Analysis of the implementation of the BIM model in the structural design

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Abstract

The Building Information Modeling (BIM) is a growing methodology in the Architecture, Engineering and Building industries. BIM appears as a new way of working between designers of various specialties. It is more cooperative and based on a three-dimensional model. It contains varied types of information of the materials – geometrical, physical and economical. The job hereunder refers to the evolution of the BIM methodology and the advantages of the introduction of this type of work in the development of the structural design.

The structures' model was made, using a basic BIM tool. Verified limits were identified and procedures which aim to achieve a correct analytical model, were suggested. The analytical model was examined, having been automatically generated in a BIM environment. Alterations referring to analytical aspects were introduced, namely the analytical information necessary for the structural calculation. The introduction of the reinforcement in the elements of reinforced concrete, was demonstrated. Later, the extraction of information of the BIM model was made, so as to obtain tables of quantities of the concrete volume, tables of reinforcement, areas of formwork and the volume of land excavation, as well as the representation of drawings of the structural design.

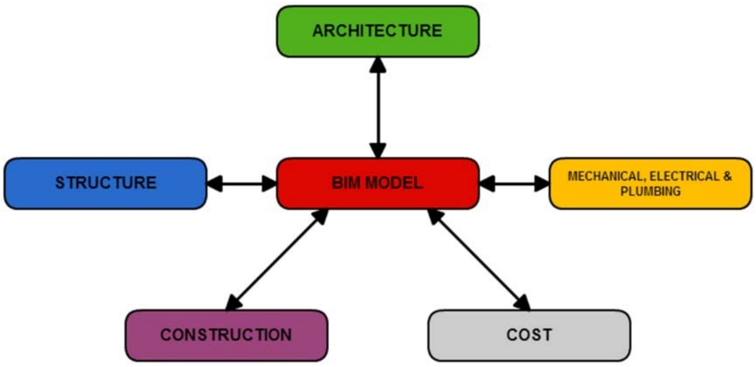
We concluded that the BIM methodology and the tool used can introduce advantages in the structural design, in spite of difficulties encountered. As it is a methodology in constant evolution, it is hoped that, in the future, the process will improve significantly in this sector.

Key-words: BIM methodology, modeling tools, transference of the model, information achievement

1. Introduction

The BIM methodology, applied to the AEC industry, emerges as a new way of working between designers. It is more collaborative, involving various specialties. This concept is slowly being applied in the building trade as it implies an alteration in the way of working, where the designer is not so much based on the drawings, but rather on the three-dimensional model and the information which can be associated to it. The BIM methodology 'is not simply a technological change, but also a change in procedures' (Chuck Eastman, 2011)

The concept on which it is based, implies alterations at developmental and project representation level, and at the level of information transfer between the various components of the project. It is based on the centralization of information of the various subjects in one digital model (Figure 1).



Figur2 1 - Chart of the BIM methodology

The methodology has been introduced worldwide, strongly supported by technological progress. International entities such as BuildingSMART, The American Institute of Architects, The NBS, Building Information Modeling Task Group, and the national entities BIM Management Institute, the BIM Club and universities have supported the propagation and development of the methodology.

With the development of BIM technology and its increased use in the various phases of the project, it was necessary to create BIM rules which could regulate the modeling process in each country, in an attempt to minimize errors which could arise from the use of various tools. Thus, some countries have adopted the creation of BIM rules. Two regulations are considered in this work: the regulation adopted in the United Kingdom, AEC (UK) BIM Protocol, and those adopted in Singapore – Singapore BIM Guide. These are considered to be the most complete worldwide, particularly the regulation used in the UK as this is a country which is strict with AEC industry companies in the implementation of the BIM methodology. It is known that a lot of such companies are in a quite advanced stage of that implementation (Khemlani, L., 2012).

The BIM implementation in the building sector is considered to be a booster for its development. As a methodology, BIM is based on the following concepts: interoperability, standardization and parametric modeling.

1.1. Interoperability and standardization

There is currently various software the AEC industry uses to make its projects, according to its needs. As the architect's vision is somewhat different from the designer's, they use different tools in the development of its components which sometimes limit the ability for the exchange of information between specialties. The concept of interoperability is defined as the ability of computational systems efficiently exchanging information. In this sense, BIM's various tools incorporate a great capacity of interoperability.

The potential success of this methodology is based on the ability of withdrawing, using and entering information which is relevant in a digital BIM model, which can be accessed with tools of different specialties essential to the project. There is therefore the need to standardize the format of the shared files. IFC - Industry Foundation Classes, Chuck Eastman (2011) presents the IFC format as a 'plan developed to define an extensible series of representations of consistent data of information of a building, which can provide exchange of information in the various sectors of the AEC industry.' It is a pattern of data format which allows the transfer of data between systems.

1.2. Parametric modelling

Within the context of the BIM methodology, the representation of an object, for example a column or a footing, is not just a three-dimensional geometrical model (3D). In a BIM modeling the user associates various types of information to the object: physical characteristics, economical characteristics or aspects related to maintenance. All information is relevant to enable the model with information which, later, may be required, and bills of quantities and budget, or to allow among others, the analysis of acoustic or energetic studies. BIM's parametric modeling process allows the user to add characteristics which he may find essential to a particular object, so that it can be accessed and manipulated at a later date. The model can be updated and enhanced at any stage of the project.

A model which includes these characteristics is a parametric model. It contains various parameters, both geometrical and spatial, maintaining a consistent relation/connection between adjacent elements. Thus, if an alteration is made to a wall on an architectural model, all elements corresponding to that wall are automatically adapted to the alterations made, maintaining a consistent connection, be it with the dimension of adjacent walls, or with elements (windows and doors) incorporated in the wall that was altered.

2. Development of BIM structural model

The modeling process of a structure, using the basic BIM tool, requires the designer to know the abilities of the BIM system which are available for the generation of the structures´ model, so as to establish the required structural solution. The model created must contain the information necessary to the automatic achievement of the project drawings. But it is necessary that the engineer knows in detail the process of modeling and its limitations so that he can be accurately critic of the modeling of the achieved analytical structure. It is also required that the designer understands the means of communication between computational systems of modeling and calculation. The designer should carefully analyze the process of the information transfer between systems and how the interpretation of the structural elements of the model is made.

The study case used in this dissertation was a structure of reinforced concrete, analyzed within the scope of the curricular unit of Structural Dynamics and Earthquake Engineering. The results of the academic work show the frequency and period associated to the structure.

2.1. Modelling the structural elements

The structure BIM model was created through the Revit software. It is a BIM tool which is increasingly being used worldwide. The model was created in the 2015 software version, which includes in a single program, the capacities of modeling of architectural specialties, structure and mechanical, electrical and plumbing elements. Figure 2 shows the bar of the program relating to the structures subject, which was used to make all the structure´s modeling. The sequence of the modeling made was: grid and structural levels, vertical elements, beams, slabs and foundations.

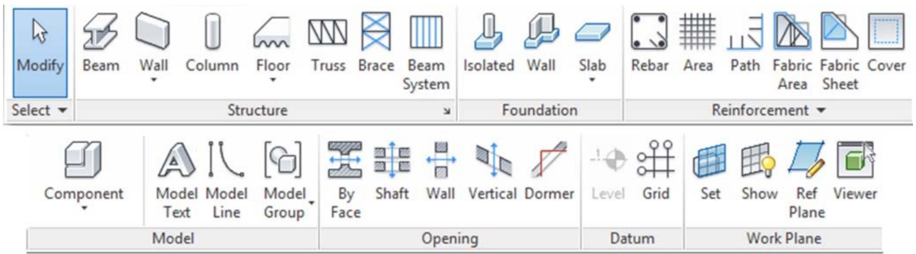


Figure 2 – Bar of the structures' specialty

In the stage preceding the project it is important that the aspects referring the material to be used, associated to its physical and mechanical characteristics, and the units of the project. Revit has the ability to make each modeled structural element as an analytical element. It interprets in bar elements the columns and beams; and walls and slabs in Shell type elements. The program automatically makes some approximation at the analytical model level. There are, however, some approximations that must be manually made on Revit, so that the analytical model can be used for the structural calculation.

Figure 3 shows the final geometrical model from the projected axonometric perspective (a), vertical section (b) and projection of vertical section (c). Subsequently, the analytical model resulting from the modeling made, figure 3 (d), is manipulated for the purpose of structural analysis.

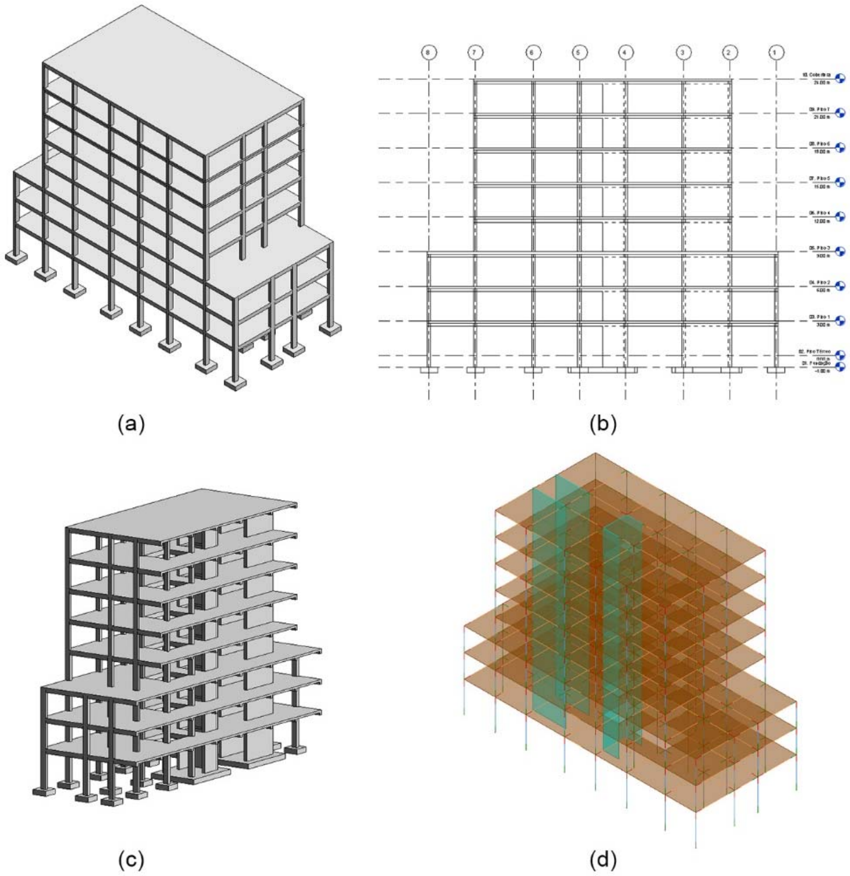


Figure 3 – Geometric model and analytical model

In the modeling process of structural elements the document Singapore BIM Guide was taken into consideration. Accordingly, the vertical elements were modeled by level, so as to safeguard the aspects related to the slenderness ratio of the elements. The beams were modeled span to span to satisfy criteria for unsupported length in the analytical models.

In this context the relationship between vertical elements and beams were analyzed for the purpose of volumetric calculation. Figure 4 shows the type of interaction obtained. The vertical element (a), the beams (b) and the slab (c) are shown in red.

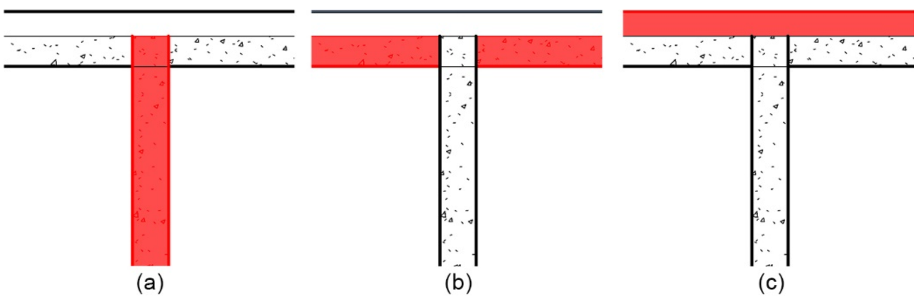


Figure 4 - Interaction between vertical elements, beams and slabs

This type of modeling and understanding of the program implies that the volume of the concrete is not in accordance with the constructive phasing, although it shows the correct total values. Considering that the construction planning of the building is not the main objective of the analysis of this case study, only the total final results are shown. It was therefore decided not to make any alterations to the model.

2.2. Validation of the three-dimensional model

As a means of validation of the three-dimensional model it was decided to compare the volume of the concrete, which was obtained manually and automatically using the BIM tool – only the foundations and the structural elements up to the first floor, were considered. Table 1 shows the results obtained for the comparison made.

Table 1 – comparison of the volume of the concrete

	Manual	Revit model*
$V_{footings}$ [m^3]	57,00	57,00
$V_{vertical\ elements}$ [m^3]	31,84	34,08
V_{beams} [m^3]	16,51	14,26
V_{slab} [m^3]	79,12	79,12
Total [m^3]	184,47	184,46

* The method to obtain these values will be show non chapter 5 of the dissertation

The difference in the total volume of concrete is owed to calculations with rounded values, the error being under 0.01%. If you compare element by element, the difference lies on the volume of the vertical elements and the beams; this difference is justified by the way the program considers each of these elements, as shown on Figure 5.

3. Analysis of the analytical model

The third stage of the study is the verification of the analytical model which is the base of the structural calculation. The analytical model and the flux of information between Revit and the Robot structural calculation system is analyzed in both directions. At the end of this analysis, the inclusion of reinforcement in the concrete elements is made, with the purpose of obtaining the correct structural drawings.

The creation of the analytical model shows some inconsistencies and it is therefore necessary to make some corrections, so as to obtain a reliable model for the structural calculation. The situation whereby the analytical element which represents the wall, Shell element, and which should end up on a vertical plan of the axis of the beams which are perpendicular to the wall, exceeds that limit and this was corrected (Figure 5). It was also ascertained that the bar elements which represent the structural beams, showed release efforts at the extremities which was not consistent with the practice in Portugal.

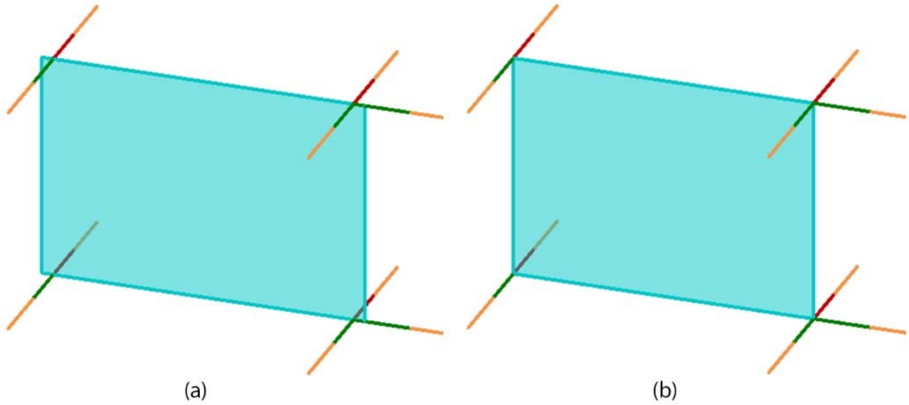


Figure 4 – Detail of the Wall element: (a) initial model and (b) after correction

Corrections were also made to other situations related to the support conditions of the structure and to the definition of the combination of actions. The adaption of the analytical model to the Robot Structural Analysis' structural calculation program was later successfully made. Additional necessary alterations were made to this program, such as the definition of the seismic activity and the modeling of the stairs, using shell elements.

A modal analysis was made so as to validate the obtained model in a Revit. Table 2 shows the results obtained for the period, for the first six vibration modes. Some variation was found due to the method/manner of modeling the elements representing the structural wall. During the academic work the element wall was modeled as a bar element and in the current dissertation the same element was modeled as a Shell element, thus giving the structure a higher stiffness.

Table 2 – Comparison of the values obtained from the modal analysis

	Period [s]		
Mode	**Robot**	**SAP2000**	**Δ**
Mode 1	0,987	1,075	-0,088
Mode 2	0,833	1,036	-0,203
Mode 3	0,746	0,858	-0,112
Mode 4	0,416	0,400	0,016
Mode 5	0,322	0,301	0,021
Mode 6	0,268	0,230	0,038

The transfer of information between the modeling program (Revit) and the calculation program (Robot), occurred with no difficulties. In reverse, from Robot to Revit, when updating model Revit, there are mistakes in the model, namely, new structural elements appear, which should not be accepted in the model. Figure 6 shows the updated model, where the stairs are shown, which was not shown in the original model. At the bottom of the stairs a footing divided in its finite elements, is now shown. It was decided not to update the model thus avoiding possible mistakes made from the updating using the Robot model as shown on the example given. It also allows a better control over the detail of the reinforcement.

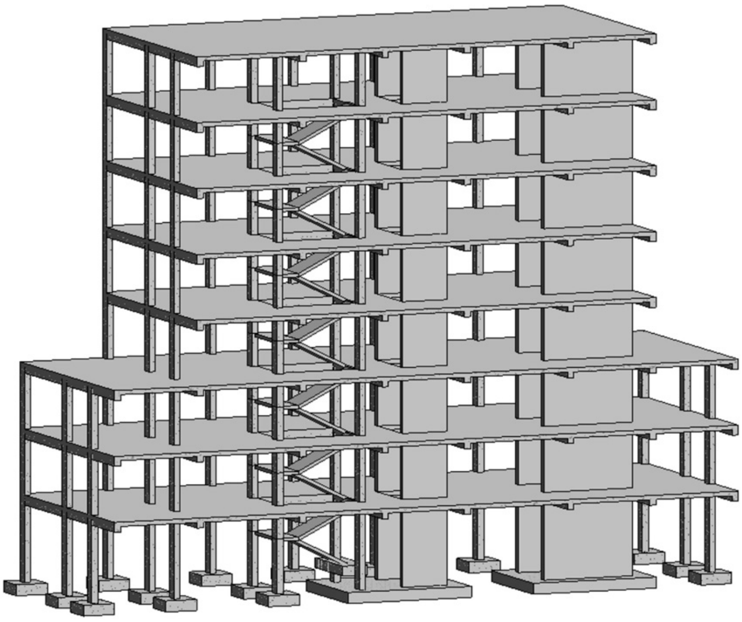
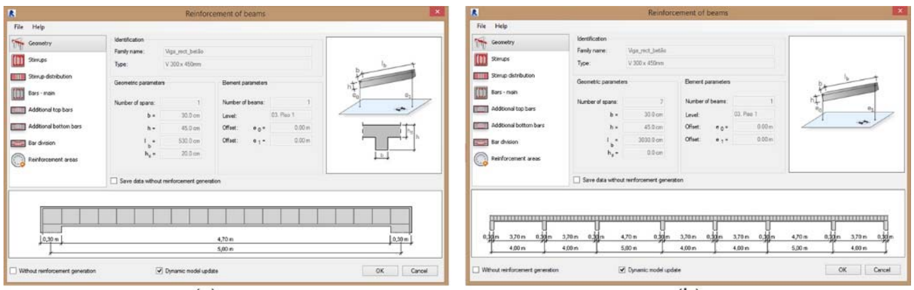


Figure 5 – Updated BIM model with Robot information

An analysis was made to the capacities of the BIM tool used for the detailing of the reinforcement, using an extension of the program Revit Extensions. This extension allows the insertion of the reinforcement in the concrete, in a more intuitive and faster manner.

It was observed, as a result of this analysis, that there is no execution compatibility between what is usually made in structural projects and what the program allows. There were difficulties in this process, namely, in the detailing of the structural beams where the program considers the insertion of the reinforcement in accordance with the modeling made. So, as the beams where modeled span to span, the reinforcement is introduced per span, and there is no continuity in the beam with N spans. Figure 8 shows both situations – one obtained with the modeling made (a) and the other with what would be desirable (b).



(a) (b)

Figure 7 – Geometric proprieties window of a structural beam

The difficulty in detailing can be solved by using tools dedicated to this type of situation, such as Autocad Structural Detailing. This software can be linked to Revit and allows the detailed manipulation of the different drawings.

4. Bills of quantities and drawings

One of the aspects of the BIM methodology is the ability to obtain information from the parametric models that were created. An analysis was made so as to understand the abilities that the BIM tool has. Using the tools available from Revit, it was possible to obtain, in a swift manner, the tables referring to the concrete volume, the quantity of reinforcement and the volume of land excavation. The values were confirmed manually, thus confirming the ability to obtain accurate information from the model. To measure the area of formwork it was necessary to make use of a pluggin, since Revit does not yet have a command that calculates the area of formwork. By using the pluggin, it was possible to obtain results and to confirm its accurateness. Bills of quantities were obtained which can be used for budgeting.

The analysis was completed by explaining how to obtain drawings to be able to move on to the next stage of the project. Drawings were thus created in an intuitive manner, using tools available from Revit, and which show a high capacity to organize the drawings.

5. Discussion of results

This methodology is particularly popular amongst architects as it benefits their capacities to give the client different options of geometric shapes and materials with advanced realistic visualization, apart from obtaining bills of exact quantities. However, it has been more difficult to spread the use of this methodology within engineering workplaces.

There is, therefore, the need to demonstrate that this is a valid methodology, which using the BIM tools is advantageous even when directed at the structural design. The proposed main aim for this study was to analyze the applicability of this methodology in a structural design, based on the development of three distinct phases:

- Generation of the structural model;
- Preparation of the analytical model for the structural calculation and insertion of reinforcement in the model;
- Achievement of bills of quantities and drawings.

The selected study case corresponds to a structure of reinforced concrete, showing a distribution of structural elements regular in height. The example analyzed represents a large majority of the type of existing buildings, and situations studied are those that reflect more common cases. However it may happen that another type of problems may arise in less linear cases which have not been considered.

Regarding the first stage, the objective was accomplished, in the sense that it was possible to obtain in a swift way, the analytical model which is the base for the structural calculation. There are still situations requiring improvement, namely, those relating to the ability to represent the program over each structural element and the association between those elements.

In the second stage there are limitations that require more attention and development in order to allow a total use of the capabilities of this type of tools. The updating of the BIM model, after the structural calculation, is not yet advisable, as instead of adding information to the model, it can undesirably alter it, as it is shown in chapter 4. The inclusion and detailing of reinforcements, although facilitated with Revit Extensions, still presents errors and inaccuracies regarding the typical design of reinforced concrete.

Stage three successfully shows one of the great capacities of the BIM methodology which is the ability to withdraw exact information from the model, thus displaying accurate bills of quantities which allow the drawing of a quite correct budget.

It is, therefore, concluded that, in spite of existing difficulties, the BIM methodology is currently a valid one and its use in engineering workplaces should be increased and motivated. In this sense, the training of new engineers should include this component, be it through training or through research work such as this dissertation.

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