

Utilization of BIM-based Automated Safety Checking in Construction Planning

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Abstract

The applications of Building Information Modeling (BIM) in building design, construction production planning, and 4D simulation are growing rapidly. BIM-based modeling and simulation has brought many benefits to safety and logistic applications. However, tedious manual work is still required to model and schedule protective equipment in current BIM software. Limited automation in modeling and planning safety processes has been exploited so far. The objective of this paper is to investigate how safety issues that are unknowingly built into the construction schedule can be automatically identified early in the planning phase of a project. The developed automated safety rule-checking prototype for BIM was tested on a residential building project in Finland. The results of the case study demonstrate the feasibility of integrating safety into BIM as an effective and practical method for detecting and eliminating fall-related hazards. Presented are also considerations which explore what impact the developed approach has on safety issues and traditional safety management practices.

Keywords: building information modeling, construction safety, design for safety, rule checking, safety-in-design, safety planning and simulation.

1. Introduction

As many research and statistics indicate, occupational safety in building construction remains a worldwide problem, of which falling from heights is a major safety risk at a construction site. In several other disciplines, safety planning has a key aspect position in the field of production planning, however, in building construction industry safety planning

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has been carried out separately with other production planning and control. For example, a concrete falling protection plan is not created in most of the existing projects (Sulankivi et al. 2010).

The growing implementation of Building Information Modeling (BIM) in the Architecture/Engineering/Construction (AEC) and Facilities Management industry is changing the way safety can be approached (Zhang et al. 2013). One starting point is to emphasize safety aspects early on in building design and engineering phase (Zhou et al. 2012). However, the application of BIM is currently increasing rapidly in construction operations management and also in safety management. BIM-based methods are being applied in planning and in implementing these plans in site management and supervision. Main approaches for improving site safety with digital models are: 1) to virtually and proactively plan 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, 3) to document planned detailed safety solutions in a self-explaining way, and to conveyed these information throughout all key players until the last worker in chain, and 4) to have up to date status information in the main contractor's site model for managing work tasks and to avoid interference of work activities when changes occur.

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-based methods and programs (Kiviniemi et al. 2011).

Based on previous research, targets of developing the automatic safety hazards identification and planning tool might include: to effectively assist labor-intensive safety related modeling and planning tasks, to get the safety checking and planning comprehensive enough, and to get visualizations as good as needed for real use on sites or for other purposes.

This research study aims to evaluate possibilities, benefits and development needs of automated safety checking and planning, as well as usability and maturity of a developed BIM-based prototype tool to support fall prevention planning in real building construction projects.

2. Background

BIM can be utilized to promote safety management, and combine safety with other construction planning processes. Downey from Turner Construction describes (Downey 2012) how the contractor's continued commitment to safety is enhanced through the use of advanced technologies for model checking. First they conducted a study of incidents across the country and determined that falls from height, and incidents related to material handling could be addressed through the integration of innovative practices and technologies, particularly the application of BIM. After that they worked to develop a rigorous modeling

standard and review process focusing on the key areas of falls from height and material handling tasks. They established a standard, model-checking procedure to ensure compliance with rigorous standards of safety. Turner's BIM specialists developed a custom, Ruleset package, a 50 point check, which users can apply to any model. For example, in a superstructure check, running a model through the rule Checking process in Solibri will verify that the model contains plans for protection at all slab edges and slab openings, and that edge protection is at a regulation height, as well as check for fire extinguisher locations in the model using the rule-checking process will not only verify standard spacing and height requirements, but also that extinguishers are present at all required places.

The strength of using Solibri Model Checker as a BIM-based tool in the previous case is its capability to use Industry Foundation Classes (IFC) data exchange format, which makes the checking independent from BIM-based software used for modeling. However, while automation is used to carry out the routine checking work, someone still needs to model all safety related temporary equipment and structures, which are not supported/are lacking from existing object libraries in BIM-based modeling software.

VTT Technical Research Center of Finland has developed detailed falling protection modeling and 4D visualization including both the parts to be permanently installed to the building and the temporary structures and equipment needed during construction work. 4D production planning is seen as a breakthrough in construction production management. 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. 4D planning 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. In early stages, essential safety arrangements to be modeled and included in 4D-modeling are related to protection against falls, such as guardrails, protective covers and nets, and safety harness anchor points (Kiviniemi et al. 2011).

In VTT research the structural model of a building has been found to be suitable base/platform for falling prevention planning, and safety modeling is suggested to be done with same level as detailed design and engineering of the permanently installed building parts. Basic hypothesis from their research was that better planning will lead to better managed site operation which improves safety. However, 4D scheduling and visualization of these parts was found to be complicated with current modeling tools. 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 (Kiviniemi et al. 2011). A significant shortcoming of 4D approach identified by Zhou et al. (2012) is the dependence on computerized construction schedules. Construction operations are dynamic and subject to frequent changes that do not comply with originally scheduled work. Hence, digital schedules are rarely updated sufficiently and frequently to accurately reflect all operations underway at any given point in time.

Another subject is development of the planning procedures because more co-operations are needed between both the main contractor and the designers and the main contractor and the subcontractors to make better value adding plans (Kiviniemi et al. 2011). Zhou et al. propose an approach, where the target is to obtain the most reliable plan possible in the multidisciplinary construction field using collaborative 4D construction planning. They suggest new kinds of interventions, such as the development of tools and processes for multi-party collaboration on safety around digital models. New directions of research on construction safety and digital design could, for example, focus on technologies that enable constructors to share their knowledge with designers; using the visualization potential of new technologies to bring knowledge of the construction site into design.

Georgia Tech (Zhang et al. 2013) pointed out that the industry is in need of improving the inefficiencies of the existing paper-based and manual safety processes in place, and has identified a need for an automated rule-based safety checking and planning system. The researchers have approached the problem by developing BIM-based safety planning procedures by applying automated safety rule checking to Building Information Models. Beside automated safety checking, there are capabilities to also model automatically the suggested fall protection, which is labor intensive task with current BIM-based tools. Possibilities and current limitations of the software are not known very well yet, since this far safety prototype tool has been in use at the university only, and there isn't experience and feedback related to utilizing it in real building projects.

3. Research Method

3.1 BIM-enabled safety rule-checking

Existing safety rules, guidelines, and best practices can be used in conjunction with existing three-dimensional (3D) design and schedule information to formulate an automated safety rule checking system. The intention is to automatically identify these dynamic conditions, as the building is constructed, identify their location in a virtual 3D space, and interactively or automatically provide solutions and visualization of protective systems to mitigate identified hazards.

Such platform developed by Zhang et al. (2013) can function as a tool for providing easily accessible and understandable visualization of up-to-date progress on construction and safety over time, and in particular, to detect dangerous hazard locations on the site. The indication of safety measures will help safety managers planning upfront for safety during the construction planning phase, as well as during construction. The rule checking process consists of the following procedures:

- Rule interpretation: The interpretation of safety rules from safety regulation or best practices (e.g., OSHA) is a logic-based mapping from human language to machine readable form. The name, type, and other properties in the rule can be analyzed and extracted from the written rule.

- **Building model preparation:** A building model must be well constructed to include needed objects, attributes and relations used to carry out the rule checking. In addition, since the need of fall prevention equipment depends on the status of the construction work, a 4D model including the installation schedule/order of building assemblies is required.
- **Rule execution:** The rule execution phase brings together the translated rule sets with prepared building model. The rule may apply to thousands of condition cases, requiring combinatorial tracking. The rule execution has two steps: (a) automatically check the model to identify unsafe conditions, and (b) identify and apply candidate resolution actions to correct the unsafe condition. This last step can be variously controlled, manual intervention for each condition, to completely automatically resolve through the application of rules to determine the best correction.
- **Rule checking reporting:** The checking results can be reported in multiple forms: (a) visualization of applied safety protective equipment in the model, and (b) PDF-generated reports of unsafe conditions and the corrective actions taken. In addition, quantity-take-off information for resource leveling of safety equipment and importing the generated information into project schedules is also possible.
- **Safety correction:** The primary corrective actions that will take place on job sites are to schedule and track logistical movements of (safety) material based on rule check reports. An implementation in the field, for example, could be reports on a BIM platform that assign work tasks to install/remove safety equipment on a building floor.

3.2 Applied methodology in case study

Once the building information model has been prepared and the connections between the model objects and the schedule have been established, rules can be applied for detecting safety hazards. Figure 1 illustrates how the algorithm works for detecting required prevention methods according to OSHA. For each task, it examines if there are slab objects linked to that task and then detect all the related slab objects. Secondly, the algorithm will check the existing slabs/the slabs will be erected before this task to see whether merge of different slab sections is needed. Finally, according to different conditions, guardrails will be installed to unprotected edges and the removal of guardrails will also be considered and inserted into schedule if two slab sections merge and guardrails in between are no longer needed.

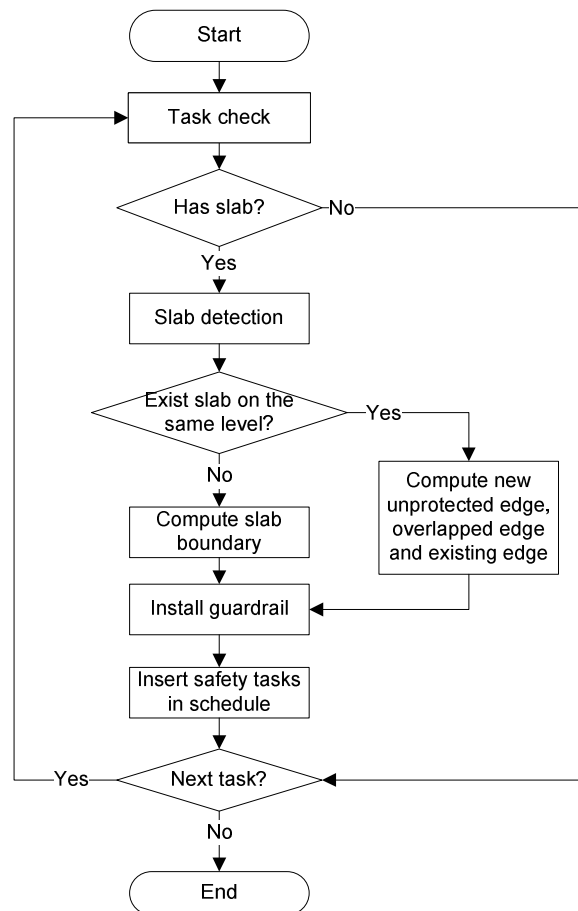


Figure 1. The rule checking algorithm for detecting required prevention methods

4. Case study: BIM-based automated safety checking and fall prevention plan

4.1 Case study project and model information

The developed automated rule-checking tool was applied on a multi-story precast apartment building model (Figure 2). All the precast concrete pieces are fabricated and transported to the construction site and will be erected with predefined order starting from section C. Section B is erected after section C has been completed, and section A is erected after completing section B. Additionally, the façade insulation and brick walls are built on site after the erection of precast concrete related to the frame. Since the focus is in falling prevention, the frame erection is in the focus of this work. The project's structural model used for the Case study has been modeled by Finnmap Consulting Oy using Tekla Structures 17.0 modeling software. 4D schedule needed for the automated rule-checking was added to the structural model based on information obtained from the contractor (Skanska Finland) in traditional format of schedule and additional information concerning the installation order received from the site engineer.

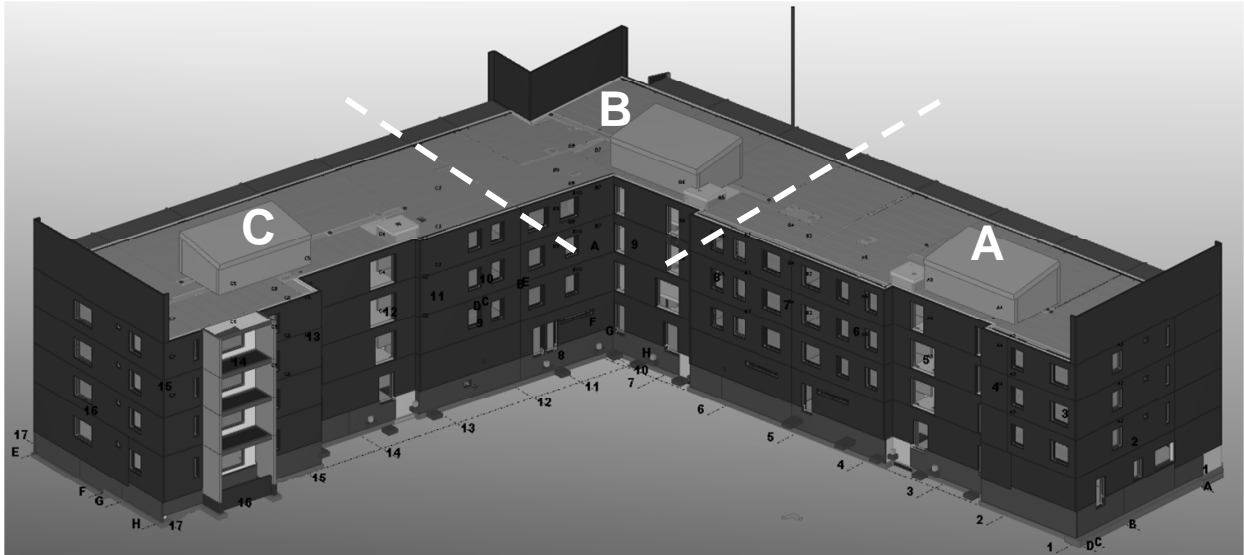


Figure 2. Overview of the multi-story precast apartment building model and its divided sections

Figure 3 shows a closer view of the slab pieces. The connections of the slab pieces are reinforced and casted after the erection of slabs, while before the erection of the following floor wall panel erection is started. Walls and lift shaft together with the slabs work as a structural system which transfers the loads to the footings which are based mainly on bedrock. The model has been divided into Section C, Section B and Section A according to the erection sequence.

The slab sections are erected by story. It takes about 7 days to erect one story of a section and about 5-6 weeks to erect one section. The guardrail solutions need to be updated according to the growth of the slab sections, for example, when two slab sections merge on the same level, the guardrail in between need to be removed.

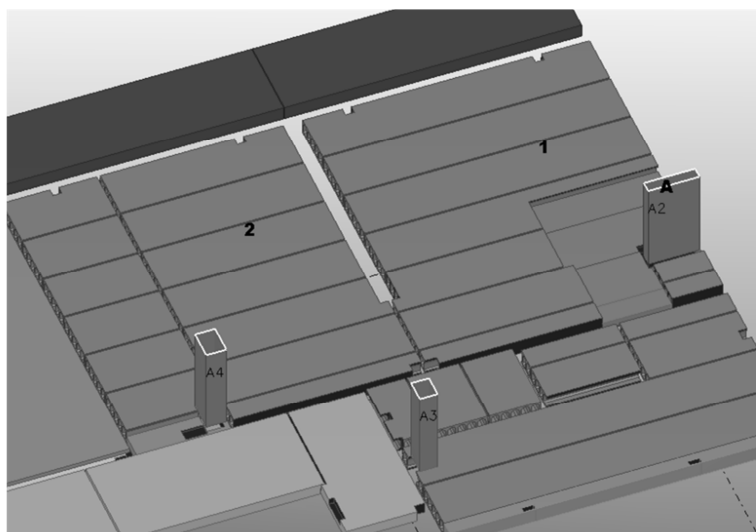


Figure 3. Closer view of precast slab panels

4.2 Utilization of automated safety checking and fall prevention planning in the case study

The rule checking algorithm is executed on the case study model automatically and install the guardrails in the model and also created subtask of its installation and removal into the schedule. Figure 4 shows the updated schedule with safety solution and Figure 5 shows four different phases of the model simulation. Since the slab on the first floor grows from section c to section b and they merge together, the guardrails exist in between has been removed in figure 5-b and 5-c.

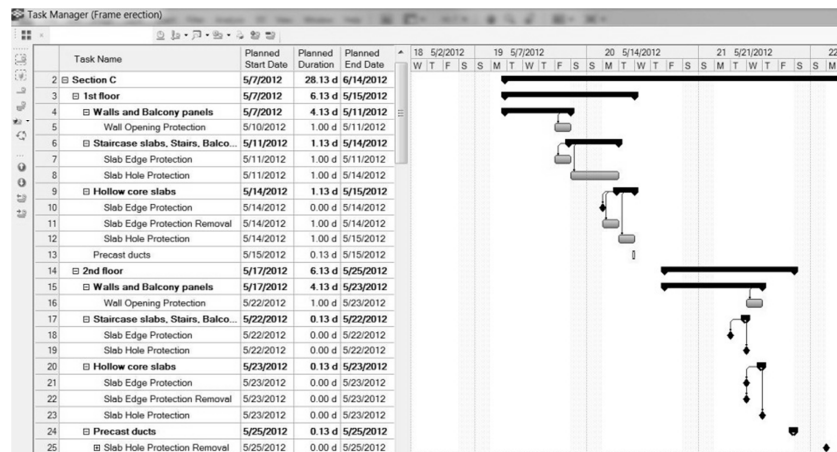


Figure 4. Updated schedule with the installation and removal of prevention methods

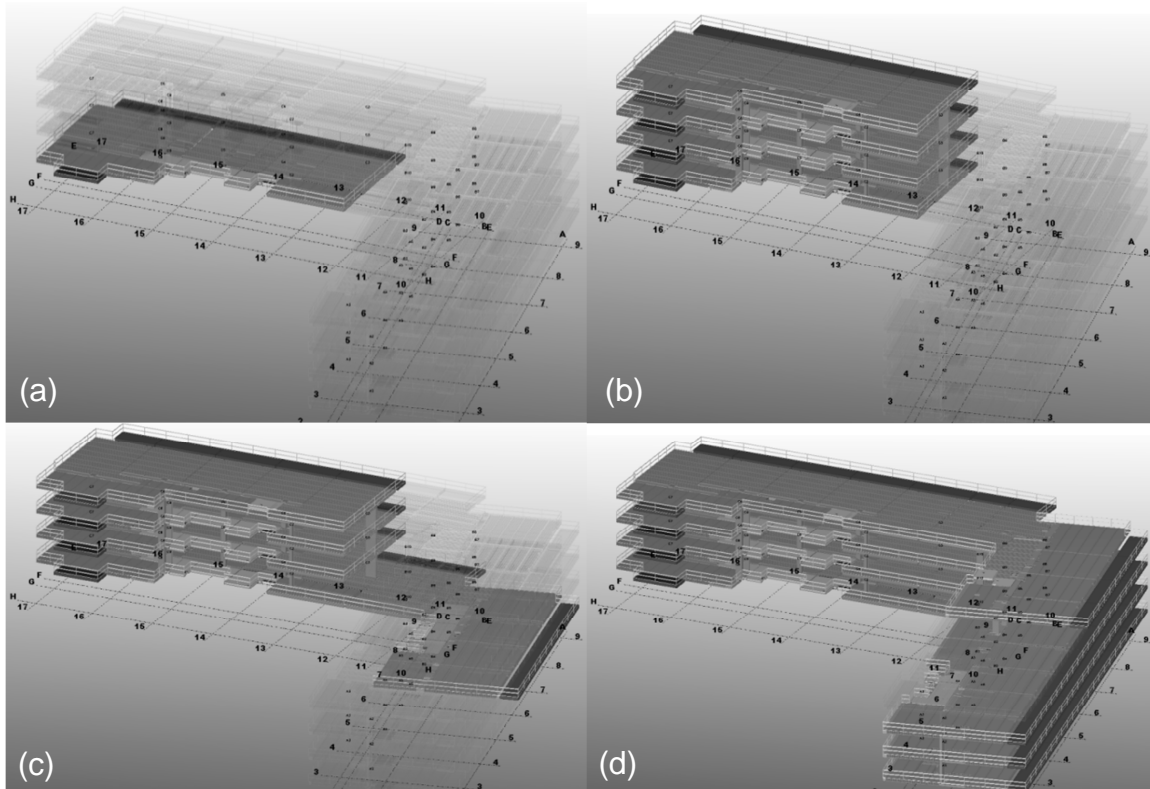


Figure 5. 4D simulation of the model slab, column and guardrail system

4.3 Discussion

The tool detected unprotected slab edge and installed required guardrail system both automatically and successfully. Quantity-take-off of the guardrails can be easily calculated using software's built-in function. In addition, the automated installed guardrail can be modified by user later flexibly.

The limitations are also identified from the case study. The case study focused purely on slab without considering wall installation and other more complicated situation which is also quite important for determining required fall protection methods and also their removal. Additionally, more case projects are needed to investigate applicability and performance of the automated safety checking and planning tool. Secondly, the presented guardrail model is rather simple than the real one used in field. More sophisticated 3D model/representation of safety equipment can provide better understanding of both its geometry and shape. In test trial, a detailed model for so-called hook post was successfully integrated to the tool, and as a result, user is able to select a simplified model representation or a detailed representation (Custom components) for safety railing modeling, but more options/different kind of post types are needed for real construction projects. In addition, with more detailed and developed guardrail model, related safety parts/components such as welded fittings could be added automatically into steel beams or concrete panels for guardrail installations. The corresponding connections can be pre-considered in the steel beam or concrete panel fabrication, hence reduce the work at height.

The potential future development based on test trial experience has been identified include the following:

- 1) More comprehensive BIM-based fall prevention planning solution need to be further developed, for example, safety nets related to prevention of either small construction equipment or humans.
- 2) Since software independent data exchange format is promising to benefit the interoperability among different project stakeholders, IFC-based solution needs to be explored for safety planning purpose. Ability to use an IFC model for automated safety checking and planning would enable more general checking capability of models created in modeling software for various modeling or viewing purpose, for instance, safety checking of combined BIM of both the structural and MEP models.
- 3) Today it's not common to make detailed BIM-based 4D-construction planning, where the installation order of all precast concrete parts in one story would had been defined. Instead, one task in a schedule may cover installation of all precast wall panels in one story, and as a result, there isn't data to plan and visualize need of falling prevention either in that detailed level in each relevant phases of the installation work. More detailed/careful construction and safety planning might take place if construction companies will get interested in taking full advantage of virtual construction (4D BIM-based construction order and schedule planning).

5. Conclusion

The developed algorithm has been successfully implemented in the conducted case study for slab boundary checking and guardrail installation along the erection of slab panels. The results show the usefulness of the proposed approach in detecting and visualizing the potential fall hazards in particular during the safety planning stage. It is recommended that temporary structures and safety protective methods are included already during project planning to enhance a project's safety understanding and communication. Some of the processes that are part of the developed framework can also be automated based on the geometry, schedule and relationship information provided in BIM. Since the construction schedule is linked to the model objects in BIM only a few weeks before the construction starts, it is essential to check the model for changes and detect any of the potential safety hazards. The developed system assists human decision makers in this review process by eliminating both the hazards in the design/planning stage and making sure that safety equipment is procure and ready for installation at the right place and time when needed.

Current concerns about the application of the developed system include: 1) Since the construction drawings and model-based designs are subject to change in a dynamic construction environment, it is necessary to frequently check the model to ensure all safety equipment is up to date; 2) Not all models provide all of the necessary information for safety planning and checking purposes, for example, the relationship/connection between wall and slab sections may not be well established; this may prevent identifying the removal of the guardrail as construction proceeds. Such safety related design standards or extended BIM requirement need to be studied and formalized; 3) Additional cases studies and in particular using more complex BIMs are needed to test the developed system; and 4) To take full advantage of BIM-based 4D-planning, a future system might need to be easy enough to use for practitioners in the field.

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