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BIM as a Computer-Aided Design Methodology in Civil Engineering

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Abstract

Building Information Models (BIM) have revealed themselves as a good tool to support construction actions, due to their ability to store all the information in one digital model and to promote collaboration between all participants in a project. Teaching Civil Engineering requires a permanent updating of knowledge concerning procedures and technologies used in the construction industry. In this sense, the school should seek to adapt its curriculum to include innovative issues to support new technologies. So, in an educational context, the aim of the present work is to disseminate knowledge concerning the benefits provided when implementing BIM in several aspects within the construction activity. In a Civil Engineering school some topics of BIM application were developed by students within MSc researches. The text describes in detail some of the main topics, showing distinct use of BIM: Generation and use of a 4D/BIM model to support construction planning; coordination of construction project based on BIM methodology; conflict analysis based in an architectural 3D/BIM model. Several study cases were modelled and analyzed, confronting the BIM use with the traditional way when performing the same tasks, and consequently recommendations were carried out. This work contributed to demonstrate the advantages of employing BIM for building tasks purposes when compared with the traditional process, and in a didactic context the main objective is to add competitive skills in the training of future civil engineers.

Keywords

BIM, nD/BIM, Construction, Collaboration, Interoperability

1. Introduction

Building Information Modelling (BIM) is defined as the process of generating, storing, managing, exchanging, and sharing building information in an interoperable and reusable way [1]. BIM represents the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a facility [2]. The resulting product, a Building Information Model, is a data-rich, intelligent and parametric digital representation of the building project. So, BIM can be considered as a digital representation of a building, an object-oriented three-dimensional (3D) model, and a repository of project information to facilitate interoperability and exchange of information with related software applications. Therefore, BIM data-rich model allows views and data, appropriate to various users' needs. The data can be extracted from the model and worked out to generate information that can support several analyses in order to make decisions and to improve the process of delivering the facility.

BIM methodology covers various sectors of the construction industry. A BIM project constitutes a complete and full database, not only the geometric model, the most visible part of the process, but the materials applied in the building and its mechanical properties and physical characteristics [3]. BIM interferes with all aspects involved in a building project: the initial stage concerning the generation of a form (architecture); the different phases of the structural study (structural solution design, analysis and production of technical drawings); the quantification of materials and budgets; the construction planning process (definition of geometric model for each construction phase); the usage of the building (management and maintenance), in a later stage [4].

BIM can generate and maintain information produced during the whole life cycle of a building project—from design to maintenance—and can be applied to various fields. Due to the consistency of design data with quality data and construction process with quality control process, the potential of BIM implementation in quality management lies in its ability to present multi-dimensional data including design data and time sequence. BIM and its applications in project management are considered nD/BIM models, namely [1]: 3D/BIM model refers to all 3D building components (architectural, structural, mechanical, electrical, etc.) and it incorporates all the building aspects, including geometry, spatial relationships, properties and quantities [2]; 4D/BIM model concerns the construction process that can be visualized by building the 3D product model through time according to the critical path network (the model supports dynamic construction site safety management, preparation of schedules and estimates, tracking and managing changes, and managing site logistics) [5]; 5D/BIM model is related with costs (take-off material quantities, cost planning and estimating, safety checking integration for dynamic safety analysis); 6D/BIM model is created to support management facilities and maintenance along the post occupation lifecycle of the building [6]. The nD perspectives of BIM use must be based in an adequate relationship between the team members improving a better collaborative project, supported in an efficient interoperability of specific software.

In a more traditional process of developing a project, each player uses a different and non-integrated work methodology, as there is not a source of complete and updated information for the overall project. This lack of process integration is one of the main drivers for the loss of information and, causing a loss of value through each stage. Information is a key factor in management in the internal context, as well as the relationship with the exterior [7]. The evolution of the information technologies has contributed greatly with new possibilities of integration and communication at distance. In a sector, such as the construction, marked by the fragmentation and where multiple players exist, usually geographically disperse; this ability to communicate at a distance has been fundamental for sharing information. For that, it is also fundamental to ensure the interoperability amongst the multiple software solutions that are used in supporting the project development.

The BIM methodology, which combines the parametric design, three dimensional (3D) models, element level information, coordination, communication and visualization within the whole building lifecycle, is changing deeply the way how information is managed within the construction sector [8]. The BIM concept aims at improving the work methods used nowadays. This new approach is based essentially in the integration of processes, supported by an information rich 3D model which allows to seamlessly tracking the whole lifecycle of the enterprise. As such, it is also expected that the whole process becomes more accessible to the multiple entities that collaborate in the enterprise either while developing the design and later in the management of the building.

In the context of the education activity in a Civil Engineering and Architectural school some topics of BIM application were developed by students within MSc researches. The main issue concerns the construction activity (**Figure 1**): The construction planning based on 4D/BIM models; Coordination and preparation of construction project using 3D/BIM models; Analysis of conflicts over an architectural, structural and MEP model.

Without BIM those tasks are usually defined based on drawings, presented in sheets of paper or in a digital form, requiring a great deal of understanding of the drawings, the correct overlapping of drawings in order to detect conflicts and a huge attention in the verification of the correctness of target design updates. The 3D model, which is often requested during the development of a project, is created using just a 3D geometric modeler. Comparing with the 2D-based work, this kind of 3D models improves the communication between the team members and the client, but does not admit the automatic detection of conflicts between components, as those elements only contain geometric information. The parametric objects that forms the 3D BIM models, constitute a very significant advance as a support to the development of projects, because the 3D/BIM model is rich in information and each element is characterized as belonging to a class (architecture, structures and net services), allowing the automatic detection of conflicts. The 4D/BIM model [9] defined using the Navisworks, a BIM viewer software, constitutes an advanced application in the construction planning as it is easy to create and allows to consult information from the model, along the construction process. The present study compares the 4D/BIM model with a 4D based AutoCAD model, reported by Santos [10].

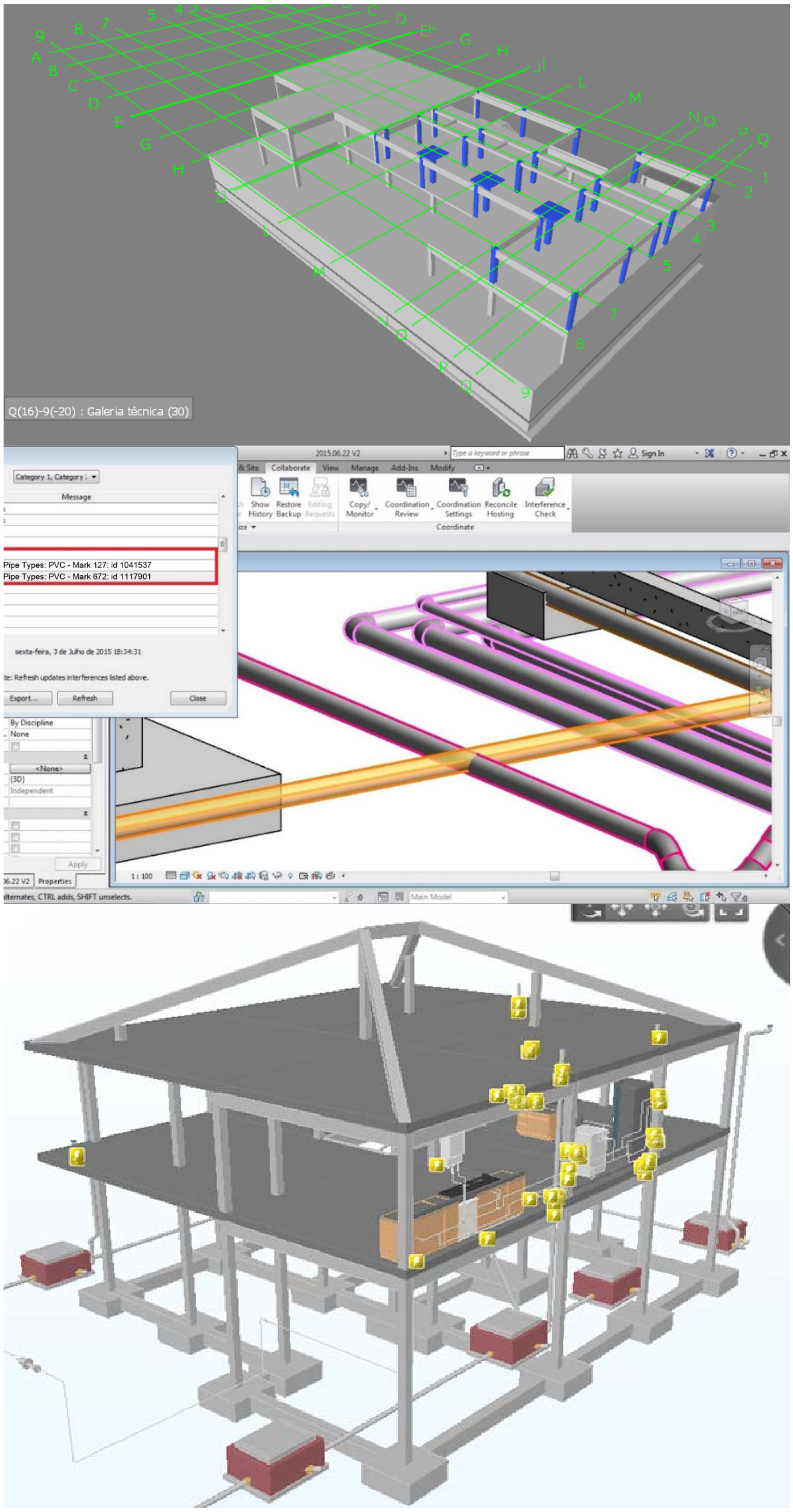


Figure 1. BIM uses—construction planning, construction coordination and conflict analyses.

2. Conflict Analysis Based in a 3D/BIM Model

The development of a building project requires the involvement of different stakeholders. As so it is necessary to coordinate the different information from all the intervenient parts. In the construction industry, stakeholders represent different experts in their design fields and specialists, collaborating in the execution of a project. However the decisions and actions taken by these parties as participants in the project team, have a decisive importance later, both in the design and construction phases, because their actions imposes constraints on the activity and solutions of other participants in the future.

The coordination of Mechanical, Electrical and Plumbing (MEP) systems is a huge challenge for technical projects. Conflict detection is an important part of the design process. When modelling, there is not only a model but several that are integrated to compose a complete model of the project. For each specialty (structural engineering, MEP engineering, environmental engineering, etc.) a component of the 3D/model is created. All must be overlapped to form one digital model of the all project.

Concerning a 1st study case, the structural and MEP component were modelled based on the initial model created by the architect, who serves as a starting point for all disciplines. After each specialty has finished their respective work, the next step in a BIM environment, is the detection of conflicts, which is the process of finding where the models go into shock: elements of distinct models occupying the same space. This item analyzes a case study looking for conflicts between the structures and components of MEP, using BIM tools [11].

2.1. Generating the 3D/BIM MEP Model

The study case is a familiar two floor house. First the architectural component of the 3D/BIM model was generated, using Revit and supported on AutoCAD drawings. Then the structural component was also modeled. The 3rd step consists of modelling the MEP component. This modelling task was carried out based on the architectural component. So, in shaping the MEP component the structural component was not visible. After when overlapping MEP and the structural components the user can visualize conflict and make the correspondent resolution using Revit. It helps the modeler to obtain a better MEP model but, normally, it is not sufficient (**Figure 2**).

2.2. Clash Detection

In a 3D/BIM model conflicts can be classified in two categories:

- Physical Clashes—geometric intersections between 3D objects, e.g., a duct clashes in a beam;
- Rule Clashes—this type of conflict is more complex because it depends on the requirements and legal standards. It's a conflict related to objects and associated rules that are not met. For example, a narrow corridor interferes with specifications for people with disabilities.

There are two predominant types of conflict detection technologies:

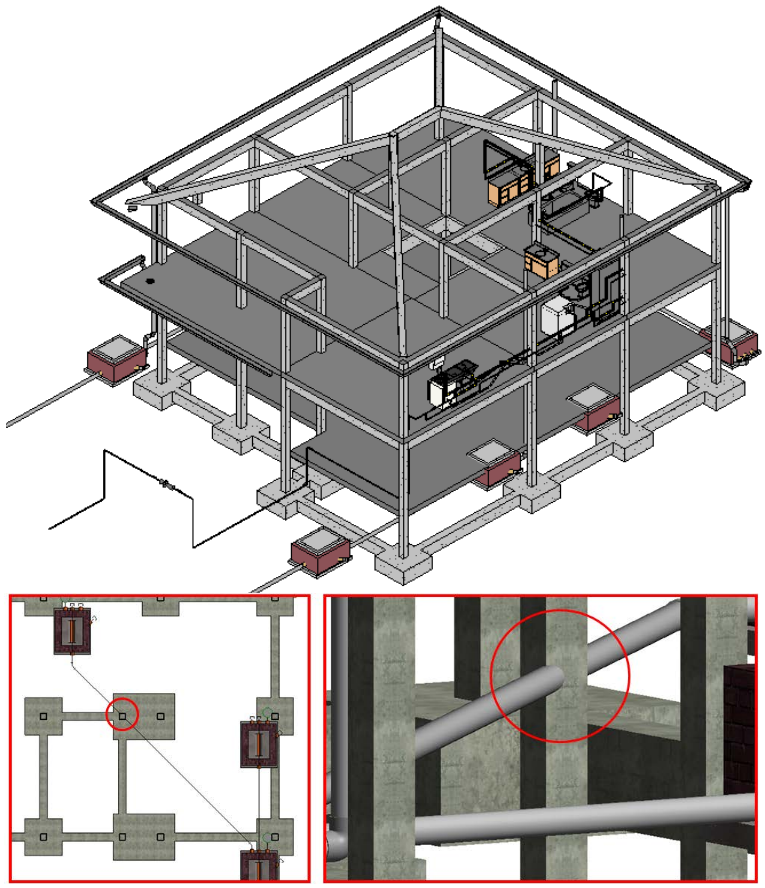


Figure 2. MEP and structural components of a 3D/BIM model.

- Checking for conflicts in BIM modeling tools;
- Checking for conflicts in BIM integration tools.

In the first case the verification is limited because, when the 3D model integrates various components, this may not be successful due to limited interoperability of most modelers BIM or due to the complexity of the various components of the models. In the second situation, the conflict checking is performed using BIM visualizers, like Navisworks Manage from Autodesk, Solibri Model Checker and Tekla BIM sight (Figure 3). This type of software allows users to import 3D models, from a wide variety of modelers, and allows the analyses of clash detection of the entire integrated model.

Each detected hard clash was analyzed. In order to obtain a correct model MEP, in relation to the architecture and structures components, an adequate rectification of the MEP model was defined using Revit after observing each incompatibility:

- The hard clash conflict related to the intersection between water distribution pipes and structural column were analyzed. Most of the detected conflicts correspond to this kind of clashes between pipes and pillars. Figure 4 illustrates one of these cases, where the user can view the hot water pipe crossing the pillar side to side across the diameter. An adequate resolution was defined changing the initial MEP model;

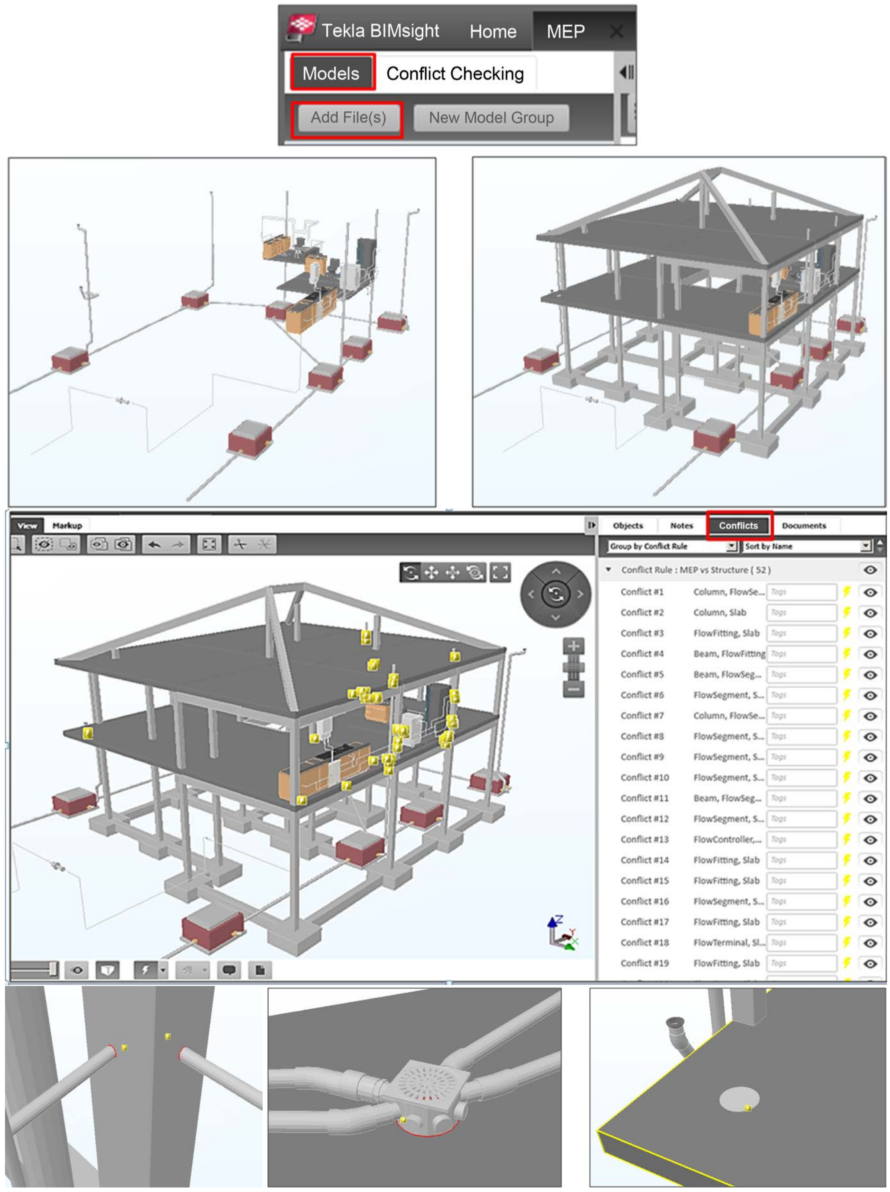


Figure 3. Automatic conflict detection using Tekla BIM sight.

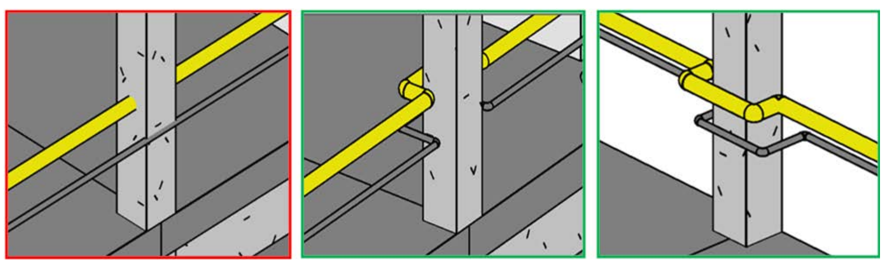


Figure 4. Conflict between column and water distribution pipes.

- In turn, the cold water pipe, although only part of its section crossing the pillar, is also a hard clash. Identified the problem, the user should proceed to its correction, after in Revit, having chosen to turn around the pillar inside (Figure 5).

- Other conflict concerns the ventilation downspout and a beam (**Figure 6**). To resolve this situation the entire pipework was moved and a thin wall around the vertical pipe was created, in order to hide it.

2.3. Traditional Process/BIM

- The development of an engineering design requires the participation of several parties involved in different disciplines, where each discipline conducts its own project in a somewhat disconnected manner from the remaining, therefore requiring project compatibility. In this context, an efficient conflict analysis between disciplines is essential to guarantee a well-developed design. The MEP design is critical for decision making, accurate documentation, budgeting, performance forecasting, construction planning and management and, eventually, facility maintenance.
- Therefore, the coordination and routing of these kinds of systems is of great importance. The traditional process of conflict analyses based in 2D drawings, leads with several limitations along the design definition and after in the field: Delays in construction process due to conflict being identified in the field; Lack of trust in the fabrication offsite due to the fear of system not fitting leading to a lot of on the site fabrication; Rework to fix the conflict issues not identified during design and coordination; Increased site supervision required to avoid conflicts between trade contractors; identification of conflicts in the field after budgets are approved; Overall reduced productivity for everyone involved in the process [12].

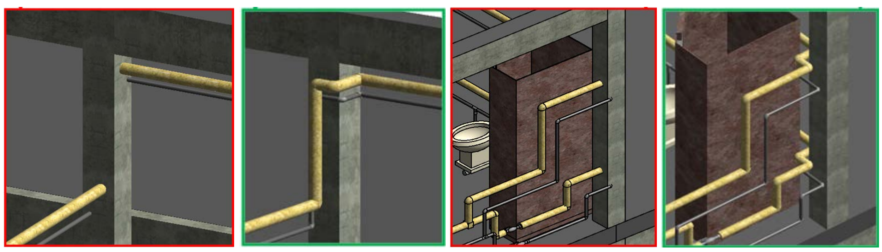


Figure 5. Conflict between pillar and water supply pipe.

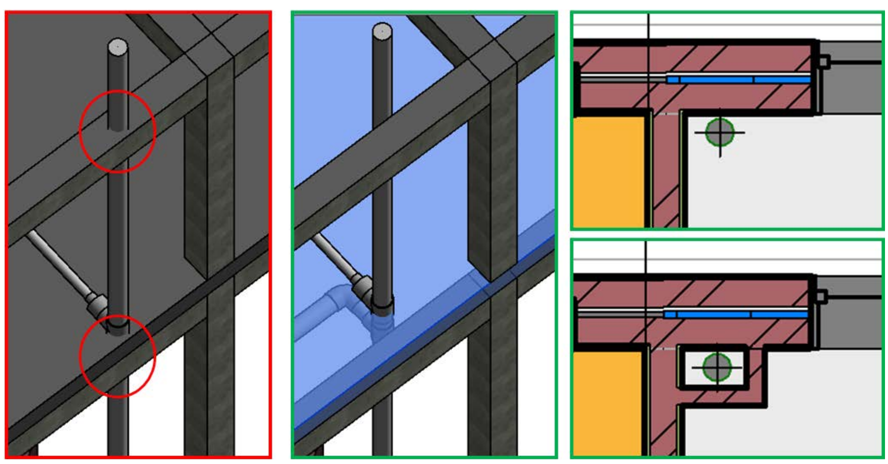


Figure 6. Conflict between downspout and beam.

Conflict detection based on BIM, offers many advantages when compared to traditional methods. The high level of detail and visualization provided by a BIM model leads to better collaboration between those involved throughout the design, hence resulting in a significant reduction of potential errors during the construction phase. BIM tools allows the user to check selectively if interference occurs between any MEP system, as for example between plumbing, mechanical, electrical, structural systems, etc. Thus, the conflict detection can be performed regardless of the level of detail of the model, and regardless of the number of systems that make up the building. Regardless of the accuracy of the model BIM, the contractor must ensure that the building is modeled with an appropriate level of detail, since for efficient detection of conflicts must be minimally detailed model with regard to piping, ducts, structural elements and other components. If the degree of detail is inaccurate or insufficient, it may happen that the real problems will be noted just in the construction phase, and leading with its resolution is more expensive and time-consuming.

3. 4D/BIM Model for Construction Planning

The planning of the construction activity is a crucial stage in the conception of a design, and involves the selection of technologies, definition of work activities, estimation and resource management, logistics and duration of each individual task, as well as all the dependencies amongst the different tasks. Planning and scheduling in construction, involves the sequence of activities both in space and in time, taking into account the allocation and resource acquisition, quantities and space constraints amongst others [13]. The estimation for the duration of the activities is a decisive stage for a good project and building planning, as the control of the schedule, depends on the proper effort and duration estimation [14].

3.1. Generation of a 4D/BIM Model

In order to explore the BIM tools, as a support to construction planning, a 3D model of a second study case was first created. Using the Revit software only the architectural and infrastructure models of the project were generated. To create a 4D model the time factor must be linked to the 3D/BIM model elements. After, by running the defined 4D model, it allows the visualizations and analysis of the activity sequence for the construction.

So, to generate the 4D model for the present case, the Navisworks software, a BIM viewer, was used [8]. This software allows the interconnections amongst sets of 3D elements of the BIM model, with the planned tasks stablished in MS Project software. Briefly, the steps for the preparation of the 4D/BIM model are (**Figure 7**):

- Export the Revit 3D model, saved in the NWC format, to the Naviswork software as well as the MS Project planning file to the Naviswork timeliner;
- In the Naviswork, the 3D elements of the models were grouped according to the tasks defined in the planning. For this purpose, adequate "sets" were created. These "sets" can be created by selecting the elements directly over the model, by executing "tree selection" or by searching for its properties;

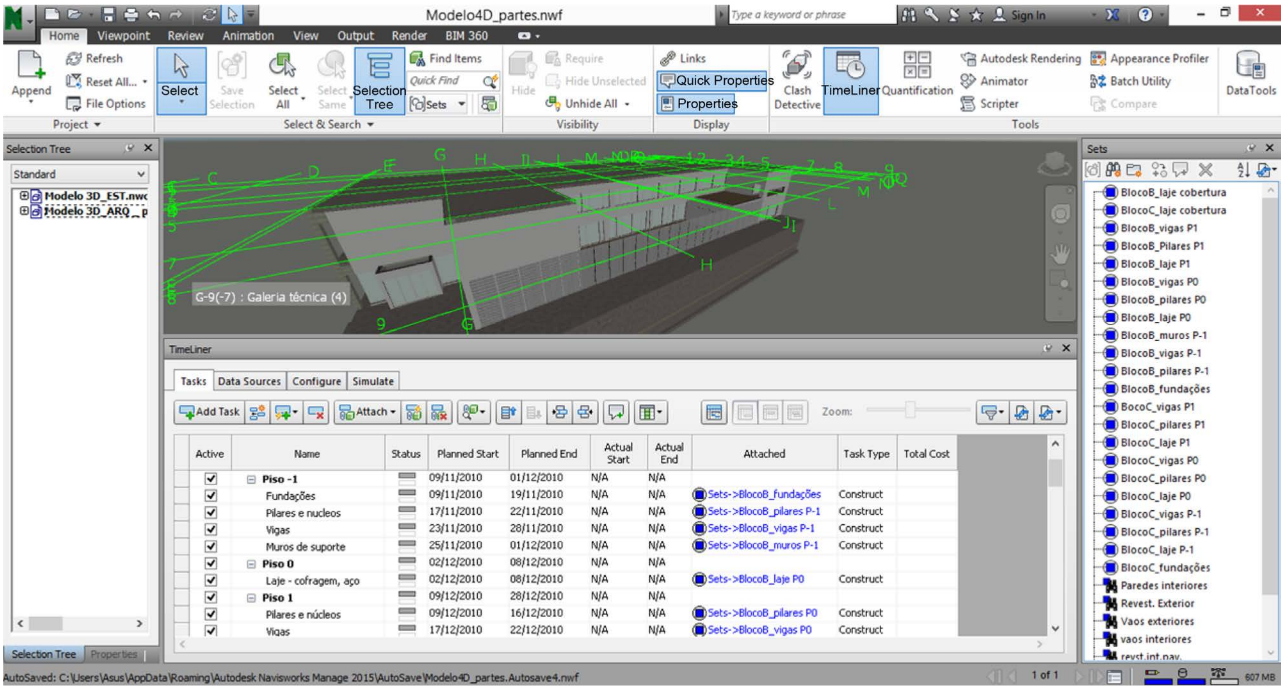


Figure 7. Screen shot of 4D/BIM application.

- Next the created "sets" were associated to the planning and schedule of tasks and set for each task its category, that is, whether it is construction, demolition, temporary activity or another.

3.2. Using the 4D/BIM Model

By running the 4D/BIM model it is possible to visualize the planning simulation. Figure 8 shows a couple of frames, extracted from the simulation of this project.

The practical part of this work fell mainly in study of the 3D modelling using Revit, and applying a model for 4D construction planning. The simulation will probably never match the reality, with its unforeseen, but this motivates the development of visualization technologies, trying to reduce the gap amongst the digital world as the reality. The aim is to minimize the number of execution errors, at least those believed to be predictable.

3.3. Traditional Process/BIM

Construction management has traditionally been focused in the creation of a timeline used more as a guide to the development of the construction, demeaning the importance of being integrated in its conception. Additionally, technical drawings are sometimes insufficient in object's total definition, and present themselves as an incomplete tool in transmitting the original idea. Geometrical 3D models offer detailed analyses of the construction project and when linked a construction planning schedule, in a 4D model, also supports the constructive process. Santos [10] created a 4D virtual model linking the geometric 3D models, generated in AutoCAD, with the time factor. The Virtual Reality (VR) technology,

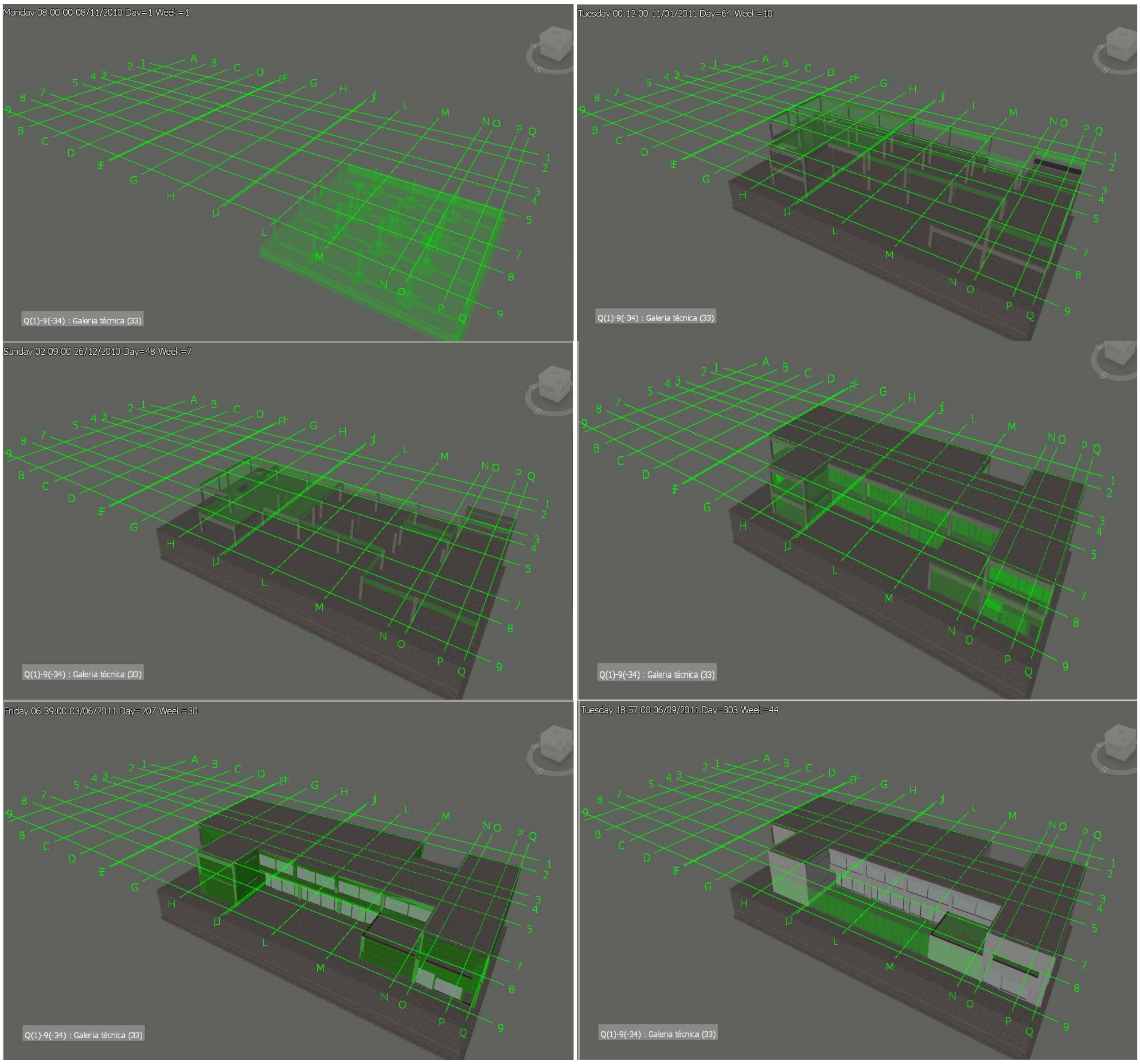


Figure 8. Construction simulation visualized in a 4D/BIM model.

used in it, allows the simulation of the construction process, as it permits a great deal of interactivity and study complex scenarios. It improves the communication between the project manager, promoting the dialog and interaction between all those involved.

But as demonstrated, a BIM model can be managed directly in BIM viewer software with benefits over a 4D/VR model based in AutoCAD. The Navisworks software helps to connect the entire project team and streamline BIM project review and coordination workflows. The software combines model coordination with project quantities and schedule to deliver simulation and quantification features, including analysis of time and cost. Comparing the previous 4D/VR model with to the 4D/BIM model, using the Navisworks software: all the element data from the 3D BIM models are available, the planning schedule can be continuously displayed as it is generated and changed in a flexible manner and the BIM viewer has the potential to provide support in the analysis and detection of conflicts amongst the distinct disciplines involved in an entire project.

4. Coordination of Construction Project Supported on 3D/BIM

In a BIM process, the execution of a building project network would be superimposed to the structure of buildings. Because the elements are delivered to the construction company, with the elements of the network components modelled with a high level of detail, during the project development. In addition, in the BIM collaboration environment, the construction company could be an integral part of those projects, according to the Integrated Project Development methodology (IPD). In this 3rd study case a 3D/BIM model was created. The model allow to support the coordination of phases of construction, the extraction of maps of quantities, the input and deleting elements of the model, to change slopes and coupling pipes, among other situations. The networks considered in the case study were: sewage, water supply network and power grid.

As part of the design review of this another case, it was necessary to start the process by developing the 3D/BIM model of the project [15]. This item describes the various situations that occurred in the workplace and conducts analysis of its resolution on a BIM methodology base, using the capabilities of the BIM software used.

4.1. Building Networks and Analyses of Conflicts

The modelling and integration of network elements in the BIM model is trimmed in parameterization of properties associated with modeled objects. Setting this property does not allow inconsistencies and provides rules with the ability to identify changes that violate the feasibility of the objects. As mentioned, the Revit tool has the ability to detect conflicts inherent to the overlap of the objects. So the resolution of each conflict situation is detected and resolved over the BIM model.

The software used checks and alert for the occurrence of transgressions between objects, therefore, any errors that may appear in the construction are previously identified during the design phase, reducing the number of errors and additional costs. The preparation work of building networks on the basis of structure is a fundamental process that is performed on site, because changing the path of the tubing is constrained due to the presence of the structure elements. The analysis of the situation on the BIM model is done automatically. **Figure 9** presents one of the conflicts identified during the development of the model, in this case, a conflict resulting from the interference between the pipe and a bunker foundation.

4.2. Coupling Elements and Estimative of Construction Costs

Changing elements, because they fulfill the same space in the same instant, it is a

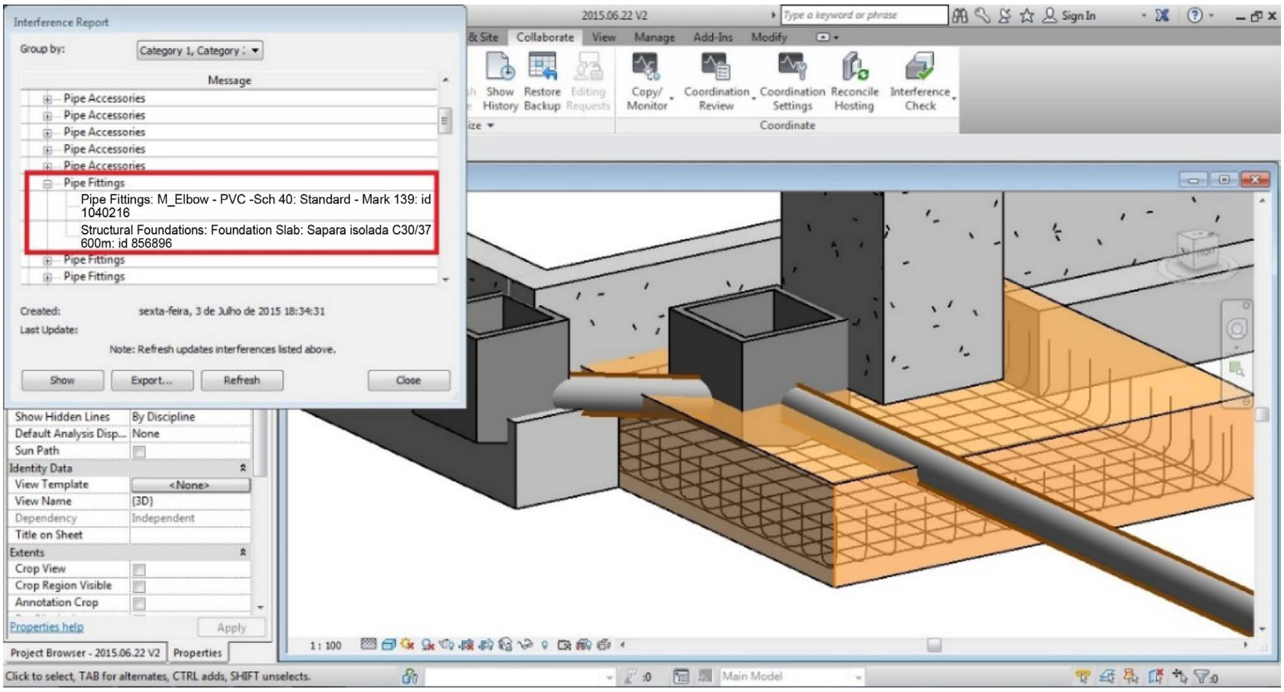


Figure 9. Conflicts between a piping and a bunker structural element.

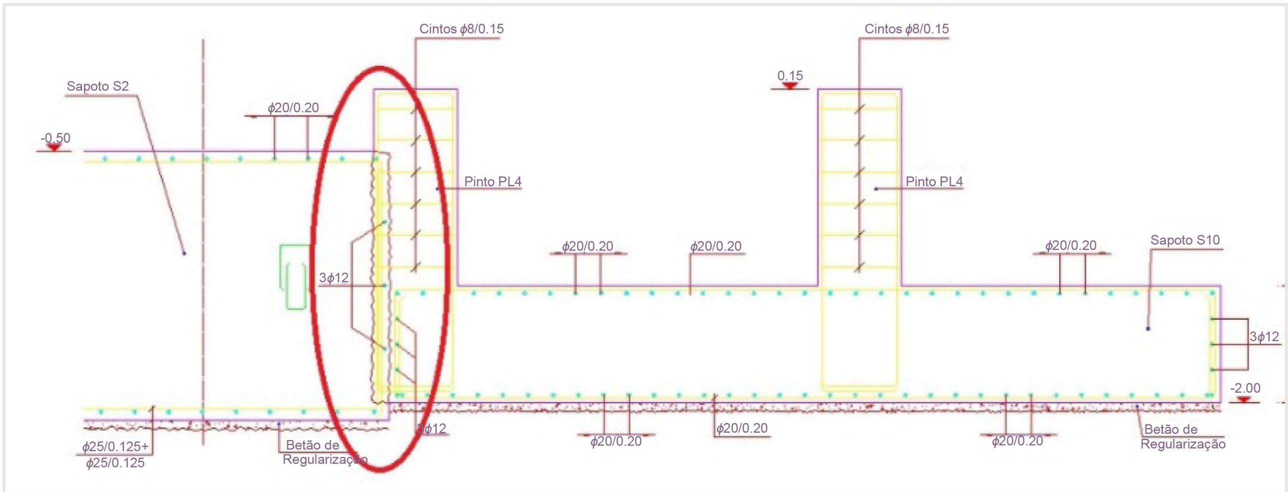
recurring situation in Design-Build project delivery, because while the work is in progress some projects are still being created. This led to one of the already implemented elements that had to be chopped in a certain area to allocate a coming slab foundation. Figure 10(a) presents the chipping area of concrete represented in an AutoCAD drawing and Figure 10(b) shows the modelling of these foundations, in the BIM model created.

The construction presented a high degree of complexity, and the presence of errors in work led to delays, more costs and the increase of complexity. All the modifications presented in this item led to increased costs and increased time needed to hand-skilled labor. Also adds the influence of the contract, because the changes occurred led to increased costs, as well as, delays due to order of materials. Interoperability between software has highly importance for the handling and processing of data. Microsoft Excel tool is considered the main application for estimating construction costs. Based on this knowledge and understanding the importance of other tools, Revit by enabling the extraction of amounts of maps, enables data to be exported to files in formats that allow the handling of data, using other tools (Figure 11).

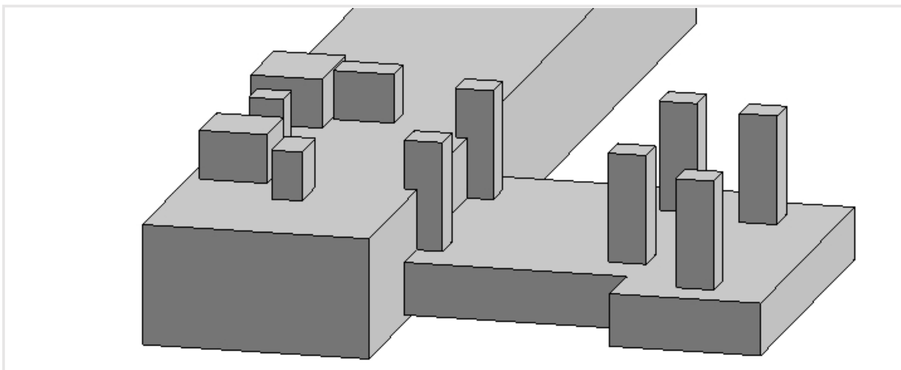
As an example, from the analyzed case was exported the quantities of maps obtained from building networks, having these been exported in a format to be used by Microsoft Excel tool.

4.3. Technical Drawings

In the traditional work methodology the design error, namely the inconsistency between representations, occurs frequently. Although the design it's a more depth study theme in project, in construction work it as a huge impact, such as



(a)



(b)

Figure 10. Docking area of the two foundations, in a CAD drawing (a) and in a 3D/BIM model (b).

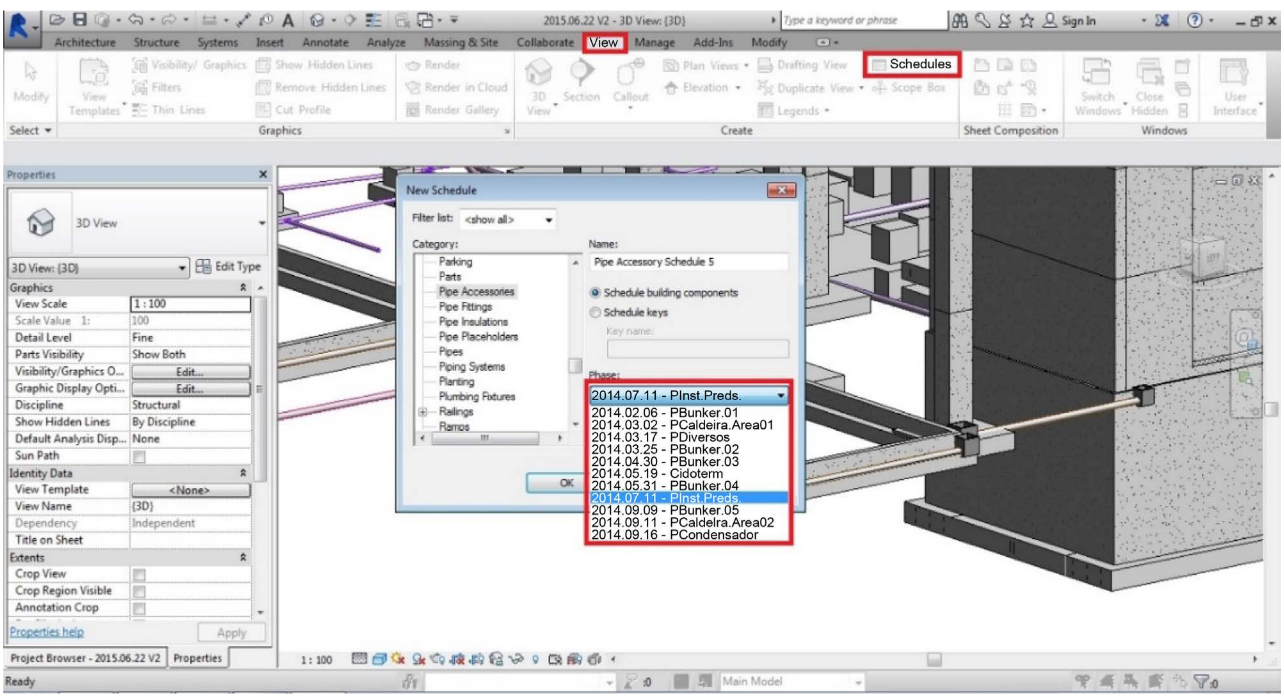


Figure 11. Selecting a quantity map by phases.

the elements to developed in work to the subcontractors, drawing solutions to accomplish several tasks, space optimization among others. BIM model allow multitasks for those cases, with 3D visualization form all space that covers construction site, allowing the instant representation of several building sections, elevations and plans.

5. Conclusions

The work enabled the knowledge of the subject BIM within an education context but oriented to the real activity. Research on the subject has exposed several objects of study covering BIM, from its origin to its application in the Construction sector, seeking to know the reasons for his development and how this methodology has been developed. The use of this methodology for the development of construction management emerged several situations that expose the benefits of using BIM. The main objective of this curricular offer to students is to add competitive skills in the training of these future civil engineers.

Concerning the 1st study, an efficient conflict analysis was applied over a 3D model composed of architectural, structural and MEP disciplines. When comparing the BIM methodology with the AutoCAD usage, the representation of elements is more complete and its 3D viewing is immediate. In addition, the ability to simultaneously conciliate the architectural component with the structural component through the coordination view aids with obvious advantages the process of establishing a structural solution. Regarding the modeling of the MEP discipline, the entire pipe and complementary accessories modeling process was performed in order to accommodate them to architectural elements, especially walls and pavements. When comparing the applied process with the traditional AutoCAD methods, a big difference can be noted, with great benefits for the designer. The use of BIM tools as a means of conflict analysis presents an irrefutable advantage over traditional methods. The use of modelers, such as Revit, for this purpose enables a virtual visualization of conflicts with a very high level of detail. The conflict detection software are only a tool to help in the decision making process.

During the usage of the 4D/BIM model, some very positive points where found, from which the following ones are highlighted: The ability to visualize the schedule and the 4D simulation show that Navisworks can be a useful tool to support the project planning, in a collaborative environment, as intended in the BIM methodology. The schedule can be continuously displayed as it is generated and changed in a flexible manner; As Revit and Navisworks are both products from the same software house (Autodesk), the interoperability was found to be is very good. All the element data from the 3D models are also available in Navisworks; The possibility to use a workflow which includes 3D element parameters in the 3D model elements, similar to the respective tasks, simplifies the automated grouping through automatic selection rules; The ability to navigate through the model allows to analyse each corner and each location of this model or from a group. It also has the ability to export in many formats, in order to share the project data and the 4D modelling in mobile devices.

Regarding the development of the 3rd case study, this showed the author that one of the great strengths of BIM, as well as various technical details of the created elements, is the development of their work in a cooperative manner, over the construction process. This situation is reinforced by IPD method, which brings together with the characteristics of BIM. In this case it was analysed the improvement allowed by the BIM model and tools in the building network coordination, the analyses of conflicts between phases of the design, the way of coupling elements, how to easily estimative construction costs and to avoid error of inconsistency between representations.

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