BIM 8D Model: Application for temporary support system of facades

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Abstract

The construction sector is one of the most important sectors for national economy and one which employs a large workforce. However, it is also very inefficient, with a low productivity rate and high count of accidents, both small and severe. BIM appears as a way of facilitating a work methodology focused on the conception phase and done through digital processes, while also modernizing a sector that is somewhat behind in comparison with others. The present dissertation seeks to elaborate a BIM 8D based work methodology, exploring it´s capabilities in work preparation, schedule management, safety, and health at the construction site. This methodology is based on a case study of a rehabilitation project taking place.in Mouraria, Lisbon. The methodology utilizes 3 software programs present in the AEC sector (Architecture, Engineering and Construction): Revit, Microsoft Project and Navisworks Manage.

Utilizing Revit, a tridimensional model of the case study was elaborated, being this the base of a BIM methodology. The planning and schedule of the construction were done in Microsoft Project. The coordination of the project was done in Navisworks Manage, while also performing a clash detection of the project. This program also enabled several simulations of possible construction risk situations and possible safety measures. Finally, it was proven the feasibility and verified the interoperability existing between the three programs. Further considerations are draw regarding the practical aspects of the programs, the viability of the methodology and how it would fit with the current reality of the construction sector.

Key Words: BIM methodology, 8D BIM model, Security, Prevention, Interoperability, Navisworks,

1 Introduction

The construction sector while being a very important sector for the national economy of a country it is also a very inefficient one. In fact, in a global context the annual productivity rating of this sector has only increased by 1% in the last 20 years.[1]. The Portuguese industry in particular suffers from overdue deadlines, exceeded budgets and poor work safety and quality of construction.[2]

The utilization of Building Information Modeling (BIM) may solve these problems, while bringing change and restructuration through digital means to a sector that needs modernization. A BIM work methodology is focused on a collaborative workflow, utilizing several software with high levels of interoperability while providing support to the various stages of a construction project. It is based on a three dimensional (3D) digital model composed by parametric objects. This 3D model has the capacity to store all the pertinent information associated with the construction project, throughout its life cycle.

This paper explores the work safety dimension of BIM(8D) while proposing a work methodology usable for planning of said safety in construction projects. This methodology utilizes three programs, with three distinct purposes: Revit for modeling, Microsoft Project for planning and schedule of construction activities and Navisworks Manage for coordination and simulations of said construction activities. The application of the BIM methodology is illustrated with a case study, a rehabilitation construction taking place at Mouraria, Lisbon. The proposed methodology is focused on the life cycle of the temporary support system for the facade.

2 BIM concept and application

2.1 Origin

Traditionally information regarding construction projects was based in two dimensional(2D) drawings. Although these drawings were done through digital means would often lead to inconsistencies, errors, and omissions. A 3D representation constitutes a clearer base of communication between technicians and designers, in comparison to the traditional 2D. Robert Aish[3] first established the bases for the incorporation of Computer Aided Design(CAD) systems, created based on a 3D model, in digital format. Aish [4] further theorizes the creation of a CAD system capable of supporting different views of a building as a way of encouraging and consistency and coordination thought out the project. It is at this time established the premises of information being compiled into a single database, accessible through a computer. This system, based on 3D visualizations of a construction, contains geometrical 3D information and specific information concerning properties of the building components, such as walls, slabs, pillars, etc. Thus it is established a system containing an accessible database concerning a construction project, this system, at the time named Building Design System (BDS), later evolved into the current concept of BIM, in which the model is created based on parametric objects[5].

2.2 Interoperability

A building project involves several different professionals from different specialties, all of which utilize different software for their own purpose. There are currently several different computer systems available in the software market that work separately from one and other. This constitutes a problem, as the concept of BIM requires that generated models may be transferred between computer systems in a efficient way and without inconsistencies or omissions. This capability of transferring data between applications is referred to as interoperability. Professionals need to be able to communicate correctly with each other while using their own computer programs, as isolated systems tend to result in inconsistencies, incompatibility or problems of redundancies in data sharing[6]. This in turn leads to a severe loss of time in the coordination phase of a project and additional costs. Figure 2.1 illustrates the complexity existing in communication between different specialties with and without interoperability. This further demonstrates the importance of interoperability between different computer systems

a *b*

Figure 2.1 – Communication before interoperability (*a*) and after interoperability (*b*) [6]

2.3 Parametric objects

A 3D BIM model of a building is composed of parametric objects, selected from the objects libraries available in BIM based programs and represent construction elements such as walls, slabs, pillars, etc. The parameters of these objects, which are defined at the beginning of the conception phase, refer to their physical properties and the materials that constitute them. This information can be altered or added in further stages of the project, allowing the user, the possibility to change and adapt according to the needs of the project. For the case study in this work the BIM models were created using objects available in the existing libraries and objects created specifically for the project for a more realistic representation of the construction.

2.4 Construction safety

The construction sector is a sector with a very high predisposition for safety accidents, both small and severe. According to data gathered from the "Instituto Nacional de Estatística" website the construction sector accounts for 13% of all accidents registered across all the employment industries (being the 3rd highest.) and accounts for 25% of all mortal accidents occurred (the highest registered). The information used for these findings refers to the most recent surveys conducted in the year 2018, for which the database was most recently updated on 10 November 2020. The growing digitalization of the construction sector has shown increases in productivity but also in the planning of safety construction and risk management. The utilization of a BIM based methodology could further improve this aspect. "The ideal time to influence construction safety is during the inception, concept design and detailed design phases."[7]. The ability to influence construction safety diminishes as the schedule advances, as demonstrate in Figure 2.2.

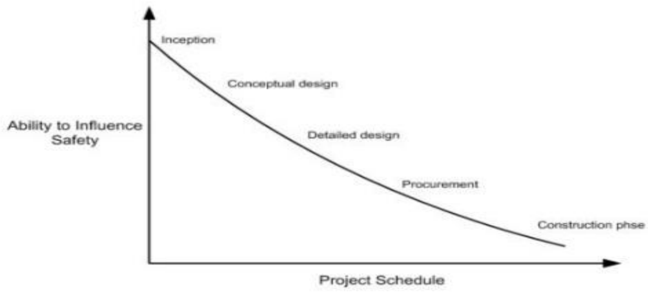


Figure 2.2 – Relation between project schedule and safety influence curve [8] and [9].

From this perspective comes the notion of accident prevention through design [7]. This methodology is applied to the conception phase and consists of the systematic identification and mitigation of safety hazards that workers may encountered in the construction site. Another way to improve safety construction whilst still in the conception phase is with clash detection tests. Assuring the compatibility between different specialties reduces eventual conflicts while improving the planning and the sequencing of work activities. This results in a safer construction environment due to a better estimate and compression of the necessary construction works and the logistics associated. The present paper seeks to attribute a greater focus to safety and hazard prevention in the conception, by adopting a BIM based methodology in the creation of the construction models and 8D, utilizing the Navisworks Manage software program.

3 Modulation of the architecture

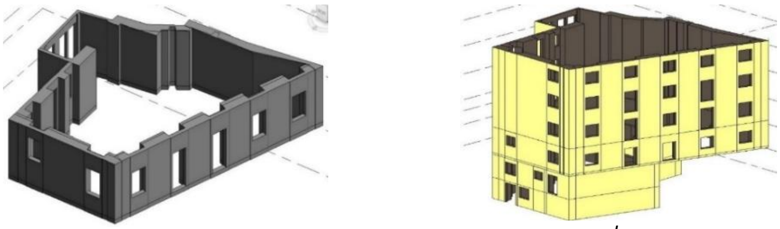
3.1 Case study

The case study is based at a rehabilitation occurring in the Mouraria, Lisbon. The rehabilitation project is the demolition and reconstruction of the building for residential use, while preserving the facades, using a temporary steel support system. At the time which this work was started the interior of the building was already demolished and only the facades remain, with the system already implemented. The localization and topology are shown in Figure 3.1. The building has 4 floors above ground level and 2 floors below.

Figure 3.1 – Localization of the case study (illustration from *google maps*).

3.2 Modelling

The modelling process was done in Revit with the generation of the 3D model being based on 2D drawings provided by the resident engineer. Due to the geometric uniqueness of the building walls, these were not available in the object library and need to be modulated through other means. For this purpose, it was used the Model in Place command, allowing for the modulation of the walls through Extrusions. The voids of said extrusions were created with Void Forms. A second extrusion with the offset of 5 mm was created for the finishing layer of the facade walls, being the material of emplastrum. Figure 3.2 illustrates the result.



a *b*

Figure 3.2 – Modulation of a single floor (ground level) (*a*) of the facade walls completed(*b*)

The interior walls were modulated using the same means and the slabs were created by utilizing objects available in the Revit library. Afterwards, the architecture model was completed with the modulation of the roof and the elements surrounding the building, which were done as illustrated in Figure 3.3 – Complete architecture model and surrounding elements. Although these elements do not have a direct impact in the implementation of the temporary support system, they grant the 3D model a greater degree of realities and detail, while also being essential for the analyses of several logistics associated with the construction project concerning the building site, loading and unloading of materials, and others associated with the available space and it´s constraints.

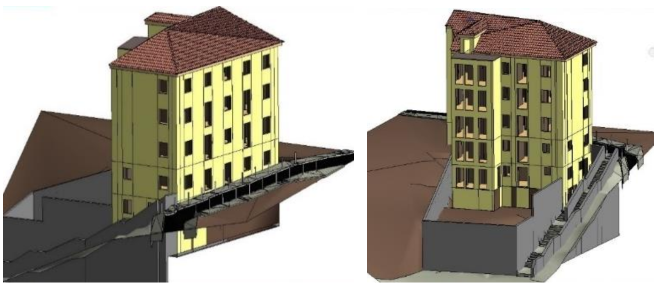


Figure 3.3 – Complete architecture model and surrounding elements

4 Modelling the temporary support structure

4.1 Description of the system

The temporary support system is steel SHORFLEX HD system with an additional exterior vertical frame. The modulation of this system was based on the technical specifications pertaining the system and its implementation. This information was provided by the resident engineer at the construction site. The system is composed by metallic elements assembled both in the interior and exterior of the building for the purpose of supporting the facade walls after the demolition. All the connections that form the system are bolted, allowing the system to be used several times and eliminate the need for welding.

4.2 Modelling the system

Due to it being a custom system, Revit does not possess the desired components in its library. Therefore, it is necessary to model such parts. This situation was resolved by taking advantage of the family creation system in Revit, with different templates. The central component of the system is c-section steel bars (Figure

4.1), while the remaining components also include horizontal and diagonal beams (Metric Structural Framing - Beams and Braces template), steel connectors and several bolts (Metric Generic Model face-based template) and steel components for the structural foundation of the exterior steel frame (Metric Structural Foundation template).

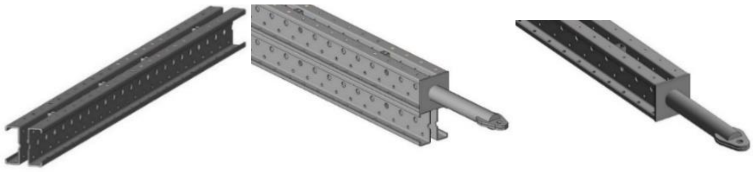
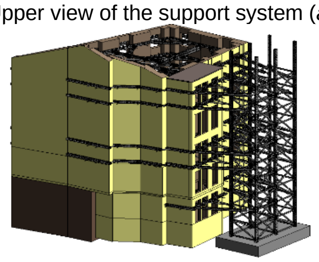


Figure 4.1 – C shaped steel beam and it´s variation used to compose the system

The result of the system´s modulation can be observed in Figure 4.2 alongside photographs of the construction site for comparison purposes.

Upper view of the support system (*a*)

aerial view of the support system (*b*)



Modulation of the system and the building (c)

System in site (d)

Figure 4.2 Complete modulation of support system and comparison with the actual construction site.

4.3 Construction Crane

In order to aide in the demolition and implementation of the support system a construction crane was used. To module the desired object into the 3D model, based on its location in the actual construction site, the command Shaft Opening was utilized. The model for the construction crane was download from the ReviCity website [10].This site offers a large variety of Revit objects, saving considerable time in modeling projects. The placement of the construction crane in the 3D model is illustrated in Figure 4.3..

Figure 4.3 – Representation of the construction crane in the model and at the construction site.

5 Planning the implementation and removal

The planning of the construction project was done via Microsoft Project (MS Project). First a survey of the physical conditions of the building was carried out. This survey was divided in the identification of the constraints of the construction and the necessary activities required in line with the objective of the rehabilitation project (demolition, preservation of the facade walls and ampliation of the building).

5.1 Constraints and construction activities

The rehabilitation project occurred in a neighborhood in Lisbon in a very narrow street. This severe lack of space results that the storage of materials and implementation of the construction crane need to be within the area associated with the building. The construction activities required are as following:

- Removal of the roof - The roof tiles contain asbestos, which is a very hazardous material to the health of workers in the building, meaning that this activity takes precedence above the others;
- Implementation of the crane tower – This process was accomplished with the assistance of an additional crane and shafts were required be made inside of the building;
- Containment of the facade walls – Due to a lack of space in the public street the support system for the facade walls was implemented inside the building and in its the small backyard. The exterior part of the system, the vertical steel frame, was raised with the assistance of the construction crane and rooted to a concrete slab created for the system. This steel frame is then connected to the interior part of the system. The interior part requires the demolition of some of the interior walls first;
- Demolition - Due to the age and materials that constitute the building, the demolition was made by manual labor. The demolish started from top to bottom, once the support system is fully implemented on the facade walls. Note that the implementation of the façade system requires the demolition of the interior walls of the -1, 1 and 3 floors;
- Construction works – Once the building is fully demolished with only the facade walls remaining the construction works begin, progressing from bottom to top and starting at the -2 floor;
- Removal of the support system - The removal is done in a phased way, occurring in tandem with the construction works.

5.2 Digitalization of the planning

Once the initial assessment is completed the process moves to MS Project. The work schedule and calendar are defined using the commands Project Information and Change Working Time. The structuration of the construction activities was made using the WBS (Work Breakdown Structure), which consist in the division of the construction activities into smaller tasks. This is accomplished by listing all the tasks in MS Project and utilizing the Indent Task command. The duration of the construction tasks is defined using a deterministic approach, meaning that a task has only one duration, the most likely. The relation between tasks were defined next. In this planning the relations between tasks are FS: Finish-to-Start, SS: Start to-Start e FF: Finish-to-Finish. For the calendarization of the planning the Critical Path Method was employed. This method consists in associating a theoretical early start time and an early finish time to the tasks. This allows the determination of the critical path, which consist in the sequence of tasks that correspond to the minimum duration of the construction project. This sequence is the longest existing and any alteration to any task associated with it results in alterations to the construction deadline. With this it was determined that the construction finish date corresponds to 13 September of 2021, starting on the 4 January of 2021.

6 Safety and safety hazards

The safety hazard assessment is an important process for the health and safety of workers at the construction site. The identified hazards, based off the construction activities that are scheduled in the project, are fall from height hazard, work that exposes workers to chemical and biological hazards, and activities that expose workers to severe health and safety hazards in the assembling and/or removal of elements, as is the case with support facade system. Every time that a safety hazard cannot be eliminated at the source it is necessary to implement measures that mitigate that hazard. These safety measures are divided in two categories: collective and individual. The collective measures include the implementation of guardrails at every site where there is a fall from high hazard possibility, elevator platforms, all floor openings must be properly protected and correct utilization of ladders (they must be properly fixed and be in good conditions). Every time that collective measures are insufficient, it is mandatory to use individual protection measures. These are known as Individual protection equipment and are divided into two groups regarding their utilization: the permanent ones that must be always used when a worker is at the construction site (helmet, steel toe boots, vests and gloves) and the temporary ones (googles, ear plugs and masks). The information regarding this chapter and case study´s safety hazard and safety measures employed were taken from the Health and Safety Plan of the rehabilitation project, provided by the resident engineer.

7 Coordination

Once the 3D model and the project planning are completed the methodology moves to the coordination phase of the project. In this phase a clash detection test and several simulations regarding the project logistics were performed via Navisworks Manage.

7.1 Clash detection

To perform a clash detection test in Navisworks the user must first define items sets. These sets are lists of objects existing in the model and they can be updated manually (selection sets) or based on parametric conditions (search sets). Two sets of objects were created pertaining the architecture and the temporary support system of the façade walls. By opening the Clash Detective application in Navisworks a clash was run between these two selections. The clash between two objects with a geometric conflict are shown in two different colors (in this case red and green), as illustrated in Figure 7.1.

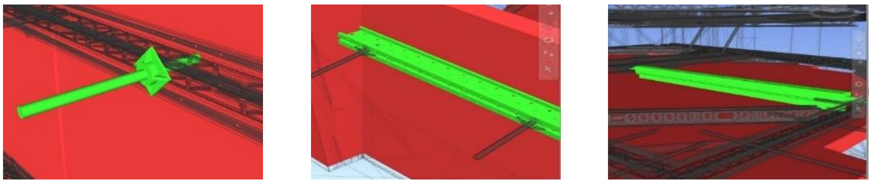


Figure 7.1– Results from the clash detection test

The existing conflicts were segregated in two groups: those that can be resolved and approved by the Navisworks user (such as expected conflicts as the placement of steel beam that secure the support system to the facade walls, or small geometric imprecisions that occurred during the modeling) and those that require re-modulation in Revit. A simple way to accomplish this is through the use Switchback command, in Navisworks. This allows the selected object to be open directly in the Revit model, demonstrating the interoperability between the two software. Figure 7.2 illustrates a schematic example of how-the interoperability between Navisworks and Revit with their different file types and commands is achieved, resulting in a dynamic methodology that can be used to swiftly correct conflicts, even for instance during project meetings.

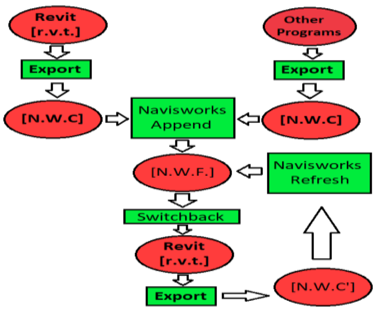


Figure 7.2 – Schematic representation of a methodology pertaining the interoperability between Revit and Navisworks

7.2 Work simulation

Once the conflicts resulted from the clash detection between the different specialties are resolved, visual and 3D simulations of the construction site and its activities were conducted. This allows for a better understanding of the nature of the construction and improves the communication between the designer team and workers. Additionally, Navisworks allows the use of an avatar for a better comprehension of the dimension and scale of the project and its logistics (in this case it was selected an avatar of a construction worker measuring a height of 1,80 meters). Furthermore, the simulations were focused on possible safety hazards and possible measures to combat those hazards. The first simulation performed was for the purpose of defining the accesses to the construction site. There are two possible entrances, a front entrance and a small adjacent on through the side of the building. The front entrance is located on a narrow street with a very small sidewalk. Additionally, there is a possibility of accidents occurring due to the fall of foreign objects onto the sidewalk. For this purpose, scaffolding with safety guards were placed above the sidewalks. The side entrance also demonstrates lack of space and requires a barrier in order to limit access to the site. For this purpose, a door was placed. Simulations of both entrances and the resulting safety measures are illustrated in Figure 7.3, with markings done via the Review panel in Navisworks.

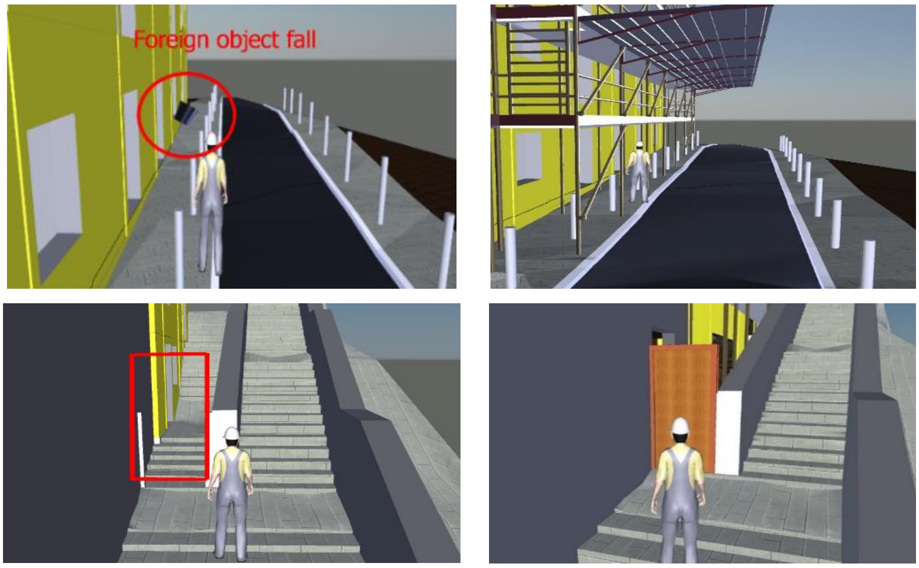


Figure 7.3 – Simulation of the front and side entrances

For simulation of the construction activities the application of Timeliner was used. This application allows the creation of a 4D model through the link of a planning file and a 3D built model. This functionality combines files from both Revit and MS Project, establishing the interoperability between the three programs, being Navisworks the central platform as shown in Figure 7.4. However, before that some preparations were made in both Revit and MS Project. In Revit a Shared Parameter was created with the properties of a text parameter. This parameter is present in the properties of every object of the model and allows the entry of any text. As of such, in the parameter entry, the name of the construction activity, that the object is related to, is typed. This entry needs to be the same as the name of the activity listed in the MS Project file. Afterword the file was exported to Navisworks, and Search Sets were created with a search based on the name of the activities, resulting in setts also being named after said activities. In MS Project a Colum was add named “Text 1”. This Colum also supports text entries and these are filled based on the type of construction the is associated with that task being three possible types: Demolish, Construct and Temporary. These types determine the visibility of the objects during the running of the Timeliner simulation and the final presentation after a task is completed.

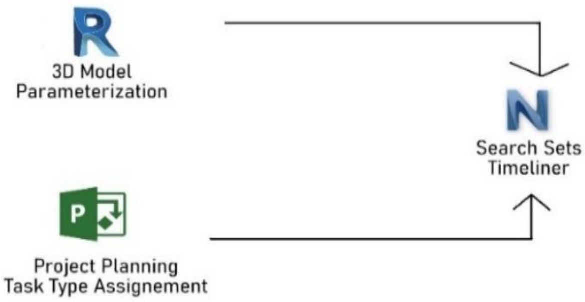


Figure 7.4 – Diagram of the interoperability between the three programs

Now back on the Navisworks, the Timeliner application is selected. The planning file is imported in the Data Source section. In the Field Selector menu, under the External Field Name column "Text 1" entry was select, in the Task Type line. This resulted in the construction activities having their appearance automatically defined at the start of the simulation, avoiding the need to define them manually. Now in the Task section, through the Auto-Attach Using Rules function the "Map Timeliner Tasks from Column Name to Selection Sets with the same name, Matching case". This results that each existing task will be automatically associated with a specific Search Set, if that Set is as the exact same name as the task. With this the Timeliner simulation may be run. Following this, some cases are presented as an example to the use of this methodology. The implementation of the construction crane constitutes an important task pertaining the rest of the project and is also an activity with a very high hazard probability. Figure 7.5 illustrates the process of the mentioned activity. It shows the very limited space, requiring the early demolition of nearby elements and a potential fall hazard situation. As of such, safety guards were modeled as a safety measure in response to this hazard. Figure 7.6 illustrates a potential fall hazard situation through a floor opening. This opening was made during the demolition of the building´s staircase. As of such, a simple wooden plank was modeled as a safety measure, being a simple solution and a material that is easily procured in the construction environment.

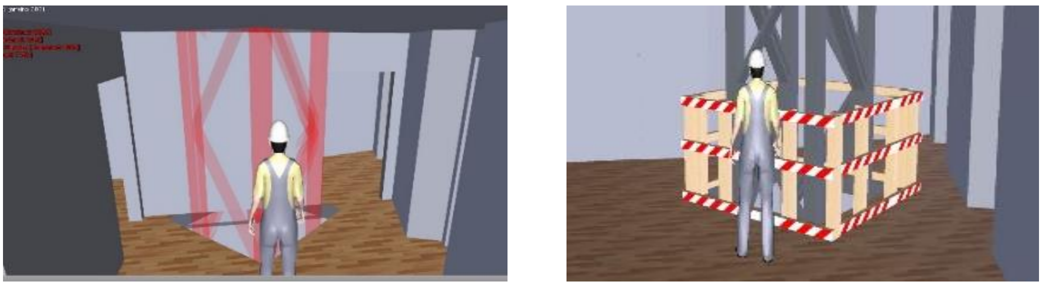


Figure 7.5 – Simulation of the implementation of the construction crane and safety measures

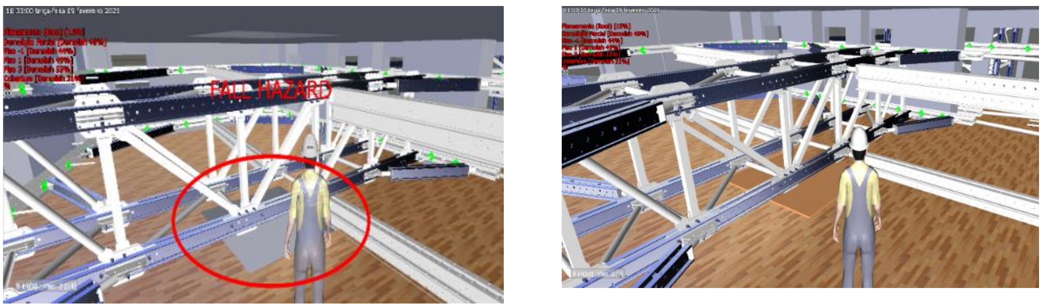


Figure 7.6 – Simulation of a fall hazard situation

8 Concluding remarks

BIM continues to be an innovating approach with a wide variety of tools that enable new ways to conduct construction projects. This paper focused on the elaboration of an 8D focused BIM work methodology for a construction project, using Revit, MS Project and Navisworks. Utilizing Revit, a precise and detailed 3D model of the project was built. This was accomplished by using existing objects in the Revit library and through the family creation system. The planning and schedule of the project was done swiftly and efficiently with the support of MS Project. The coordination phase of the methodology was conducted via Navisworks. A clash detection text was performed, and preexisting conflicts were resolved this being segregated into two groups: those that could be solved by the Navisworks user and those that need to be remodulated in Revit. Once the conflicts were resolved, several simulations of the construction site and its activities were conducted. Through this simulation the entrances to the construction site were identified along with the constrains and hazards associated with them, while also proposing safety measures for said hazards. This procedure was also applied to the simulation of a few construction activities. The simulation of said activities was made possible by combining the 3D model of the project with the planning file, thus establishing the interoperability between the three programs and proving the feasibility of the methodology,

References

[1] McKinsey & Company, "Reinventing Construction: A Route To Higher Productivity," *Mckinsey Glob. Insititute*, no. February, p. 168, 2017.

[2] J. P. Couto and J. M. C. Teixeira, "As Consequências do Incumprimento dos Prazos para a Competitividade da Indústria de Construção – Razões para os Atrasos," *3ª Conferência Eng. 2005*, pp. 1–6, 2005.

[3] R. Aish, "Building Modelling: the key to Integrated Construction CAD," *fifth Int. Symp. use Comput. Environ. Eng. Relat. to Build.*, no. October, pp. 55–67, 1986.

[4] R. Aish, "Three-dimensional input and visualization," *Comput. Archit. Des. Futur.*, pp. 68–84, 1986, doi: 10.1016/b978-0-408-05300-6.50013-5.

[5] C. Eastman and Others, "An Outline of the Building Description System. Research Report No. 50," p. 23, 1974.

[6] "IFC - Where it all started - The End of Babel - Part 1/2 - YouTube." [Online]. Available: https://www.youtube.com/watch?v=g_jmGQvr6dQ. [Accessed: 06-Oct-2021].

[7] I. Kamardeen, "8D BIM modelling tool for accident prevention through design," *Assoc. Res. Constr. Manag. ARCOM 2010 - Proc. 26th Annu. Conf.*, no. September, pp. 281–289, 2010.

[8] J. Mroszczyk, "Designing for construction worker safety," 2008.

[9] P. G. Furst, "Prevention through design (safety in design).," 2009.

[10] "RevitCity.com." [Online]. Available: https://www.revitcity.com/index.php. [Accessed: 18-May-2021].