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Multi-Project in an Integrated BIM Model: Clash Detection and Construction Planning

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Abstract

The Building Information Modelling (BIM) methodology has been adopted in the construction industry, supporting the development of projects. Its implementation has improved the collaboration and integration in the design context, increasing the accuracy of the project preparation and the decreasing additional costs and delays of the construction work. The main objective of the present research is to provide an overview of the state of the art of BIM applications, namely, concerning the construction planning. For that, the generation of a BIM 3D model, involving the disciplines of architecture, structures and water supply system was performed. After, over the model a conflict analysis was applied, in order to verify the consistency of all the disciplines, when linked together. In order to obtain a visual simulation of the construction process, the correspondent 4D BIM model was also generated. Along the development of the study, distinct BIM software was applied over a case study. The main remarks of the capacities of the software, as well as the benefits and limitations verified were identified.

Keywords

BIM, Planning Construction, Conflict Analysis, 4D Model, Visual Simulation

1. Introduction

The delay in the adoption of advanced digital technologies to support the project has created some difficulties faced by the construction sector, revealing consequences in additional costs and inefficiency in the organization of information with the increase of the building complexity. In order to improve the quality of the construction design and planning, the Building Information Modelling (BIM) methodology has been adopted in the construction industry. Its implementation in project offices introduced new strategies concerning collaboration and integration in the design development, increasing the accuracy in the project elaboration, and reducing the volume of project corrections and construction delays. The BIM concept, since the beginning of its application, has admitted a process of evolution and maturity regarding its applicability and potentiality in building activity. The base of the BIM concept is the centralization of information, the integration and the collaboration between parts of the project and the team involved.

With the increasing difficulty and complexity of construction projects, problems of weak connection between project phases and inefficient transfer of information have become more common. Low productivity and difficulty in adapting reveal a difficult barrier to overcome in the quest to promote developments in the construction sector. Currently, BIM methodology has been presented as a potential solution to empower project quality. BIM allows all project stakeholders to create digital three-dimensional (3D) geometric models, in which all the information regarding each modeled object is contained, as well as information regarding its mechanical properties. This process enables a better visualization of construction projects and facilitates the generation of collaborative environments for all stakeholders. In addition to providing tools for creating 3D models, BIM allows professionals to go even further by manipulating elements, creating nD dimensional models.

Charles M. Eastman [1] proposed an initial idea, in 1974, related to the definition of a virtual building model. The study describes a "building descriptive system" composed of three-dimensional (3D) geometric elements, containing information regarding, basically, geometry, and relations between elements. The term Building Model was first used, in 1986, by Ruffle, related to Computer Aided Design (CAD), followed later by Nederveen and Tolman that first refer the designation Building Information Modelling [2]. BIM refers to an approach to the building modelling concept with the ability to represent multiple tasks for different stages of project development [3]. The virtual digital model, designed as BIM model, is obtained from a parametric modelling process, and represents the project of the building in analyses. More recently, BIM has been used in a multitask project as it admit the realization of a set of processes associated with the production and analysis of the building, referred as nD BIM models [4]. A BIM model is composed of parametric objects representing construction components that contain not only geometric attributes, but also information about the physical properties of the applied materials. This innovative methodology allows material costs reducing, by providing reliable construction cost estimates, before the construction phase begins. The BIM model allows an easy verification of inconstancies between disciplines, optimizing the collaboration strategy and achieving a better quality project delivery. These topics were explored, over a study case, in the present work [5].

The ability of an enterprise to perform a task, deliver a service, or generate a product can be defined in distinct phases: Pre-BIM, BIM phase 1, BIM phase 2, BIM phase 3 and Post-BIM. These BIM phases or stages define the main goals to be achieved by teams and organizations as they adopt the BIM concept and associated technologies. Each BIM phase is defined based on establishing minimum requirements [6]. An enterprise in BIM phase 3 implementation is capable to provide more BIM services to a client or project partner than a company that is in an earlier stage. In this context, the term maturity corresponds to the adoption of admissible measures relative to a structure that encourages repeatable, stable, well-defined, and quality results. The maturity corresponds to the ability to differentiate the execution of tasks or delivery of BIM services or products, and it is defined as the degree to which business processes and activities are performed according to acceptable bases [7]. Following the rapid adoption of BIM in the architecture, engineering and construction (AEC) industry, the academy have introduced BIM in their curriculum, mainly in the ordinary curriculum of construction management programs [8] and in workshops and professional short courses [9].

In the present work, in order to promote the dissemination of the use of BIM in the coordination of several disciplines in a global project, a 3D BIM model involving the disciplines of architecture, structures and mechanical systems was first generated. After, a conflict analyses study between the three disciplines was performed, as well as a 4D model representing the construction process was generated. In the process several limitations were identified and strategic resolutions were presented.

The main objective of the research was the dissemination of the benefits of BIM when applied in a multitask project. For that the achievements reached in technology, that integrates the available software, become a great support on the development of distinct components of the BIM model. So, how to handle a software is an import skill the engineer must train. All steps of the modeling process, of the collisions analyses or of the generation of a 4D simulation of the construction, were described supported in the use of distinct software. But this training is necessary to capacitate the engineer to the functionalities available in the software, as a support of the BIM implementation in the activity. As BIM is not a tool but a way of working, this perspective is now clearly exposed, having the necessary support in the technology.

2. Generation of BIM Models

The selected case study, a single-family house, with two floors above ground and one basement floor, was used to illustrate how to develop the required multi-project, using BIM platforms. The BIM software Revit (Autodesk) was used to develop of the integrated model, composed of the architectural, structural and water supply network projects. As the available Revit library contains a wide range of families of objects, it easily allows to generate, with accuracy, the design model of each disciplines. The parametric modelling process contributes to improve the flexibility of selecting appropriate building components, and to reduce time consuming and effort spent on the definition of distinct BIM models.

2.1. Architecture

Before starting the modelling process, a set of initial definitions were established, beginning by the establishment of the project units, the working levels and the plan grids. These first elements help to insert adequately all elements in the model. The establishment of correct coordinates, in each discipline model, is essential in the development of an efficient design that involves several expertise's. The grid lines representation allows the mitigation of possible coordinate errors and conflicts between elements.

The parametric objects, representative of architectural components, were selected from the Revit library concerning architectural families, and adjusted to the case study. The objects present geometric characteristics and properties of the materials.

The parametric objects used in the modeling process are initially selected from the menu of architectural elements (doors, windows or walls), and then adjusted to the required configuration and associated material. The walls are first inserted over the alignments grid and after the floor for each level, followed by all the architectural elements adequately positioned in the model.

In the model, the walls were first inserted, followed by windows, doors, floors and stairs (**Figure 1**). The objects concerning the sanitary and kitchen equipment were selected from internet sites, as Autodesk allows an easy access to a large range of specific equipment.

The BIM architectural model was then created with all the required components. In the process, several views can be obtained, in distinct perspective point of views and from the interior of the model. In addition, any kind of drawing can be obtained automatically. These capacities of Revit help the architect to analyze the project in development and conceive easily alternative solutions by replacing components or adjusting the respective parametric parameter (**Figure 2**).

2.2. Structures

Next, the structural model was generated. The Revit library contains also a large range of structural parametric objects. The structure solution represents an important component of a building as it supports the loads imposed over it. It is composed of several elements, such as foundations, columns, beams and slabs. The first step was to create a new project in order to separate the disciplines into different files, and thus avoiding visual information overloaded. Next, the architectural model was attached to the new project as a link, so that it is possible to ensure a correct relative position of the building structure, using the architectural model as a base of modelling. The modelling of the structural objects was carried on, following the modelling sequence: columns, beams, slabs and foundations (**Figure 3**).

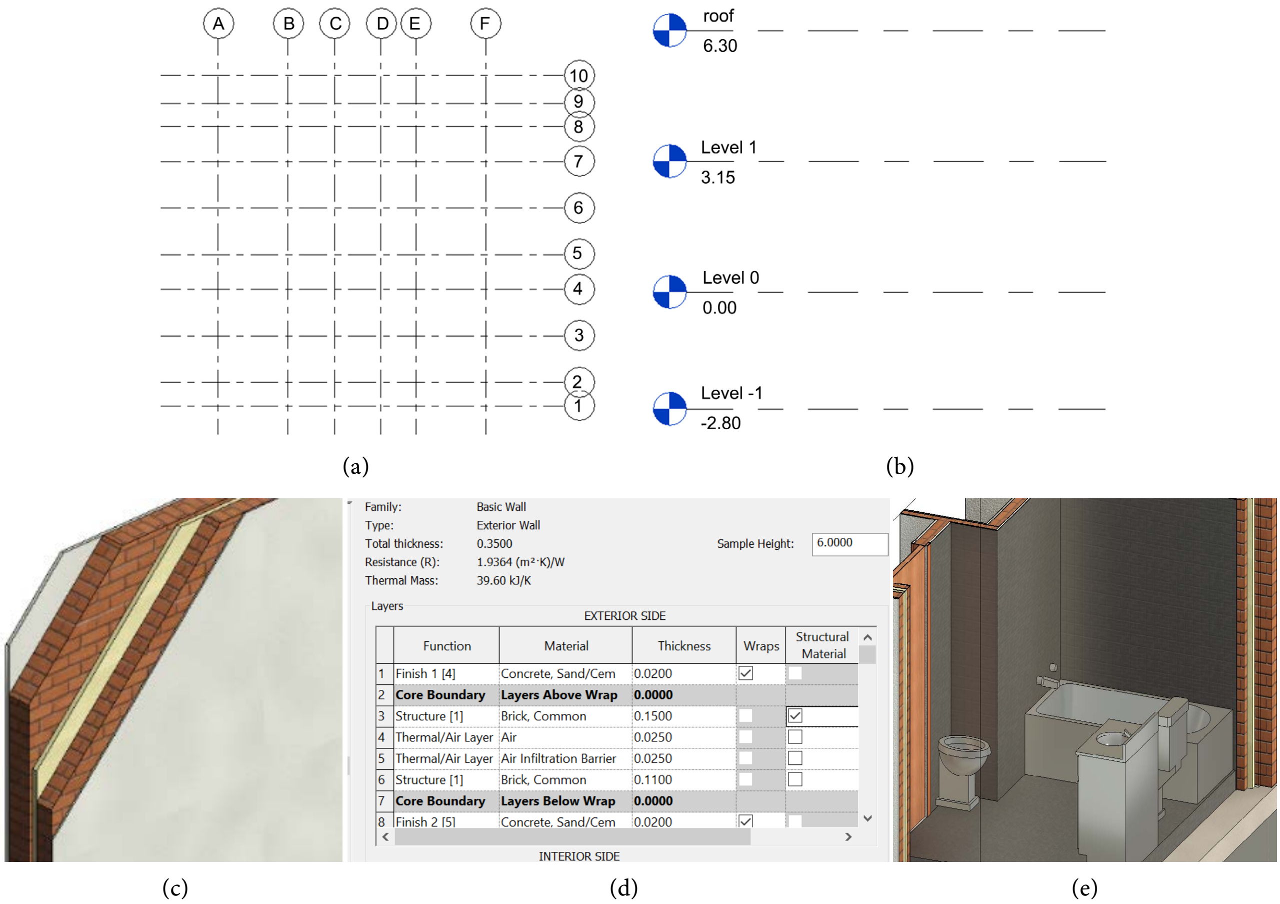


Figure 1. Grid of alignments (a), levels (b), parametric object of an external wall (c and d) and sanitary equipment (e).

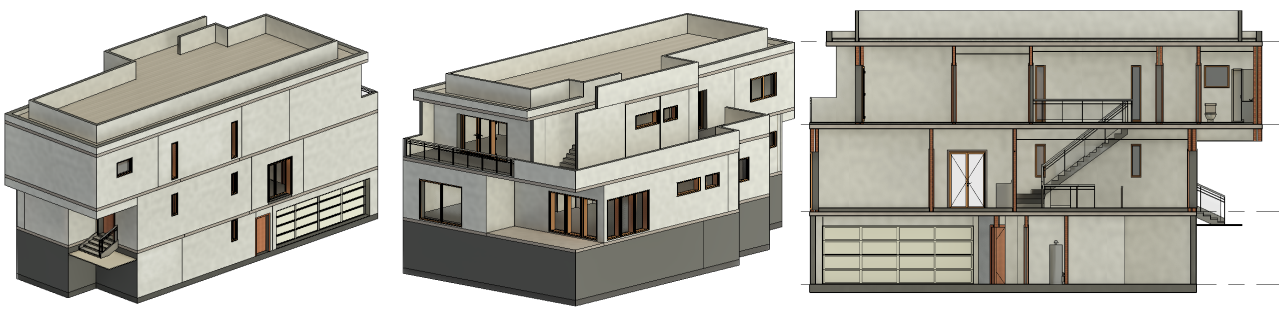


Figure 2. Perspectives of the 3D architectural model and longitudinal cut section.

Once more, the modeling process began with the selection of the required parametric objects, found in the structural menu of Revit. All elements were first adjusted to the required project, but following the generated architectural model, in order to define with accuracy all the structural components. The materials associated to each selected object were the concrete and the still, for the reinforcements.

2.3. Water Supply System

The water supply system aims to ensure that water archives the consumer in

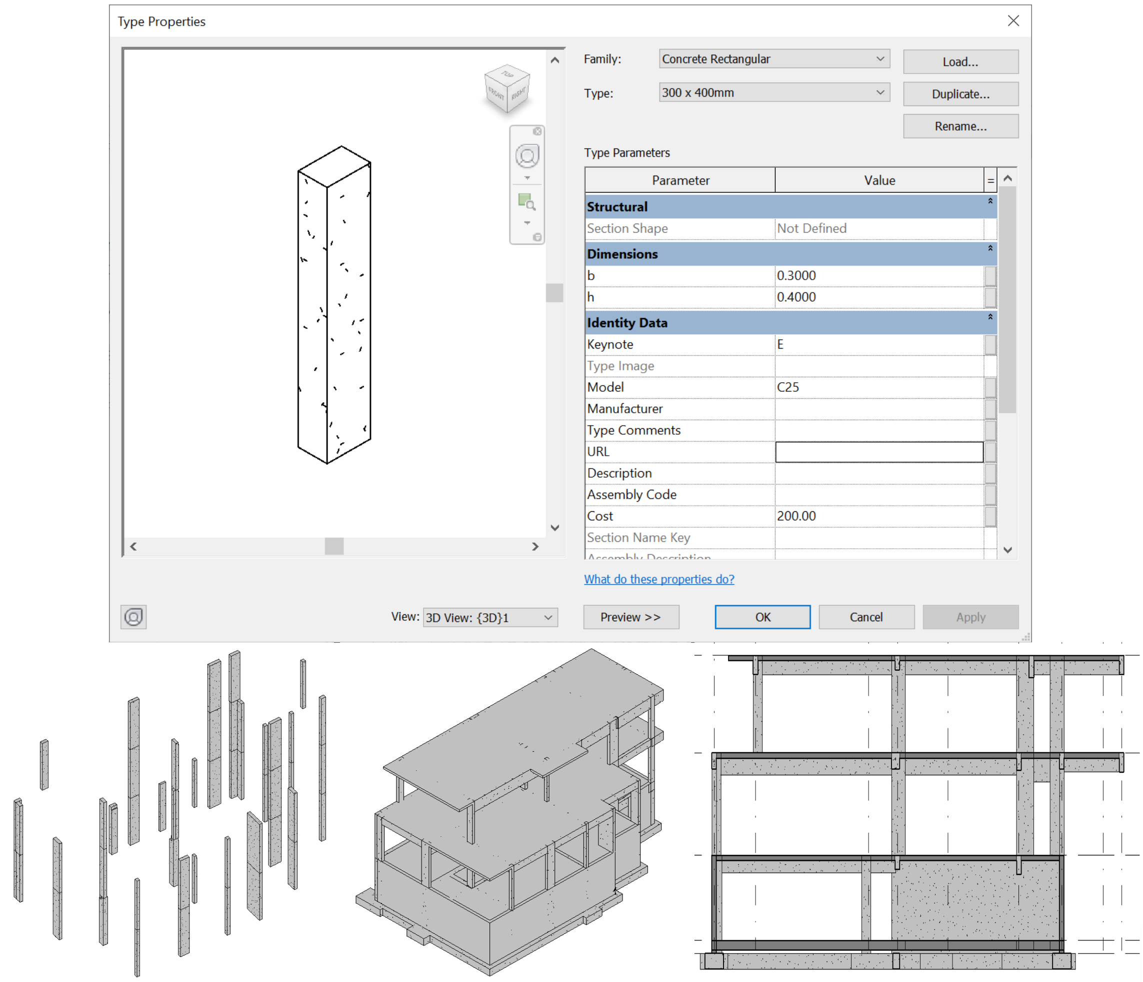


Figure 3. Parametric object of a column and the generated structural BIM model.

perfect conditions. The present case study makes use of the public network supply of water. The cold water supply to the building is provided through the connection branch that links the public water distribution pipe and the domestic distribution system. However, the hot water that feeds the kitchen and I.S. is obtained using a boiler.

A new BIM model was then created and linked to the initial architectural model. This establishes an adequate working basis, to start modelling, with accurate geometric coordinates, levels and alignments. Since the equipment and levels represented in the architecture are the same as for the current project, a copy of these elements was made through the software's collaboration option. Before starting to design the pipes of the water system it was necessary to create and define the dimensions and materials of the families of objects to be used. As well as the type of system to which the pipe to be inserted belongs. Once the definition of the pipes was concluded, they were drawn using plan and longitudinal views of the building for a better perception of the pipe layout. Both systems of cold (blue) and hot (red) waters were generated, with a distance, between both, of a minimum of 5 mm, following a national normative (**Figure 4**).

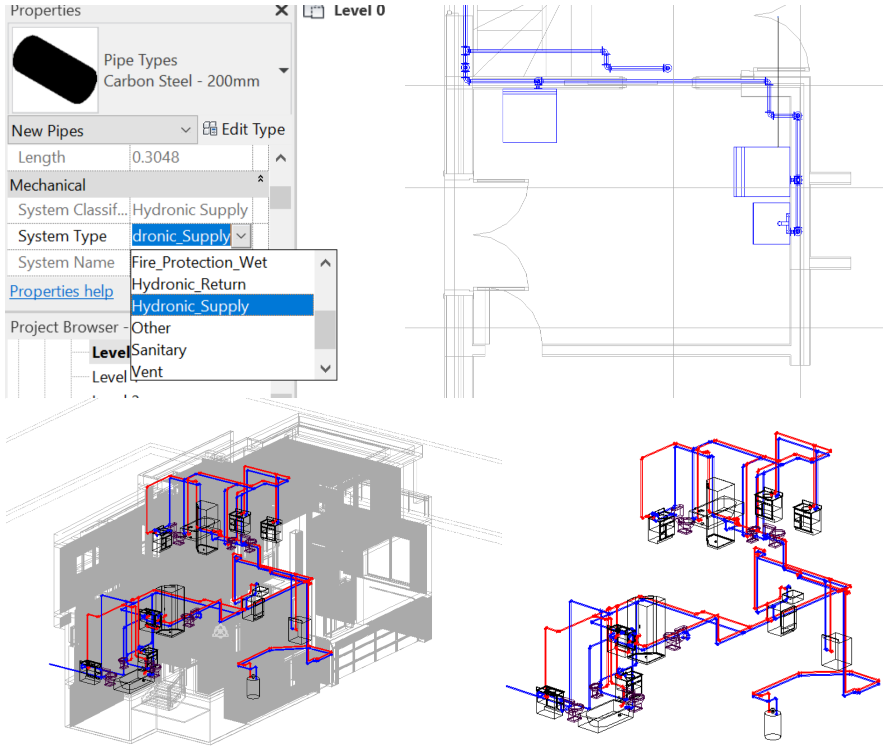


Figure 4. Parametric object of a pipe and representation of the water supply network model.

3. Conflict Analysis

A building is composed of several components concerning distinct disciplines. Frequently, the elements belonging to each discipline presents inconsistencies, namely, distinct components located in the same place. The occurrence of this kind of errors or incompatibilities is common, and normally it is detect over the drawings of each discipline project. Alternatively, even later when the building work is in progress, bringing additional time consuming and overall costs.

The detection of conflicts is a BIM capacity supported in the modelling process based parametric objects, which belongs to distinct disciplines. When the objects were selected from the some family of objects of a discipline, the connection of the elements is made in a union function. But when the objects belong to two distinct disciplines, no connection take place, and a collision is identified. The conflict analysis systems included the capacity of identifying the origin of each object, of the models, and presents an alert when two objects are position in the someplace. This identifies a physical collision that must be eliminated.

Using BIM platform it is easy to verify inconstancies between disciplines. The detection of conflicts, using BIM software, allows the identification of inconsistencies between distinct models, helping architects and contractors to eliminate in a project stage relevant errors that could occur after in construction. A conflict analysis study should be considered as an iterative process, in which all important design errors should be reported and reviewed, changing and updating solutions until the desired level of coordination is achieved.

The use of automatic conflict detection tools can present a vast number of irregularities, however, not all of them should be considered. The conflict analysis present in this work was performed between all the components that constitute the architecture, structures and water supply system models previously created, using Navisworks 2021 software (Autodesk). Like Revit, Navisworks belongs to the same enterprise, providing a high level of compatibility and interoperability, suitable for the transference of models from one software to another without errors or loss of information.

The conflicts were detected after the overlapping of all disciplines, a capacity allowed by Revit. The Navisworks is another software frequently used in the compatibility analyses activity. Navisworks presents a friendly interface that allows the analysis of BIM models, using tools for integration, evaluation and communication between teams. It aims to provide support in the coordination of different disciplines in a project and conflict detection analyses. After the architectural, structural and water supply system models, of the study case, were introduced in the Navisworks, several conflict tests were performed (**Figure 5**).

The type of conflicts that can be defined are: hard clash, interaction between two objects in the same specific place; soft clash, occurs when the geometric tolerances of a person's object or move zone are affected; workflow clash, material and equipment delivery scheduling conflicts or general schedule inconsistencies. Once the models were imported from the Navisworks, the coordinates at the origin and units of the model were checked.

This step is essential for the correct positioning of all specialties in the model, avoiding the erroneous identification of an excessive number of intersections between discipline's components. For each error a message of alert in visualized. The conflict analysis process was initialized using the clash detective command. In the present case, two tests were requested: between the architecture and the water system; between the structures and the water network. In both tests, the interaction between geometric surfaces was evaluated. The correspondent interference reports were also obtained.

Figure 6 shows several examples of conflicts found during the hard clash tests performed: between pipe and wall, between pipe and sanitary equipment and

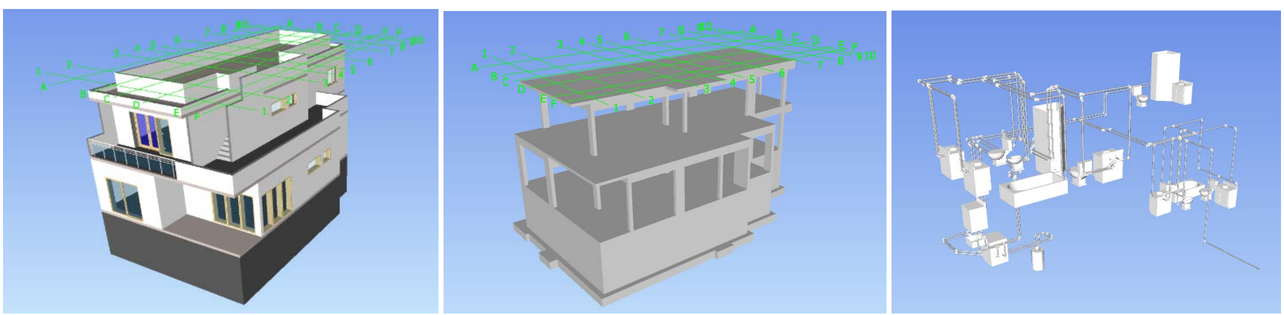


Figure 5. Models of architecture, structures and water system transferred to the Navisworks software.

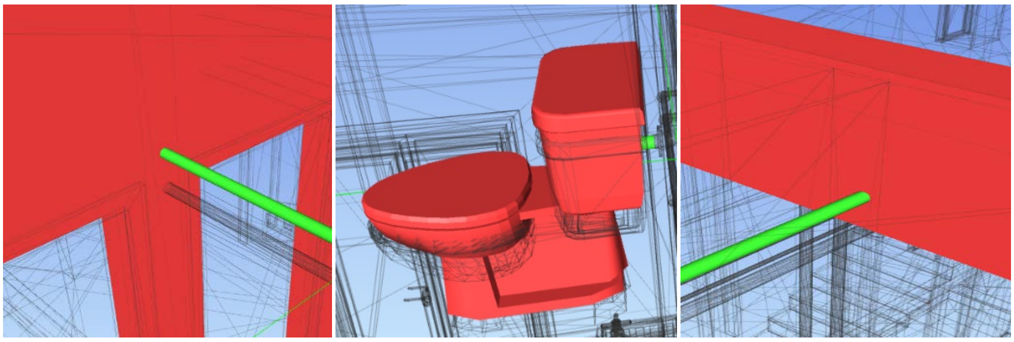


Figure 6. Different type of conflicts that were identified in the tests.

between pipe and beam. The type of conflicts like the connection between a sanitary equipment and the wall, were not considered, as this connection must be established. However, the conflicts between pipes and walls or beams must be remodeled in Revit. As so, before the construction work take place, the multidisciplinary project presents no conflicts, contributing to obtain a more economic construction and with no delays, improving the quality of the final product.

4. 4D BIM Model

The BIM 4D model concerns the simulation of the building construction process, planned according to the studied network of critical paths, that is later associated with the respective groups of components, selected from the BIM model. The 4D model provides a dynamic support for the evolution of the real construction, management of the construction site, chronological control of materials supply, and availability of human resources and monitoring of the construction work [9]. 4D models have been used by several professions in the AEC sector to optimize projects, analyze construction capacity, and manage resources. Poor quality construction work and inefficient construction planning can be significantly reduced with the adoption of BIM in the design phase. The use of 4D BIM model, in line with the effectiveness analysis of project schedule, reduces delays in the current real construction, as it can improve the construction performance work, on site, by enhancing construction information models with schedules of materials handling and local logistics, prefabricated structure production, and environmental and equipment management [10].

The 4D model presents the relationship between the 3D model and the construction schedule work. Using the 4D model makes easy to identify errors, such as inconsistencies in the level of detail, missing activities, and time and places conflicts in the schedule [11]. The 4D model assists engineers in visualizing planning information while avoiding the conceptual need [12]. Using the BIM model composed with the three disciplines, and verified against any clash error, a 4D BIM model was generated.

4.1. Construction Planning

Construction is a complex process composed of a large number of activities that are interconnected in some ways, therefore good planning is necessary to ensure as few accidents as possible. The basic principle of planning is to break down the construction project into elementary activities and to define the duration of each one, with the main objective of guaranty an efficient time path for the construction project with an optimized quality of the building. Planning aims to analyze the construction project considering its technical feasibility, manpower, equipment, materials, among others, until its conclusion. Planning organizes, elaborates, and coordinates the project work throughout all the construction process. The planning performance domain addresses activities and functions associated with the initial, ongoing, and evolving coordination of the organization, providing results necessary to deliver the project deliverables. However, a process should be undertaken for adapting plans throughout the project based on emerging and changing needs or conditions [13].

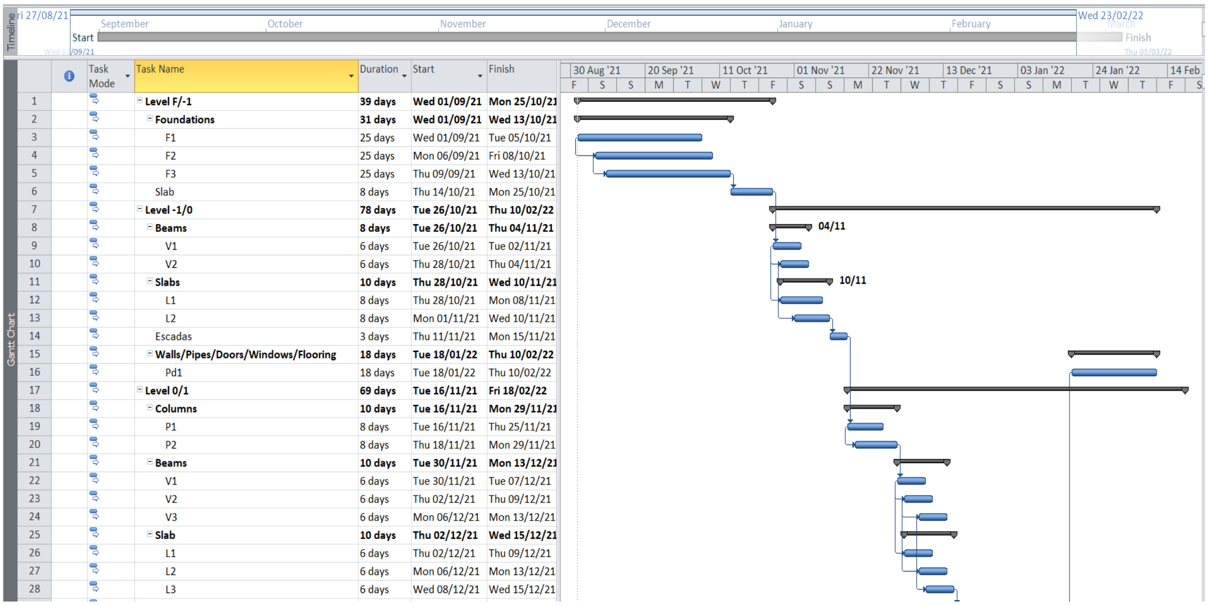
High-level planning may begin before the project is authorized. The project team progressively drafts the initial project documents, such as the objectives, project opening statement, business case, or similar documents to identify or define a coordinated path to achieve the desired outcomes. Predictive planning approaches start by defining the tasks to be accomplished and breaking them down in more detail. A common decomposition approach is the Work Breakdown Structure (WBS), used to decompose the scope into lower levels of detail, these being made of multiple activities. The WBS method can be carried out according to several principles, such as: nature of the work, hierarchical organization, phasing, location, among others. For the present study, the principles of location and phasing were chosen, dividing the activities by the locations of the works to be performed and construction methods.

Using a Gantt chart, it is possible to represent the schedule of the activities that make up the project, providing an overview of the project's scheduling. For the construction of this diagram the Ms Project software, owned by Microsoft, was used. It is one of the world's most widely accepted project management software, easy to use and with a great versatility. Planning with Ms Project, managers can associate human resources, evaluate budgets, create schedules, measure performance, analyze alternative solutions, and prevent risks. For the present building case, a Gantt chart was created (**Figure 7**).

4.2. Visual Simulation of the Construction

After, the correspondent 4D BIM model was obtained, by adding the time factor to the created 3D BIM models. The incorporation of this new information allows visualizing the planned construction process. The 4D model was developed following these steps: creation of the 3D models; importing the 3D models into BIM Navisworks viewer; importing the planning obtained with Ms Project into Navisworks; connecting the planning to the 3D models.

Using the Navisworks Time Liner command, the user is allowed to import the construction schedule from Ms Project. With the introduction of the tasks, Navisworks automatically generates the Gantt bar chart. However, the precedence



	Task Mode	Task Name	Duration	Start	Finish
1		Level F/-1	39 days	Wed 01/09/21	Mon 25/10/21
2		Foundations	31 days	Wed 01/09/21	Wed 13/10/21
3		F1	25 days	Wed 01/09/21	Tue 05/10/21
4		F2	25 days	Mon 06/09/21	Fri 08/10/21
5		F3	25 days	Thu 09/09/21	Wed 13/10/21
6		Slab	8 days	Thu 14/10/21	Mon 25/10/21
7		Level -1/0	78 days	Tue 26/10/21	Thu 10/02/22
8		Beams	8 days	Tue 26/10/21	Thu 04/11/21
9		V1	6 days	Tue 26/10/21	Tue 02/11/21
10		V2	6 days	Thu 28/10/21	Thu 04/11/21
11		Slabs	10 days	Thu 28/10/21	Wed 10/11/21
12		L1	8 days	Thu 28/10/21	Mon 08/11/21
13		L2	8 days	Mon 01/11/21	Wed 10/11/21
14		Escadas	3 days	Thu 11/11/21	Mon 15/11/21
15		Walls/Pipes/Doors/Windows/Flooring	18 days	Tue 18/01/22	Thu 10/02/22
16		Pd1	18 days	Tue 18/01/22	Thu 10/02/22
17		Level 0/1	69 days	Tue 16/11/21	Fri 18/02/22
18		Columns	10 days	Tue 16/11/21	Mon 29/11/21
19		P1	8 days	Tue 16/11/21	Thu 25/11/21
20		P2	8 days	Thu 18/11/21	Mon 29/11/21
21		Beams	10 days	Tue 30/11/21	Mon 13/12/21
22		V1	6 days	Tue 30/11/21	Tue 07/12/21
23		V2	6 days	Thu 02/12/21	Thu 09/12/21
24		V3	6 days	Mon 06/12/21	Mon 13/12/21
25		Slab	10 days	Thu 02/12/21	Wed 15/12/21
26		L1	6 days	Thu 02/12/21	Thu 09/12/21
27		L2	6 days	Mon 06/12/21	Mon 13/12/21
28		L3	6 days	Wed 08/12/21	Wed 15/12/21

Figure 7. Extract of part of the Gantt chart constructed in Ms Project.

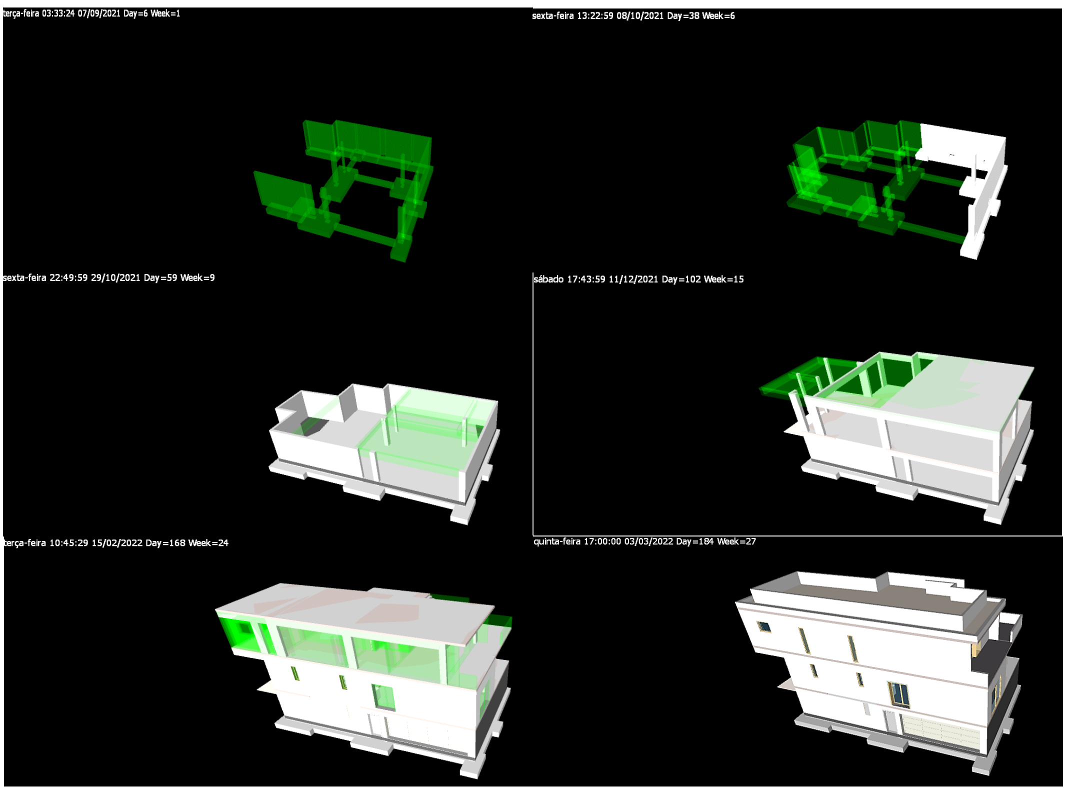


Figure 8. Visual extracts from the case study construction simulation.

between tasks is not imported, in the process. The chart keeps the same dates and task durations, allowing users to follow the same chronological sequence created in Ms Project. Once these initial steps were completed, it is necessary to link the 3D objects of the models, with the respective task. In order to assign, with accuracy, an activity to more than one building element, it is necessary to group the elements in Sets. Using this capacity, a quickly selection of groups of objects, was performed. Various functions were assigned to each set, providing an effective way of linking the elements with their respective chronological activity. After, the sets of the model were linked to their respective activities. They were associated with the type of task and with a visibility function, allowing each set to be visualized or not, after in the simulation representation. **Figure 8** shows the simulation of the planned construction.

The simulation of the construction process allow the engineer to control the real process, as the 4D model can be actualized with the advances or delays identified in the construction place, when compared with the construction planned. The quantity of material and the analyses of the needs concerning the human resource can be also studied and planed over the 4D model.

5. Conclusions

The practical component developed throughout this work involves the 3D modelling, the clash detection and the 4D model generation. The first activity was performed using the Revit software and for the second step, the Navisworks software was used. The modelling process was based on the selection of parametric objects, representative of the components of the three distinct required projects (architecture, structure and water supply system). All components were created in an integrated way, facilitating the conflicts detection analyses. In addition, a visual simulation of the planned construction was performed.

The main objective of the work was to analyze the capability of BIM methodology in the support of the generation of an integrated model, and how to handle the model in order to verify inconsistencies and to simulate the construction process. A correct 3D modelling process is the basis for the development of tasks supported by the global BIM project. The design of objects in a 3D environment, when created with an adequate level of detail, allowed the incorporation of more detailed planning comparable to that obtained in the construction execution phase; moreover, the ability to link several models from different disciplines encourages the collaboration of all participants, ensuring a higher level of transparency. The conflict analysis activity provides an adequate means of screening out possible inconsistencies in the models, avoiding the propagation of errors as the design is updated. In addition, the 4D application aimed to represent the simulation of the construction in order to identify constructive incompatibilities and to provide support for decision making in a collaborative environment, anticipating possible risks in the project that may reach the execution phase, and thus avoid delays and additional costs.

In summary, the BIM tools used during this paper allowed the conclusion of the proposed objectives, representing a good solution for tasks of similar origin, however, the application of BIM brings with it several threats and constraints. The use of different modelling software by the project team causes the need to implement new programs to move the models from one environment to another or to combine these models. This implementation can generate additional complexity and introduce potential errors and time increment in the project. The use of BIM software entails additional consequences, such as training and education of professionals and acquisition of equipment capable of performing all the functions effectively. The cost of training and equipment is expensive and the learning curve is slow, causing a possible financial stalemate in companies and pushing away possible adaptation to BIM.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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