

# The Potential of BIM Technology in Generating 4D Models - An Analysis

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## Abstract

The exponential increase in labour productivity driven by technological innovation has taken place in almost all economic sectors in recent decades. The construction sector has also taken part in this change, but with a lower intensity on a global scale. The introduction of technological innovations and new construction practices has been facing resistance constantly among the AEC professionals.

The Building Information Modelling (BIM) methodology emerges as a concept with potential to reduce this resistance, bringing a comprehensive integration perspective, reduced risk and making it possible to study the entire life cycle of an enterprise in a virtual and centralized way.

The following case study demonstrates the main benefits of using this methodology in the planning process of a building. Various disciplines were modeled, including architecture, structure, building networks, electrical installation and excavation works. Subsequently, an analysis of conflicts between disciplines was carried out. Based on the 4D model developed, the simulation of the construction process is presented. Additionally, the technical drawings and tables normally required were obtained through the complete and centralizing 3D model of all the generated information. This project promotes the use of BIM-based tools within the integrated and collaborative development of a building project. This essay contributes positively to the dissemination of BIM in the AEC sector.

**Keywords:** Construction, BIM methodology, 3D model, 4D model, parametric modelling, Simulation.

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## 1. Introduction

Construction activity is a fragmented, complex and somewhat uncertain process. This sector is often referred to as having low productivity due to the incompatibility of tasks, outdated construction practices, ineffective coordination of the construction site, poor communication between the owner and the contractors. This in turn influences the profitability of a given project and the quality of the final product. Recently, there has been a growing concern on the behalf of governments to encourage this sector to adapt to a process of digitalization in order to speed up activity and make it more efficient.

The report produced by Mckinsey & Co. (2017) indicates that in the U.S., the construction industry has shown a progressive decline in its productivity since the 1960s, while other industrial sectors like agriculture and production have seen a significant increase (which, nowadays, is 10 to 15 times higher than in this period). The productivity of construction is strongly conditioned by the verification of incompatibility errors between projects when they are already in the construction phase. Such errors are caused by omissions in design as well as inconsistency between drawings, which then require rectification, adjustment and updating, further increasing the amount of time and money spent on the a

given project. Farrington (1987) stated that the volume of repeated activities and correction caused by design errors are responsible for about 20% of the total number of irregularities observed in the construction process. The quality of a project's planning process and the identification of inconsistencies and flaws within the designs and blueprints of the various specialties are determining factors in the success of the execution of the global project.

The implementation of the Building Information Modelling (BIM) methodology has been increasing efficiency in the construction sector. As Kemp points out in the NBS BIM report of 2016 issued by the UK Institute of Civil Engineering (ICE), a BIM model is not only an improved geometric version of a CAD model, but is also associated with improving information management, supporting the entire lifecycle of a building, integrating all the information involved in the development of multiple projects as well as streamlining communication between technicians and services.

The main objective of the present study is to demonstrate the potential of the BIM methodology in accurately planning construction tasks. This research study involves various modelling projects of different specialties related to a case study. Modelling software (Revit, Autodesk) was used to detect inconsistencies between various disciplines. Furthermore, a BIM viewer (Navisworks, Autodesk) was used to generate a 4D simulation model of the execution of this construction project.

## **2. The BIM Methodology**

In the literature consulted there are several definitions that try to generalize the concept of the BIM methodology. However, because it is an innovative methodology that allows a frequent expansion of its application and technological transformations, it is difficult to establish one singular definition. However, in "BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors" (2008), Charles Eastman argues that the BIM methodology is based on three main pillars. It must be:

- Digital and three-dimensional;
- Measurable (quantifiable and scalable) and comprehensive (allowing multiple tasks to be performed);
- Accessible (to all partners) and updated (maintenance and permanent update).

The use of parametric objects which represent construction components such as walls, pillars or tubes, constitutes the fundamental characteristic of the modelling. The parameters are naturally geometric, but also have behavioral qualities, such as the thermal and acoustic resistance or the density of the materials. The information included in the BIM model is obtained through the modeling process based on the use of parametric objects and the data transfer between steps is based on the use of universal data file formats.

The ability to efficiently transfer data is where the concept of interoperability resides. Interoperability is supported by native software formats and universal data formats. The level of understanding between software is understood as the capability of different systems to communicate. To stimulate this connection, the consortium was created that would later be called the International Alliance for

Interoperability (IAI). It is responsible for creating and disseminating versions using the IFC format file as a universal standard. The language used in .ifc objects considers the establishment of designations and characteristics of parameters but also of procedures, rules, and restrictions.

Efficient interoperability between systems makes it possible to reduce the need to duplicate information and correct transferred data by facilitating the integrated workflow. The McGraw Hill Construction Report (2009) highlighted that 79% of BIM users in the US reported that the lack of effective software interoperability is still the biggest obstacle to adding the value of BIM in the sector.

Succar B. (2008) presents strategies to increase the maturity of BIM use in construction companies. There are several stages that must be implemented gradually, causing progressive changes. The stages are designated by:

- **Prior BIM** - Documentation in 2D representing a three-dimensional reality. Obtaining a map of quantities, costs and specifications from 2D graphic documentation.
- **Stage BIM1** - Creation of BIM models in three phases of the building's life cycle - design, construction or occupation. Use of BIM processes only for the generation and coordination of 2D documentation, but with a 3D view. There is no exchange between disciplines in an integrated digital way, with collaboration between asynchronous and unidirectional parties.
- **Stage BIM2** - Participants in each discipline of the project collaborate mutually and actively. Collaborative exchange can be established between projects (architecture and structures), design and construction (structural elements and steel specification), between design and management (architecture and maintenance plan). The level of detail required is high, but communication between participants is still asynchronous.
- **Stage BIM3** - Integrated semantic models are created that are shared and maintained in collaborative mode throughout the project lifecycle through the use of Software as a Service (SaaS). The BIM manager is responsible for providing the technicians involved who use the systems via the Internet. Interdisciplinary models are used in parallel by the different collaborators under the coordination of the manager. The collaborators are then able to manipulate all the information contained in the model for the realization of different types of analyses (energy, sustainability). The intended goal for this stage is to achieve an integrated project delivery process with the complete integration of users and systems, the purpose of improving the final product, reducing waste and increasing efficiency throughout the lifecycle of the enterprise. This stage corresponds to a full consolidation of the BIM in the Technological, Political and Processual (TPP) field.

Also, according to Succar (2008) the maturity of BIM is a process of push-and-pull transactions between and within TPP fields. The policy intervention corresponds to the definition of guidelines, regulations or contractual agreements that safeguard the correct implementation of the BIM methodology and also the mandatory imposition of its adoption. The processual aspect corresponds to the definition of specific guidelines for activities related to design, construction and management requirements, as well as to the

maintenance of facilities. The technological field is described as the application of scientific knowledge with practical purposes, corresponding to the interaction between software and network systems.

Regarding the benefits of adopting the BIM methodology, the most relevant in any activity is to achieve a reduction of global costs. As an example, this 2017 study [1], conducted on 10 school buildings of primary and secondary education, in the US, which showed economic gains of around 120 thousand and 150 thousand dollars, respectively. However, although the BIM methodology is currently the main innovative tool in the construction sector, there is still some resistance to its implementation. The barriers are political, procedural, technological, labor and human. Traditionally, the construction sector does not immediately adopt new technologies, due to the initial investment required and the necessary staff training.

### 3. Generation of the Architectural and Structural Components

The case study selected for the generation of the BIM model (using Revit 2021) belongs to an enterprise located in the interior of Portugal. The building consists of 4 floors: two of which are above ground level, and two of which are in the semi-basement. The construction site has a slope of about 30%, which required complex geotechnical work. The main stages of the modeling process of the architecture, structures, MEP and coordination disciplines are presented. The company responsible for the construction did not use any BIM tool, having ordered only the final representation of the project, a 3D geometric model (Figure 1).



*Figure 1. 3D non-parametric model. (Source: Project leader/ july,2017)*

3D parametric objects extrapolated from Revit's library were adapted in order to realistically replicate architectural and structural components such as walls, windows, floors, columns, beams, and foundations. In modeling the first discipline of the required BIM model, many challenges had to be overcome and suitable modeling alternatives had to be found. Table 1 below describes the procedure carried out that led to the complete generation of the specialties analyzed.

Step Order		Step description
<b>Initial Settings</b>	1st	Simplifying the case study 2D model received by the architect designer
	2nd	Transforming the blueprint to facilitate the 3D modelling of the walls
	3rd	Importing the DWG file, setting the project units and organizing the project browser
	4th	Setting the levels and grids
	5th	Creating the topography and the idle surrounding elements
<b>Architectural and Structural components</b>	1st	Creating and adding walls from the lowest level towards the top
	2nd	Loading and adding columns
	3rd	Adding structural slabs
	4th	Creating and adding foundation beams
	5th	Loading and adding micropiles
	6th	Loading door's and window's families and modifying their appearance
	7th	Adding door's and window's families
	8th	Creating and adding stairs
	9th	Adding components (railing, ramps, elements located outside of the house)
	10th	Loading the rebar components
	11th	Adding the rebar in columns and foundation beams
	12th	Adding the rebar in slabs
	13th	Adding the rebar in stairs

Table 1: Steps taken in modelling the architectural and structural components of the BIM model.

The structural components were defined in the architectural stage. As there was no structural analysis, the rebars were modeled with the sole purpose of quantifying and demonstrating the potential of BIM software in detailing the most hidden elements. Figure 2 shows a general representation of the disciplines' modeling phases.

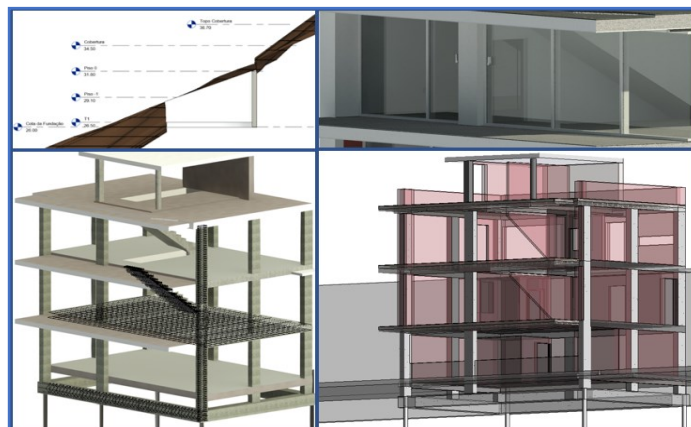


Figure 2: Site construction (Upper left), Rendered image of the windows (Upper right), Structural component with a few rebars highlighted (Lower left) and Structural and Architectural Component overview (Lower right).

#### 4. Mechanical, Electrical and Piping (MEP) BIM Model

One of the benefits frequently mentioned by users of BIM based technology is the ease with which MEP systems can be developed, overlapped on architectural and structural models. The software has the autonomy to define the ideal pipe routes, thus allowing one to work with millimeter tolerances, avoiding many incompatibilities and errors during the construction of the building. Table 2 describes the steps necessary to model the water project.

	Step Order	Step description
<b>Initial Settings</b>	1st	Loading the pipe families.
	2nd	Establishing the routing preferences.
	3rd	Setting the plumbing fixtures according to the 2D model.
<b>Hot and cold water supply system</b>	1st	Adding the horizontal pipes.
	2nd	Connecting the pipes vertical shafts with the horizontal ones.
	3rd	Connecting the water system with the fixtures
<b>Domestic Wastewater drainage system</b>	1st	Adding the pipes vertical shafts
	2nd	Connecting the pipes vertical shafts with the horizontal ones.
	3rd	Connect the plumb system with the outputs of the fixtures
	4th	Guarantee enough inclination in the horizontal pipes to allow the flow of the system

Table 2. Steps taken in modelling the piping project of the case study.

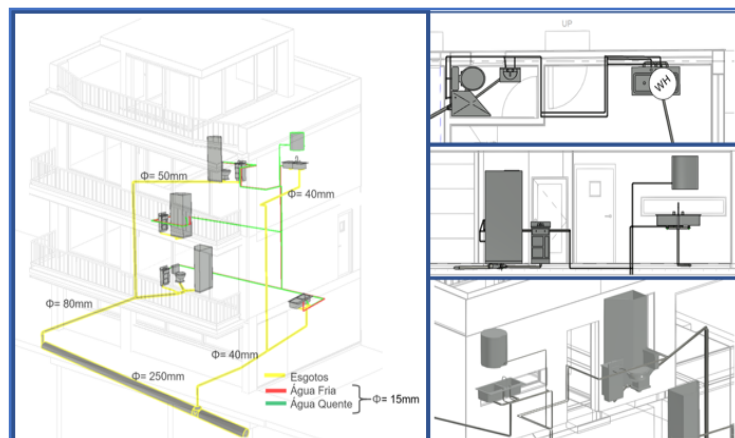


Figure 3. Watersystem different views.

#### 5. Modelling of the Coordination Elements

Prior to the time simulation (BIM 4D) of the construction using the Navisworks software, the steps related to the formwork of the structural elements of reinforced concrete and earthmoving were also analyzed and modeled. These complementary activities, required in the elaboration of a real project, enrich the present simulation study of the construction process. They were then used to model the formwork of the retaining wall, and the volume of excavated soil by constructive stages.

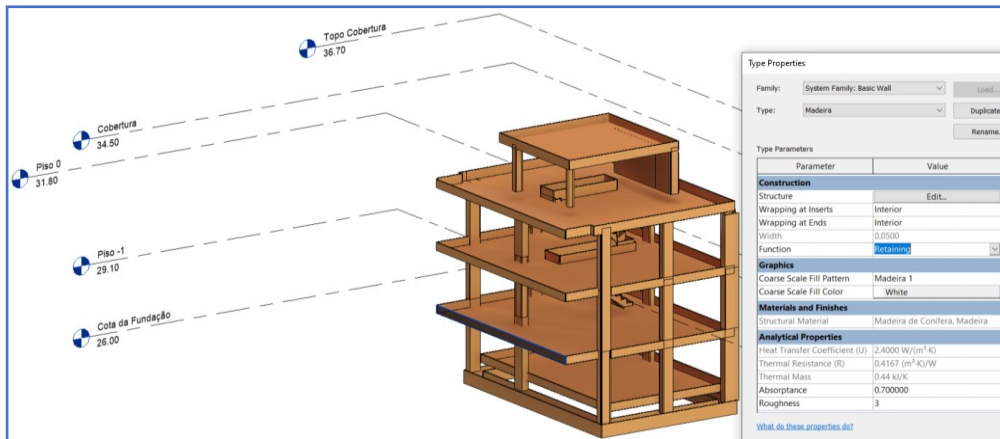


Figure 4. Formwork final scope and its properties.

The formwork elements were modeled considering them as walls and added using the Pick-Up line tool, which allows adding elements to adjacent ones by selecting their border lines.

The excavated amount of soil was modeled from a *Mass Inplace* which is ideal for unusual geometry elements. It is modeled through topographical lines which generate planes and, when combined, form a mass that can be quantified.



Figure 5. Mass In-place element representing the excavated soil.

## 5. Quantity Estimate Map

As mentioned, one of the biggest benefits often recognized by professionals who already use the methodology is the possibility to automatically quantify various elements of the model. To illustrate the potential of the system used, the quantification of the formwork area (m<sup>2</sup>) is requested from the Material Takeoff tool located in Revit Project Browser.

Although this case study made use of this quantification tool superficially, the benefits of this software in creating accurate models without inconsistencies as well as centralizing several disciplines were very evident. The tables can be enriched with a greater detail of the model, by associating temporal actions to provisional elements and by incorporating new parameters to parametric objects such as cost, manufacturer, year of manufacture, contact, etc.





## 6.1. Clash Detection

The last resource that was used in the Navisworks system, was the ability to detect conflicts between specialties. The Clash Detective tool is highly valued by designers and contractors for identifying inaccuracies between different disciplines in the design and preparation phases. This is because, when discovered on site, produce additional costs and delays. In the case study, errors were detected which were subsequently corrected in the BIM model by resorting to the Revit system once again, as these types of corrections should not be performed in Navisworks.

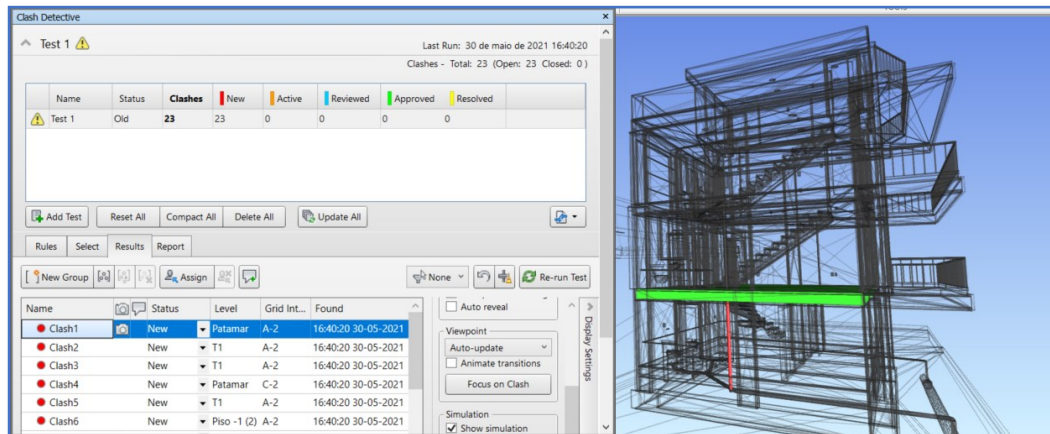


Figure 7. Report of the first clash detection run between the wastewater system and the structural model.

When the Clash Detection tool was used it identified various inconsistencies. One of these was the passage of the water pipes inside one of the pillars, which led to the solution illustrated in figure 8.

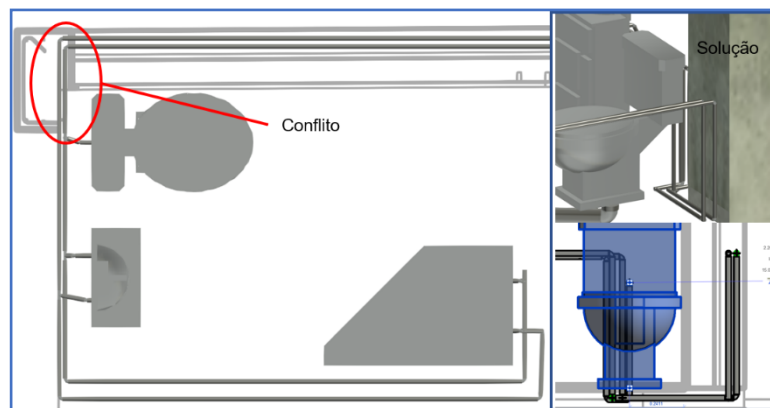


Figure 8. Clash (left image) and solution (right image) between the pipes and structural column

As this case study is relatively simple, the existing collisions are easy to solve. However, when the range of disciplines is larger and include architecture, structures, MEP, HVAC, fire safety and telecommunications projects, the task of conflict analysis brings important benefits. When carried out in the embryonic phase of the project, the planning of activities becomes more reliable, and the execution time of the work is reduced.

## 7. Conclusion

The implementation of BIM methodology can be incredibly valuable to the AEC market. The greater degree of assertiveness and higher quality of design and construction planning (based on the parametric modeling process) leads to a more controlled use of technical and human resources. The greatest advantages observed in this study, were the possibility of overlapping different models (architectural, structural and MEP), eliminating possible conflicts between disciplines, creating a realistic visualization of the interior and exterior (3D perspectives in sections) and attaining a better understanding of the complexity of placing elements in the same building. Moreover, estimating the quantity of materials through take-off material spreadsheets provides a more accurate estimation of construction costs. Finally, the 4D model makes it significantly easier to plan construction activities during the conception of the project. During the execution phase, it helps ensure the correct implementation of the activities.

On the other hand, during the modeling of this case study, some limitations were observed. Being innovative, the BIM tool requires a long, exhaustive and detailed training period, sometimes leading to some demotivation. Finally, another drawback was the difficulty in finding objects that faithfully represented the context of Portuguese civil construction.

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