Use of BIM Tools for Organization of the Construction Site in the Aspect of Work Safety

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Abstract. The construction site and its elements create circumstances that are conducive to the formation of risks to work safety during the execution of works. Analysis indicates the critical importance of these factors in the set of characteristics that describe the causes of accidents in the construction industry. In this paper the selected issues relating to the health and safety on the construction site are presented and widely discussed. The new design concept is recommended by the Authors including the identification of all potentially possible threats to health and safety at work through the use of the 3D1 modelling in the planning stage of the building project. This modern approach to the analysis may be used both to identify the basic hazards that may occur on site and to create the appropriate security systems protecting against these threats. The numerical tools that can be applied for this purpose as well as the available ways of presenting the proposed solutions are indicated and described in detail.

1. Introduction

Construction still remains one of the most accident-causing industries in Poland. Safety standards and observation of the OSH rules still leave a lot to be desired. In order to change this image and minimize the causes of accidents, long-term activities are needed first of all to change the mentality, awareness, attitude and habits of the participants in the construction process. One of them may be a concept that encourages "taking into account" the threats to health and safety at the design stage: safety by design.

Traditional design, where everyone did his work independently and passed the result to the next participant of the process, unfortunately has a few drawbacks. Such a process is based on serial work, which may cause perturbations in the flow of information to individual recipients, e.g. the lack of current updates of architectural foundations provided to constructors and installers. Providing out-dated information by one user on correct placement of walls, columns and architectural elements and carriers, most often results in errors in the placement of the installation at the execution stage.

1 3D - three-dimensional graphics in which 3D solids and surfaces are visualized using polygon meshes, voxels or Bezier surfaces or in a different way, in combination with rendering techniques.
BIM² (Building Information Modelling) has recently become very popular. This process is based on the virtual presentation of information about the site to which in real time all participants responsible for the investment, design, construction and use of the building have access [1, 2, 3]. This article indicates the possibility of using this modern design technology to analyse, already at the design stage, all threats occurring on the construction site and planning appropriate safeguards. It presents the basic tools that can be used for this purpose and available ways of presenting the proposed solutions (3D and 2D modelling).

2. Elements used in modelling work safety in 3D

2.1. Guidelines for planning work safety

At present, all participants in the construction process should understand the essence and requirements for occupational safety at the construction site. Individual goals in terms of security level, their quality and a defined hierarchical scheme of persons responsible for construction works should be identified and designated individually. All employees should be aware of their tasks and their duty to promote work safety. Already in the design phase of the investment stages, the investor should be informed about the security conditions that should be maintained when creating architectural and construction solutions, designing particular construction works and technical systems.

In the light of above, the following goals can be set that should be implemented by the BIM software:

- **BIM-based safety planning** - layout and location of individual security measures, altitudes and distances of barriers, fences and support of planning works involving specific hazards and security risks, e.g. earthworks or works at heights,
- **3D visualization in the scope of security** - the use of a separate layer or layers of the model for security visualization, the selection of secure communication routes at each stage of the construction project implementation and information and warnings about current threats in the performance of individual technological processes,
- **Risk analysis and assessment of designed solutions and technologies** - BIM software should enable risk assessment and be used to analyse technological solutions, and in more advanced systems of automatic evaluation, risk assessment and identification.

2.2. Review of BIM software including health and safety planning

As the BIM software progresses, its availability and quality increased and good opportunities a few programs with an established reputation widely used by designers appeared on the market. These tools are the starting point for reflection on the possibility of implementing security issues in the project's structure.

Based on a study of literature and personal experience, 6 software packages available on the market were selected and analysed. The individual qualifying criteria for the software were:

- User-friendly interface and simplicity of 3D modelling,
- Availability of colours and material textures for visualization of individual elements,
- Native planning of building structure security,
- Available collection of 2D³ and 3D objects (systems and elements of various types of security) and the possibility of obtaining them in the process of 3D laser scanning or traditional digitalization [4],
- Possibility to exchange data, import and export using IFC format, communication with MS Project, Primavera software and data exchange with cost estimate software.

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² BIM (Building Information Modeling) - the term was popularized in 2002 by building analyst Jerry Laiserin for the description of virtual design and building management in all building life cycles. BIM data is the basis for data exchange between participants of the investment process and facilitate the cooperation of teams implementing the project.

³ 2D - designation of two-dimensional graphics with such flat objects as the plane, segment, line, polygon, as well as the definition of computer systems supporting drafting work on the plane.
• Possibilities and characteristics of the software in aspect of designing safety measures on site and minimising the occupational risk.

Selected programs included:
• ArchiCAD software package, producer: Graphisoft
  A program dedicated to architects, providing a high level of tools to perform visualization, with the ability to preview the object by setting multiple virtual cameras and the ability to create very good quality of animation and presentation directly from the model. The package also includes tools for modelling the surroundings of a given project, including landscape. The system has a plug-in functionality (plug-in) in the field of security planning (Safety Equipment).

• Google SketchUp software package, producer: Google
  This is a very simple 3D modelling software. It allows primarily to draw architectural sketches, but also allows modelling and subsequent printing of models on three-dimensional printers. The program is easy in use, has a rich database of films and tutorials describing its functionality. A unique feature of the software is access to a very large library of ready-made 3D elements (Google 3D Objects Gallery) and integration with Google Earth. Unfortunately, the system at the moment has limited capabilities in the field of construction safety modelling.

• Tekla Structures software, produced by: Tekla
  An extensive software package containing tools for modelling concrete structures, modelling steel structures, and a library of prefabricated elements. It enables modelling corresponding to individual construction phases to which custom elements and components for work safety planning on the construction site can be applied. The software makes it easy to import existing models in IFC\(^4\) and DWG\(^5\) formats and has developed export possibilities and adaptations of the final project in IFC format.

• Tekla Construction Management system, producer: Tekla
  Contrary to the previously discussed software, this system has no modelling tools. The package manufacturer focused here on tools in the field of planning, organizing and time management. The program performs the tasks of visualizing projects, plans and schedules, and also enables planning in the field of work safety. It is possible to combine and copy, duplicate and transfer both temporary protection elements as well as take into account and operate data provided by the designer in the scope of construction elements. Comparing the capabilities of the software, in the scope of the module, scheduled with available MS Project or Oracle Primavera packages, a serious limitation is already visible at the initial analysis - the shortest unit of time in which the project is carried out is one day. This restriction causes disqualification of this software in specialist technological processes at the construction site.

• Navisworks, manufacturer: Autodesk
  The main advantage of this software is the collection and collection of information from various sources. Additionally, the package enables detection of collisions between the designed elements. Unfortunately, it does not contain any tools for modelling, and in particular, to implement the issues of occupational safety and occupational risk.

• Solibri Checker, manufacturer: Solibri Inc.
  The last analysed program is the Solibri package, intended to analyse already existing models. It is basically based on automatic checking rules. The user can create sets of his own of rules, checking and controlling, for example, the geometry and shape of individual project elements. It has standard functions of loading and exporting IFC files. The package will be a very good choice for frequently repeated analyses of similar elements contained in the model [5].

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\(^4\) IFC (Industry Foundation Classes) - format for saving and exchanging virtual building models. IFC defines such elements as the structure of the building, doors, walls, zones in the same way, regardless of the CAD system.

\(^5\) DWG - a proprietary, binary file format created by AutoCAD
Choosing software to implement a job security system and assessing occupational risk in individual stages of the construction process is not easy. Successful completion of the task using the above participants in the project. The basic principle should be the integration and cooperation of all participants, from the earliest moment of project creation. It also seems crucial to create a BIM Manager position, which will be responsible for the digital information flow process and will supervise proper cooperation within the project.

3. The rules for preparing a 3D model.
When preparing the 3D model (Fig. 1, 2) with the layers of safety modelling and occupational risk, it is necessary to keep as much convergence with the drawings in the flat system (layout, colours and symbols).
Otherwise:
- for a given security, each stage of system operation should be introduced as a separate, complete layer (this will facilitate the subsequent identification of a given sub model),
- 2D descriptions - should be placed as "flat" objects, (this is important in the case of passive safety, information boards, signs, warnings),
- a separate model for intermediate structures, e.g. in the case of foundation works with the ceiling technique, modelling this stage with the required security,
- using elements from the modelling system database or if they are missing, modelling a simple shape with a description (code) to be able to identify it easily,
- colours:
  - avoid the standard backlight colours in Navisworks (a program that allows you to collect design data contained in a variety of file formats; the result is a comprehensive preview of the project enabling verification, coordination and visualization) for industries categories (= shades of blue),
  - elements in different colours, contrasting,
  - where possible, use textures.

![Figure 1. Comparing model and live situation: Safety railing detail in the corner of the slab [6]](image-url)
4. Guidelines for the development of the construction site.

Particularly important factors that can be taken into account at the design stage of the BIM model, improving the safety of work of construction workers are:

- List of technological processes carried out during construction works on the construction site,
- Selection of appropriate machines taking into account the specificity of a given construction site, such as:
  - dimensions and shape of the construction site,
  - the mutual location of buildings,
  - place of media connection,
  - location of the entry gate and temporary roads,
- The correct marking of workplaces and hazardous areas with health and safety symbols and the use of, in particular, collective protection measures.

The parts of the current hazard prevention model on the construction site, described in the OSHAS 18001 [8] standard, comply with the implementing rules [9], giving priority to the use of collective protection measures over personal protective equipment. This approach gives the possibility of designing and placing in the BIM environment data on an active approach to designing work safety in construction [10].

At the stage of a BIM project, independent layers should be created that include elements of the construction site development, such as:

- fencing of the construction site;
- designation of hazardous zones;
- construction of roads, exits and pedestrian crossings;
- supplying electricity, water and other utilities;
- sewage disposal or utilization;
- a device for sanitary and social rooms;
- providing natural and artificial lighting;
- providing telephone communication;
- device for storage of materials and products.

The guidelines of the BuildingSMART organization should be taken into account when designing. In particular, the basis should be the Industry Foundation Classes - IFC standard, which describes the hierarchical structure of data, including, inter alia:

- geometric models (constituent solid and shell elements),
- geometry - dimensions, surfaces, volumes, coordinates of elements,
- type of element - (for occupational health and safety, e.g. fencing, barrier, cover, etc.).
properties - gives an additional set of information about the element,
quantities - the total number of elements used (of a given type),
graphic representation of the element,
topology - relations of element inclusions, security hierarchies (e.g., object - excavation - type of machine - slope / wall protection),
design tools,
participants of the investment process - tasks and mutual relations,
date and time - technological dependencies and mutual relations.

5. Elements of the construction site development in the BIM model.

An example of the software that allows designing the development of the construction site and the location of individual construction machines is Tekla BIMsight. The free version of the software offers many design examples containing structural elements, installation elements, examples of building foundation and material solutions. Additionally, you can use the base of collective security elements in the form of fences, barriers, platforms, and protective nets. The software package also allows placing in places deemed unsafe both at construction machines and on the designed walls and building elements of warning information and health and safety symbols.

![Figure 3. Tower crane on the construction site](image)

Figure 3 shows the location of a tower crane. The software enables detection of collisions with other elements of the construction site and construction of the building during machine operation. The key parameters necessary to obtain this functionality, however, is the specification of the operating parameters of the construction machine.

It is also possible to place warning and health and safety symbols at the design stage, both on building machines and auxiliary elements such as fences, barriers, and the design of the building itself. In contrast, Figure 4 shows a construction excavator with the marking of possible collisions at the site of operation (plate with the index "1").
Autodesk InfraWorks together with the Autodesk NavisWorks program is another software package useful in the design of the development of the construction site.

The software makes it possible to level the selected area in order to adapt to the guidelines of the designed buildings.
Analysing Figures 5 and 6, which are screenshots from the InfraWorks software, one can notice the main features of this package, which allow the designer to create a flexible and simple construction site design project, and to introduce an additional layer covering health and safety protection.

A library of predefined objects is particularly useful, such as the sanitary facilities, land fences and barriers shown in Figure 7. In addition, most standard construction machines are available to be displayed at the construction site and assembly stations (fixers, carpenters), concrete factories, and material repositories.

6. Summary and conclusions
Building information modelling (BIM) can be used as a process of active approach to work safety management: "safety by design". 
Having access to current information contained in one coherent model, we can actively expand this model with additional elements that will help us to improve the level of occupational safety at the construction site. Each piece of documentation we generate from the BIM model, both geometric and non-geometric, is always up-to-date. All changes and comments made to the project by designers, contractors or investors are automatically included in all printout templates that we have prepared. Thus, BIM is becoming a good tool for managing work safety. The sets of individual and collective protection measures prepared in the 3D model allow a better communication between the designer and the contractor, presentation of various protection options and, as a result, better work safety conditions. Having a model, we can predict some threats and prepare procedures that will protect us from them in advance.

In case of any doubts during the implementation of the works, even a tablet can be used as a tool to communicate with the designer. It is enough to indicate a specific part of the model, attach to it actual photos from the construction and your own commentary so that the designer responsible for the indicated element and work safety, seeing all this information, modifies the model and the construction engineer immediately makes it real.

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