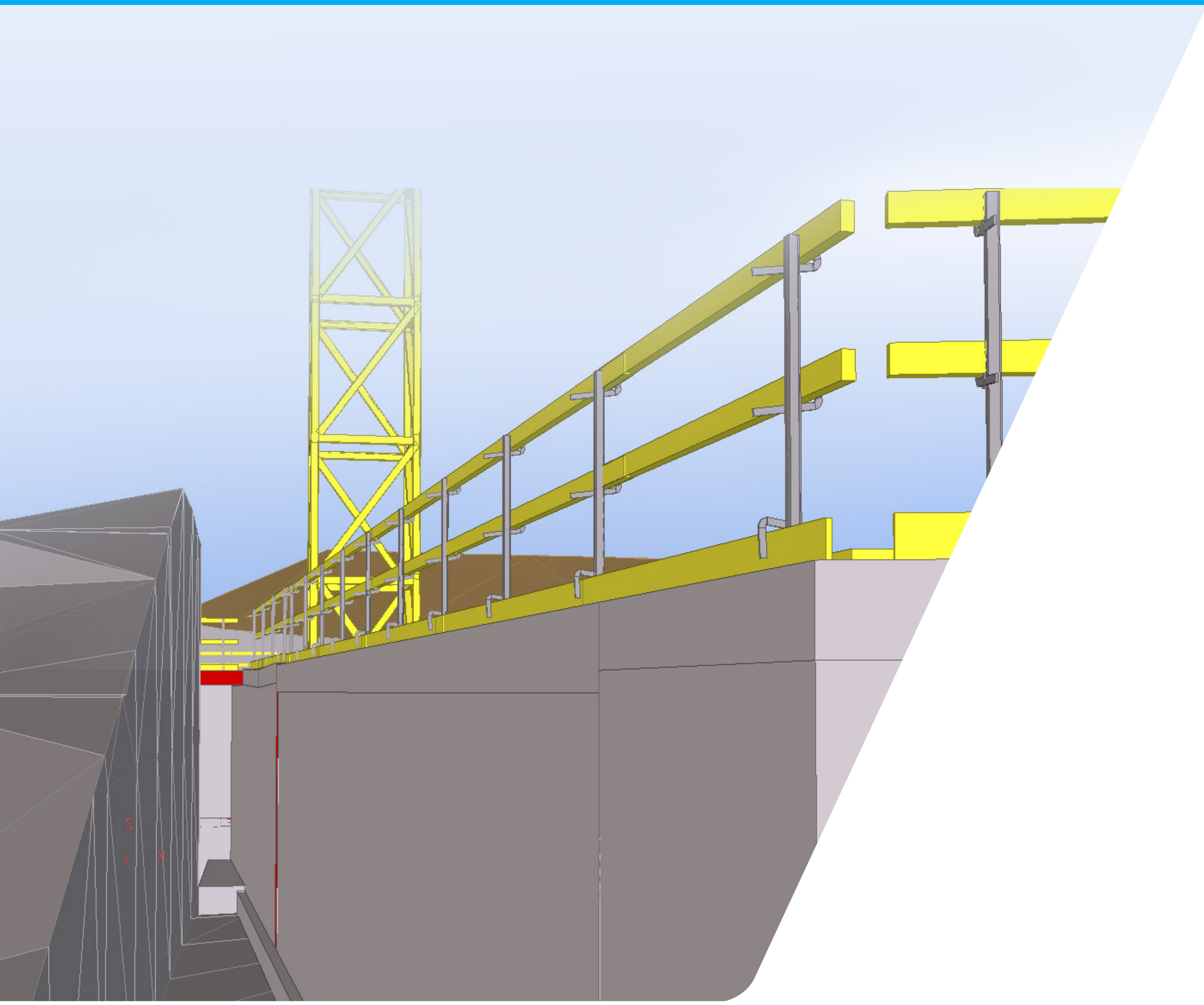

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BIM-based Safety Management and Communication for Building Construction

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Abstract

This report presents the main results of the BIM Safety research project (BIM-based Safety management and Communication System) carried out April 2009 – June 2011. The main objective of the research was 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 was the main development method used, meaning hands on trials with the state of the art software, consultations and support by the participating companies, and feedback data collection from case projects. All together seven different field trials were carried out to study the possibilities and development needs of BIM technology from the viewpoint of safety.

BIM technologies are moving from the worlds of architecture and engineering to the arenas of construction companies and other players in charge of construction operations. 4D-BIM was recognised as a central technology for construction site safety related planning activities, connecting the safety viewpoint more closely to construction planning, enabling visualization of safety arrangements in construction projects at different moments of time, and providing more illustrative site plans for communication. As a starting point it was considered that BIM technologies could present a new way to solve still existing site safety problems.

The experiments have been sources for an improved understanding to apply BIM technologies for the purpose of site safety planning and management. The BIM-based site layout plan itself, or as bases for crane reach/collapse analysis, proved to be a versatile and useful visualization source, and is constituting one clear use case of building information modelling in the construction industry. BIM-based falling prevention planning, various 4D visualizations including temporary site equipment and arrangements, as well as visualizations concerning demolition work are in their early stages. However, these seems to have poten-

tial to become novel and good visual support for planning, discussing, managing and communicating safety related issues at building site. Additionally, there are existing and arising new technologies that can be used together with BIM-based 3D or 4D material to promote safety, such as information display screens and virtual reality rooms (such as the tested CAVE). However, more experience is needed concerning 4D safety simulation as well as further development of modelling tools such as object libraries, and site progress/status data recording and storing solutions to broaden the use of the BIM-based safety planning in the design-build process.

Preface

BIM Safety research project was a part of The Safety and security programme of Tekes – the Finnish Funding Agency for Technology and Innovation. The main objective of this programme is to help Finnish enterprises and researchers to develop international business activity and competence in safety and security technologies, services and solutions. The topics of the programme cover national, industrial and citizen's safety and security aspects.

Via deployment of BIM technologies the whole built environment sector is facing a need for a very big transformation where new processes, professional roles and organizational changes are taking place. This is also a significant opportunity to improve the sector itself. The BIM technology itself and how different partners, professionals and trades can take advantage of it can also be an important driver to improve significantly construction site safety for which in general the whole sector is infamous not only in Finland but in numerous countries worldwide despite of looking at either or highly developed countries or developing countries.

The characteristics of modern construction business, its projects and site operations are very challenging. In practice construction projects means complicated interplay of numerous partners and companies. Construction site workers are increasingly multinational in most countries. This is a relatively new thing in Finland but as a phenomenon it is strengthening all the time. At the moment on construction sites in southern Finland over 50% of workers can be from abroad, e.g. from Estonia. This complicated set up is also a challenge for site safety management. BIM technology enabled new tools, communication chances and procedures addressing site safety aspects can in an effective manner help us to promote top quality site safety planning even in a highly multinational and dynamic environment.

The BIM Safety project has produced new understanding and concrete results that can provide useful next stepping stones for companies and research community to reach the next level. With its demanding characteristics and challenges the construction sector can also provide an interesting benchmarking possibility to other business sectors. Therefore we would encourage representatives of other sectors as well to get familiar with the results we have gained.

The BIM Safety research project have enjoyed substantial support from Tekes and from our industrial partners in the terms of finances and chances to carry out exciting trials in real construction projects. Our industrial partners were Skanska Corporation, TVO Ltd, Tekla Plc. and A-Insinöörit Ltd. We wish to acknowledge all pilot project participants and site staff for their support in making the test trials and surveys possible. Furthermore, we would like to express our gratitude to our research partner Finnish Institute of Occupational Health with whom we have had most fruitful co-operation.

The executive steering committee of BIM Safety research project provided very valuable support and stimulating guidance for our work from which we are very thankful. The members of this steering committee were Tiina Koppinen (Skanska Corporation), Timo Leppänen (A-Insinöörit Ltd), Raimo Niemelä (Finnish Institute of Occupational Health), Juha Riihimäki (TVO Ltd), Jukka Suomi (Tekla Plc), Ilkka Tahvanainen (The Finnish Work Environment Fund), Antti Tyrväinen and Kari Hiltunen (Tekes), and Heikki Kukko (VTT).

Tampere October 2011

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Executive summary

BIM technologies are gradually moving from the worlds of architecture and engineering to the arenas of construction companies and other players in charge of construction operations. Furthermore the widening use of BIM solutions won't stop here but is to cover various needs and operations taking place throughout the building life cycle. Still at the moment the BIM tools and their features represent very much the needs and requirements of their main user groups who are those in charge of designing the end product. The needs of construction companies are quite different. Construction planning, site operations and their control represent areas where the focus of construction professionals lies. Also these are origin of new kind of objects and features that can be found only partially in the current tools.

The research described in this report is addressing the possibilities of BIM-based procedures and needs of construction professionals for BIM tools. Site safety planning and management procedures are getting a special attention and form the main research viewpoint. As a starting point it was considered that BIM technologies could present a new way to solve still existing site safety problems. The research project behind this report, known as BIM Safety research project, was carried out within the period April 2009 - June 2011 by research team representing VTT Technical Research Centre of Finland and Finnish Institute of Occupational Health. The research team considered the following as the main ideas for using BIM for improving site safety:

1. **BIM-based safety planning:** This covers site layout planning and falling prevention planning, which are required by authorities at some level for example in Finland. BIM can be used also to support planning of work tasks that include remarkable safety risks, e.g. form work.

2. **Risk analysis and safety related evaluations of plans with help of BIM:** BIM can be used for risk analysis and safety related evaluations

of plans first visually, and in the future for more automated risk identification.

3. **3D- and 4D-visualizations in safety related communication:** BIM-based visual 3D presentations promote the level of communication in all stages of construction projects. From viewpoint of safety, for example when introducing the project to site staff, presenting safety arrangements related to a specific work stage or task, and for warning about current hazards.

4. **Other use of BIM-based plans at site:** Examples of those are viewing the BIM-based plans to gain a common understanding or to see the details, or product and quantity information.

All together seven different field trials were carried out during the research project to test and demonstrate the presented ideas (Table 1).

Table 1. Field trials for studying and demonstrating BIM technologies for construction safety planning, management and communication.

Field trial	Results
1. Site layout plans and crane reach visualization related to a crane collapse	BIM-based site layout models (spatial arrangements, temporary facilities and structures), and visualizations of risk areas related to any possible crane collapse at site
2. Visualization of wall demolition procedures	BIM-based model for visualizing wall demolition work.
3. Modelling of safety railings	BIM-based detailed models with 3D guardrail components
4. 4D-visualization of floor form work with needed falling prevention solution	BIM-based 4D model of form work for one concrete casting area/segment
5. Expert analyses with the aid of virtualised construction site	Experiment of visualizing the falling prevention plan in multi-wall virtual reality room (CAVE)
6. Automatic safety analysis using BIM technologies	Knowledge about automated safety checking of buildings to be built using model checker software (SMC)
7. Site safety communication and BIM	Pilot use of LCD information displays on a construction site for conveying safety relating information.

The following provides an overview of the field trials.

Site layout plans and crane reach/collapse visualization

Elements of a BIM-based site layout 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 arrangements, such as area reservations for material storage, and 4) visualizations of safety related issues, such as illustration of risk zones.

Examples of BIM-based site layout plans are the plans created in Pilot Project 2 (PP2) related to the research. This construction project is an enlargement of an industrial building in Eurajoki Finland (the client TVO). PP2 was fully designed using 3D building information modelling, and included challenging cast-in place structures to model and to build, and nearly 30 meters high concrete wall between the old and the new part of the building to be demolished in two phases. In this construction project both the site engineer and the BIM Safety research team carried out site layout planning experiments using BIM software packages ArchiCAD and Tekla Structures.

Since Tekla Structures software package has been already developed towards the needs of construction operations including for example 4D-simulation tool, it proved to be more suitable for dynamic site layout planning compared with another type of software package purely meeting the needs of designers. Tekla Structures was used at the research for creating a BIM-based site plan that covered both the elements 1–4 of a BIM-based site layout plan listed above, and representation of status of the buildings/construction work at the same time and in the same Tekla-model.

3D visualization methodology developed in the previous research project (VTT's TurvaBIM research project) was utilized in this pilot project for evaluating risks associated with the fall/collapse of the crane. The visualization was based on the site engineer's site layout plan, modelled using ArchiCAD, and the same software was used for the crane fall visualization as well (Figure 1).

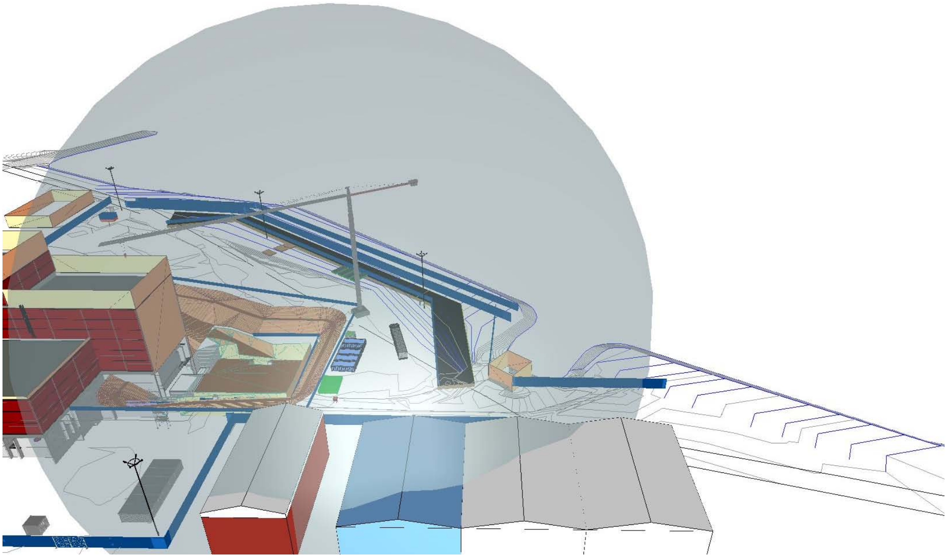

Figure 1. A view to the visualization of the second fall case.

On the basis of tests carried out in this research effort, some clear strengths were identified in the software package (Tekla Structures) where the building model can be equipped with objects that do not represent actually the final product itself. This means that when the status of the construction work concerning the permanent building parts was presented, the needed temporary construction equipment could be included and presented by the same BIM-based status view. On the other hand/vice versa, together with 4D model view presenting planned or realized construction work status, the site status including temporary parts around the building could be presented at reviewed moment of time.

From the viewpoint of BIM-based site planning, the weaknesses of the structural modelling software were the lack of ready-modelled site planning components, the lack of visualization tools such as perspective “camera view tools” and animation tools to create videos, as well as the weak visual appearance for this kind of use. The site layout plans do not look as realistic as those modelled using architectural modelling software (e.g. ArchiCAD).

Visualization of wall demolition procedures

BIM-based modelling and 4D-visualization presenting the planned phases and sequence of wall demolition work was experienced in PP2. The lower part of this wall was demolished at the early stages of the project, and the upper part was to be demolished later.

First, a BIM-based visualization was carried out relating to the demolition plans of the lower part of the wall, and it was used for the communication between the contractors at site. The structural engineer and the contractors planned the demolition work first using traditional methods. After this, BIM-based modelling and visualization was carried out at VTT based on the traditional 2D-drawing and textual specification describing the planned demolition parts, order and equipment. Demolition parts were modelled using BIM-based modelling software Tekla Structures 15, and special tools (Task Manager and Project status visualization) of the software for setting up the 4D visualizations.

Later on another visualization was built up for evaluating two alternative sequences of demolition work concerning the upper section of the same wall. Two alternative sequences of demolition work were visualized for decision-making. The latest tools available in a development version of the modelling software were tested at the same time for modelling the demolition parts of the wall. These tools are "*Wall manager*" and "*Seam controller*" tools being developed for concrete element walls by Tekla corporation. The second visualization (Figure 2) covered also testing and utilizing unlimited colour options provided in the software (Tekla Structures 17).

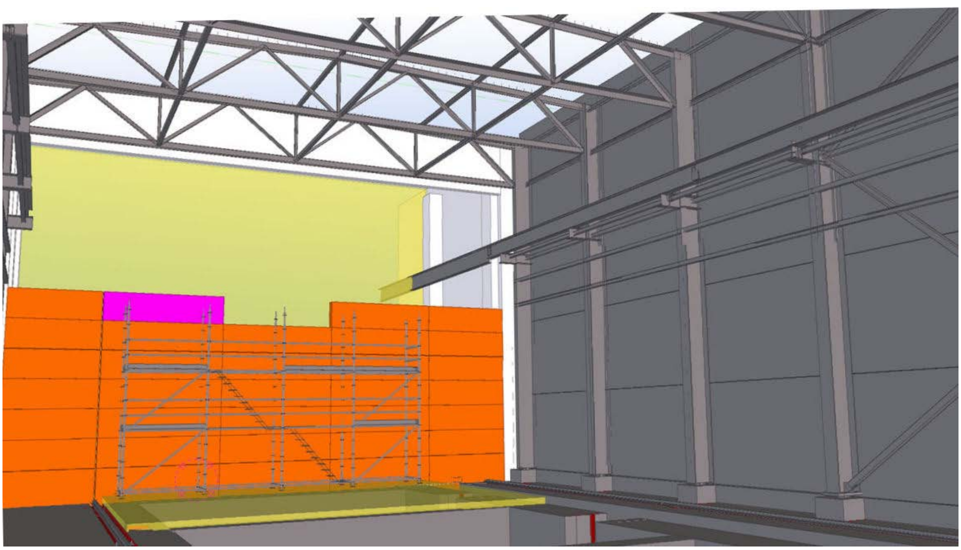

Figure 2. Visualization of the second phase of the wall demolition work using new BIM-based tools and more realistic colors together with some highlighted parts.

Developing BIM-based falling prevention planning was one of the main targets of the research project and in focus in the first pilot construction project related to the research. The pilot project 1 (PP1) was an office building construction site in Helsinki, Finland (new office premises of Skanska). Also this project was fully designed using 3D building information modelling, Tekla Structures 15 being the structural modelling software. The project's structural model and the same software was used in the research as bases for detailed falling prevention planning, including temporary safety railings and floor opening coverings.

Falling prevention planning consists of many different operations and covers more than just safety railings and floor opening coverings, but those were considered as obvious subjects to model into a building model. As a starting point 3D guardrail components were modelled to be used in BIM-based site safety planning. These safety components (Tekla Custom components) were used in PP1 for detailed BIM-based falling prevention planning based on the Tekla structural model of the building (Figure 3). All safety modelling was conducted at VTT, and the main modelling viewpoint in this effort was how the site staff could plan falling prevention in advance.

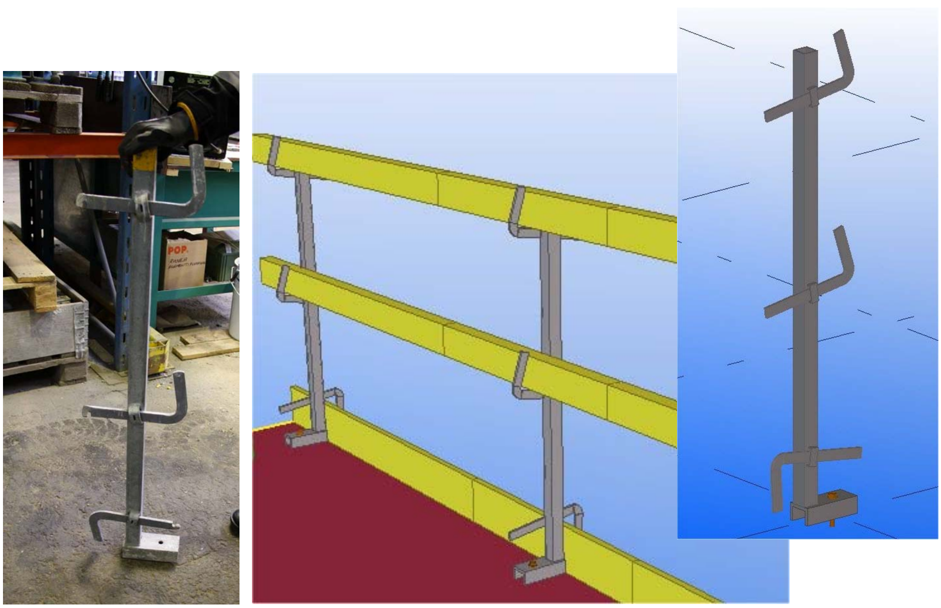

Figure 3. Safety railing equipment modelled for the first pilot project (guardrail post for surface installation used together with timber railings).

A comprehensive BIM-based falling prevention plan was expected to improve 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.

If considering the suitability of the used software (Tekla Structures) to carry out BIM-based falling prevention planning and 4D-visualization, the most significant limitations were 1) lack of tools to easily manage so-called temporary structures (such as safety railings) and 2) one calendar day is the smallest time unit for visualization of construction work at the moment (time frame/steps between review phases in a visualization), which seems to be too long time for ordinary building projects. Even one can define the sequence of those parts that are to be installed during one day, this sequence can't be displayed in the corresponding 4D visualization. This made also the above-described visualization of wall demolition work complicated. In the real schedule several parts were planned to be demolished during one work day, but one calendar day was needed for each demolition part in the 4D visualization, to be able to show all demolition phases.

Today, lack of specific components for site planning is also a problem. This slows down remarkably the utilization of the tool for the 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 premodelled components may be used as source of product and quantity information on construction site.

4D-visualization of floor form work with needed falling prevention solution

In PP1 also form work and related falling prevention solution was modelled concerning one concrete casting area/segment. 4D visualization was also prepared for this model, presenting roughly the progress of the work at site during the planned time period. Tools used were again 4D scheduling and visualization tools in Tekla Stuctures.

The safety railings were modelled in detail, but the casting mould parts were modelled only in a rough manner for the visualization. This is since the final mould supplier was not even selected at that time, and as a result the geometry of mould parts was not known in detailed level when the model was generated. The use of safety nets provided an interesting modelling task. The safety nets represent a novel falling prevention solution to be used during form work, and thus visualizing them could be even more helpful than modelling traditional solutions (Figure 4).

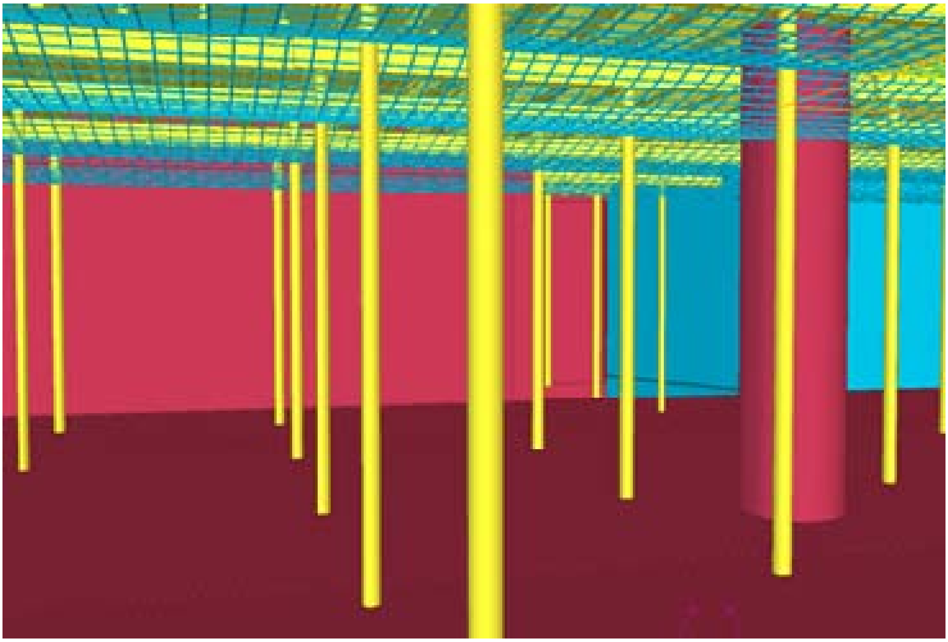

Figure 4. Modelling of safety nets for concrete casting formwork.

In pilot project 2, the aim was to test the modelling of form work in greater depth than in pilot 1. The aim was to model the geometry of the molds in more detail and corresponding better to the real plans, and to carry out BIM-based 4D construction scheduling for the mold parts in the structural model, together with cast-in-place concrete parts.

Since the mold supplier was able to make 3D mold planning, a technical test was carried out as a part of research to investigate the connectivity and usability of the supplier’s 3D mold plans in structural modelling software. The test revealed that a 3D mold plan can be combined with a Tekla structural model successfully. Similarly, under certain conditions, 4D scheduling and visualization can be carried out to the mold parts together with cast-in-place concrete parts of the structural model.

The molds that were modelled by the supplier were successfully combined and displayed in the structural modelling software (Tekla Structures 15) as a reference model. However, the mold system includes a lot of small parts, and it is essential to be able to select appropriate assemblies from the model (corresponding to installations at site) for 4D scheduling. Based on the technical test, this can be done if the model parts are modelled in the original modelling software using appropriately selected and named layers, because it is possible to filter reference model parts in the structural modelling software with help of the used layers. Additionally, a simple test visualization showed that the mold parts combined into Tekla as a reference and selected with help of layers, can be scheduled and visualized as a date specific representations, and the visualization colors can be selected as desired, just like for native Tekla model parts.

Expert analyses with the aid of virtualised construction site

This part of the research addressed the use of multi wall virtual reality room (CAVE) for analysing interactively the 3D and 4D models from site safety viewpoint. The CAVE environment was composed of three screens with rear screen projectors and multi touch table for controlling the vision and movement on the screens. The multi touch table was used to view 2D projection of the storey of building and then for moving inside the virtual building from one location to another. Basic movement functions were only applied in this research.

The visual evaluation of the falling prevention plan was done with Tekla Structures model presented on two screens in the CAVE environment. The virtual environment provides obvious values compared to a basic video projector presentation. A wider view of the model gave more realistic and natural scene even with normal projector presentation without any 3D stereoscopic visibility (Figure 5). Also the model didn’t have to be rotated or moved as often as with a narrower view. According to our experience this makes evaluation situation more relaxed for the group of people and is supposed to bring better results.

The visual evaluation of the falling prevention plan was done with a static model (a view from the 4D model, corresponding to a specific calendar date). The basic errors and deficiencies can be detected quite easily. In addition to the visual evaluation, all Tekla Structures tools were available. Also the 4D scheduling of the structures could be used for evaluating the work sequences, but the software would allow to present this kind of construction status visualizations only on daily bases, like mentioned previously. More detailed sequence analysis or animation at part level would be useful for evaluating risks.

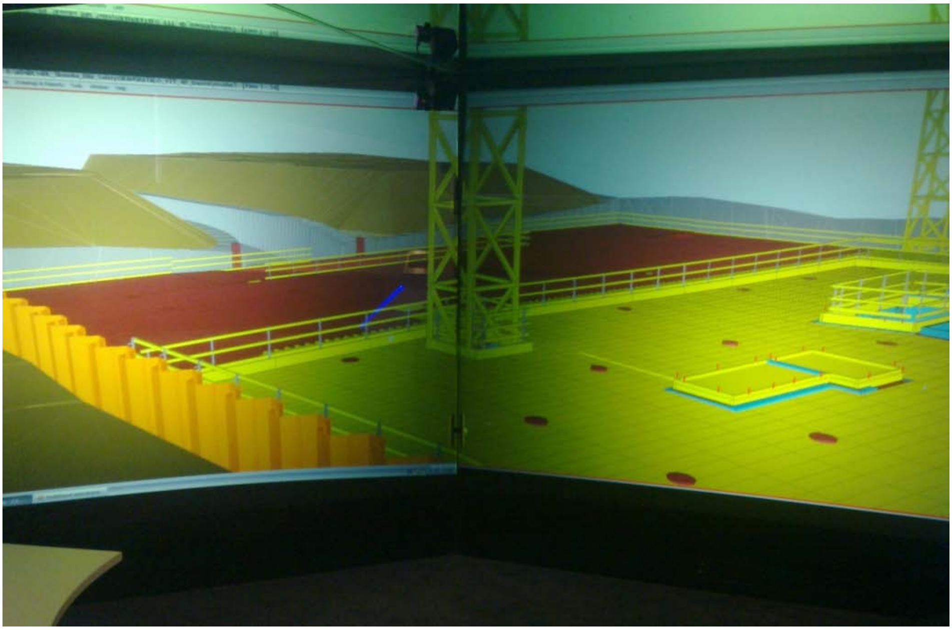

Figure 5. Two joined screens for viewing wide scene of 3D falling prevention models.

Automatic safety analysis using BIM technologies

BIM can be used for visual risk analysis, but its possibilities are broader and can in future cover automated or semi-automated analysis of BIM-based site and safety plans. A BIM-based 3D site layout plan was selected to be a subject to study possibilities of safety related automated checking. This exercise was carried out using Solibri Model Checker software (SMC). Already at the moment SMC is used in construction projects for checking the content and the consistency of BIM-based architectural, structural and HVAC-models, as well as for quantity take-off using the information take off -tool in the software.

SMC has a set of predefined and hard-coded rules for checking the basic conformity of building models. These rules with some appropriate modifications can provide useful functionalities also for safety analysis purpose.

Site safety communication and BIM

As a part of developing safety communication towards a more strategic direction, new means of communication should also be taken into account. Visual tools such as BIM are already a part of many construction projects and the possibilities in improving communication by using these new means should also be looked into.

In the PP1, a pilot study was carried out where two LCD information displays were placed at construction site premises and used for presenting weekly updated information relating to safety issues. The target of this pilot was to test usability of LCD information display screens together with novel material, to advance safety communication at construction sites and to experiment the use of 3D and 4D model views as a part of broader site safety communication.

One display was placed in the office hall and the other one in the staff break room, so that as many as possible of the site personnel would have access to the screens. The presentation shown on the display screens consisted of in average 25 slides, lasted less than ten minutes, and was run as a continuous loop throughout the day. The research team designed the content of the first presentation in co-operation with the contractor's safety personnel and site staff, and it was updated weekly with new information. Contents of the slides were gathered from the company's general site safety instructions and from site-specific plans and models, focusing on information that was important on the specific week, relevant for this specific site, and related to occupational site safety (Figure 6).

Figure 6. Example of slides in a presentation showing 4D-model views presenting the weekly plans.

The pilot trials lasted 4 weeks, after which feedback over the display screens and presentations was collected with a questionnaire. Based on the feedback, the information display was generally considered as a good source of knowledge on site affairs. Site staff reported they had gotten information about particularly dangerous spots on site, and the shown material had also improved their general understanding what is happening on site. Weekly timetable and accident reports were mentioned as good examples of useful information as well. After pilot trials, the site staff have continued the practice independently.

The research team consider there is promising possibilities related to the usage of information display screens on construction sites, such as keeping current safety issues visible at all times, providing equal, as well as visually high level safety information for all involved. Identified challenges and development needs include e.g. keeping site staff interested in the weekly presentations and establishing and spreading the practise to other building sites.

Conclusions and recommendations

BIM Safety project is revealing the characteristics of safety oriented construction process planning. More generally our effort was addressing the needs of construction management and those parties involved in it. Examples of such companies are construction companies and construction management consultants. BIM technologies are gradually moving towards construction operations and therefore it is getting more and more important to have a close look at the needs of key parties and professionals.

The most straightforward starting point for modelling are the software packages developed for building design. Nevertheless, they come with some strengths and weaknesses regarding the use of them for construction site modelling. Development work is needed for having workable and efficient site safety planning that would then fully capitalise the potential of BIM technologies. In particular we see that i) object and component libraries, ii) site planning functions and ii) site plan analysis solutions should be in focus in the research and concerning development efforts by software companies. For example, the 4D scheduling and visualization of temporary equipment is complicated with current modelling tools.

The BIM-based site layout plan itself, or as bases for crane reach/collapse analysis, proved to be a versatile visualization source and useful in real projects.

The BIM-based site layout plan is constituting one clear case of building information modelling being used in the construction industry.

BIM-based falling prevention planning, various 4D visualizations including temporary site equipment and arrangements, as well as visualizations concerning demolition work are in their early stages. However, these seems to have potential to become novel and good visual support for planning, discussing, managing and communicating safety related issues at building site.

Additionally, there are existing and arising new technologies that can be used together with BIM-based 3D or 4D material to promote safety. Examples of identified techniques are information display screens, virtual reality rooms (such as the tested CAVE), augmented reality solutions, and personal mobile devices.

Contents

1. Introduction

The usage of BIM-based construction production planning and 4D simulation is growing rapidly globally and also in Finland. These solutions are based on building information models created in the design and engineering phases. 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 building construction sector. There is a positive and encouraging experience of utilizing BIM technology in building design and production planning (Sulankivi 2004, Sulankivi 2005, Kiviniemi 2005). The use of integrated models where a product model and a production model are combined is mostly still in its infancy. These so called *4D production planning and management* solutions are step by step reaching more matured stage and therefore getting gradually more industrial usage. A lot of potential for variety of improvements has been consolidated to 4D, especially regarding its suitability for solving conflicts and preventing problems pro-actively in an effective manner (Porkka & Kähkönen 2007).

The current solutions (software) seem to have shortcoming concerning their main modelling approaches and resultant modelling capabilities. Even in the cases of most advanced construction process modelling solutions 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 more detailed 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 role in the field of production planning. However, in the construction sector safety planning has been carried out to a certain extent as a separate task in respect to other production planning and control tasks. For example, concrete falling protection plans are prepared only for projects which have clear or even urgent needs for such plans. Safety communication in the worker level is particularly challenging under the site conditions. Partly for these reasons the construction accident rate has remained very high compared to other industries. In Finland, one in four fatal occupational accidents takes place in the construction field. Several previous studies have shown that the problem of the high accident rate and hazardous activities on site has been identified in many countries, for example Vacharapoom & Sdhabhon 2009.

This publication presents the research carried out within the *BIM Safety* research project. *BIM Safety* project continued the work started within the earlier research project: Building Information Model promoting safety in the construction site process, TurvaBIM 10/2007–2/2009 (TurvaBIM 2011, Sulankivi et al. 2009b). The main results of the TurvaBIM project were 3D construction site layout planning procedures and their testing in co-operation with industrial partners. 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 BIM Safety research project was a joint effort by two research centres VTT and Finnish Institute of Occupational Health. Main public sponsor of the project were Tekes – the Finnish Funding Agency for Technology and Innovation and The Finnish Work Environment Fund. Additionally the BIM Safety project enjoyed industrial support from four companies which are A-Insinöörit Ltd, Skanska Corporation, Tekla Plc and TVO Ltd. The BIM Safety project started in March 2009 and it was completed in June 2011.

The BIM Safety research project aimed to develop and test novel solutions for construction site safety planning, management and communication by taking the advantage of 4D models. This means that construction schedules are linked with i) the building parts, ii) the temporary structures, and iii) site production equipment. BIM technology can be then applied to safety planning, safety management and safety communications, and these activities can be integrated with the 4D-construction management (more information available at the project website, http://www.vtt.fi/sites/bimsafety).

Generally, two main approaches for improving construction safety was 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 BIM Safety research project encompassed action research approach. Accordingly the most important experimental task was the piloting of the designed BIM-based procedures in real on-going building projects. At the first stage of the research, preparation work for piloting was carried out which included literature study, safety hazard record analysis, pilot planning, hands-on modelling testing, and tool development in co-operation with the research partners. Additionally, some part of early work covered possible technologies for safety communication where BIM and mobile solutions formed the main starting points. A practical demonstration using available technology was a target of these studies. Furthermore, literature study and analysis of records of real safety hazards/accidents was also carried out to find out the major problems of occupational safety at construction.

The Tekla Structures software package was selected as the main research platform. Functionality tests concerning 4D-features in the selected modelling software were carried out using Tekla structural model of a completed building project. Testing was carried out to assure that the selected software can be used for safety planning and relating visualizations in the coming pilot projects. In the modelling experiments so far and in the software itself the main attention has been in planning, modelling and visualization of permanent construction assemblies of buildings. In the BIM Safety research project one of the main interests was to incorporate the modelling and visualizations for temporarily used safety equipment. A specific rule set was developed for this purpose, and that was 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.

During the second stage the usability and potential of BIM was tested and studied in on-going building projects, and feedback was collected on the experiences when using BIM for safety planning, safety management and safety communication. Accordingly two different building construction projects formed the main case studies. These were

Pilot Project 1 (PP1)

> Office building construction project in Helsinki, Finland. Skanska is the client and the main contractor (new office premises of Skanska). The project was fully designed using 3D building information modelling. Structural engineering and modelling was carried out by Magnus Malmberg consulting engineers using Tekla Structures 15 modelling software, which was the main BIM-software used at site as well. The project's structural model was used for piloting and testing carried out in BIM Safety research by VTT.

Pilot Project 2 (PP2)

> Enlargement of an industrial building in Eurajoki, Finland. TVO is the client and Skanska and Hartela are the main contractors. PP2 was also fully designed using 3D building information modelling. The project included challenging cast-in place structures to model and to build, and nearly 30 meters high concrete wall between the old and the new part of the building to be demolished in two phases. Architectural design and structural engineering and modelling was carried out by Pöyry using ArchiCAD and Tekla Structures 15 modelling software. Both models were used for piloting and testing carried out in BIM Safety research.

2. Results of relating research and development work

The high accident frequency is still globally a real safety challenge in the building construction sector. When compared with other industries the construction jobs are infamous for being the most dangerous occupation. According to the United States based Occupational Health Administration (OSHA) 31 per cent of all work-place fatalities occur in the construction industry. This frequency in figures meant 9,5 fatalities per 100,00 construction workers in Europe in 2006 and 11 fatalities per 100,000 workers in USA in 2007.

An accident always challenges the quality of construction site operation and it surely produces both direct and indirect costs which can be substantial. According to the current understanding the successful accident prevention includes the following fields (Työtapaturmat ja ammattitaudit 2008, Lappalainen et al. 2007b).

i) efficient organization of the construction site,

ii) good quality planning over the use of the site and over the actual site operations, and

iii) proper safety communication and influencing the safety attitude of personnel.

BIM-based planning and plans seem to have good potential to contribute to the all fields listed above. This includes also safety planning and management methods. At the same time, implementation of new technology is an opportunity to change the traditional way of working by including the site safety viewpoint more fully into the standard production planning and management procedures. It is still a common practice to position construction safety management according to the official demands, which has isolated safety planning viewpoints and methods from the main production planning tasks (Sulankivi et al. 2009b).

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. 2010). 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 et al. 2009).

Communication and collaboration. BIM centric practices have been found to have significantly beneficial to the industry (Mahalingam et al. 2010). 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 & 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 publication 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.

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. 2007a). 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 focused 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 can encourage other partners to involve both risk assessment and planning. These partners are designers, other contractors, safety specialists, occupational health care etc. Additionally 4D-BIM can mean 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.

2.1 Work place accidents in Finnish construction sector

About 8500 work place accidents leading to at least four days of absence occurred to construction workers in Finland in the year 2008. That is 15,8% of work place accidents leading to at least four days of absence in all sectors in Finland. The amount of construction work place accidents has diminished 11,6% from 2000 to 2008. In 2008 there were 35,2 construction workers' work place accidents leading to at least four absent days per million work hours whereas in 2005 the accident frequency was 42,8. Work place accidents leading to at least four absent days but not death or pension caused on an average 25 absent days. (Työtapaturmat 2010.)

The Finnish construction industry has seen 1–3 occupational deaths caused by falling to a lower level annually during the years 2003–2009. Altogether this makes 27% of all fatal occupational accidents in the construction sector. In every branch of industry, the rate of fatal falling to a lower level was six per year in total. Approximately 40% of fatal accidents involving falling to a lower level occurred in the construction industry. (TOTTI-system.) Approximately 4 000 slighter falling, leaping, tripping and slipping accidents occurred yearly during 2003–2008 in the Finnish construction industry (Tapaturmapakki 2010).

According to the study of fatal accidents occurring in 1999–2004 in Finland, there were 66 persons who were killed on construction sites. Those persons were experienced professionals. The most usual working phases were actual working or walking at the construction sites while the accident happened. The typical accidents at construction sector were fallings, walking at sites and site traffic/logistics and element erection. (Lappalainen et al. 2007b.)

2.2 Accidents at work in other European countries

In Europe construction is the only sector where accidental injury rate has been reported to be over five per cent concerning male employees in the past 12 months. In 2007 the construction sector at 15 EU countries (without Greece) was a target of 51% of accidents with more than three days absence. (Health and safety at work in Europe 1999–2007: A statistical portrait 2010.)

In the British construction sector occurred 11.400 accidents more than three absence days (RIDDOR).

Construction sector in France had 129.239 work accidents in 2009. That is 18,6% of all accidents at work in France. Incidence rate that is the number of accidents per thousand workers was 76. Frequency rate was 48.1. Severity rate was 2,8 temporary disability lost days per thousand working hours. The severity rate does not take into account fatalities. (Statistical review of occupational injuries FRANCE 2009 data.)

Construction sector in Spain had 122614 accidents at work in 2009. That is 19.9% of all accidents at work in Spain. (Statistical review of occupational injuries SPAIN 2009 data.) The branch of Construction of buildings; development of building projects had 76 fatal accidents in 2009. That is 12% of all fatal accidents at work in Spain. (Ibid.)

2.3 Fatal and serious falls in the United States

OSHA investigated 7.543 fatalities and serious accidents occurred in the construction industry for the time period from January 1990 through October 2001. 34,6% of these was falls; 2687 falls from elevation and 54 falls from the same level (Huang & Hinze 2003). 59% (566 fatalities) of fatal fall accidents inspected by OSHA during from July 1, 1992 to June 30, 1995 was occurred in construction industry (Janicak 1998).

Aerial lifts was involved in 306 work related fatalities occurred between 1992 and 2003. 228 of those occurred with boom lifts and 78 with scissor lifts. (Pan et al. 2007).

Furthermore concerning the United States, it has been estimated that one third of fatal accidents in the construction industry involved falling (Dong 2009).

Main accident types in the construction of greenhouses are cuts, punctures, contact with hard or rough material, and falls from one level to another. Typically the eyes, thorax, back, sides, lower legs, or feet injured in those accidents. The injuries cause bone fractures, twists and sprains, distended muscles, contusions, and crushes. (Pérez-Alonso et al. 2011.)

Personnel lifts have been related to many deaths in constructions. Main causes of construction workers' death related to personnel lifts are falls (36%), collapses/tip overs (29%), and electrocutions (21%). Typical personnel lifts related to fatal accidents were boom-supported lifts (42%), suspended scaffolds (26%), and scissor lifts (19%). (McCann 2003.)

2.4 Accident prevention

In construction 44% of fatal accidents have been definite or probably design-related (Driscoll et al. 2008). Gambatese & Hinze (1999) have analysed design suggestions and developed software for designers to help their work in site safety design. This software package is based on 400 design suggestions that were collected and analysed. One third of the suggestions addressed falling from heights. Some big construction/engineering firms have their own PtD (Prevention through Design) practices. However, this practice is not widely diffused. One reason for that is unclear liability issues (Behm 2008).

Behaviour modification through safety objectives and feedback has proved to be one way of improving safety in construction sites (Mattila & Hyödynmaa 1988).

2.5 Safety Management System SMS

Organisations have different ways to carry out occupational safety and health (OSH). Organisation with little expertise in OSH has usually only the reactive way as a means towards safety problems and their incidents. On the other handsome others with more OSH expertise can have special safety management systems (SMS) and thus they deal OSH issues in a more systematic way. Some organisations act in a more proactive way by integrating the OSH management into their general operations management systems. Models such as ASET and Turnbull Report try to describe the OSH management in an organisation and the cause-effect relationship between culture, systems, exposures and injuries. (Mainstreaming OSH into business management 2010.)

The basic and most important regulation influencing OSH management in all EU Member States is the Directive 89/391/EEC, which requires a systematic, integrated, proactive and participative approach towards OSH management. The main aim is to ensure continuous improvement of the safety and health of workers. Risk assessment is the main tool used in the OSH management processes and the preventive measures must be integrated into all activities at all levels. The efficient OSH management system can result in decreased accident rates and workers' compensation premiums, a related increase in productivity, better safety culture; improved employee perception of the physical and psychosocial working environment both increased hazard reporting by employees and increased worker participation in safety and health activities. (Mainstreaming OSH into business management 2010.)

The four stages of maturity in organisational OSH management: (Zwetsloot 2004, pp. 392–393)

i) the reactive (ad hoc) stage: organisations have little OSH management expertise and react to problems as they arise

ii) the systematic stage: organisations develop their internal OSH competency, they carry out periodic risk assessment, action planning, prioritisation of problems and implementation of planned control measures;

iii) the system stage: organisations implement and maintain an OSH management system by continuous structural attention to OSH which is organised before the start of new activities;

iv) the proactive stage: organisations integrate OSH management into other management systems and/or into their business processes; the focus is on continuous improvement, more effort is expended at the design stage of products, processes, workplaces and work organisation, and collective learning is promoted.

At the moment most EU companies are knowledgeable on the Act of Occupational Safety and Health and they do safety risk assessments, but improvement is needed in ensuring sufficient competence of superiors and other personnel (Niskanen et al. 2009). Nowadays and even more in the near future the increasingly complex work processes and changes in working conditions create new kind of safety risks, coexisting with the traditional ones, or changing types of hazards that call for OSH to form part of the overall management of enterprises. Without a systematic assessment of the risks and a genuine integration of OSH into the general management of the organisation it is not possible to develop a preventive approach to safety. New integrated, proactive approach to OSH management in companies differs from the traditional, prescriptive approach to OSH issues. This has been supported by policies and practices established at international, European and national levels, including strategies, legal provisions, standards and guidelines. (Mainstreaming OSH into business management 2010.)

The co-operation between management, workers, companies and other participants is one important element of both company-related and site-related safety prevention at construction sector.

BIM-based safety management

Safety management by using BIM can be realized in several ways. In BIM-based safety management the most important matters are safety communication, safety planning and risk management (Figure 7). BIM-based orientation, introduction, education and supervision are possible ways to reinforce safety communication by visualization. BIM-based safety planning offers possibilities to execute the planning process together with several partners. This way the safety planning process attains better results and solutions which are additionally shown as 3D safety plans. BIM-based risk assessment and risk management offer the same benefits. All this requires that there is know-how to use BIM-based safety management process and practices and also that the safety management is incorporated in the whole construction process.

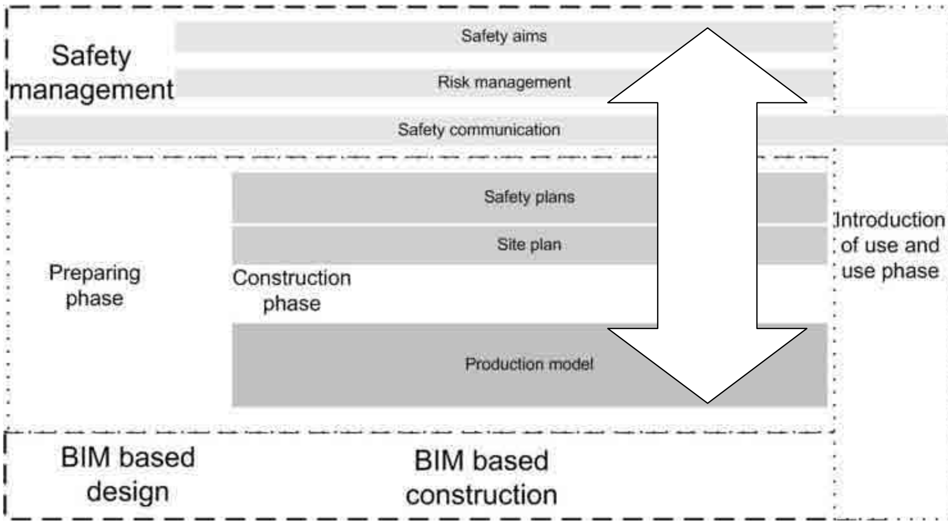

Figure 7. Safety management as a part of BIM-based construction procedures.

2.6 Safety communication and construction sites

Safety communication is an integral part of an organization's safety effort. It provides support to the continuous, every day work on safety promotion and management. It helps to create and maintain prerequisites to safety and health at work, and contributes to promoting the organizations safety culture and atmosphere. Encouragement towards positive safety behaviour is an important task for safety communication. Thus the focus is on messages that promote a pro-safety atmosphere. (Real 2008.)

The basic aim of safety communication is to help personnel to make conscious decisions regarding safety and adopt an attitude that can improve their health and safety. Communication can act as a means to disseminate company safety norms and beliefs. It can facilitate understanding over safety systems, risks, production pressures and organizational policies on safety. When utilized in an optimal manner it can act as a lubricant between organizations, employees and tasks (Real & Cooper 2009). Examples of important factors in safety communication are i) openness of communication, ii) two way communication and iii) easy access to information. According to Kines et al. (2010) safety communication should be an integrated part of the entire construction process, from planning to construction and operation (Kines et al. 2010).

Openness in communication, which means open access to everyone, is a key factor in creating a positive safety climate. Openness in communication helps the personnel feel that they have the organization's support and their thoughts and opinions are valued (DeJoy et al. 2004). Openness is also important since the events that lead to accidents and injuries are mostly non-routine and unpredictable (Zohar 2002). This is especially true in changing environments such as construction sites. Furthermore, open communication in working conditions also enables two way communication, in which the employees can e.g. raise their concerns on safety issues and suggest solutions to identified problems. This can also facilitate injury and accident reporting, which then provides basis to learn from past accidents.

Easy access to information means that safety information is effortlessly available to everyone. In example target groups, location, form, time and use of messages and media should be taken into account when planning safety communication. Using a multi-channel approach is seen as an effective communication way to reach the personnel in organizations and to improve information availability. This means that more than one communication medium is used in delivering safety messages. It ascertains that everyone has seen, read or heard the message, reinforces messages and increases exposure to information (Real 2008). When designed and planned well, safety information can be provided without detail overload. Safety messages should be kept simple and easy to understand, but also make additional information easily available for those individuals, who want to seek more information. (Real 2008.)

Recent studies show that the increase of safety topics in daily communication on construction sites does not affect production topics. Safety and production related communication can be used to complement each other along with topics concerning production quality (Kines et al. 2010). Thus, investments on better safety communication will most likely support also production and quality.

As an essential part of a company's safety promotion and management, safety communication should be developed further towards a more systematic direction, although it must be recognized that because of the nature of construction work all safety communication can not be planned in advance. Still, by setting specific goals to communication it could become a more target-oriented tool that could be used successfully in improving organization's safety culture and performance.

2.6.1 Visual communication

Visual communication is considered to be one of the oldest ways to communicate; the first versions of writing were, after all, pictures. People rely on vision to be the most reliable of their senses and so consider things they see to be true. (Hietala 1993.) Because of this, visual communication is a very high-impact way of communicating. Visualizations can be used to clarify and extend verbal communication. Visual materials such as plans, sketches, photos, videos and slide shows are used every day in most companies. The visual acts to support the message in a similar way as body language, expressions, intonation and volume does in direct oral communication (Yazdani & Barker 2000).

Still, the relationship between seeing and understanding is problematic. How one understands a certain message or even artefact one sees depends on social background and experience. The practices around visual materials may lead the focus of attention away from the relevant and also make the message more difficult to understand by complicating or concealing information from the viewer. (Weick 2005.) On the other hand, visualizations can have ample benefits in making information understandable and crossing borders created by i.e. different native languages. Good visual design supports the message by presenting the essential (Brusila 2000).

Additional communication solutions like physical models (mini models or demonstrations) and virtual models are often used as a part of design, construction and management of the built environment. We often can have needs to visualize the building or environment or simulate different functions over the life cycle of the built environment. For that purpose we can use BIM first to link the construction methods to building objects and second to make those visible and more understandable via animations. According to Schrage (2000), we often model only what we want to see. Some studies, like Snook & Conner (2005), show the potential for a systematic organizational blindness to the relevance of information that may be available in visual materials. Today the interactions with visual materials are central to the knowledge-intensive work of practitioners in the built environment (Whyte et al. 2007).

The 3D/4D models of the project support the visual aspect and that way more effective communication between the numerous stakeholders of the project. Good 3D visualizations can be close to photo-realistic representations and can make the construction tasks and processes easier to understand also for people who are not familiar with that field. One major task during construction planning is to understand the relationships between the many trades of work on the site and to simplify these relationships as independent, dependent or interdependent. By using the animation of 3D/4D model it is easier to understand the nature of such relationships between work activities and communicate these relationships and the reasons for a particular dependency between them (Hartman & Fischer 2007).

2.6.2 Information and knowledge

Information and knowledge are closely related concepts and can be easily misused in practise. According to Kock and McQueen (1998), information is descriptive and relates to the past or present concepts in an often historical context, while knowledge is predictive and associative and provides the basis for the prediction of the future as well as the basis for unveiling hidden facts that are expressed as hypotheses, models, and theories. Knowledge and information are often exchanged at the same time (Kock and McQueen, 1998) as knowledge is communicated through meaningful and organized exchange of information (Kakabadse et al. 2003).

In construction projects the main knowledge types are product (design) knowledge and process (sequencing and scheduling) knowledge, which are usually possessed by two different groups. Product knowledge is possessed by the design team, while process knowledge on how to build the facility is possessed by the construction team and they need to collaborate closely with each other to evaluate whether the planned design can be constructed. Information-rich tools are needed during the knowledge communication process to coordinate between the opinions, concerns, and issues specific to each party. (Hartmann & Fischer 2007.)

Several computer applications exist for viewing, understanding, marking-up, and presenting 3D/4D models. The mark-up capabilities are particularly useful during collaborative meetings to annotate views of the 3D/4D model while engineers communicate existing personal knowledge and develop new solutions effectively. These can support synchronous and asynchronous communication and generation of new knowledge. (Hartmann & Fischer 2007.)

3. Safety planning within building construction

3.1 Construction production planning and site safety planning procedures

Construction planning is a fundamental managerial activity that provides baseline for understanding the content of work to be done, for organizing the needed site operations, for starting the actual work and for controlling the performance of activities. First the construction project is divided into hierarchically structured units (e.g. activities, sub-activities, tasks). This project break downing is, traditionally, supposed to cover all the needed work to complete the project and reach its objectives. This is also known as 100 percent rule of project break downing. However in practice, building design and construction activities are often underway in a parallel manner that can result unexpected design and scope changes making then project break downing much more challenging.

The described project break downing is a source for first production models of construction that can explain the required work and deliveries of different project partners (supplies, special contractors, different trades etc.). During the next stages of planning these models are equipped with additional explanatory attributes and their content. These are dependencies between activities, technology choices, needed resources, activity durations and more detailed work arrangements such as site layout preparation.

BIM solutions have been gradually developed to a direction where besides of the basic product data they are also including construction process data such as activities and their logic (Figure 8). Construction schedule animations are an important side product of such models. These are also widely called 4D models where 3D building model is equipped with an additional dimension which is *time*. Construction schedule animations can be most useful communicate solutions that in many ways facilitate planning and commitment creation amongst different project participants and experts. This also can include construction safety engineering aspects and involvement of needed experts and expertise.

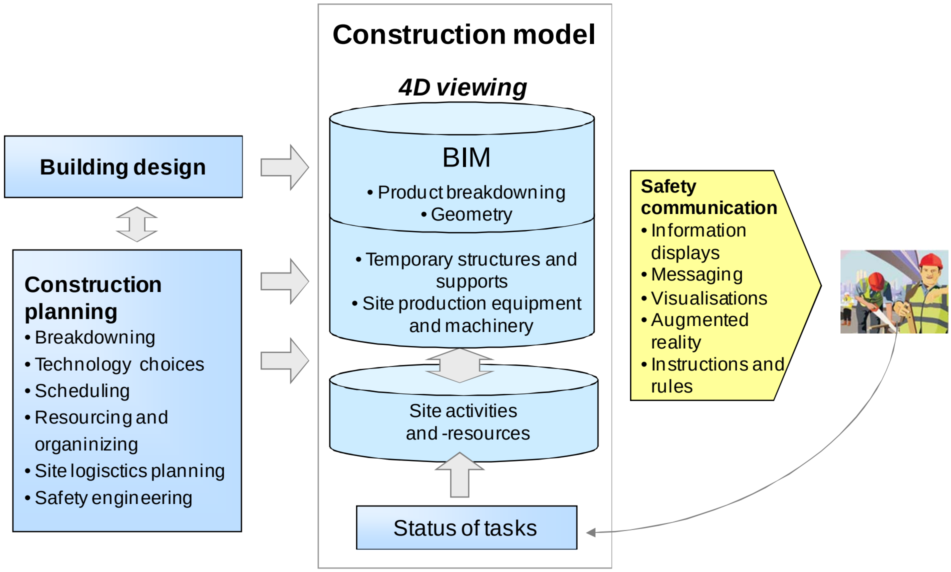

Figure 8. Construction planning produces model that can also capture the construction safety engineering aspects.

Construction safety engineering means strongly interplay between partners and trades. The practices of Prevention through Design (PtD) and Designing for Construction Safety (DfCS) emphasises the role of addressing construction site safety and health in the design of a project. Construction site safety is seen as a design criterion and a part of constructability studies.

The main target of the research project described in this publication was to develop BIM-based solutions for construction site safety planning and management as part of the 4D-construction planning and management solutions. 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. Nowadays the use of models for construction planning and management including safety purposes is at its early development stage. 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 is more common that contractors have their own CAD experts to create models. Obviously the main reason for this arrangement is that the BIM-based tools are not commonly used during design and as a result no models are available for contractors needs. (Sulankivi et al. 2010.)

3.2 Legislative background to safety planning

All key people of any construction site need to understand what the Occupational Safety and Health Act (738/2003) demands from them. The Government Act on the Safety of Construction Work (205/2009) includes specific safety aims, performances, operations and responsibilities for construction work in Finland. All participants at construction project have tasks and duties to promote safety. These acts together create the principles for minimum level of safety at construction work.

In the design and planning phases of a construction project, the client shall ensure that the practical construction work will be taken into account in the architectural and constructional design, design of technical systems and design of arrangements for the practical construction work which creates preconditions for safety. All this enables to carry out the work safely and without causing any harm to employees' health.

All participants involved in site operations are expected to co-operate with each others, but the project supervisor has the main responsibility of the site safety and safety planning. The project supervisor shall present to the client the safety plans concerning occupational safety in the construction work before initiating the construction work. Those plans need to be in written form. They shall be revised if the site conditions change and they need to be kept up to date. Aim of the safety planning is that the various tasks and work phases shall be carried out and scheduled in a way that no danger arises from any activity to those working on the site or other persons in the zone affected by the activities. The project supervisor shall systematically identify and analyse such general safety hazards and risk factors of the construction work that depend on work tasks, work conditions and work environment, also taking account of the data in the client's safety document. The basic principle is that hazards and risk factors shall be eliminated by appropriate means or, when it is not possible to eliminate, their significance shall be evaluated with regard to the health and safety of those working at the site and other persons in the zone affected by the work.

In connection with the planning, the project supervisor shall also take account safety measures for work that can have impact on special safety and health risks, referred to in Annex 2 of Act 205/2009. In addition to all this, the safety planning shall also pay special attention to the following at a minimum:

- arrangements at the construction site, and maintaining good order in the workplaces and in material handling during the various construction phases
- blasting, quarrying and excavation work
- carrying capacity of the ground and support of excavations
- electrification and lighting during construction work
- work methods
- use of machinery and equipment
- lifting work and transfers
- protection against falls from heights

- work on work platforms and scaffolds
- storing, lifts and assembly of prefabricated elements, formwork, and other large structures
- reduction and prevention the spreading of dust
- procedures for occupational hygiene measurements
- demolition work
- factual timing and duration or the various tasks and work phases, and their coordination to make them fit together when the construction work proceeds
- coordination of the various tasks and work phases on the construction site to make them fit together, or to fit to any other industrial activity, work activity and public traffic going on in the vicinity of the construction site
- piping and electric cables causing risks
- where and when personal protective equipment shall be used
- action in connection with injuries and accidents.

Site safety plan

Before initiating the construction work, the project supervisor shall prepare construction site layout plan showing how the site area is going to be used for organizing the required construction operations. In that connection the project supervisor shall, systematically and adequately enough analyse and identify the hazards and risk factors relating to the organisation, practical arrangements and use of the specific construction site, and eliminate them with appropriate measures.

According to the Act 205/2009, at a minimum the following matters shall be taken into account when planning the use of the construction site area:

- number and location of office facilities, personnel rooms and storages
- placement of cranes, machinery and equipment
- placement of excavated earth and filling earth
- placement of areas for loading, unloading and storing construction materials, substances and prefabricated elements

- traffic in the construction site area, and connecting points between internal and public traffic
- means of access, ramps and transport routes, and their maintenance
- order and cleanliness on the construction site both placement of structures and equipments used to defence and manage dust
- collecting, storing, removing and disposal of waste and material which cause hazards for health and safety
- fire fighting
- confining and arranging storage areas specially while handling materials and substitutes which cause hazards and harms for health and safety.

The topics mentioned above shall be taken into account in such a way that any risks of accident, health hazards and risks of fire are minimised on the construction site. Central parts of the plans for the construction site use shall be presented as a construction site layout plan, by construction stages when necessary. The site layout plans shall be checked if conditions change and they shall in any case be kept up to date.

3.3 Main ideas for BIM-based site safety procedures

The research team had the following as the main ideas for starting to use BIM for improving site safety:

1. **BIM-based safety planning,** such as site layout planning and falling prevention planning, which are required by authorities at some level for example in Finland. BIM can be used also to support planning of work tasks that include remarkable safety risks, e.g. form work.
2. **Risk analysis and safety related evaluations of plans with help of BIM:** BIM can be used for risk analysis and safety related evaluations of plans first visually, and in future for more automated risk identification.
3. **3D- and 4D-visualizations in safety related communication:** BIM-based visual 3D presentations promote the level of communication in all stages of construction projects. From viewpoint of safety, for example when introducing the project to site staff, presenting safety arrangements related to a specific work stage or task, and for warning about current hazards.

4. **Other use of BIM-based plans at site,** such as viewing the BIM-based plans to gain a common understanding or to see the details, or product and quantity information.

Chapter 4 present the field trials carried out at the research project, to test and demonstrate these ideas, as well as to evaluate the resulting benefits against amount of work related to the modelling.

3.4 Evaluation of software packages

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.

As a part of early stages of research the current **BIM-based software tools** available for site safety planning were identified, and 6 software of those were analysed to find out the various suitable tools for construction safety planning, based on the identified main strengths and weaknesses.

The software analysis and its conclusions are based on authors' experimental modelling excercises and earlier modelling experience. It is considered that the most important BIM software features for BIM-based 3D/4D safety planning, management and communication include i) 3D modelling and viewing capabilities, ii) tools for modelling landscape, iii) extended 3D object library, iv) 4D tools and features, v) tools for analysing risks or safety of the designs and plans, and, vi) data exchange capabilities. The following text provides additional thoughts over these viewpoints.

1. *3D modelling and viewing capabilities such as choice of colors and material textures, as well as tools for visualization and presentation purposes*: E.g. structural models are often colorful, because the colors of the building parts have their particular structural meaning. However, in some cases such as in safety communication, it's good to be able to present issues as natural as possible to provide easily and quickly understandable messages. On the other hand, there may be a need to highlight issues in a model using contrasting colors, by e.g. leaving irrelevant parts in the background (using e.g. gray color), and highlighting the key issues using chosen highlighting color (e.g. red color). That's why it's good if the user is able to select the needed modelling or visualizing colors without limitations in color range.

An example of another kind of visualizations is e.g. an animation created from the same model. For example a virtual site tour was created from an architectural BIM in VTT's previous TurvaBIM project using animation tools included in ArchiCAD modelling software.

2. *Tools for modelling landscape, soil masses, temporary excavations at site* etc.: Presently, this data is increasingly captured with the aid of 3D laser scanning technology. Such data can be valuable if considering as-built data. From the viewpoint of safety, one identified need was planning of temporary excavations or levels in various phases on construction site. Such detailed modelling should be considered as a new kind of practical software requirement.

3. *Extended 3D object library*: One crucial precondition regarding BIM-based site planning in real-life projects would be that planner has a predefined set of 3D objects over most often used site equipment. This would facilitate and accelerate site planning clearly. (Sulankivi et al. 2009a.)

4. *Tools for analysing risks or safety of the designs and plans*: At the moment there is hardly any tools available that are suitable for BIM-based occupational safety analysis. However in the future it should be possible to speed up the routine work related to safety checking by BIM-based software.

5. *4D tools*: this should include ready tools/procedure also for temporary site arrangements such as safety equipment. Moreover, user's possibility to choose the accuracy of 4D visualization (steps between visualized phases), and possibility to choose representation rules (which parts are presented and with which color) in 4D-visualizations are relevant features from the viewpoint of safety.

6. *Data exchange capabilities*: capability to import models from other software, especially using IFC file format, and the capability to export data in IFC format for combining and using a model in another BIM-based software. Other useable file formats include e.g. 3d-dwg. The geometry of one model may be integrated and used in another model in 3d-dwg format, but it does not include any intelligent product or other information like IFC file does.

Software explored and evaluated here covers Google SketchUp (Google), ArchiCAD (Graphisoft), Tekla Structures and Tekla Construction Management (Tekla), Navisworks (Autodesk), and Solibri Model Checker (Solibri Inc.). They were considered to be interesting for use in safety planning, because safety should be considered already in design phase, models created in design phase are used in construction phase as source of information or bases for production planning with help of the same or compatible software, and additionally staff responsible for safety planning are not willing to use many separate software in their building projects. A short description and the main strengths of each discovered from the viewpoint of site safety planning are presented in the following table.

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.

From the viewpoint of safety, the strengths of architectural modelling software such as ArchiCAD and Revit 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 (Google Sketchup 2010). 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 or Solibri Model Checker. They do 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 visualizations.

Table 2. Features of BIM-based tools from the safety planning and management viewpoint.

Software:	**Google SketchUp (by Google)**
Short description:	A simplified 3D modelling software meant especially for architectural sketching. Additionally, some contractors use the software for BIM-based site planning and supporting communication.
Specific strengths:	Visual, easy to use, low cost, and achieved considerable popularity in professional use (especially among architects). Supports the use and distribution of pre-modelled 3D components (www: Google 3D Warehouse) and placing models of buildings into the Google Earth. One special feature is also dynamic components. Considering software features from the viewpoint of safety, weaknesses include limited tools for modelling landscape, temporary excavations at site etc., as well as lack of 4D-tools and IFC data exchange capabilities.
More information	http://sketchup.google.com
Software:	**ArchiCAD (by Graphisoft)**
Short description:	The most used BIM-based architectural design and modelling software in Finland, for example.
Specific strengths:	Visually of high level, and provides visualization tools such as virtual camera and possibility to create animations directly from the model. Includes a tool for modelling landscape and soil layers (the mesh-tool). Developed IFC data exchange capabilities. Easy to use but very limited 4D-tools if considering temporary safety equipment (4D-tool available as a plug-in).
More Information:	http://www.graphisoft.com
Software:	**Tekla Structures (by Tekla)**
Short description:	A BIM-based structural modelling software. Covers modelling tools for steel structures, and concrete precast-elements and cast-in-place structures, including details such as reinforcements, welding, and other connections.
Specific strengths:	Provides opportunity to model and define the assemblies of the structures corresponding to the construction site implementation, as well as the opportunity to create "intelligent" custom components for safety planning also. Software features from the viewpoint of safety: Not a specific tool for modelling landscape, temporary excavations at site etc., but one modelled using another software can be inserted to a Tekla model as a reference in IFC or dwg-format. Developed IFC data exchange capabilities. Selection of colours in modelling view very limited, but wide range of colours available with help of object representation rules up from version 17.
More Information:	http://www.tekla.com
Software:	**Tekla Construction Management (Tekla CM, by Tekla)**
Short description:	This version of Tekla do not include any modelling tools, but is a BIM-based planning tool for use at construction site especially, and can be used for e.g. viewing designs and organizing the content of a, creating lists of model parts, quantity take-off, scheduling and time management, as well as visualizing designs, plans and schedules.
Specific strengths:	With the help of the software, one is able to take full advantage of the structural model of the building project (which includes the building parts corresponding to the real construction work at site). Provides advanced 4D capabilities, which are being developed further like other features important for use at site. The

	use of the software requires special expertise. User needs to define the visualization rules for the temporary site components, to get the 4D views work correctly, but on the other hand allows choosing object representation quite freely (which parts to display and by which colour). If considering safety planning, one can't model with help of Tekla CM. This means that such temporary structures as safety equipment can't be added to the model, or even to move and copy the parts that the structural engineer has added to the model. Concerning 4D visualization features, the smallest time unit is one calendar day, which is not suitable for all projects and purposes. Selection of colours in modelling view is very limited, but there is wide range of colours available in 4D-visualizations (up from version 17). Developed IFC data exchange capabilities.
More Information:	http://www.tekla.com
Software:	**Navisworks (by Autodesk)**
Short description:	A BIM-based software for combining, viewing and examining the content of various models, as well as clash detection and 3D/4D visualizations. Does not include any modelling tools.
Specific strengths:	Able to read in and combine many different file formats, and combined models are small of file size.
More Information:	http://usa.autodesk.com/navisworks
Software:	**Solibri Model Checker (by Solibri Inc.)**
Short description:	For combining, viewing and examining the content of various BIM-models. Includes special tools for rule-based automated checking and analyzing, as well as for quantity and other information take-off (a new Information take-off – tool). Does not include any modelling tools. Models created with help of other software can be used in IFC-file format in Solibri.
Specific strengths:	Rather easy to use and yet versatile software for reviewing and examining models. A good option if for example there is often need to examine the geometry and other information content of models created with help of different modelling software. The user can also edit and create new rule sets for rule based checking and information take-off.
More Information:	http://www.solibri.fi

The tool selection for construction safety planning depends in practice on e.g. what kind of models are obtained from the designers, what kind of skills and tools the contractor/the person conducting safety planning is possessing, and how the modelling result is aimed to be utilized. Safety planning is usually based on an architectural or structural BIM, but the other options are a combined model as basis for safety planning or to start over/from the beginning. Here are some advantages and disadvantages related to the use of an architectural model and the use of a structural model:

Suitability of architectural BIM for site safety planning:

- visual outlook is good
- geometry is correct but the division into the sound structures is only suggestive or lacking
- lacks some structural parts or details.

Suitability of structural BIM for site safety planning:

- includes (most) structural details
- allows detailed planning (e.g. fixing of temporary installations) lacks non-structural parts (e.g. doors, windows, non-load-bearing partition walls).

4. Outfitting BIM with site safety planning dimensions

4.1 BIM-based site layout planning

4.1.1 From traditional practice towards more advanced solutions

Traditionally the project supervisor prepares a 2D site layout plan. The aim is to plan the site operations and the required arrangements for enabling the planned work to proceed as efficiently as possible during all stages of construction. The site layout plan is used to inform all parties of construction project about internal and external logistic arrangements and the work and safety arrangements (Rakennustyömaan aluesuunnittelu 2007). Numerous viewpoints, dimensions and factors need to be taken into account during the site planning phase. Examples of those are 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 logistics 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 the top of town plan drawings with the use of a CAD program, plans that are drawn by hand or made with using sticker labels (Sulankivi et al. 2009b).

The same standards and good design principles apply to BIM-based site layout planning as they do with the traditional two-dimensional planning. However, the BIM-based practice offers also 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. (Sulankivi et al. 2009b.)

At present, a static three-dimensional site layout plan can be considered as a basic approach for preparing a BIM-based site layout plan. Such a model is like a snapshot of construction site at a certain point of time. Therefore additional site layout models are needed while the site arrangements change throughout different construction phases. The ultimate target is to tackle these dynamic changes with 4D site models in the future (Sulankivi et al. 2009b). The site layout planning and management systems based on 2D drawings can no longer meet the planning needs, especially when some resources operate or facilities are put inside the building under construction. Site layout model should neither be a static one nor a two-dimensional, instead, it should be a dynamic encapsulating the whole 3D site (Zhaoyang et al. 2005).

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.

4.1.2 Prerequisites for BIM-based site layout planning

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 et al. 2009a.)

One of the main objectives of the VTT’s previous 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 did 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 main dimensions can be changed and the 3D appearance can be improved by selecting a suitable 3D surface material for the case. Examples of TurvaBIM library objects that are particularly safety-related are the temporary pedestrian shield and the precast element stud, as well as the safety railing found as ready-modelled. Useful ready-modelled objects were found mainly in the Construction Equipment library from Graphisoft Object Depository (ArchiCAD-Talk Forum). The standard library of the used modelling software (ArchiCAD 11) contained only single usable 3D objects for site planning, such as a truck. The TurvaBIM-library was used to create a building information model-based site layout plan for a case project. Additionally, the library was later tested and developed further in an ongoing BIM-based site planning pilot project.

The development of the TurvaBIM objects further in the BIM Safety project is related to the creation of parameters for some TurvaBIM GDL-objects (more information in chapter 5.2), creating few new GDL-objects for the pilot construction project, as well as using GDL-objects as a reference while creating safety related custom components for Tekla Structures modelling software, which has been the main tool in BIM Safety research and modelling trials. Next figure presents the new GDL-objects (a soil storage and a storage for hazardous waste), together with examples of site planning objects created in the previous TurvaBIM-project (Figure 9).

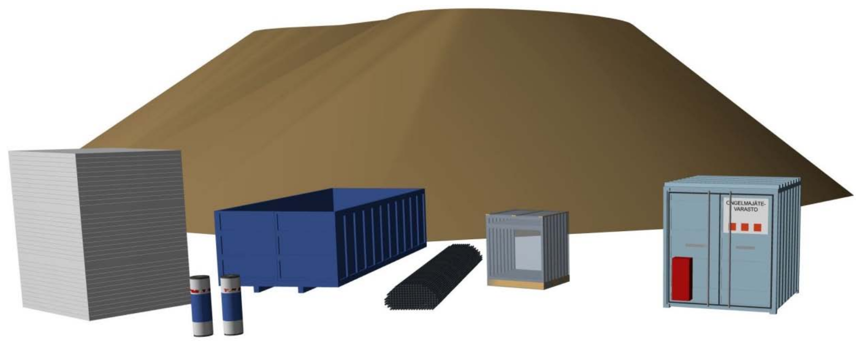

Figure 9. Examples of site planning objects created in the previous TurvaBIM-project, together with new GDL-objects created in the BIM Safety research project.

The software used here in the BIM Safety research project has originally been developed for structural engineering, and again, does not include ready-made 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 Tekla custom components created for site layout and safety planning in the BIM Safety research project (Figure 10).

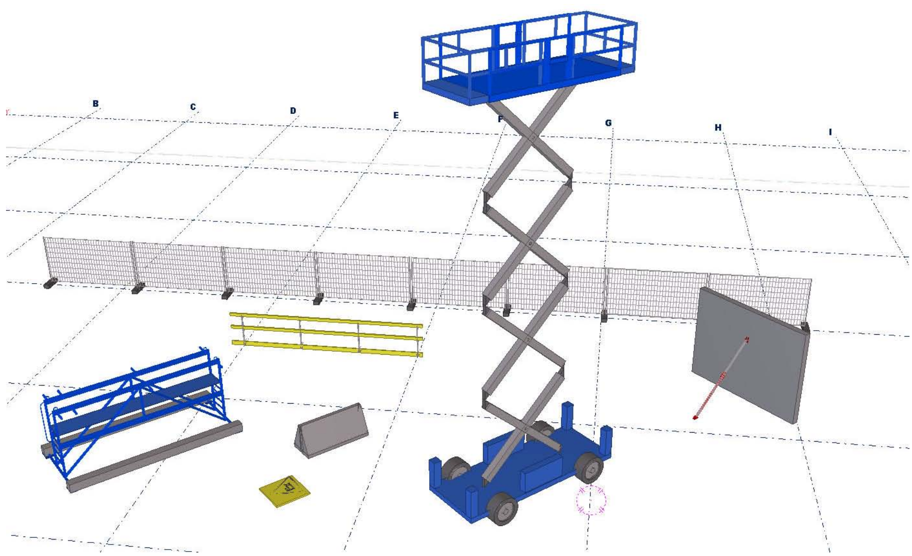

Figure 10. Examples of site and safety planning objects created for Tekla in the BIM Safety project.

A Tekla Safety library was prepared for research use, containing custom components made both at VTT and by the contractor (Skanska). The structure of the library is presented in the following figure (Figure 11). The custom components have been organized into 13 groups, which differ a little bit from the groups in the previous TurvaBIM object library created for ArchiCAD modelling software. While modelling, the contents in each Safety library sub-folder can be viewed as a list showing the names of the components only, or by viewing custom component thumbnails.

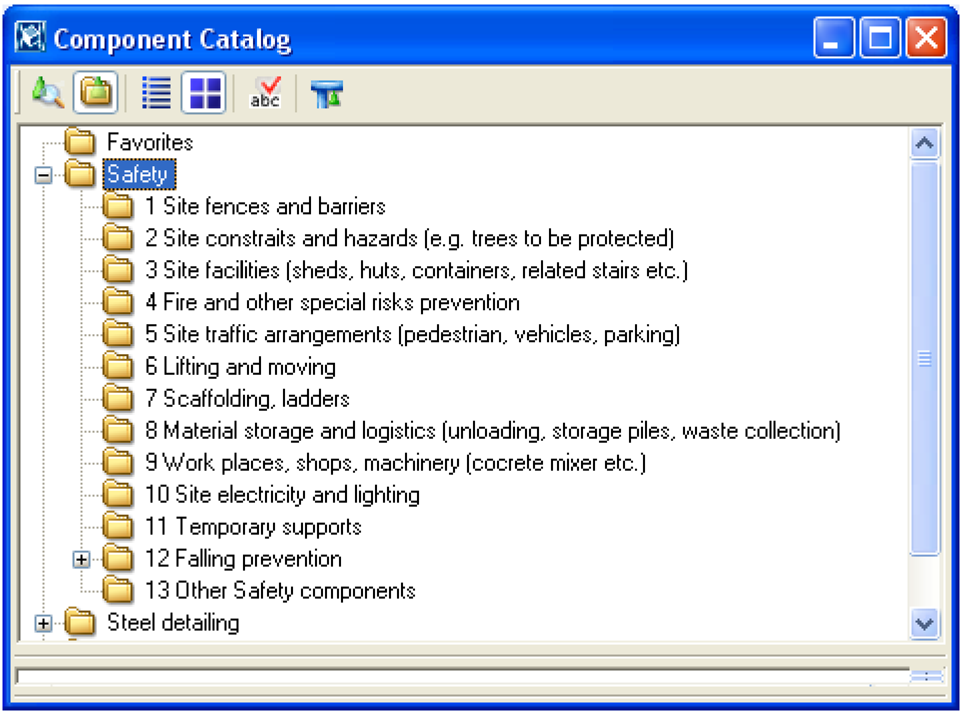

Figure 11. The structure of the Safety component library created for Tekla Structures.

4.1.3 Examples of BIM-based site layout plans

Residential building project Ankkahovi

As the first example of a BIM-based site plan, Figure 13 presents one modelled in the previous project using architectural modelling software ArchiCAD 11. 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, and their original 2D site plan was used on the bases for testing BIM-based planning. Besides the 2D site plan, there was the architectural model available (created by Arkkitehtitoimisto L-N Oy) and used for testing. The site plan was modelled and visualized at VTT.

The construction site area was modelled according to the traditional site layout planned for the frame construction stage. Additionally, the immediate surroundings including streets and buildings were modelled roughly. Modelling was based on the architect's model and the site plan prepared by the contractor (Figure 12). 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.

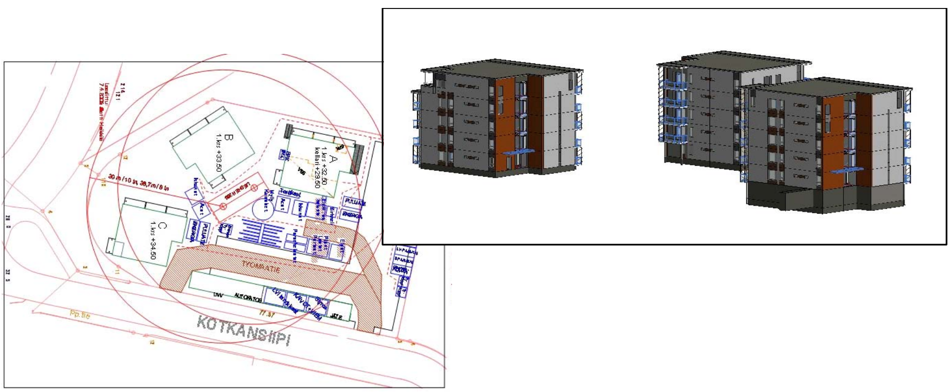

Figure 12. The original 2D site plan and the architectural model in the case building project.

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 13). 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.

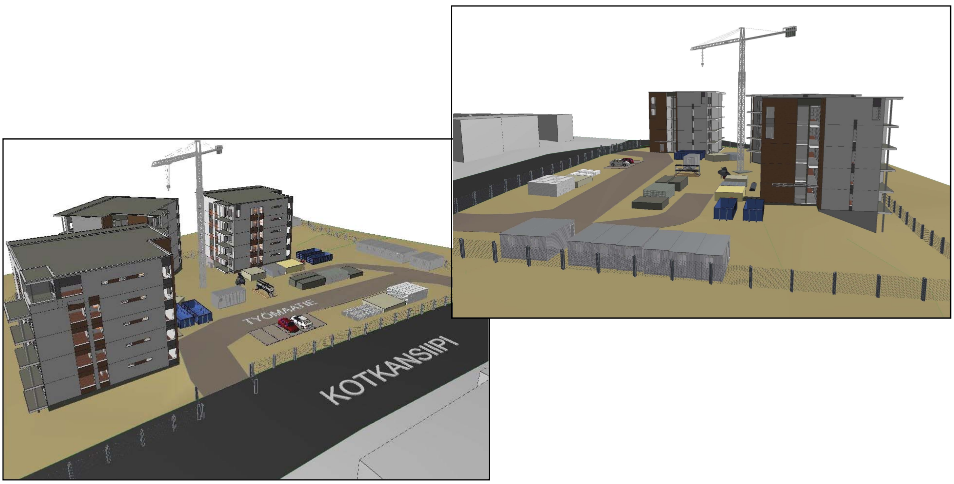

Figure 13. General views of the BIM-based site plan created using architectural modelling software ArchiCAD in the previous TurvaBIM research project.

Industrial building project

As the second example of a BIM-based site plan, the following pictures presents a plan created with help of Tekla Structures modellling software in the BIM Safety pilot project 2 (Figure 14 and Figure 15).

In this construction project site engineer made BIM-based 3D site layout plan with help of ArchiCAD modelling software and TurvaBIM object library. On behalf of the BIM Safety research project the same was done with help of Tekla Structures 15. Testing was performed because in the VTT's previous TurvaBIM project it was found that the 4D tools provided by Tekla are more developed and flexible than those available for ArchiCAD as a 4D-simulation plug-in, and make more dynamic site planning possible.

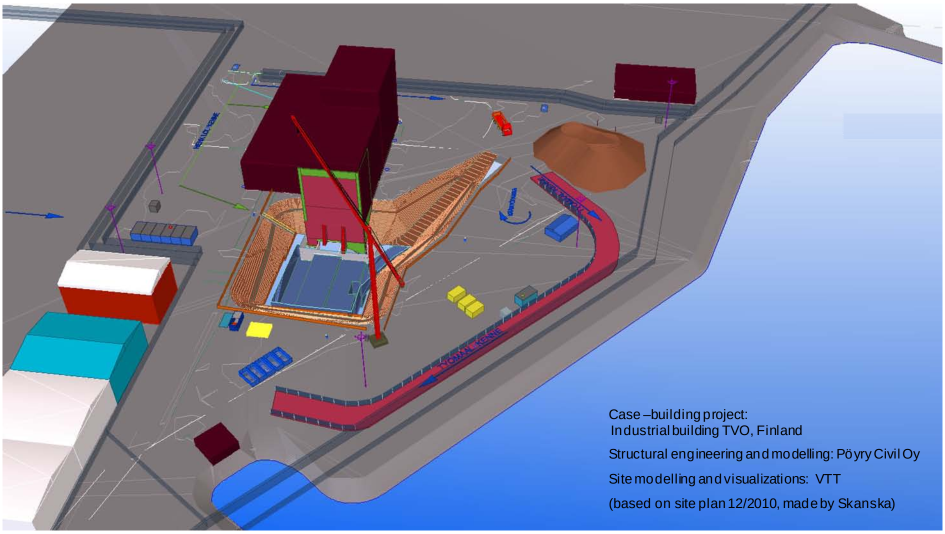

Figure 14. BIM-based site layout plan created using Tekla Structures modellling software in the BIM Safety pilot project II.

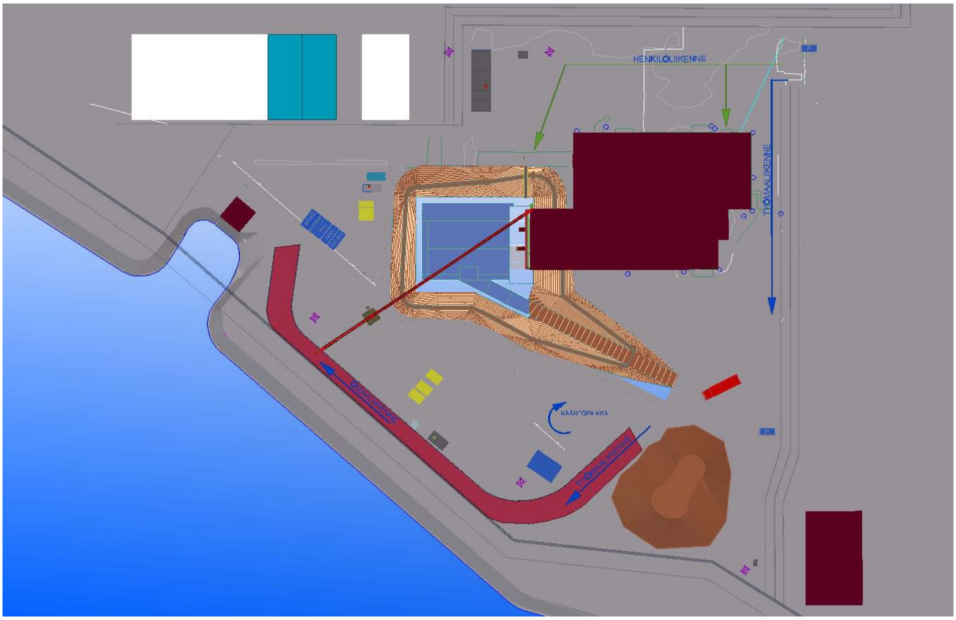

Figure 15. Corresponding view from above to the same BIM-based site plan.

4.1.4 Lift planning and safety reviews for tower crane

Visualization of crane reach and risk zones

Visualization of crane reach was carried out in the previous TurvaBIM project by making a 3D reach-cylinder object, which was used together with the crane object (Figure 16). 3D visualization can be used to check crane reach and capability in construction work, as well as 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.

Figure 16. Visualization of crane reach (Sulankivi et al. 2009b).

Visualization of crane collapse

A 3D visualization methodology developed in the previous research project was utilized in BIM Safety pilot 2 for evaluating risks associated with the fall of the crane. There was project specific viewpoints for the analysis, but the principle of BIM-based visualization was the same. Two different fall cases were examined using 3D objects to show the affected zone. This visualization was used for example to evaluate if there is need to restrict the crane's operating area (jib’s turning radius). Crane fall visualization was based on the site engineer’s site plan, modelled using ArchiCAD, and the same software was used for the crane fall visualization as well. Two views to BIM Safety visualization in pilot project 2 are presented in the following pictures (Figure 17 and Figure 18).

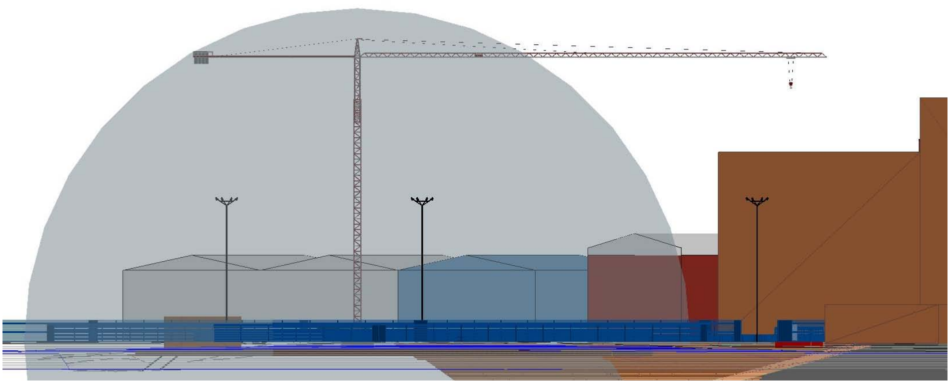

Figure 17. A view to the visualization of the first fall case.

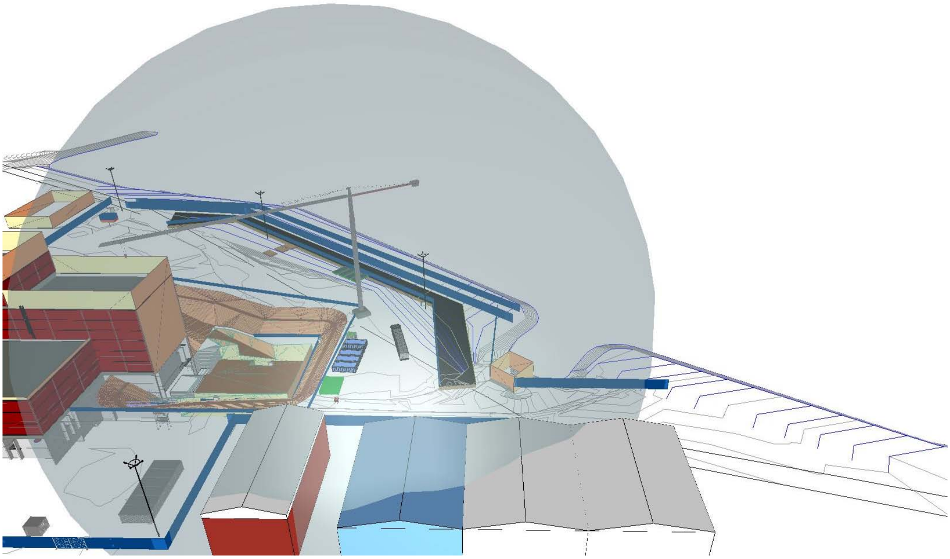

Figure 18. A view to the visualization of the second fall case.

4.1.5 Experience on BIM-based site layout plans

The content of a BIM-based site plan can be scheduled in Tekla. In addition, Tekla structural model is crucial from viewpoint of construction site implementation, because it contains the geometry of the building parts corresponding to the real site assemblies and structural details, and it is often used as a basis for 4D scheduling of permanently installed building parts and following the realized construction work at site as well. Safety planning should be part of the site production planning and therefore one should be able to model and schedule the temporary equipment and situations together with the permanent building components of a structural model.

On the basis of tests carried out in BIM Safety research, a clear strength of conducting modelling with help of Tekla Structures instead of architectural modelling software is that while presenting the status of the construction work concerning the permanent building parts, the needed temporary construction equipment can be included and presented by the same BIM-based status view. On the other hand/vice versa, together with 4D model view presenting planned or realized construction work status, the site status including temporary parts around the building can be presented at reviewed moment of time.

From the viewpoint of BIM-based site planning, the weaknesses of the structural modelling software were the lack of ready-modelled site planning components, the lack of visualization tools such as perspective “camera view tools” and animation tools, as well as the weak visual appearance for this kind of use. The result does not look as natural as those site area plans created with help of architectural modelling software. Architectural designs are intended to be made as real-looking as possible, and the tools serve well construction site modelling in this respect as well. Tekla is a structural modelling software, in which the colors has their own structural meaning, and there is very limited palette of colors for modelled parts. However, the latest version (TS 17) has brought a wide range of colors available through the use of object representation rules. This means that the part can’t be directly modelled by freely selectable colors, but after modelling one can define Object representation rules, which defines which parts are taken into a group, and then choose the appropriate presentation color for the group from wide range of colors. Another weakness of the software is for example, that animation or moving picture production with help of a model is not possible in the current software versions, but the same can be done using architectural modelling software. This was tested in the previous TurvaBIM project, e.g. for creating a virtual construction site tour. Animations can be used for example when introducing the project to site staff.

Site staff experiences

According to an interview study conducted on a construction site (Merivirta 2011), currently 3D and 4D models are used mostly for planning and visualization and are considered to be of help in example in clarifying the building process. Generally BIM is seen as a tool that brings added value to site safety planning. Building the structure virtually in advance helps to identify possible risks and eliminate unexpected situations, both of which are always major safety concerns. The visual aspect is seen as one of the best benefits of modelling. Pictures are easier to understand than traditional plans.

Active use of BIM on construction sites still requires learning of use and also some change in working methods. Further development of the tool itself and development of IT will most likely make using it easier. Some members of the older generation of construction site staff are still not very well accustomed to working with computers, so they are inclined to be more critical towards modelling and the use of 3D and 4D models on site. Still, BIM is seen as a definite tool of the future, albeit views of its current use and necessity do still divide opinions. Integrating modelling into the whole planning and building process is seen as a central challenge in future. (Merivirta 2011).

4.2 Visualization of wall demolition procedures

BIM-based modelling and 4D-visualization were tested in Pilot project 2 for visualization of wall demolition work. This construction project is an enlargement of an industrial building, where nearly 30 meters high concrete wall between the old and the new part of the building were to be demolished in two phases. The lower part was demolished at the early stages of the project, and the upper part will be demolished later. As a first step, a BIM-based visualization was carried out relating to the demolition plans of the lower part of the wall, and it was used for the communication between the contractors at site. Later on another visualization was prepared for comparing two alternative sequences of demolition work in relation to the upper section of the same wall.

The visualization of the first demolition phase: The structural engineer and the contractors planned the demolition work of the lower part of the wall first using traditional methods. After this, BIM-based modelling and visualization was carried out based on the traditional 2D-drawing and textual specification, and using Tekla Structures 15 modelling software, as well as 4D scheduling and visualization tools it contains. 2D-drawing defined the parts and the order in which the wall was planned to be demolished (Figure 19). The textual specification described for example, methods and equipment to be used for the work.

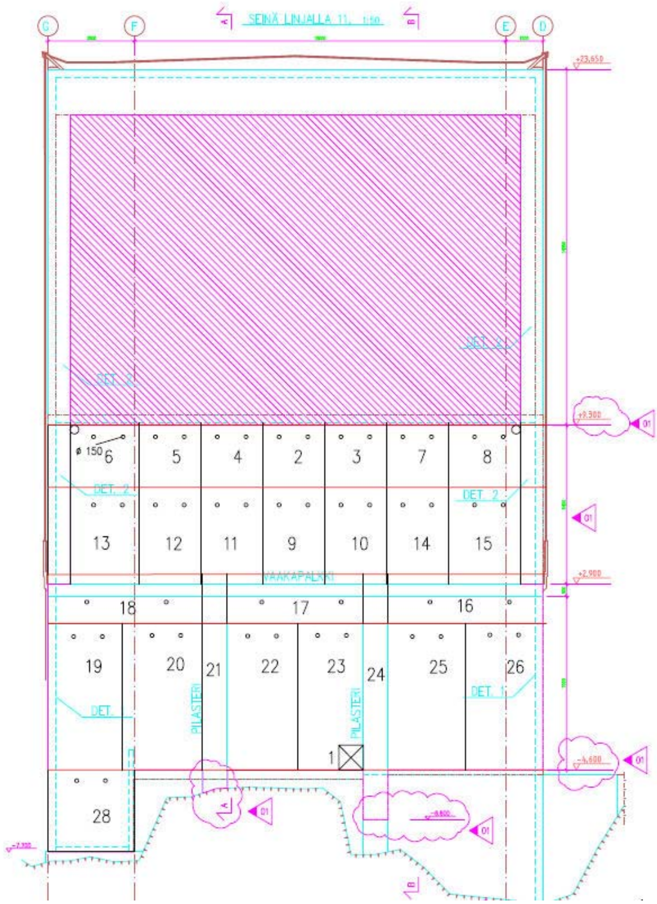

Figure 19. The traditional 2D demolition plan showing the wall demolition pieces and sequence.

Demolition work was planned to be carried out so that the wall would be cut first into smaller-size parts by horizontal saw cuts spanning the entire width of the wall, after which the actual demolition work would proceed piece by piece, by vertical saw cuts and lifting the pieces out of their place with a crane. This was presented in BIM by modelling first the demolition parts into the structural model as 3D pieces, and scheduling them in accordance to planned demolition order with help of Tekla's Task Manager tool. In practice, demolition tasks were created into a task list in the Task Manager tool, and tasks were scheduled and linked to corresponding 3D demolition parts in the model. In addition, a new 4D visualization rule set was created for the visualization to define the wished object representation at any review date, because the software did not have the appropriate ready-made rules for demolition work. Same way as the temporary construction equipment, 3D demolition parts are to be hided in a model view as soon as the related work is completed in accordance to the schedule. Additionally, in accordance to the real demolition plan, several parts will be demolished during one working day, whereas the smallest time unit for visualization is one calendar day in the software. As a result of the technical limitation, the calendar dates of the visualization do not correspond to the real demolition work schedule, but one calendar day is equal to one demolition phase.

The following figures present the progress of the demolition work with help of the BIM-based visualization. The first figure shows the site status at the beginning of the wall demolition work (Figure 20). The second figure presents the principle of the visualization: The part being demolished is highlighted by pink color, and parts already demolished are hided in the model view (Figure 21). Figure 22 and Figure 23 presents few steps, when the progress of the work is reviewed at different moments of time with help of the 4D visualization. These are views to the model, representing site status at the selected calendar day. At the end of the demolition work all the pieces have been demolished, and water drilling conducted at the corners (Figure 24). In this last view, steel reinforcement at the corners are missing from the visualization, even though the corners were drilled without breaking the old horizontal reinforcement. Lack is due to the fact that structural design has been carried out with help of BIM concerning the new part/enlargement of the building only, and only the main geometry of the old structures were modelled while designing the enlargement of the building.

The last view (Figure 25) is a visualization of a single stage of the work including modelling of the planned equipment and resources. The visualization was conducted using partly different colors than those originally used in the Tekla Structural model. The aim was to test possibility to create clearer and more natural visualization of a work stage.

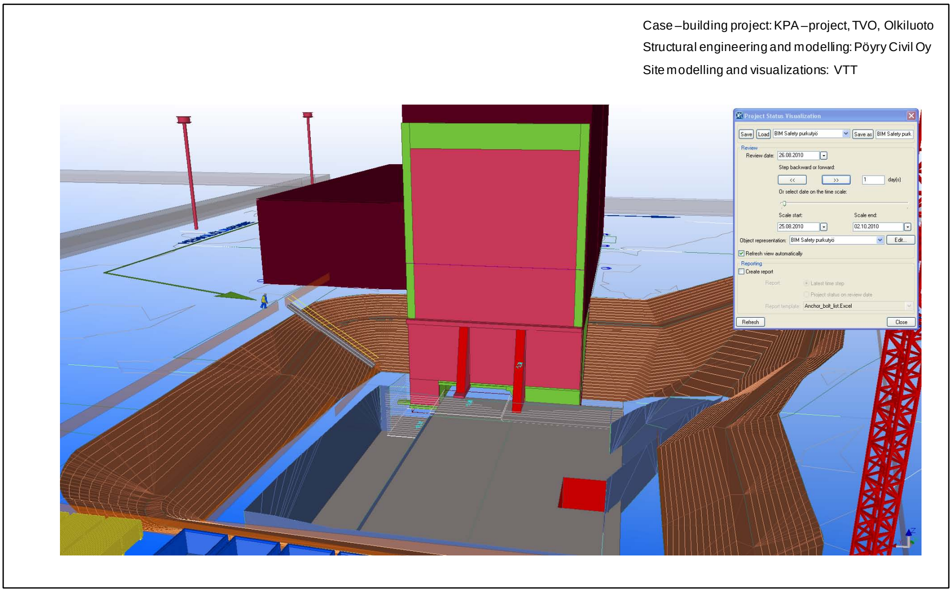

Figure 20. Site status at the beginning of the wall demolition work as modelled with the BIM software.

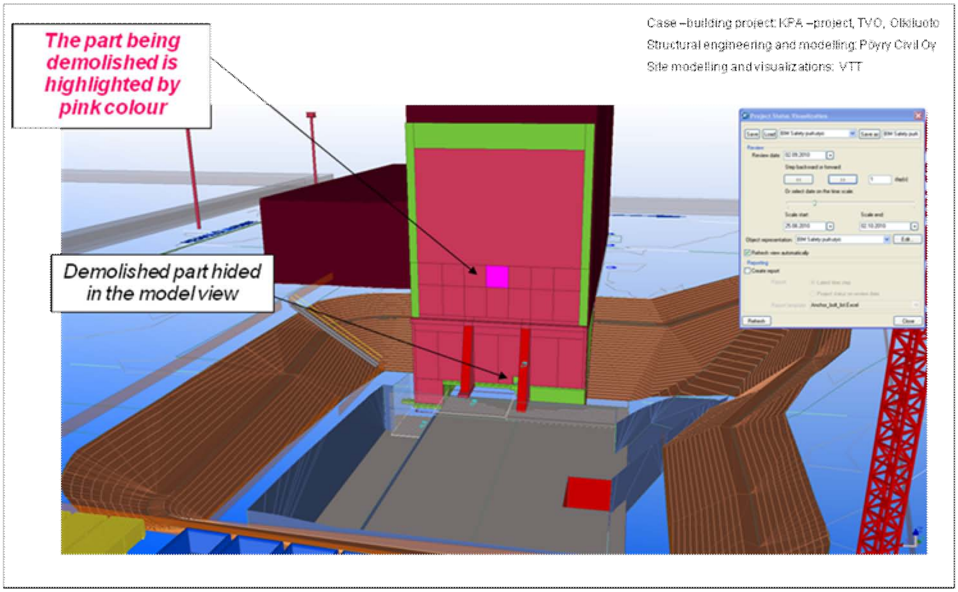

Figure 21. The principle of 4D-visualization of wall demolition work (Tekla project status visualization tools). The second concrete part is being removed from the wall.

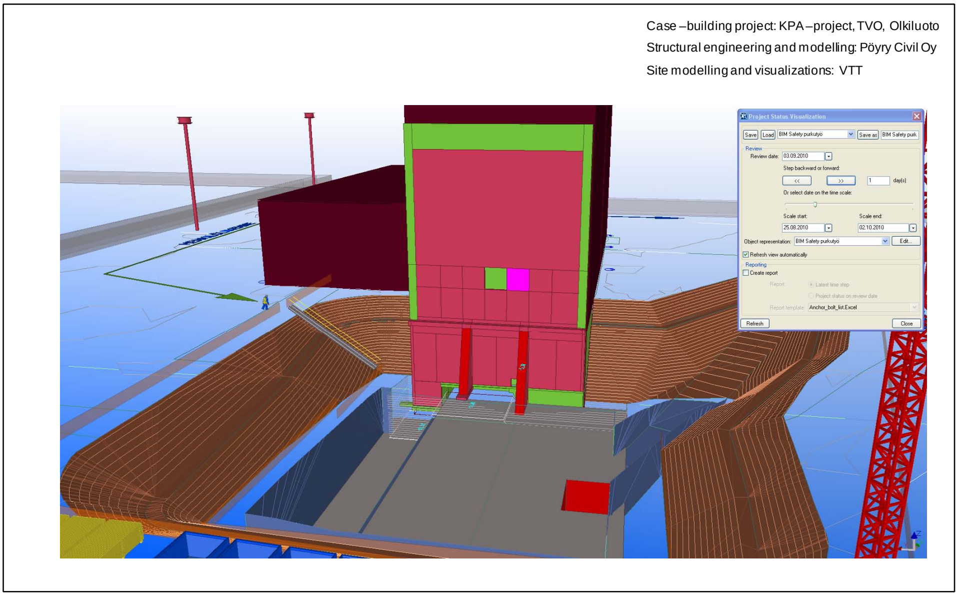

Figure 22. 4D-visualization of the part 3 demolition work (Tekla project status visualization tools).

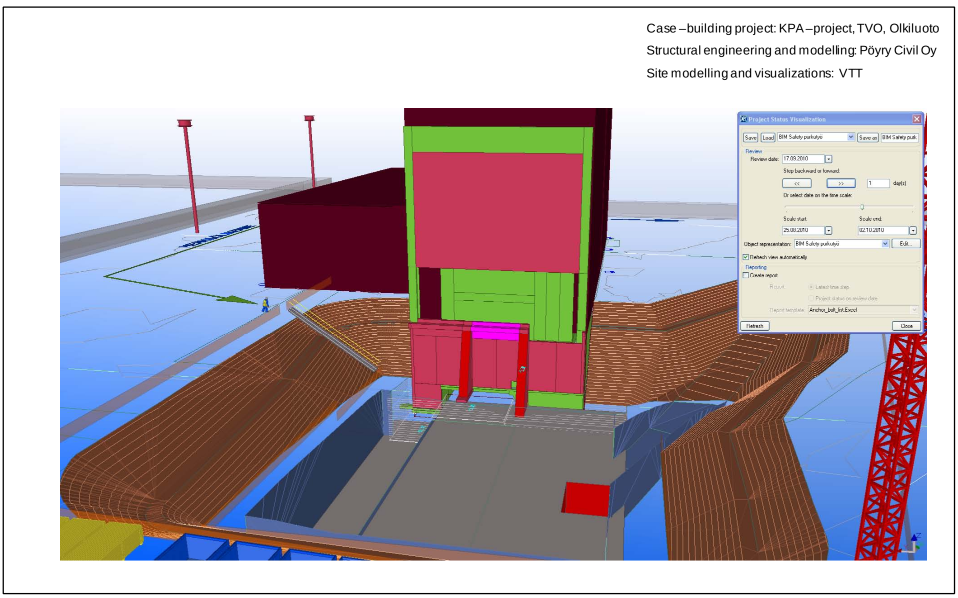

Figure 23. 4D-visualization of the part 17 demolition work (Tekla project status visualization tools).

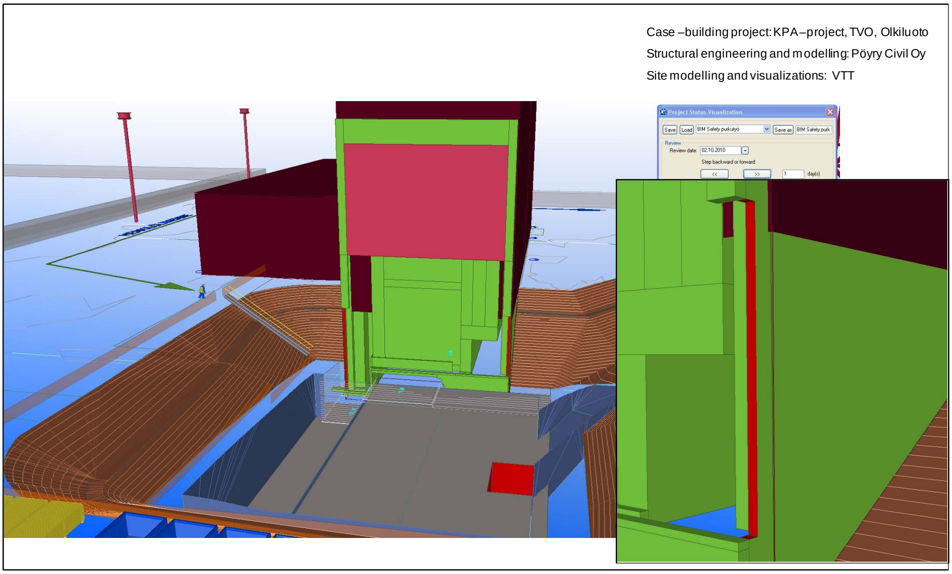

Figure 24. The end result the wall demolition work as modelled with the BIM software.

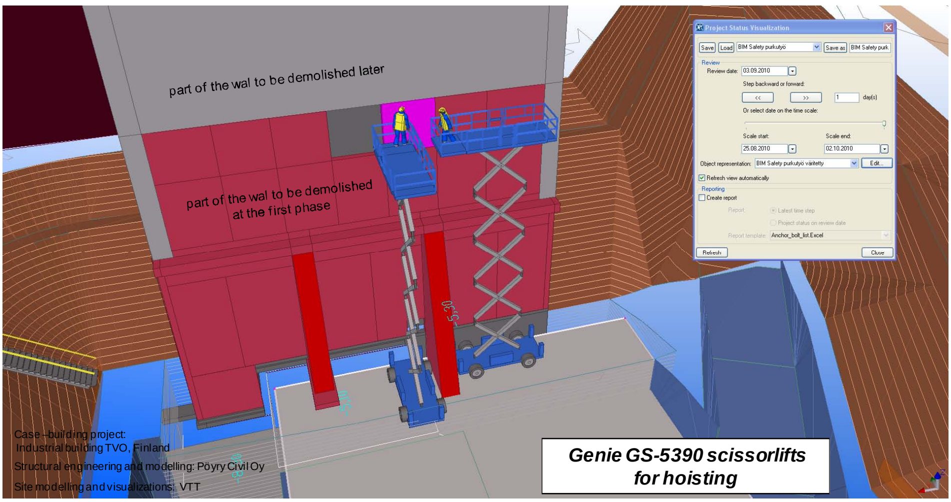

Figure 25. Visualization of a hoisting needed for the wall demolition.

Visualization of the second phase of the demolition work: Another visualization was conducted later concerning demolition work of the upper section of the same wall. Two alternative sequences of demolition work were visualized for decision-making. The latest tools available in a development version of the modelling software were tested at the same time for modelling the demolition parts of the wall. These tools are “Wall manager” and “Seam controller” tools being developed for concrete element walls by Tekla corporation, and currently they are available in Tekla Structures 17.1 alfa. The following figure shows the wall split into demolition parts with help of these tools (Figure 26). The key idea is, that after the wall is split into “elements” (demolition parts), the positions of the “seams” (saw cuts) can be easily adjusted by moving the seam-component, and the geometry of the demolition parts will be updated at the same time (parts will follow the seams). This feature can make the planning of demolition work more dynamic.

The second visualization covered also testing and utilizing unlimited color options provided in the latest version of the software (Tekla Structures 17). The visualization was conducted using a special coloring: More natural colors were used for existing building parts, irrelevant parts were left in the background using the gray color, and the key issues were highlighted using chosen highlighting colors (Figure 27). Beside the wall to be demolished, highlighted issues include for example the temporary protections that will be required during the demolition work. For example the white color used for building parts at the old part of the building, has not been available in previous versions of the software.

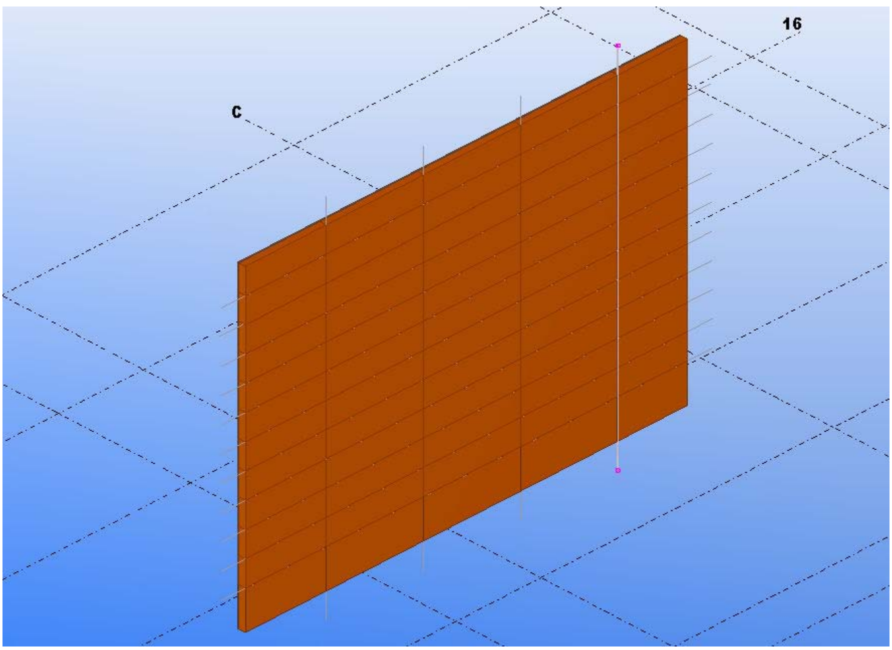

Figure 26. The complete wall is split into demolition parts. The positioning of the saw cuts can be easily adjusted by moving a selected seam-component.

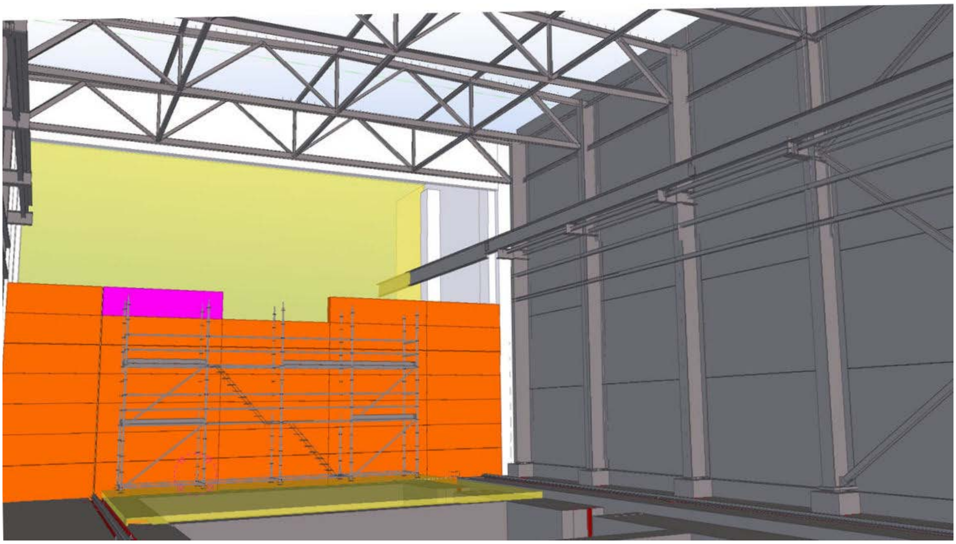

Figure 27. Visualization of the second phase of the wall demolition work using new BIM-based tools and more realistic colors together with some highlighted parts.

4.3 Modelling of safety railings

Developing BIM-based falling prevention planning was one of the main targets of the research project and in focus in the first pilot construction project related to the research. BIM was used for detailed falling prevention planning, including temporary safety railings and floor opening coverings.

Falling prevention planning consists of many different operations and covers more than just safety railings and floor opening coverings, but those were considered as obvious subject to model into BIM. That's why 3D guardrail components were modelled for the structural modelling software Tekla Structures, which was used for BIM-based safety planning. The following picture (Figure 28) presents an example of a traditional safety railing plan, where various guardrail types have been marked into a 2D-plan by different colors. Figure 29 presents a photo and the modelled 3D safety railing components that were planned to be used in the construction project.

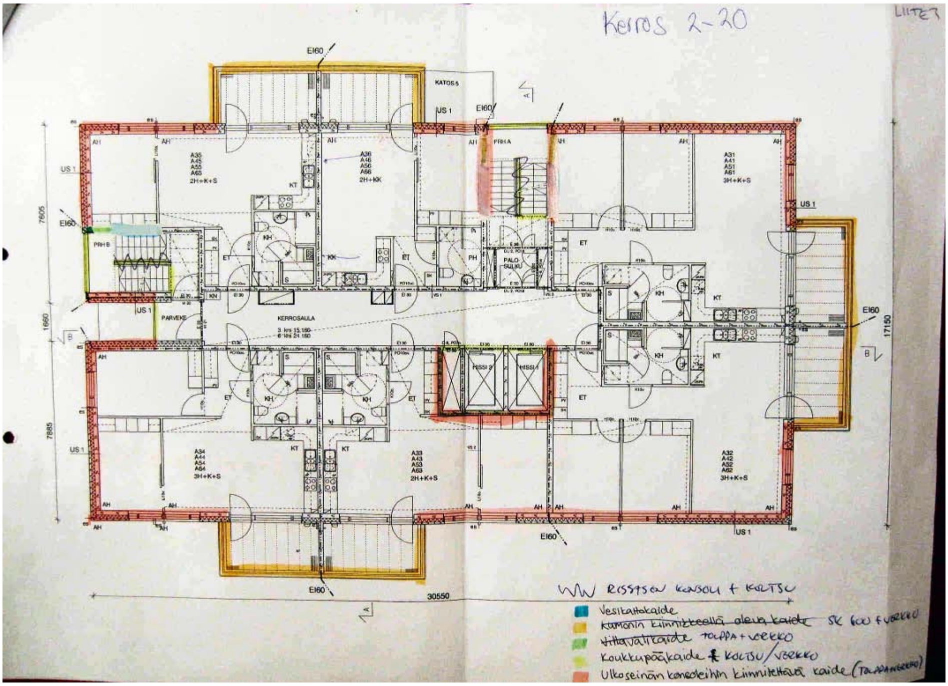

Figure 28. An example of a traditional safety railing plan.

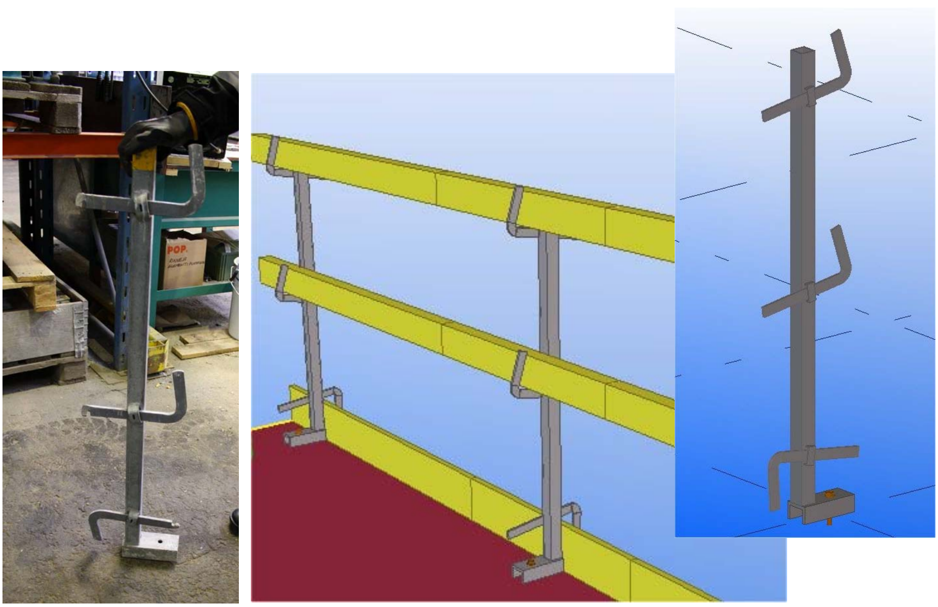

Figure 29. Safety railing equipment modelled for the first pilot project (guardrail post for surface installation used together with timber railings).

Selected safety railing solution consists of a guardrail post for surface installation and timber railings used together with the post. 3D presentation of the Tekla custom safety components have been modelled corresponding to the real guardrail solution used at building site: the geometry of the post corresponds to a Finnish Vepe product, and the dimensions of the handrail, intermediary guardrail and toe board correspond to the existing specifications for timber used with the posts. Additionally, assemblies in the components correspond to site installation and removing of the railings, which is relevant for 4D-planning and creating 4D-visualizations with help of Tekla scheduling and visualization tools.

Created Tekla custom safety components were used in the first pilot project for detailed BIM-based falling prevention planning based on the Tekla structural model of the building. All modelling was conducted at VTT, on the basis of how the site staff planned to take care of falling prevention in advance. Consequently, presented BIM-based railing plans are based on the ideas and information got from contractor’s project staff in related meetings and discussions.

Underground floors of the office building are cast in place concrete structures, and a leading idea was to plan the position of the guardrail posts to vault edges so that there would not be a need to move them in any phase of the construction work. That’s because the posts were to be bolted to the vault, and avoiding a need to move them during the work would both, save time and decrease risk of falling from heights. The railing posts were positioned to a right distance from the designed columns, to be able to install the mould for the column without need to move the posts (Figure 30). Another example, how safety was considered and modelled is the edges of elevator shafts. In this case railings were located far enough from the slab edge to leave room for installation of wall elements, again without need to move the posts until the wall elements would be assembled and risk of falling from heights eliminated.

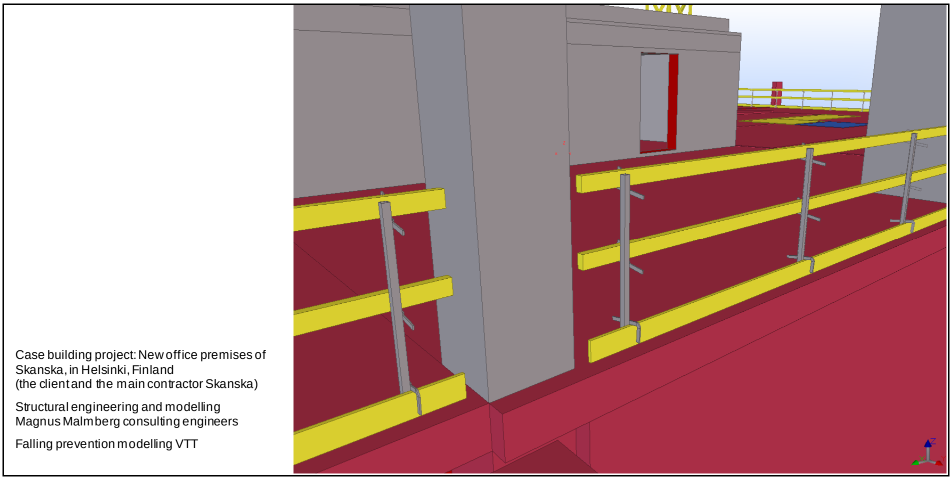

Figure 30. BIM-based falling prevention planning in Pilot project 1: safety railings in cast-in-place vault edges.

The overground office floors are constructed of pre-fabricated steel and concrete elements. The same safety railing solution was used in these overground floors, but railings were to be installed to pre-fabricated fixings in the steel beams (Figure 31). From the viewpoint of modelling, the positions of the railings were planned beforehand by the structural engineer, and the post components were fitted to the fixing parts existing in the Tekla-model, after which the timber railings were added using one Tekla custom component for the handrail, intermediary guardrail and toe board.

BIM-based railing plan was carried out to one of the eight office floors, and the same plan was to be repeated in the other floors. The presented safety railing solution was aimed to be the only temporary safety railing solution. Additionally, designed permanent enclosure/railing was to be used for falling prevention in a specific area during the construction phase (Figure 31).

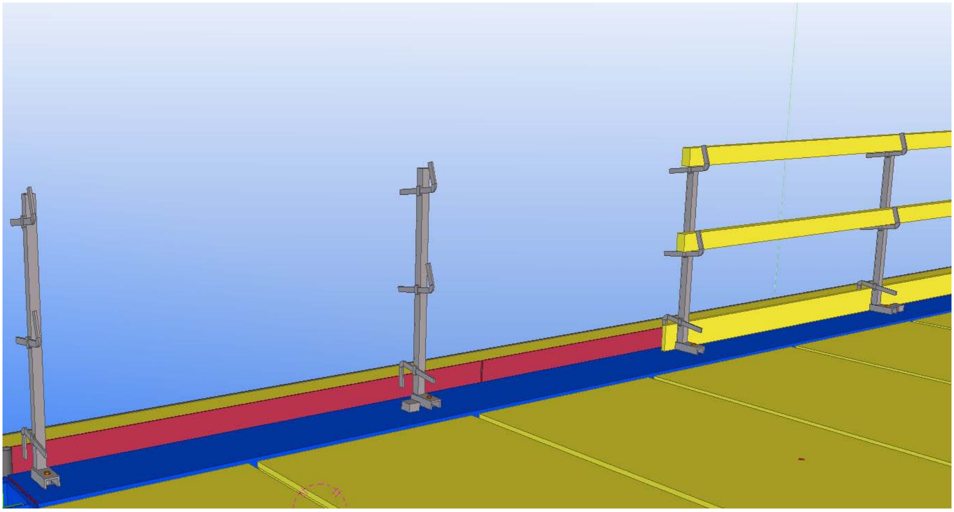

Figure 31. The same safety railing solution modelled into an overground floor: guardrail posts installed to fixings in the prefabricated steel beams.

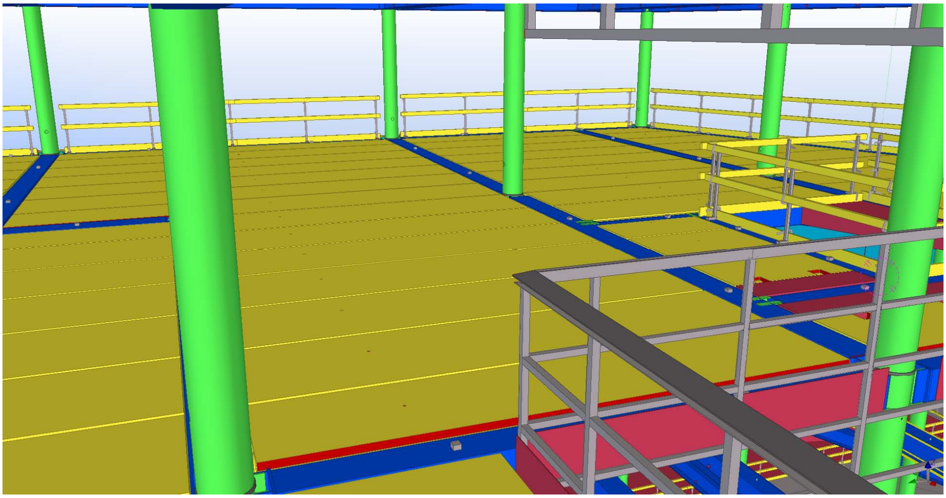

Figure 32. Temporary and permanent railings used for falling prevention during construction.

BIM-based railing plan was delivered for the contractor, together with some model views presenting modelled safety railing solution. The contractor carried out 4D scheduling of permanently installed building parts using Tekla and it would have been possible to combine the BIM-based railing plan to the same model, as well as schedule and visualize the falling prevention related to frame construction. Nevertheless, railings were not included in the 4D-plan.

The 4D scheduling for temporary equipment is complicated with current modelling tools. 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 visualiza-tion 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 visualization 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 including tasks corresponding erection of precast elements and related safety railings was created into a task list in the task manager -tool. After linking and scheduling tasks and 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 33). 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.

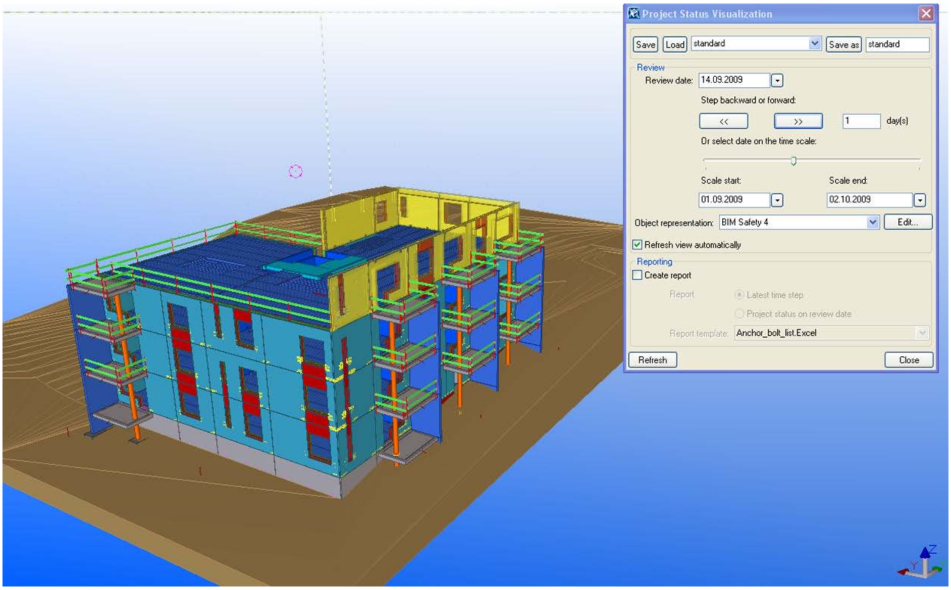

Figure 33. 4D safety railing visualization as part of precast element erection visualization.

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 soft-ware 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 (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 34). The rule set can be used and developed for different purposes in building projects.

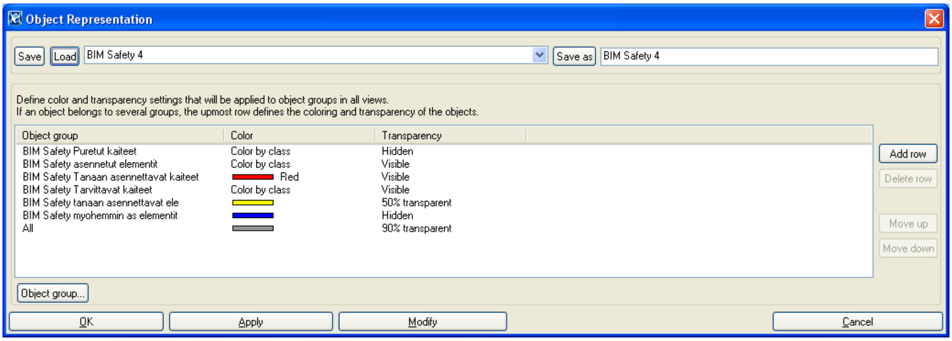

Figure 34. Object representation groups for the precast elements and safety railings in the 4D safety railing visualization test.

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.

The most significant weakness in tools identified was, that the shortest step between visualized phases was one calendar day, 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. However, this sequence can’t be visualized with project status visualization tool. 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. (Sulankivi et al. 2010.)

4.4 Modelling of formwork equipment and procedures

4.4.1 4D-visualization of floor form work and related falling prevention solution

Beside the safety railings, form work and related falling prevention solution was modelled into the Tekla structural model concerning one casting area/segment in pilot project 1. 4D visualization was also made for these parts, presenting roughly the progress of the work at site during a certain time scale. 4D visualization was carried out with help of Task Manager and Project status visualization tools included in Tekla Structures 15 software, and the result is presented in the following figures.

At the beginning of the visualization, casting molds for load-bearing columns have been installed in the first casting area of the vault, as well as all needed safety railings (Figure 35). In the second phase columns of the floor mold system are to be installed (Figure 36). In the third phase safety nets, which are needed while timber panel installation, are installed and primary beams of the floor mold system (Figure 37). After this, installation of secondary beams and timber panels of the mold system starts (Figure 38). In the last phase, just before reinforcing and pouring, also edge beams of the mold system and safety guardrails have to be installed (Figure 39).

The safety railings have been modelled in detail in this project, but the casting mould parts have been modelled roughly for the visualization. That's because the final mould supplier was not even selected, and as a result geometry of mould parts not known in detailed level at the time when the modelling was conducted. The safety nets were modelled, because they represent a new falling prevention solution to be used during form work, and thus visualizing them could be even more helpful than modelling some previously seen and used equipment.

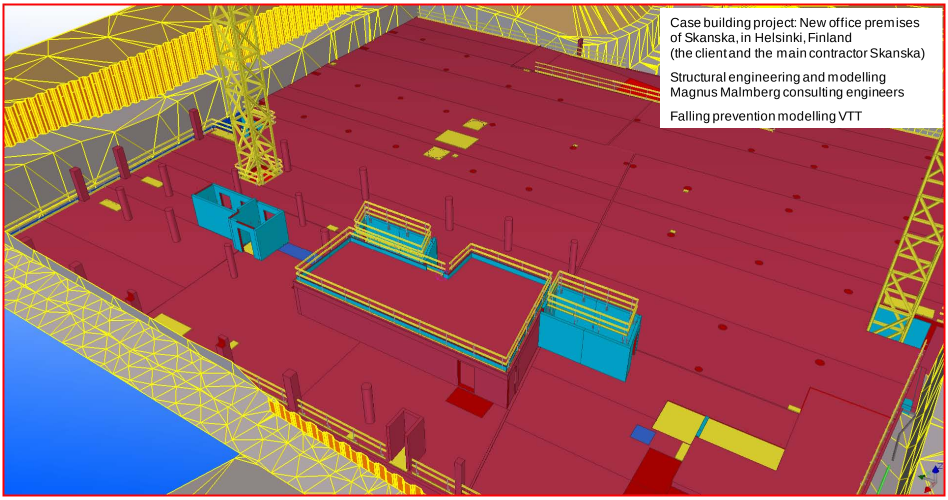

Figure 35. Starting point of the form work visualization: Casting moulds for columns are installed in the casting area 1.

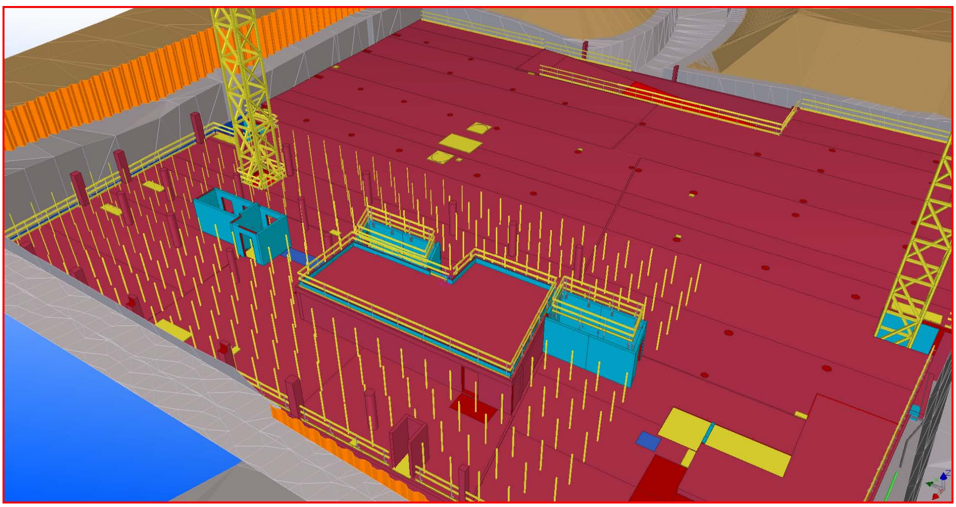

Figure 36. In the second phase the columns of the floor mould system are to be installed.

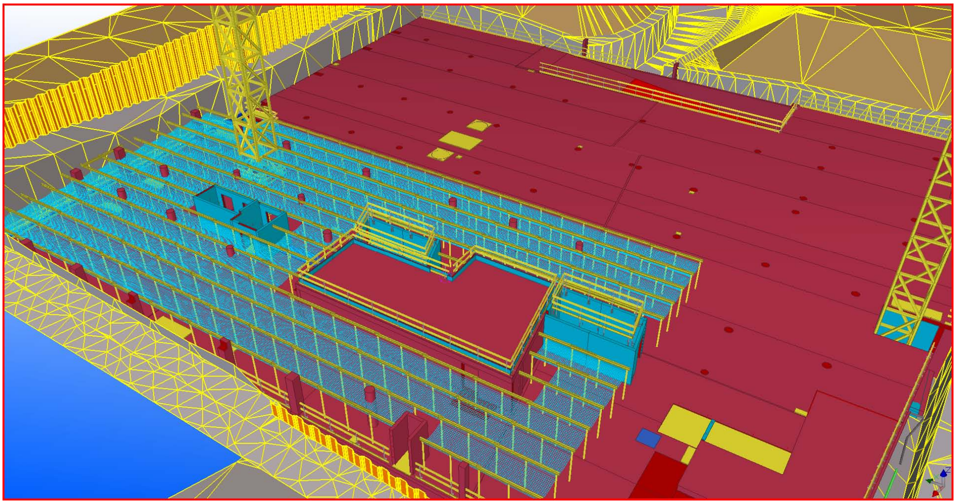

Figure 37. In the third phase primary beams of the floor mould system and safety nets are installed.

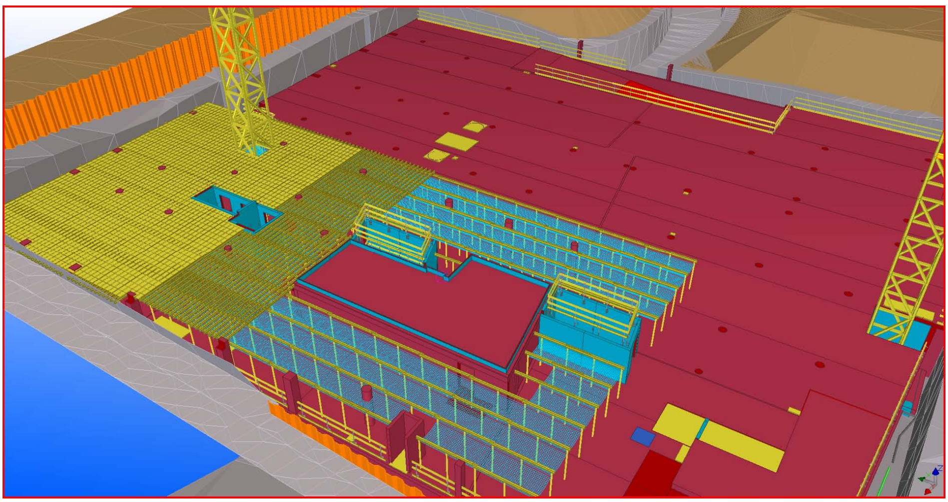

Figure 38. In the fourth phase secondary beams and timber panels of the floor mould system are installed.

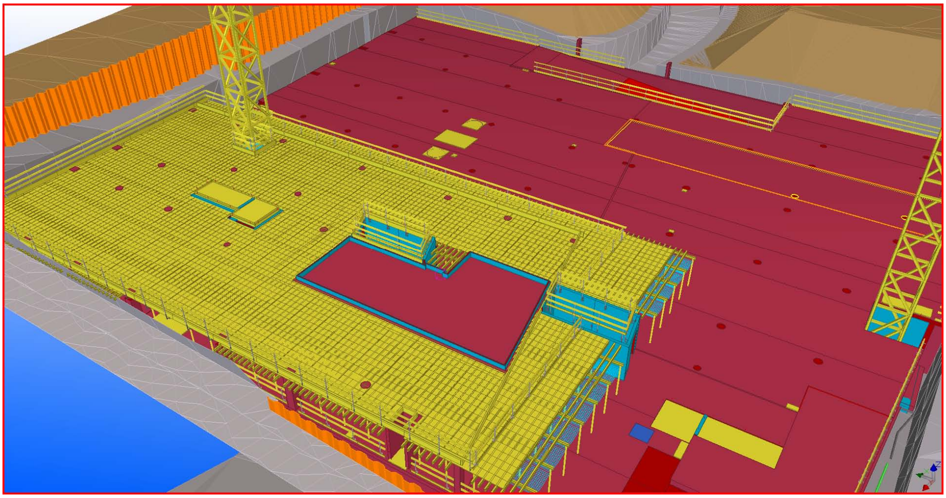

Figure 39. In the last phase of constructing the casting moulds, timber panels and edge beams of the floor mould system, and related safety guardrails have been installed.

BIM-based plan can be viewed from the viewpoints needed and one can also zoom to the details also. The following figure presents a closer view to the same plan.

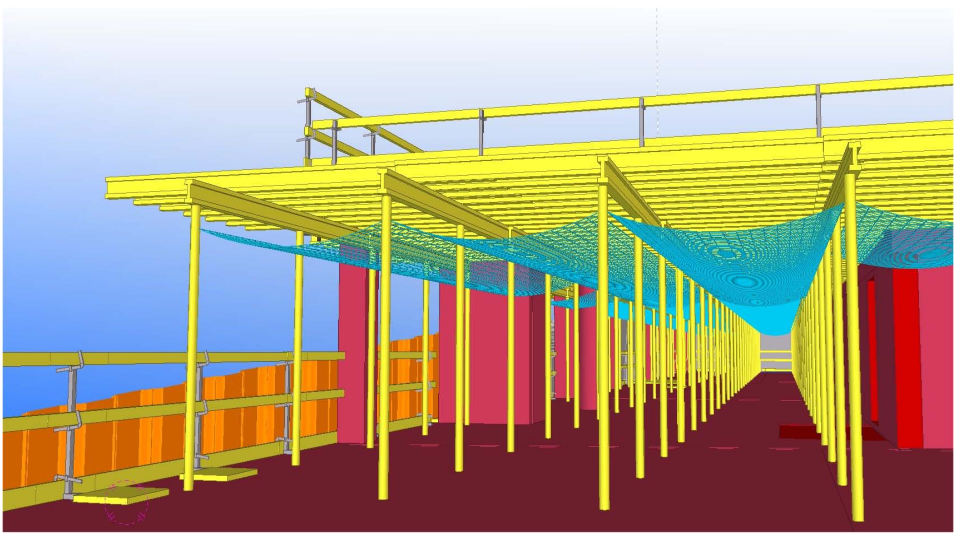

Figure 40. A close view to the form work visualization. The casting mould parts have been modelled roughly, but the safety railings have been modelled in detail.

4.4.2 Developing BIM-based form work planning

In pilot project 2, the aim was to test the modelling of form work in greater depth than in pilot 1. The aim was to model the geometry of the molds in more detail and corresponding better to the real plans, and to carry out BIM-based 4D construction scheduling for the mold parts in the structural model, together with cast-in-place concrete parts.

Since the mold supplier was able to make 3D mold planning, a technical test was carried out in the research project to investigate the connectivity and usability of the supplier's 3D mold plans in structural modelling software. The test revealed that a 3D mold plan can be combined with a Tekla structural model successfully. Similarly, under certain conditions, 4D scheduling and visualization can be carried out to the mold parts together with cast-in-place concrete parts of the structural model.

A 3D-dwg test model got from the mold supplier was used for this test. The test model represented so-called climbing form/mold selected to be used in the construction project. The molds that were modelled by the supplier were successfully combined and displayed in the structural modelling software (Tekla Structures 15) as a reference model (Figure 41, on the left side). However, the mold system includes a lot of small parts, and it is essential to be able to select appropriate assemblies from the model (corresponding to installations at site) for 4D scheduling. Based on the technical test, this can be done if the model parts are modelled in the original modelling software using appropriately selected and named layers, because it is possible to filter reference model parts in the structural modelling software with help of the used layers. Appropriate use of layers can thus significantly facilitate the selection of the mold parts from the reference model for scheduling. After filtering certain parts first, it is easier to manually select a smaller subset of those parts for scheduling.

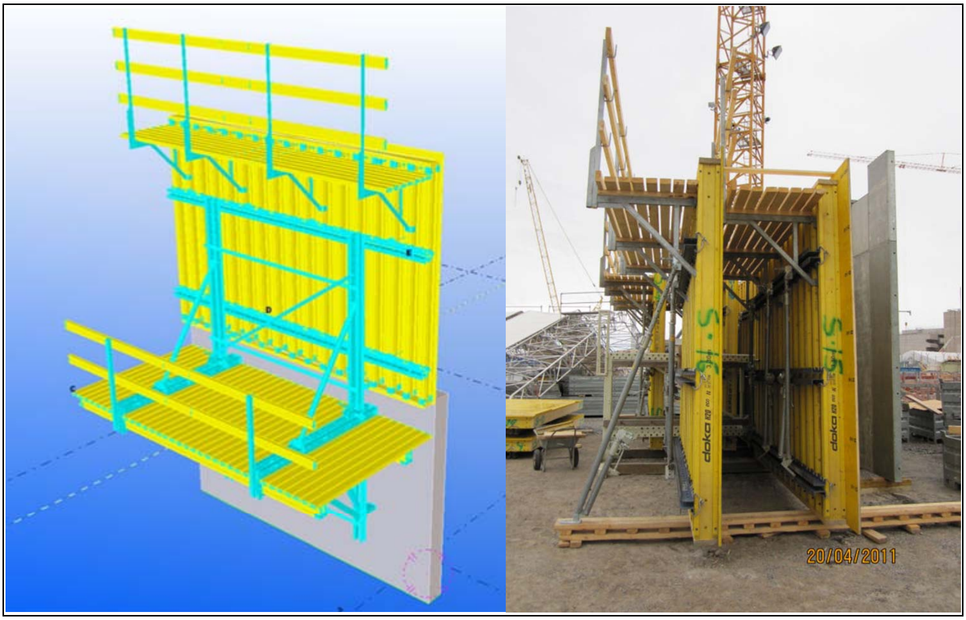

Figure 41. 3D-wall-mould used in the technical test, and the real mould at construction site.

The mold parts contained in the test model were scheduled in three phases (three tasks were created into Task Manager, and selected dwg-reference model parts were linked to these tasks), and a simple project status visualization rule set was created. The result was a simple test visualization, which showed that the mold parts combined into Tekla as a reference, can be scheduled and visualized as a date specific representations, and the visualization colors can be selected as desired, just like for native Tekla model parts.

Later, the contractor's site engineer combined the real 3D-form plans into the project's structural BIM, and this model was used for reviewing and evaluating work procedures at site. Additionally, the structural engineering used the 3D-molds for clash detection, to avoid collision of mold parts and reinforced concrete parts.

4.5 Comparison of plans with the actual process

4.5.1 Safety railing solutions used at site

In the pilot project 1 the falling prevention planning was carried out by modelling safety railings and floor opening coverings in structural model of the office building (Figure 42). This planning was applied in more detailed level than the traditional planning is carried out, and for which the modelling software Tekla Structures provides support (ready tools).

The site staff guided the planning and modelling that was implemented by the research group. This planning and modelling was done about 3 months earlier than these work phases started at site. In the current planning practice this kind detailed falling prevention planning is not carried out in such an early phase. Only the needed safety equipment types are usually selected and reserved, and more general plan of falling prevention arrangements is presented in that phase.

In the next picture pairs it is presented how the model based falling prevention plans where implemented at site. There are some visual differences between pictures due to slightly different viewing point and angle but the comparison between the plan and the actual implementation can be made.

In some pictures also the concrete form work is modelled while it has influence on need of safety railings, but the parts of the form system are modelled in more general level than the safety railings.

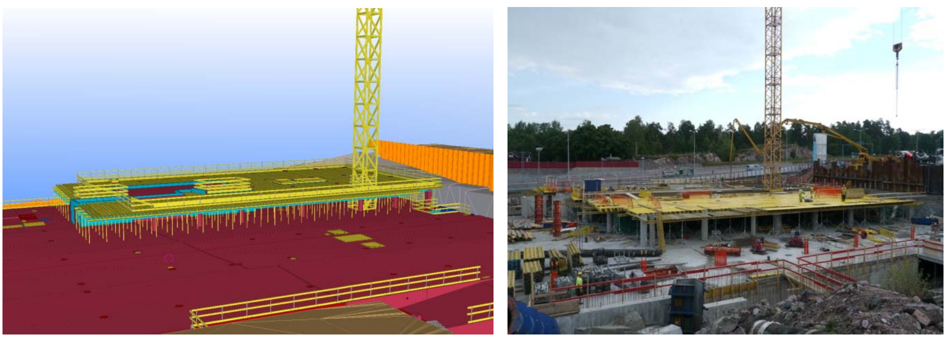

Figure 42. Comparing model and live situation: A general view to the pilot site in basement construction phase.

The picture above presents the second basement floor below the entrance floor. While this floor is two floors above the foundation level (and the ground level at this construction phase) the falling prevention is needed around the floor. In the photo the formwork has proceeded compared to the model picture. Other visual difference between pictures is the coloring. The typical Tekla Strucutures colors used in the model may be confusing for an occasional viewer.

Additionally, one obvious difference is the construction material and equipment stored at the site and seen in the photo. Aim of the falling prevention modelling was to present the appropriate safety equipment and demonstrate where they are needed. Also other temporary structures were presented like formwork but it should be highlighted that this modelling isn't the construction operations modelling covering all needed resources and incidents. From the viewpoint of safety it might be useful to analyse also these highly dynamic space needs and detailed work but the simulation methods and tools were not studied in this research.

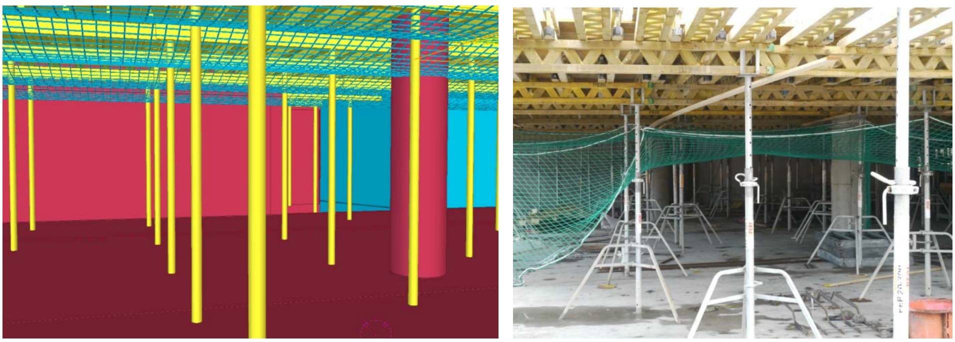

Figure 43. Comparing model and live situation: Example of falling prevention in slab form work with safety nets.

In the slab form work the falling prevention was implemented with safety nets that were hang on the form supporting shores. The shores, form primary beams (stringers) and the safety net are installed from the slab below and the secondary beams (joists) and decking above the net while the net is securing the work. Schematic modelling of form system parts don't present the fixing hooks for hanging the safety net. Also the three-legged supports are not modelled and needed space can't be seen in the model (Figure 43).

The use of the safety net was an experiment in the pilot project and it is not typical solution for falling prevention in Finland. Also the total strength or stability of the net area was not analysed thoroughly and the method needs further development and testing.

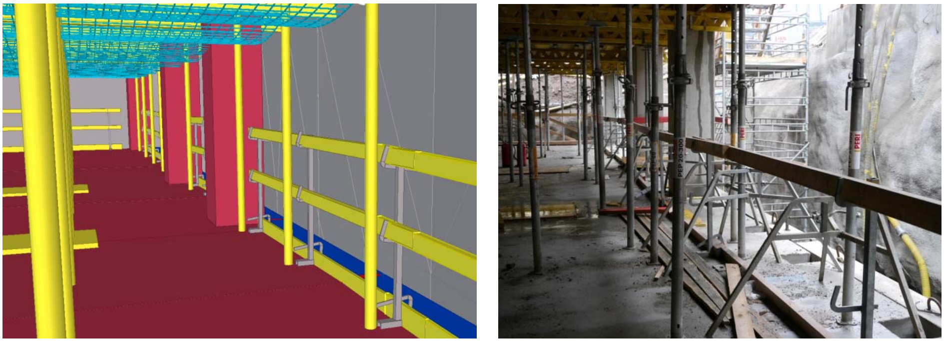

Figure 44. Comparing model and live situation: Safety railings in the slab edge in the second basement floor.

Figure 45. Comparing model and live situation: Safety railing detail in the corner of the slab.

The positions of the safety railings on the slab edge has changed substantially compared to the plan (see Figure 45). The initial idea for the planned position was to allow installation of the wall elements behind the railings while they are near to the edge. In implementation the railings were positioned beside/inside the column line as a continuous railing. In the first photo (Figure 44) one can see also the inserted temporary stairway that was emergency exit from the basement floors.

Basic reason for changing the positions of the safety railings was the floor area needed for the three-legged shores for form support. That's why also the middle rail is removed in the photos. Other reason might have been that the version of the structural model used in planning phase didn't contain the reservation holes for wall fixing attachments seen at the edge of the slab. The holes are limiting the area for these temporary construction devices.

The third reason for the change is that the safety planning that was done about 3 months before actual construction work won't guide the work enough. The detailed planning should be done closer to implementation with all the needed information. It also has to be done in cooperation with the subcontractor who is responsible for the implementation.

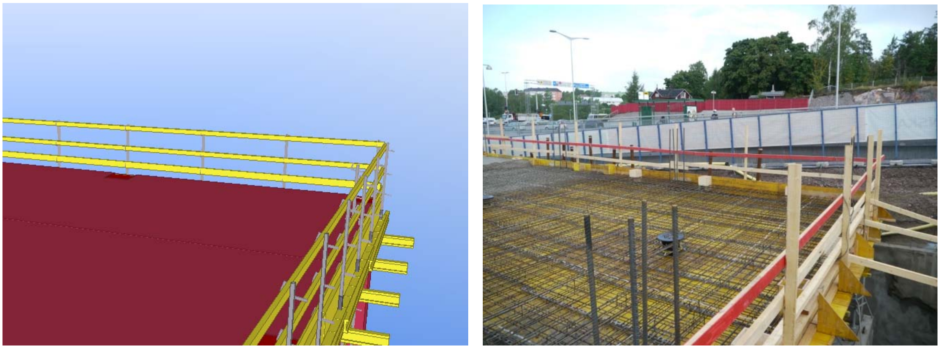

Figure 46. Comparing model and live situation: Safety railings on the slab formwork.

The safety railings in the slab formwork were planned with railing posts that were parts of the form system. In practice the railings were implemented as timber railings (see Figure 46). If the formwork is to be designed in detailed level it is appropriate to design also the safety equipment, but this should be done with intended equipment. The form system suppliers have started to offer also 3D planning services related to use of their products but these services are typically used in demanding form structures only.

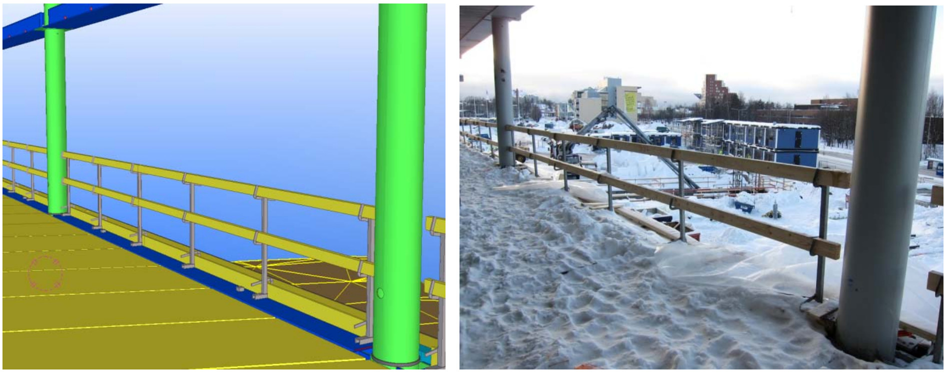

Figure 47. Comparing model and live situation: Safety rail posts are attached with bolts to the welded thread sleeves on the steel beam.

Figure 47 presents a safety railing in an office floor of the pilot project. A railing solution where the posts are attached with bolts to the thread sleeves in steel beams is used around the floor. Those fixings were welded to the steel beams in engineering works and they were presented in structural model of the steel frame. The sleeves provide a fast and reliable fixing method for rail posts.

In the photo one can see also the weather conditions at site while snowfall has past the site. The weather affects the safety risks at site, but it is difficult to take that into account in BIM-based detailed planning.

Figure 48. Comparing model and live situation: The final handrails of the building were intended to be used as falling prevention in construction phase.

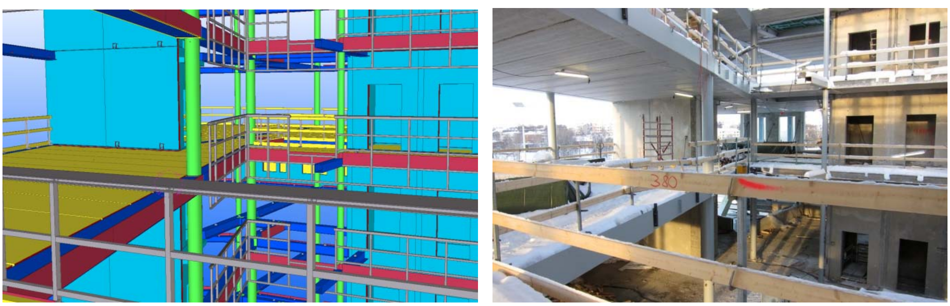

Figure 49. Comparing model and live situation: General view of falling prevention in the office floors around the atrium.

Inside of the pilot building there is an atrium space where falling prevention is needed. The suggested method for this was to use the final railing in construction phase. The initially designed final railings were proposed to be installed at same time with the steel frame. However, the type of these railings changed in the design so that they had to be replaced with temporary railings in the falling prevention plan.

In Figure 48 the railing at the left side has been changed to a work surface in the technical shaft. In the lower picture (Figure 49) a part of planned railing is missing in the model, because it was thought that there would be a wall preventing falling, but this wall will be installed later.

4.5.2 Demolition work process

BIM-based visualization of demolition plans was used in pilot project 2 for communication between contractors before starting work at site. However, some changes for implementation were made on the basis of the last evaluations made by the structural engineer and the contractors, such as saw cuts were made piece by piece instead of doing all horizontal saw cuts first. The order of demolition work was also changed a little bit after modelling, as well as the hoisting equipment. Two scissorlifts were planned to be used, but eventually one scissorlift and one other kind of personnel lift was used.

The following pictures present the modelling of the demolition work in parallel with photos corresponding to the same phases of the real demolition work at site. In the first figure the starting point of the work is presented as a model view and as a photograph taken at site (Figure 50). In the second figure (Figure 51) there is a model view concerning demolition of the part number 15, together with a photo corresponding to the real work at site. In practice, the up most parts of the wall were removed first on the right side of the center line, but in the visualization work progresses throughout the width of the wall from top to down.

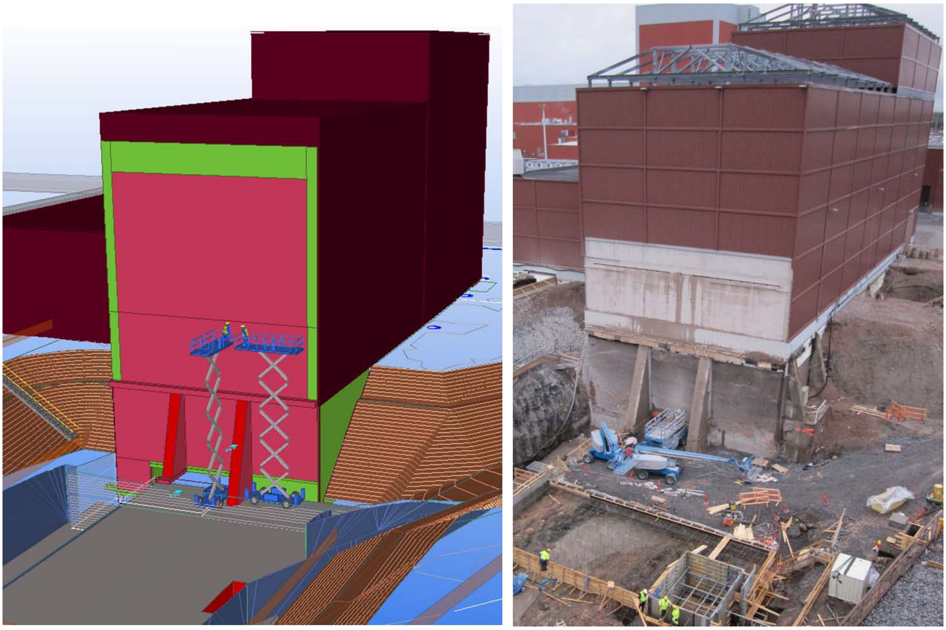

Figure 50. Comparing model and live situation: BIM view and a corresponding photo on construction site at the beginning of demolition work.

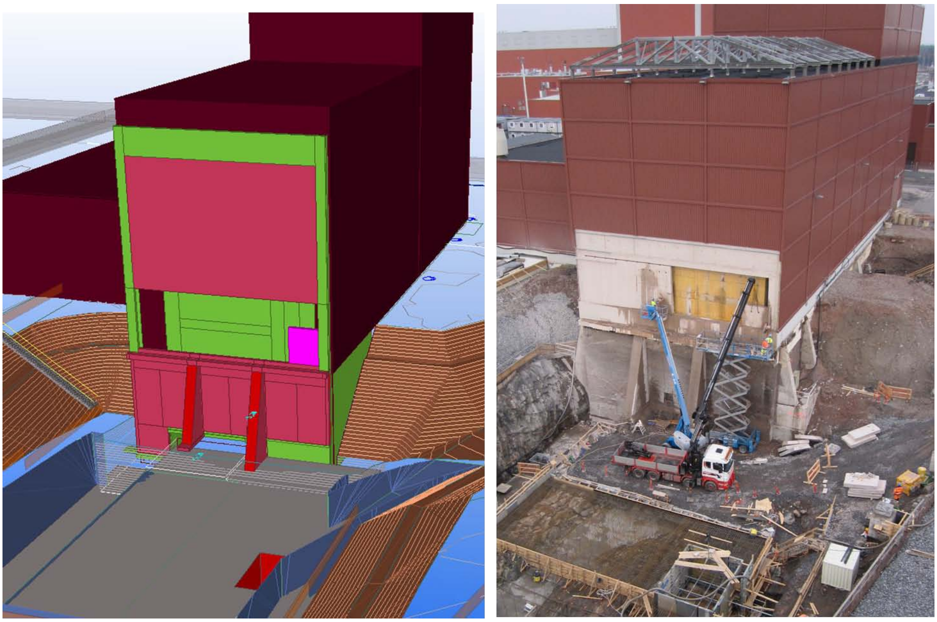

Figure 51. Comparing model and live situation: BIM-based demolition visualization and corresponding photo of the actual demolition work of the same part at the construction site.

BIM-based visualization was found to be useful for the discussions between the contractors (the two main contractors and a special contractor) while planning the implementation of the demolition work. However, the visual quality of the work sequence visualization was found not to be optimal in the modelling software used. Presently, the new version of the used software provides improved features in terms of object coloring options for project status visualizationsHowever, 3D material textures, which are typically used in architectural modelling software, are not provided. Lack of visualization tools such as perspective “camera view tools” was also identified while generating BIM-based views from the Tekla-model. Even the views above are perspective views to the model, they do not have similar perspective and depth as the corresponding photos have. Dimensions of the building cannot be discovered in the model views.

5. Locating potential safety problems

5.1 Expert analyses with the aid of virtualised construction site

One major issue of safety management at construction project is to evaluate the potential risks and prepare proactive prevention activities. This evaluation can be arranged as workshop with the responsible project participants and utilize BIM with safety plans for visual risk analysis. The so called CAVE virtual environment with sophisticated 3D presentation technologies would be ideal place for such working method.

In the research project the CAVE technology was briefly evaluated for construction safety risk analysis by the research group. The actual workshop with pilot project representatives was not arranged. The main facilities in tested CAVE environment were three screens with rear screen projectors and multi touch table for controlling the vision and movement on the screens. The multi touch table is fully programmable screen and typically there is presented the 2D projection of the floor and it is used for fast movement inside the virtual building. In the testing the multi touch table was used with basic movement functions (Figure 52).

In the CAVE environment there was also a possibility to 3D vision of the scene with the polarized eye classes. The environment didn't support the stereoscopic presentation of a Tekla Structures model on the screens so it was tried to import to programs those were supported for 3D vision. The Tekla Structures model was imported in Autodesk 3ds Max modelling software and in 4D Studio that is special program for 4D scheduling of building information models (Figure 53 and Figure 54). The import testing was done briefly and the result was found inadequate without further manipulation of the colours or the transparency of the surfaces.

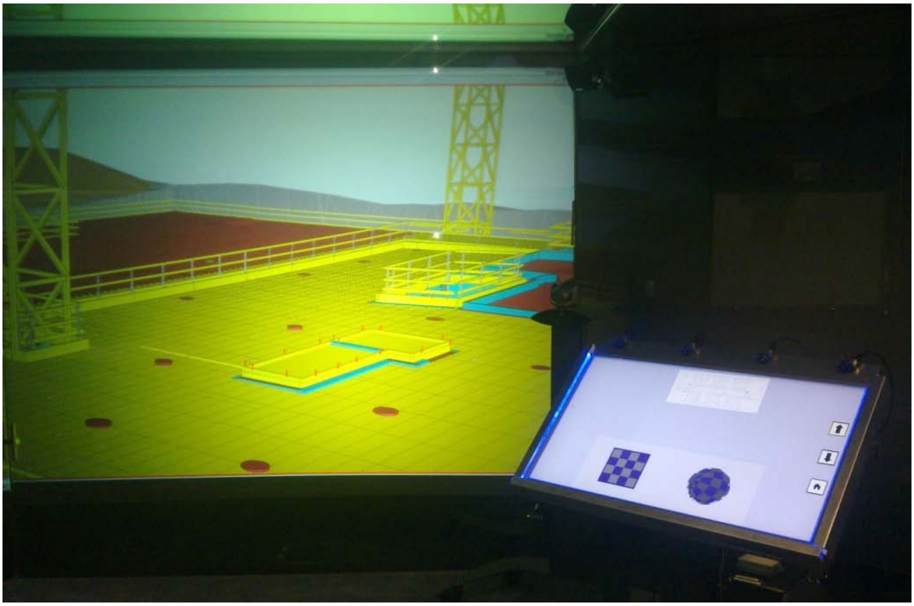

Figure 52. In the virtual CAVE environment the movement in 3D scene was controlled with multi touch table.

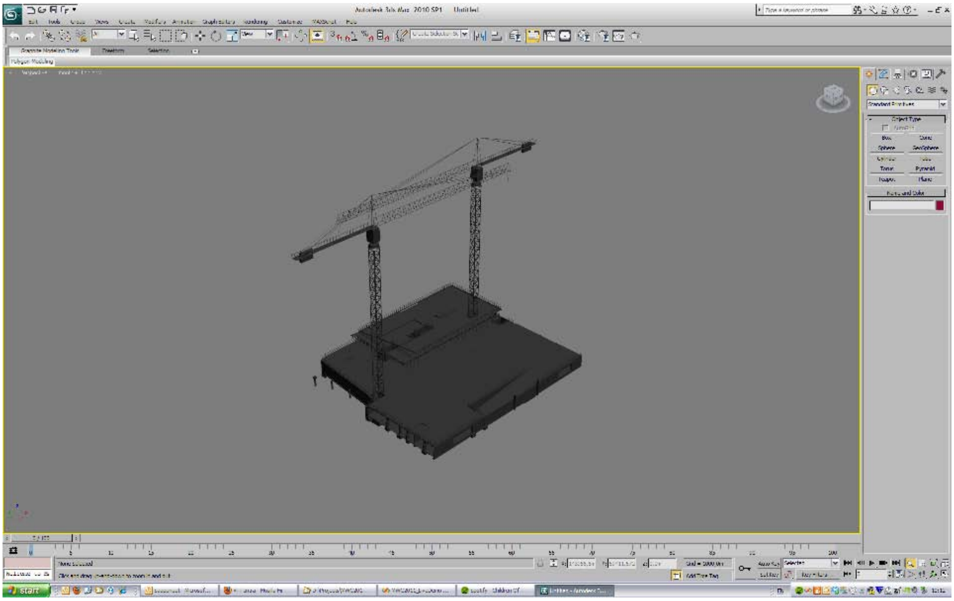

Figure 53. Tekla Structures model with safety plans imported in the Autodesk 3ds Max software (picture by Kari Rainio).

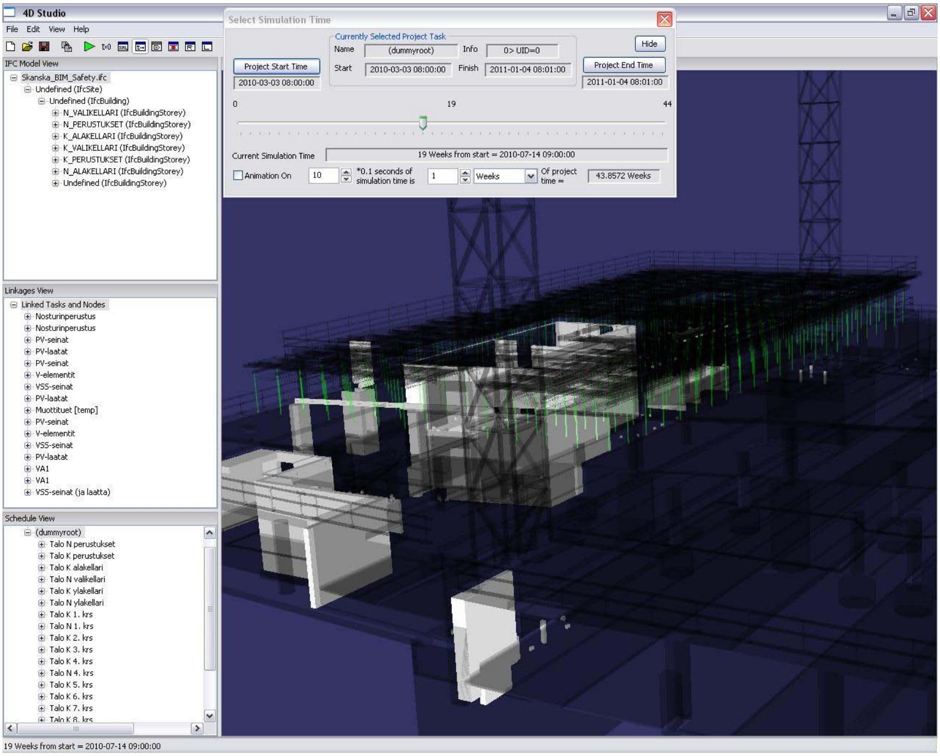

Figure 54. Tekla model of the pilot project transferred into 4D Studio software (picture by Kari Rainio). 4D Studio is developed at VTT.

The visual evaluation of the falling prevention plan was done with Tekla Structures model presented on two screens in the CAVE environment (Figure 55). The virtual environment provides obvious values compared to basic video projector presentation. A wider view of the model gave more realistic and natural scene even with normal projector presentation without any 3D stereoscopic visibility. Also the model doesn't have to be rotated or moved as often as in narrower view. This makes evaluation situation more relaxed for the group of people and is supposed to bring better results.

The visual evaluation of the falling prevention plan was done with static model. The basic errors and deficiencies can be detected quite easily as the error in Figure 56. Beside the visual evaluation there were all Tekla Strucures tools available, e.g. the measuring tools. Also the 4D scheduling of the structures could be used for evaluating the work sequences but used version of the software allowed to present only the daily views. More detailed sequence analysis or animation at part level would be useful for evaluating risks.

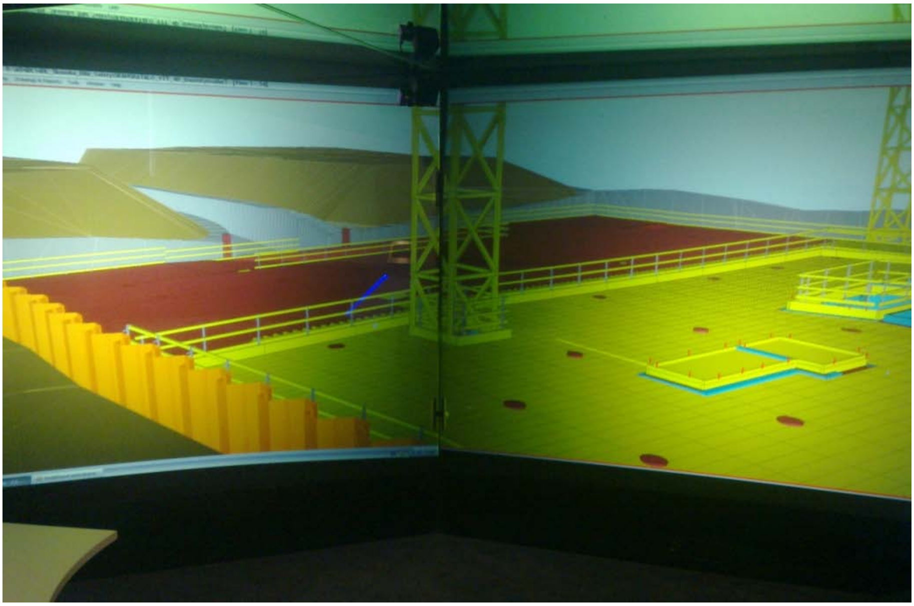

Figure 55. Wide scene to the virtual site in the tested CAVE environment.

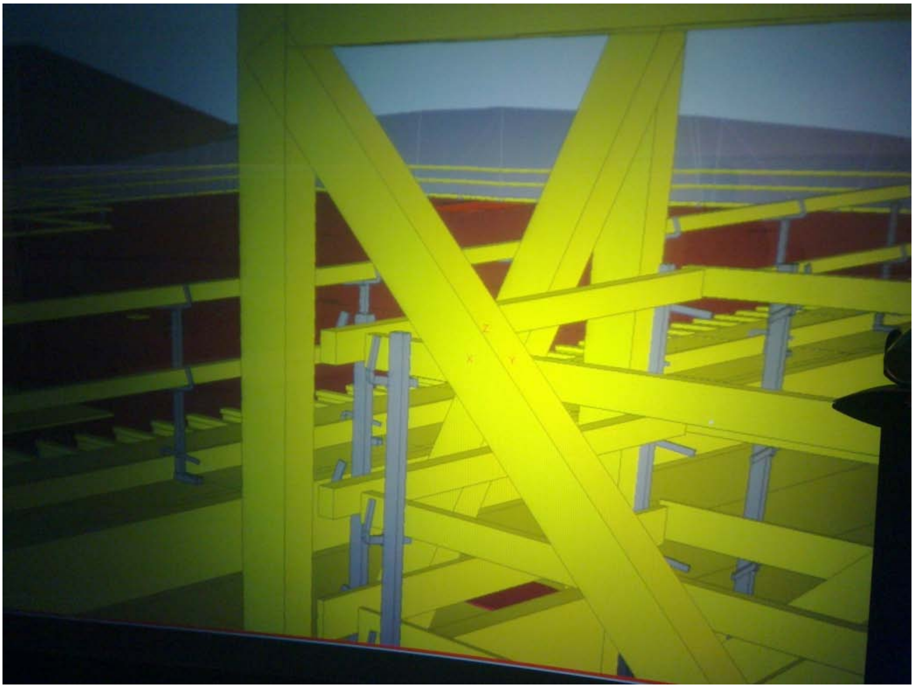

Figure 56. Identified error in the BIM-based falling prevention plan. The safety railing must be outside of tower crane structure.

5.2 Automatic safety analysis using BIM technologies

BIM can be used for risk analysis and safety related evaluations of plans visually, but there are possibilities to develop more automated analysis related to BIM-based site and safety plans in the future.

Approaches to the automatic/semi-automatic analysis of the occupational safety risks are 1) checking model content and details from the viewpoint of safety, or 2) identification of the conditions and factors that cause occupational safety risks. The first is based on the fact that there is experience and knowledge of which issues to pay attention to, what is the required content of the plans, and which are the things/issues that should be checked. The latter approach would require data concerning features of naturally safe spaces, as well as properties/features that increase safety risks, and therefore requires basic research first. A BIM-model for an automatic analysis can in turn be “a static 3D-model", such as the BIM-based site layout plans are currently created in practice, or a 4D production model. Time is an essential dimension in 4D models, and in practice, the model to be used in the automatic analysis would be a model representing a particular moment of time as a “4D status-model” of the situation at site. Such development work and test trials have been carried out by Georgia Institute of Technology. Their preliminary results (Zhang, S. et al. 2011) demonstrate that a computer-based automated tool can assist in detecting different types of openings that could be potential fall hazard and also automate the BIM-based falling prevention planning.

In the BIM Safety project, a BIM-based 3D site layout plan was selected to be the subject to study possibilities of safety related automated checking, and it was carried out with help of Solibri Model Checker software (SMC). The main reasons for selecting this focus and the tool was, that contractors has started to utilize BIM-based site layout planning, and SMC is currently used in construction projects e.g. for checking the content and the consistency of BIM-based architectural, structural and HVAC-models, as well as for quantity takeoff using Information take off –tool included in the software. For this test, the ArchiCAD site plan of the pilot project 2 was developed further by modelling the site area landscape roughly, as well as by modifying content of the 3D site planning objects to be usable in computer-aided analysis. After this, the model was imported to Solibri in IFC format. Model used in the test is presented in the following picture (Figure 57).

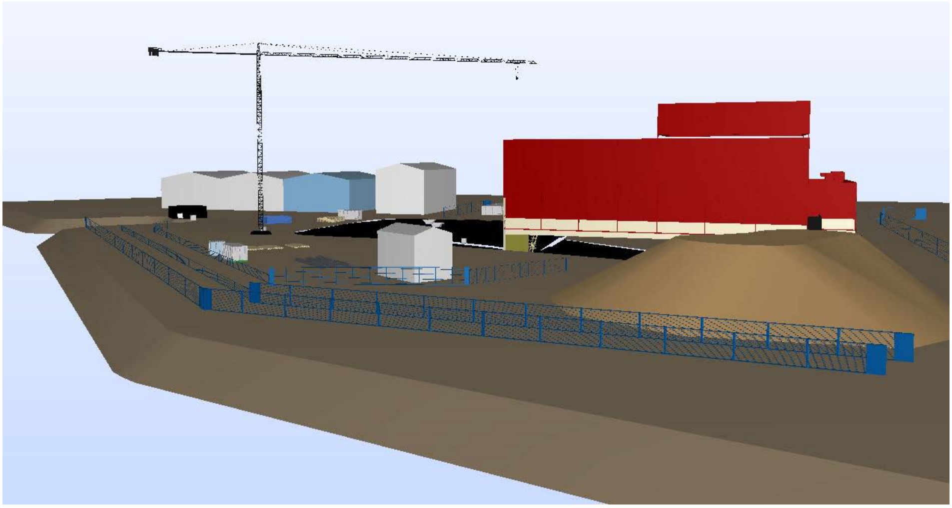

Figure 57. A view of the model used in BIM-based safety analysis testing, in Solibri Model Checker software.

The geometry information is sufficient for such automatic analysis as collision detection. If analyzing for example the contents of a BIM-based 3D site layout plan, identification of IFC model objects is essential for the analysis with help of Solibri. For this reason, GDL objects included in the site plan, were modified (objects have not previously contained any intelligence beside 3D geometry). In practice, data fields were added to site planning objects first using so-called basic object available in the Finnish ArchiCAD 13 Basic library, and then needed identification information was stored to those data fields so that all necessary information for the analysis was successfully exported in IFC-format to Solibri. The following figure presents an example of the modified objects (a storage for hazardous waste), its data fields and the information stored into the object in the test model (Figure 58).

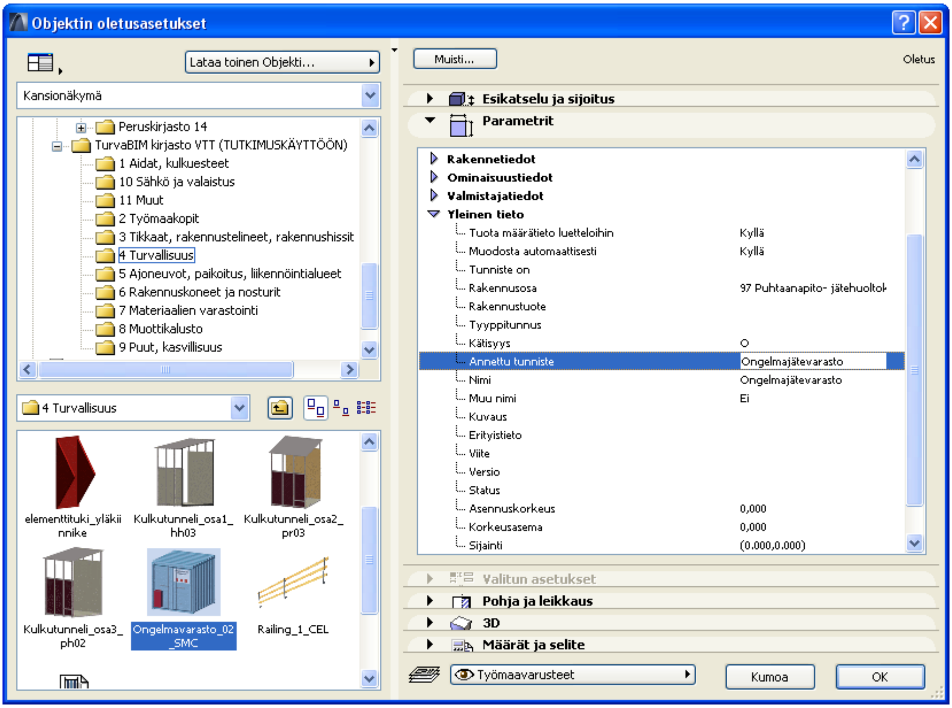

Figure 58. An example of a GDL-object and it's information content in BIM-based safety plan used in the test ("hazardous waste storage" as identification information).

SMC has a set of predefined and hard-coded rules for checking the basic conformity of building models. These rules with some appropriate modifications can provide useful functionalities also for safety analysis purpose. Based on the test, issues to check concerning a site layout plan might be related to e.g. existence or properties of site objects, requirement of the free space around site or building objects, the measurement of distances between model objects, and collision detection. Additionally, one interesting identified development opportunity is related to space-based reviews of site plans, which would however reflect on the basic issues such as how to model and define various areas of building sites in BIM-based plans.

6. Safety communication on construction site

At the moment safety communication on construction sites is mostly reactive and the content is largely based on the staffs' daily experiences and ad-hoc risk assessments. It utilizes mostly traditional means of communication, such as personal discussions, notice boards, plans and reports. Safety communication is a part of a construction sites' daily routine, but is usually not recognized or used as a productive tool. (Merivirta 2011.)

As a part of developing safety communication towards a more strategic direction, new means of communication should also be taken into account. Visualizing tools based on BIM are already a part of many construction projects and the possibilities in improving communication by using these new means should also be studied.

6.1 Communication and BIM

The use of site specific, up to date and visualized information for safety communication is considered to have a considerable potential to improve site safety. BIM technologies can enable easier communication and dissemination of information for example by crossing language boundaries that often exist in the multinational construction sites. Visualizations can work as a democratic way of communication, since the information accessibility is same to everyone regardless of status, reading abilities or language understanding. Moreover visual-aids can particularly be useful when illustrating the building process and safety solutions on site. A visual presentation provides support to other means of communication by reinforcing the message and facilitates sharing of up to date information. BIM-models can be sources for versatile communication, for example to help discussions on the construction process between professionals and to disseminate information to project stakeholders. This approach can also help make the site processes more approachable to people with no background in construction.

6.2 Trial with information displays

A pilot study was carried out where LCD information displays were placed at construction site premises and used for presenting weekly updated information relating to safety issues. The target of this pilot study was to test usefulness of LCD information displays for safety communication. The focus of test was to advance safety communication on construction site and to study the use of 3D and 4D model views as a part of safety communication. Intention was to improve site safety communication by supporting new communication channels i.e. those that can provide needed material for the information displays. Improved understanding and knowledge over the events on the construction site that have clear associations with safety were seen as an important way to increase site safety. Examples of such events are past but recent happened or close to happen safety incidents reflecting safety performance, and, on-going activities where particular attention should be put due to safety risks. The overall idea was to bring pressing safety information closer to the site staff and more into their daily operating environment.

The pilot study took place on BIM Safety Pilot project 1. The information displays were placed at site premises, one in the main entrance hall of the site management offices and the other one in the staff break room, so that as many as possible of the site personnel would have access to the screens (Figure 59).

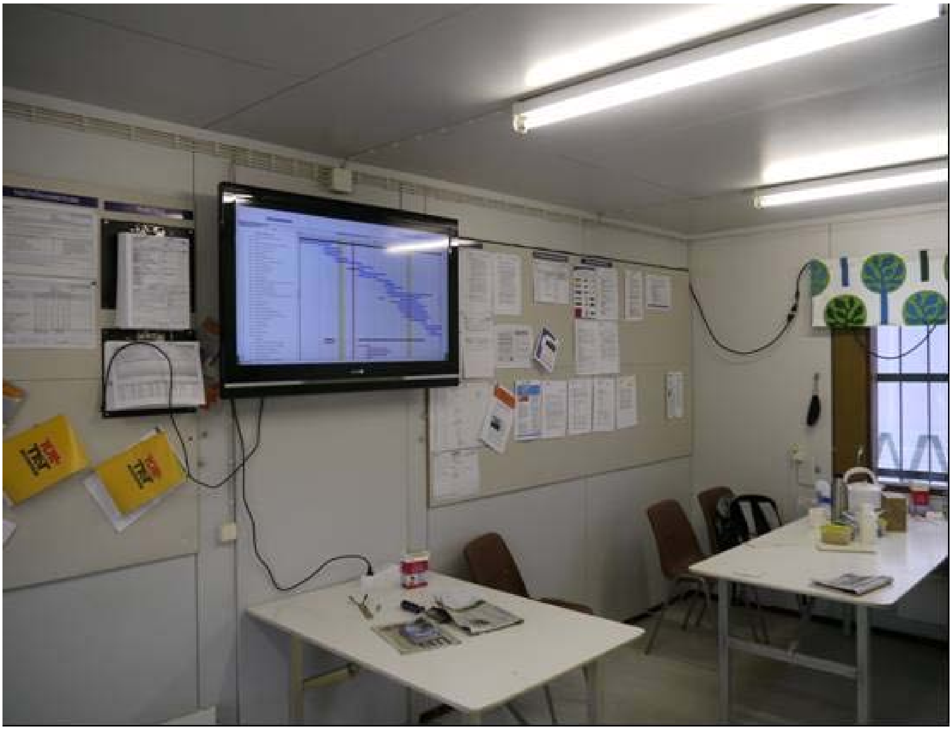

Figure 59. Example of LCD information displays at the construction site staff break room.

The staff break room is built from five hut modules that are connected via doorways. Personnel can use two doors to the room. The doors are in the module one and four. The information display was in module one, up on the end wall, next to a door and in the middle of the general information boards (Figure 60). The watching area of the display is restricted because of the distance from the display and the walls between modules.

The personnel have two daily coffee breaks, both last 12 minutes and a lunch break which is 30 minutes long. Watching the display for the whole length of a break is possible only if a person is in the area marked grey in Figure 60. People who are not sitting in the watching area can walk past the display few times a day and have a chance to view its content, only if they use the door in module one. The share of the personnel who would have used only the door of the module four wouldn't have contact at all with the display.

The display in the staff break room is of primary importance for reaching the site personnel, since they did not stop to watch the other display in the entrance hall while visiting the site management offices.

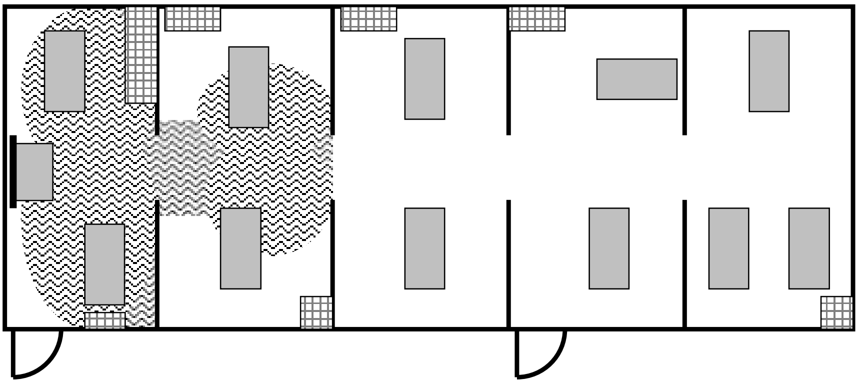

Figure 60. The layout of the staff break room. The information display is placed on the wall left hand side. Altogether the space includes 12 tables. The main kitchen is in the module one on left. This and other microwave ovens and refrigerators, are marked with grids. The watching area is marked with the wave grid.

6.2.1 Presentation material

The pilot project was fully designed using 3D building modelling technologies. In this case, the management personnel had experience in working with 3D views and relating tools, and had a professional BIM software user on site. Thus it was possible to take the 3D model usage to the next level for improving site-communication. Since creating videos with the used BIM tool was not possible, a slide presentation with views from the model was prepared. The presentations were planned to show up-to-date views and visualizations based on 3D and 4D views of the building under construction.

The presentations consisted in average of 25 slides. The actual slide show lasted less than ten minutes and it was run as a continuous loop throughout the day. The research team designed the content of first presentation in co-operation with the contractor's safety personnel and site staff, and it was updated weekly. The content of slides was gathered from the company's general site safety instructions and from site-specific plans and models. A member of the site staff used weekly one hour to gather the needed material and update the slides.

The presented slide shows focused on information that was 1) important on the specific week, 2) site-specific and 3) related to safety, and provided information related to the following topics:

- current affairs and events
- schedules and more detailed weekly plans

- positive safety notes
- safety observations
- accident or near-miss reports
- safety issues that need improvement
- particularly dangerous places on the site presented with help of 3D site plan
- 3D site plan
- TR safety observation results
- 4D-model views presenting the weekly plans (Figure 61).

Figure 61. Example of slides in a presentation showing4D-model views presenting the weekly plans.

The pilot trial/testing lasted for 4 weeks, after which the site staff have continued updating the presentation and showing it independently.

6.2.2 Collecting feedback from the site

The construction site in question employed 50 people at the time of the trial. Feedback over the display screens and presentations was gathered with a questionnaire which was distributed to all of the site's personnel by a member of the site managerial staff. It consisted of 12 questions divided into three categories: i) watching habits, ii) display placement, iii) perceived necessity and content of the info screens. Both dichotomous and multiple choice variable questions were used and complemented with open questions. The questionnaire was responded anonymously, and 36 employees returned the questionnaire, resulting in a 72% response rate. 20 of the respondents were the main contractor's employees and 16 were subcontractors' employees.

6.2.3 Results of the survey

The results propose that the display screens are mostly viewed on a weekly basis (37%), which means that viewers watch the entire slide show once in short portions during the week. Watching time is mainly short; more than half of the respondents watch the information display half a minute at a time. 20 per cent of respondents did not watch the display at all.

The information display screens with the information content used in the study were seen as useful for site operations and their safety. Respondents have received information about current site events (83%), safety issues (82%) and timetables (77%). Weekly updating was considered sufficient, only 9 per cent of respondents replied that updates were not often enough.

Each information category included in the presentations was considered a somewhat useful at a minimum. Over 50 per cent of respondents considered weekly events, current matters, site timetables, weekly plans and positive safety notes to be of importance (Figure 62). The least important were weekly 4D target plans, TR safety observation results and 3D site plan.

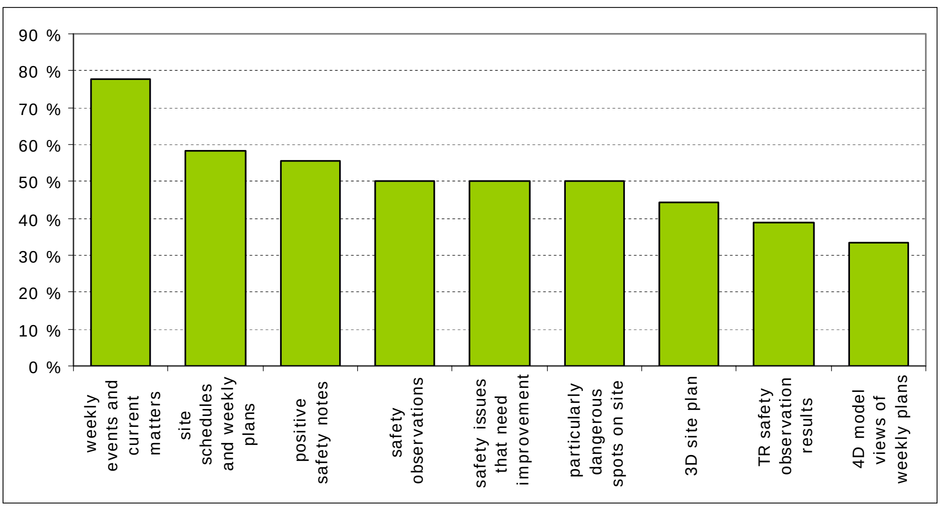

Figure 62. The usefulness of main information categories according to the completed survey.

Information displays were generally considered as a good source of knowledge on site affairs. The site staff in place reported they had e.g. recognized useful information explaining particularly dangerous spots on site and furthermore they see in a clearer way the total picture what is happening on site. Weekly timetable and accident reports were mentioned as good examples of useful information. Only three of the respondents reported that they did not get any benefits from the display screens.

Additional findings from the survey:

- Information of interest: responsibilities of different site managers.
- Information of interest: the location of first-aid supplies.
- The flow of slide show: changing of the slides was too quick.

6.2.4 Administrative prerequisites

Updating and editing presentation material require some effort and certain skills. Although the work time required seems not to be a significant factor, some basic IT knowledge is required to update the presentations. On the test site, an IT-capable project secretary took care of the weekly updates of the displayed material. She was engaged positively and pursued to develop further the weekly content. However, it looks obvious that only limited number of construction sites can have people with the needed capabilities. This may lead to a need for an off-site support for up-dating the weekly presentations.

The content of the presentations is naturally of significance. Rather than providing general knowledge the more the content is explaining characteristics and peculiarities of site in question, the more valuable the site personnel consider the displays. However, if the off-site updating of presentations is required, the collection of data content and its editing becomes more cumbersome. This can result in presentations where the main content is about generic company information with the cost of having less valuable site experiences.

6.2.5 Final results and discussion

Based on the pilot study, possibilities for further developments of the display screens were identified. Firstly, placement of the information display screens is critical. A shortcoming of the performed trial was that one display unit was placed in the staff break room in a way that the unit was not seen from all over the room. This possibly explains that 20 per cent of respondents did not watch the display at all. A solutions to this problem could be reached by e.g. providing a second screen or making the current screen movable to a different location in different times of the day or week, or placing display screens in places where people are waiting or queuing and so have free time to pay attention to them. Another solution would be to design the staff premises with communication in mind, creating places for effortless receiving and exchanging of information and open spaces where the displays are seen by a larger number of people at a time.

Secondly, the possibilities of using 4D and 3D visualizations are also somewhat limited at the moment. Currently there are only limited possibilities to create videos of building models without special software. The use of plain screen shots of 3D and 4D models is not as impressive and eye-catching as video clip would be. There are also some issues with the coloring and rendering of visualizations that are showing structural BIM-models or parts of those. Different colors have their specific meanings to structural engineers, but those may not be appropriate to the site personnel. Converting these model colors from their profession specific meaning to other color sets has become possible, but should be developed further and easier to use in the future, so that more photorealistic images can be created and the pictures are more interesting and easier to understand. For example in the BIM Safety Pilot project 2, the project staff selected the tested more natural colours for the wall demolition work visualization instead of the original colours used in the structural model. This visualization was created to be used for the comparison of the alternative demolition sequences.

Thirdly, a passive medium such as the information display screen has a risk of becoming gradually a background noise. Hence people become uninterested if the information is not catching enough and also if changes in the content are not clear enough. The manner of representation should be changed from time to time to keep up interest and viewer's opinions of what information is needed should be heard and taken into account.

For the information displays to stay in active use, it should be easy to edit and update their content. The existing site specific information, such as timetables, current safety information and BIM visualizations or videos should be easily transformed to be used on displays. It would be also beneficial to have participation from contractors' communication department and from safety specialists, as they could equip the site specific information with more general content that could be as next step used in all of the company's work sites.

6.3 Orientation of site workers with help of BIM

Carefully prepared orientation sessions can provide valuable information to all site workers. The BIM-based orientation practice has promising opportunities to influence the site personnel. The use of visualisations in orientation sessions can reinforce the safety messages. It helps to understand the safety rules and practices with those people, who may have language problems (e.g. foreign workers, junior workers) (Table 3 and Table 4).

Table 3. Examples of BIM-based material to be used in site orientation sessions.

Brief project introduction • What, When, Where, Who? **Basic principles** • Safety first • Zero accident -aim • Safety rules • Non-drugs and alcoholic • Smoking rules • Personal protection **Site specific information** • Site organisation • Staff premises • Meeting and education practices • Traffic and parking • Occupational health services • First aid **Permission practices** • Fire works **Environment** • Oil damage protection etc. **The case of emergency** • First aid • Fires	**Working on site** • Fall protection • Order and tidiness • Waste management • Site logistic and lanes • Storing areas and principles • Machinery and equipments • Site electricity • Site lighting • Lifts • Scaffoldings • Steps and ladders • Excavations **The special dangers of the site** • in on-going and future phases **Motivation** • Responsibilities • Problematic situations • Safety observation

Table 4. Content categories and their match with the various communication needs.

Content	General site view	Site view, special	Neigh-bour-hoods view	Safety practice	Video	4D BIM
Brief introduction			x			x
Site specific information						
• Staff premises	X situation	X inside view			x	
• Traffic and parking	X parking site		X incoming			
Working on site						
• Fall protection				X fall pro-tection examples		X
• Order and tidiness						
• Waste management	X waste stage areas	X recycling				
• Storing areas and principles	X					
• Site logistic and lanes	X				X	
• Machinery and equipments	X storing places					
• Site electricity	X			X safe situations		
• Site lighting	X	X inside				
• Lifts	X tower crane exten-sion	X personal lifts				
• Scaffoldings				X examples		
• Steps and ladders						
• Excavations	X situation			X		
The special dangers of the site • in on-going and future phases	X	X				
Environment • Oil damage protection	X			X equipments		
The case of emergency						
• First aid	X places of first aid	X places of first aid				
• Fires	X places of fire extin-guishers	X places of fire extin-guishers				

Some examples of the BIM views suitable for use in orientation sessions are shown on the following Figure 63.

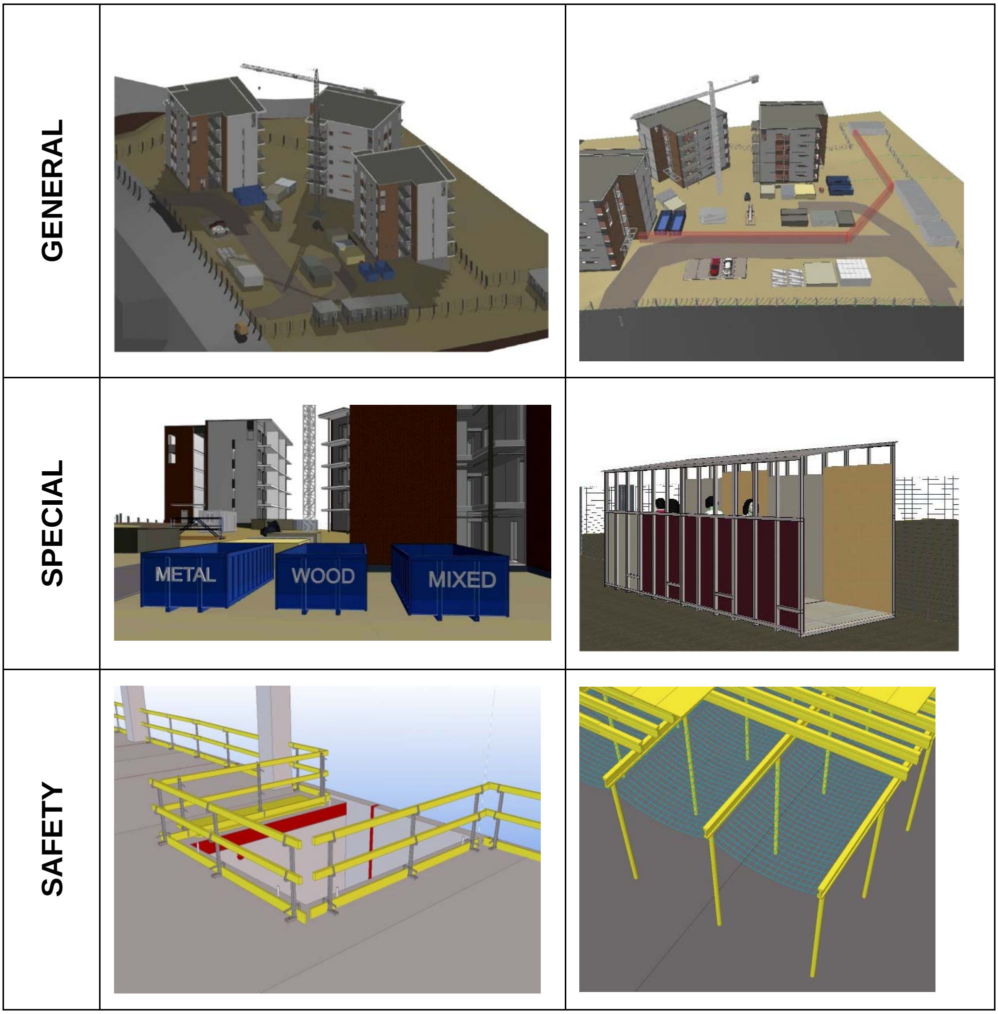

Figure 63. Types of BIM views suitable for use in orientation.

7. Discussion

7.1 Towards new improved site safety planning practice

In the BIM Safety research project several testing cases of implementing BIM technology in safety management were applied. This research method was a practical attempt to analyse the potential of BIM technologies in improving the occupational safety in construction. Following seven field trials were carried out:

1. Site layout plans and crane reach visualization related to a crane collapse
2. Visualization of wall demolition procedures
3. Modelling of safety railings
4. 4D-visualization of floor form work with needed falling prevention solution
5. Expert analyses with the aid of virtualised construction site
6. Automatic safety analysis using BIM technologies
7. Site safety communication and BIM

Detailed outcomes of these trials are presented above in this report and some general thoughts of these findings are presented here.

It is obvious that BIM usage will increase in construction operations management and as a result also in safety management. BIM-based methods will be used in planning and in implementing these plans in site management and supervision. Visualizations will be also used for more general communication purposes. This expanding utilization will be diverse process with several types of applications. For example there are activities where the site area and the buildings are modelled by the contractor in general level to plan and visualize the site area usage in 3D. A different approach is to use the structural model as a starting point for planning temporary site structures in detailed level. At the moment all this kind of experiments are needed to get more experience and to encourage the construction professionals to utilize BIM technologies. This will also produce new innovations of BIM-based construction management.

In the short term the main problem is how the BIM-based safety planning could be organised. The site personnel have started to use the models and browse them with viewer software but modelling requires more skills and in most cases also more expensive modelling software. The designers have the needed software and modelling competence but they don't have knowledge of site safety arrangements in practice. So there is a need for user friendly software with limited modelling functions dedicated to site operations modelling (see example in Figure 64). On the other hand, more extensive co-operation between contractor and the structural engineer is needed to improve the safety planning methods and effectiveness.

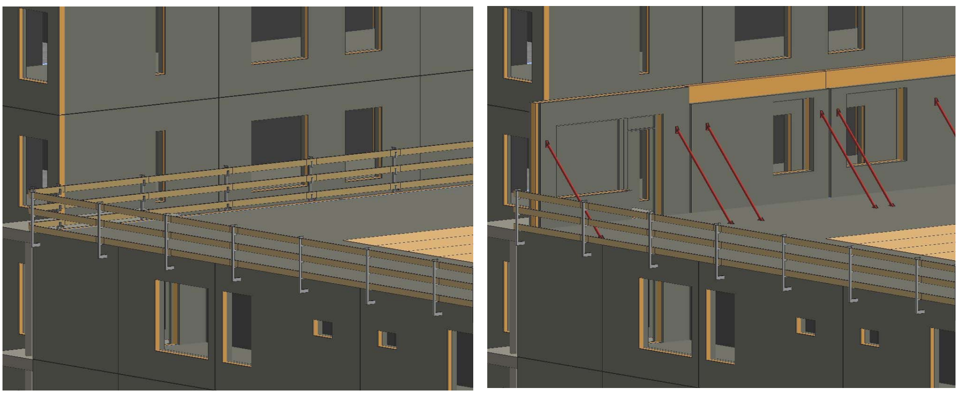

Figure 64. Model-based falling prevention planning related to precast unit construction (Sulankivi et al. 2009b).

Beyond these tools and skills related practical obstacles of BIM-based safety planning and management there is the question if these BIM-based methods are improving occupational safety or not. Basic hypothesis is that better planning will lead to better managed site operation which improves safety. In a short term new human and technical resources are needed in the BIM-based planning activities which mean also costs and those will be compared with the benefits. Clear benefits of BIM-based procedures must be identified and emphasized, or there must be demands from the client, before construction companies will in wide scale do investments to increase the use of BIM for safety purposes.

A natural demand for planning will arise when the subject is complicated or the actors are unfamiliar with it. On the contrary many aspects of safe site environment are considered quite simple temporary installations or operations and those are not usually planned at detailed level. Another issue is the continual changes in construction work where the plans are changed in practise quickly according to new circumstances. Consequence is that little effort is put in planning because plans change easily and planning work might be considered as waste of time.

Significance of safety management will increase steadily in responsible organisations and therefore expectations for new management techniques exist. Site safety is affected in different conceptual levels in the construction process and one of the next research questions is how the BIM technologies should be implemented at these levels or stages to improve the safety i.e. adding value in planning activities.

One starting point is to emphasize safety aspects in building design and engineering. For example the needed supports, safety railings and other temporary structures should be modelled into the project's structural model to ensure proper structural details. This will add structural engineers' consciousness of the safety issues and increase interaction with contractors. In the architectural and HVAC design and engineering it not as clear how the safe installation should be considered in modelling and more research is needed. One issue for example in HVAC installations is the ergonomics that could be improved in product development.

For the main contractor the starting point is to evaluate different BIM-based safety planning opportunities to get more knowledge of the subject. Another subject is development of the planning procedures because more co-operation is needed between both the main contractor and the designers and the main contractor and the subcontractors to make better value adding plans. Additionally, a same kind of formal revision procedure as exists for building design documents should be considered also for production plans to manage the changes and to emphasize the importance of these plans.

7.2 How to take advantage of the current technology?

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

The concrete benefits of a BIM-based site plan are related to its visual nature, which encourages more accurate planning regarding the use of site space, and improves both risk management and risk communication. 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 of site workers, task guidance and instructions, 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 are related 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 as 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 conducting 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. Furthermore, 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.

7.3 Site safety communication with information displays

The usage of information display screens on construction sites has promising possibilities. Such displays can provide support to other means of communication and disseminate messages to a wider audience, e.g. site staff, subcontractors, cooperation partners, and authorities. Information displays can provide equal information access to all those involved. Keeping safety issues visible at all times can help to build and reinforce the openness for site safety communication. This and the nature of visual communication as crossing language and other communication boundaries make it a very democratic medium that has great potential.

Site staff, subcontractors and cooperation partners are on a construction site in an uneven manner. The information displays in such conditions can provide an updated information package that is available regardless of date or time of the day. Such information can increase safety by making the people on site more aware of what is going on there. Also, as can be seen from the survey results (presented in 6.2), only nominal amount of time is needed to comprehend messages from the screen, which makes a functional medium for job sites with only limited time to disseminate and assimilate information. Placement of the screens should be such, that the target audience has sufficient access to the screen in terms of placement and attention. New ways of designing construction site staff premises should be considered to enable better possibilities for communication, this means in example open, joint spaces and better technical resources.

The display screens can be used to reinforce safety regulations and values of the site. Communication is an integral part of safety management and information displays can be used as a management tool.

As the use of BIM is rapidly increasing in the whole supply chain, it has a great potential to be developed into an easy-to-use method to support the supply chain and to spread up-to-date information about construction activities on site and related safety hazards. It can be developed towards new ways of planning and communicating safety related issues to all stakeholders in an easily understandable virtual 3D environment.

7.4 Future scenarios

The development and utilization of BIM is rapid and several applications presented in this report have already been taken in expanding usage in the leading companies. E.g. BIM-based site layout plan is becoming common planning method. There are needs to speed-up this progress, by e.g. more user-friendly BIM tools and personnel training, but these will happen as natural development of BIM utilization. More important is to identify the new possibilities related to BIM that may also need changes in organization and procedures of a construction project.

Possible future scenarios of exploiting BIM technologies in safety management include:

- detailed planning of safety related temporary structures
- construction simulation methods
- construction status management
- personal communication and
- alarm and notification systems.

Detailed planning of temporary site structures has been limited in major structures such as large form systems or scaffoldings. Also the other safety related temporary structures as safety railings or passenger routes/temporary site walkways should be planned at more detailed level and should be documented for installation of these structures. Detailed plan and inspection of the installation will also assure that the intended structural strength of safety installations will be met. Detailed planning will be done by modelling but the problem is who in the project is capable for planning and still has knowledge of functional site structures.

Construction risk analysis should be improved with model based simulations. Nowadays the used 4D construction simulations are mainly too coarse methods to analyse detailed work sequences and the risks. 3D virtual models of spaces, machinery and even persons are commonly used in simulating and animating of a new production lines or plants in the other industries. Same kind of methodology and technologies should be included in the 4D modelling software used in construction sector to improve safety and productivity simulations.

Construction site is constantly changing environment which makes safety management demanding. One basic technique to support this is to manage the status of different activities and visualise the situation with BIM. This status information must be up-to-date at least on daily basis and cover the location information for the tasks, as well as the planned working direction. Also the incoming deliveries should be known, because unloading trucks affects the usage of site area and this could be presented as a site area reservation in BIM.

Basic problem with this activity management is that the related source data is spread in different systems or they are not documented anywhere. This is part of fragmented information management in a construction project. There is a need for comprehensive definition of this data management and interfaces and especially BIM's role in this network. This "production" or "construction" model could be a 3D...nD interface to integrated project data.

One type of site status information is the presence of personnel at site. There should be extensive site passage control system as common in office buildings. This would also restrict grey economy if the access of unauthorized persons can be hindered. Authorization and orientation of the site personnel gives also opportunity to be connected with person during construction time although person might be subcontractor's employee. When this connection is established, more dedicated information could be provided to the people with their smart phones. These personal terminals have been promising technology for long time but nowadays these opportunities are realizing in practise mainly due to the social media applications. These are very interesting communication possibilities also for safety information at site.

For providing tailored information to the site personnel, different information sources should be linked for determining the recipients profile and needs. This information contains e.g. recipient's task, role, planned working area, smart phone address and the presence at site. The next level is to get real time location of the personnel and connect it to the dynamic 4D model. With this information also warnings of reaching in hazardous zones or other real-time notification applications might be reliable enough. Of course these alarms and warnings or guidance information could be delivered also with much more conventional systems. Intelligent alarming light and voice systems would be more useful to notify others than common sign warnings.

There are technical problems to get the location information with GPS inside the building and new kind of location sensor technologies and sensor networks are needed inside building site, e.g. Ultra-Wideband (UWB) sensor network (Cheng et al. 2011). When the intelligent sensor network tracks the person's presence with electrical identification, the system should also interact directly with the person to guide him/her to make the actions that are needed (Teizer and Reynolds 2011).

8. Conclusions and recommendations

BIM technologies are gradually moving towards construction operations and site processes. Therefore it is getting more and more important to have a close look at the needs of key parties and professionals. Site safety planning and management is an example of an important viewpoint of contractors and others in charge of activities on construction site. The use of BIM for site safety planning and management is in its infancy but this is a field of importance that is requiring new innovative solutions for solving the persistent site safety problems.

The experiments within the BIM Safety research project have been sources for an improved understanding to apply BIM technologies for the purpose of site safety planning and management. Hands on trials with the state of the art software, consultations and support by the participating companies, the case projects and feedback data from those as a whole formed the completed research unity. The gained results can be classified in the following three groups:

I Principles for applying BIM technology for site safety

- Main approaches for improving site safety with digital models are: 1) to plan and model proactively the sequences of tasks together with the needed safety arrangements and utilities, 2) to ensure that all constructions can be built without any safety threat and necessary joints exists for fixing the safety utilities, and 3) to document planned safety solutions in detail and self explaining way, and, this information to be conveyed throughout all key players until the last worker in chain.
- The BIM-based site layout plan proved to be a useful tool and versatile visualization solution for communication in real projects. The prepara-

tion of such site layout model requires useful reasoning and thinking that produces high quality site production plan compared with traditional approaches which do not force one to study carefully all needed arrangements.

- Safety planning can be a part of 4D production planning. This can create a safety planning practice that is undertaken earlier than traditionally in construction projects, and furthermore it can capture a more detailed planning level.

II Lessons from field studies

- The state of the art BIM tools are special tools for certain professional trades (architects, structural engineering) and are thus only in a rather limited manner meeting the needs of site personnel and site safety planning.
- Knowledge for the holistic use of the BIM technology for site safety management does not exist. Definition of the BIM based site safety management could be useful for this purpose and advancing it.
- Falling prevention planning, demolition work procedures, formwork and temporary site equipment are examples of safety critical topics that are valuable starting points for BIM-based site safety planning and management. 4D scheduling and visualization of these parts was found to be complicated with current modelling tools.
- Falling from heights is one major safety risk at construction site, but detailed falling prevention planning has traditionally not been carried out. Structural BIM has been found to be suitable base for falling prevention planning, and safety modelling is suggested to be done with same level as detailed design and engineering of the permanently installed building parts.
- Site equipment and safety utilities needed in BIM-based planning, have received little if any attention in object libraries of the modelling software, and hardly any free public sources neither exist.
- Safety communication is not planned on construction sites in a systematic and holistic manner, only limited solutions exist.
- Information displays can be valuable for site safety communication. However, the present site huts and their space layout are making diffi-

cult the full scale use of them and all possible benefits cannot be gained. What are needed are site huts with larger open spaces for all site personnel. Additionally, from site personnel's viewpoint it is of importance that the details of shown visualizations are updated and realistic. In other words, the visualizations can be associated with the site in a self explaining and immediate manner.

- The project planning and management process with its systematic procedures must come closer to the actual site management process. Otherwise the benefits of BIM- based safety planning and management remains fairly small and limited.
- 4D production planning is seen as a breakthrough in construction production management. At the same time it is an opportunity to integrate safety management more intensively with the construction processes. Connecting safety management tasks into the 4D-model opens up entirely new chances to review and evaluate safety as part of construction operations, 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 nets, and safety harness anchor points.

III Directions for future research and development

- Identified research topics and development needs for software companies are i) object and component libraries covering temporary site utilities and safety equipment, ii) site layout and operations planning functions and ii) site plan analyses.
- Site progress and status data recording and storing solutions. At the moment, recording and storing such data and incorporation of these with BIM-models is not regular, systematic or reliable.

There are existing and arising new technologies that can be used together with BIM-based 3D or 4D models to improve safety communication. Examples of identified techniques are information display screens and virtual reality rooms (such as the tested CAVE), and in longer term augmented reality solutions, and personal mobile devices.

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BIM-based Safety Management and Communication for Building Construction

Abstract
This report presents the main results of the BIM Safety research project (BIM-based Safety management and Communication System) carried out April 2009 - June 2011. The main objective of the research was 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 was the main development method used, meaning hands on trials with the state of the art software, consultations and support by the participating companies, and feedback data collection from case projects. All together seven different field trials were carried out to study the possibilities and development needs of BIM technology from the viewpoint of safety.

BIM technologies are moving from the worlds of architecture and engineering to the arenas of construction companies and other players in charge of construction operations. 4D-BIM was recognised as a central technology for construction site safety related planning activities, connecting the safety viewpoint more closely to construction planning, enabling visualization of safety arrangements in construction projects at different moments of time, and providing more illustrative site plans for communication. As a starting point it was considered that BIM technologies could present a new way to solve still existing site safety problems.

The experiments have been sources for an improved understanding to apply BIM technologies for the purpose of site safety planning and management. The BIM-based site layout plan itself, or as bases for crane reach/collapse analysis, proved to be a versatile and useful visualization source, and is constituting one clear use case of building information modelling in the construction industry. BIM-based falling prevention planning, various 4D visualizations including temporary site equipment and arrangements, as well as visualizations concerning demolition work are in their early stages. However, these seems to have potential to become novel and good visual support for planning, discussing, managing and communicating safety related issues at building site. Additionally, there are existing and arising new technologies that can be used together with BIM-based 3D or 4D material to promote safety, such as information display screens and virtual reality rooms (such as the tested CAVE). However, more experience is needed concerning 4D safety simulation as well as further development of modelling tools such as object libraries, and site progress/status data recording and storing solutions to broaden the use of the BIM-based safety planning in the design-build process.

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