BIM model analysis on a structural design perspective

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Abstract

The increasing complexity of projects in the Architecture, Engineering and Construction industry (AEC), contributes to boost the development of methodologies and practices used and, additionally, stimulates the development of information technologies to support its implementation. Presently, this sector is still characterized by low levels of efficiency that affect its competitiveness and technological requirement. In the project development it is important to produce accurate and reliable information, based on a high level of interoperability between systems, and it is also necessary to establish good communication between those responsible for developing the project.

The main objective of this dissertation consists of a comparative analysis between the traditional process and the Building Information Modeling (BIM) methodology, focusing on the structural component of the project. The study allows the identification of limitations and problems resulting from the analysis of a specific case, and the proposed recommendations and best practices to promote achieving a higher degree of efficiency. The comparison made relatively to different transfer modes of information between systems, leads to the conclusion that the ability of the interoperability, in the used technological applications, is still a problem that requires significant research because it conditions the collaboration between the different project specialties, and therefore, the obtaining of a higher quality project. However, it has been verified that the work process based on the BIM concept brings obvious advantages to a fragmented and uncooperative industry.

Therefore, despite of interoperability problems verified, the adoption of BIM methodology brings benefits to the AEC sector through technical improvements, reducing the duration of tasks and increasing their efficiency. These aspects, besides improving the transparency and quality of the project, reduce its cost, thus making the AEC industry more competitive.

Keywords: BIM, Structural Design, AEC Industry, Interoperability, Collaboration.

1. Introduction

Due to the increasing complexity of the construction industry, on design, execution and maintenance, it is mandatory to employ specialized techniques and demand greater efficiency and profitability from contractors and designers. Cooperation and collaboration among the different disciplines of the project is essential to the achievement of a common work, in order to make the process more productive and qualitative, thus obtaining a more efficient building in a competitive and demanding market. Low levels of productivity reported in AEC sector can be understood through the observed fragmentation, explained by the difficulty of introducing new technologies, in which the main mode of communication is based on paper [1], and also, by the fact of construction at the site did not
benefit significantly from automation techniques introduced in recent years [2]. The high rates of modifications observed in the early stages of the project, resulting in reconstructions and repairs, affect the overall efficiency of the sector [3] which should accompany the technological - automation and modernization - and methodological change, promoting the sharing of information and interdisciplinary communication [4].

The increasing project complexity in the AEC industry, besides boosting the development of methodologies and practices used, stimulates the development of information technologies to support their implementation. The computational systems to support the project (Computer-Aided Design, CAD) are used based only on geometric entities without physical properties and relationship between elements. On the contrary, AEC industry emerging tools, like parametric modeling systems, have the ability to produce parameterized object, with the physical information and the associated relationship, in which the BIM methodology is based. This methodology is characterized by the project execution on a collaborative manner through appropriate working tools, allowing a better understanding of the project and congregating, in a single 3D digital model and a structured way, all necessary information for project development, construction and building maintenance.

The main objective of this dissertation is a comparative analysis between the traditional process and BIM methodology in the structural design phase. Aims to evaluate the advantages of the adoption and use of BIM methodology, relatively to the usual procedure presents in the AEC industry. Additionally, the dissertation will permit to identify the limitations and point out the problems that are adhered to the considered study case, allowing defining recommendations regarding procedures and best practices, in order to obtain a higher degree of efficiency in this industry.

2. Building Information Modeling

BIM is frequently referred at three levels: a software application, a process to design and document information, and also, a new approach to the profession which requires the implementation of new policies, contracts and relationships between the stakeholders [5]. BIM methodology is defined as a modeling technology and an associated set of processes to produce, communicate and analyze models of a building [1]. Succar et. al [6] define BIM as an interactive set of policies, processes and technologies producing a methodology capable of managing key project information and simulate the building in a digital format throughout his entire life cycle. Within a technological perspective, BIM is a project simulation based on the 3D representation of its components, with a link to the necessary information related to all project phases [7]. It is important to understand the theoretical foundations inherent to this methodology, in order to continue stimulating and developing the technological base, necessary for the implementation and evolution of the BIM process. However, the theoretical BIM concept only acquires practical meaning, by the use of software that admit this integrated methodology, with the most recent information technologies [4]. BIM helps to reallocate the time and effort that designers apply in each project phase, bringing the focus of the effort to the earliest stages of the project, where the value of decisions is more significant, at the level of cost, functionality and benefits. Regarding the design phase, the main objective of the present work, these benefits consist of: more precise perception and visualization of project; changes imposed on the BIM model are
automatically reflected in corrections; accurate and consistent extraction of 2D drawings at any stage of the project; facilitated collaboration, from the early stages of the project, between different disciplines and stakeholders; better estimation of the enterprise cost during the design phase; and improvement of energy efficiency and sustainability [2].

The parametric modeling, a basis of BIM methodology, consists of represent objects through parameters and rules that determine its geometry and properties of geometric relationship. The relation parameters allow automatic update regarding the geometry of each object whenever any change is made in the 3D model (change of context). Parametric objects are integrated non-redundant geometric settings, not allowing inconsistencies, and can be customized allowing the modeling of complex shapes, impractical and inefficient resource using a CAD system. The modeling through parametric objects provides a powerful way to create and adapt model geometry, leading to a modeling process faster and less error-prone, when compared with CAD systems. While in traditional 3D modeling CAD is necessary to manually edit all the geometry of an element, the form and composition of parametric model geometry is automatically adjusted to their context (adjacent elements), based on rules that define it [2].

BIM should be understood as a dynamic process, since the BIM model is built based on the contribution of different teams, supported by BIM tools in performing of their tasks and the transfer of information between them. The BIM model development is a continuous process throughout the building life cycle, characterized by progressive and collaborative elaboration of the design information [3]. The successful implementation of BIM process requires, from the early stages of the project, the involvement of all stakeholders and a correct and efficient communication between them [8]. Interoperability, characterized by the ability of BIM tools exchange and operate building information between them, is a fundamental requirement for communication and collaboration between stakeholders and BIM platforms. It facilitates the workflow of data and its automation, as well as strongly encourages iteration during the design phase [2]. The buildingSMART organization has developed an open format for representing and exchanging information between AEC software applications, standardized format designated as Industry Foundation Class (IFC) [W1]. The universal standard for data exchange models of construction, including geometry, attributes, behavior and structure of the object, although quite extensive, it still has some limitations, among which the representation of complex geometries [9]. Thus, it is important to continue developing a standardized vocabulary of rules that lead to solving the problems of parametric models interoperability between BIM platforms.

3. Traditional Process

In this work was selected, for modeling example, a two-storey building located in northern Portugal. The creation of the Revit architecture model (Figure 3.1, left) based on architectural drawings provided in paper format, was performed using a BIM base software (BIM platform), Revit 2013 (Revit) developed by Autodesk [W2]. The modeling process is based on parametric objects (parametric modeling) with well-defined parameters and characteristics which require previous knowledge and definition of the composition and properties of the object elements. This invariably
involves customization and standardization of Revit according to the project in question [10]. Frequently this aspect is mentioned as restrictive to the adoption of BIM, because is required a significant investment of time collecting information and formatting it.

The structural solution was defined based on the architecture model and the options considered are consistent with a sufficiently complete structural design to perform the comparison between the traditional process, without a direct transposition of structural elements, and the one presented by BIM. The preliminary design of the structural elements geometry was carried out based on the architectural constraints of the building, the imposed actions, and the used materials. With this information and using the Structural Analysis Program 2000 v15.1.0 (SAP2000) software, developed by Computers & Structures Inc (CSI), proceeds to the modeling of the building structural elements reaching the SAP2000 model (Figure 3.1, right). The structural design made according to this methodology does not include any form of interoperability for structural elements (with format recognition) between the applied software, and therefore, requires manual data entry without information transfer. Finally, based on the stresses in the structure, the amount of steel to be used in reinforced concrete elements was determined through present regulations.

4. Information workflow between Revit and SAP2000

This chapter discusses the ability of interoperability between Revit and SAP2000 platforms, where essentially, is tested the transposition of the Revit structural model for SAP2000. In this process is analyzed the type of information that is maintained or amended, and which adaptations are necessary make on obtaining an effective and correct SAP2000 model. The transposition of data between the Revit geometric model and the SAP2000 model is conducted only in one direction, not allowing subsequent updates.

The structural model is defined resorting to the Revit Structure component. In its definition is considered the preliminary design where the dimensions of the building structural elements were established. Thus, the structural solution and dimensions adopted are similar as the ones used in the SAP2000 model conception according to the traditional procedure. By the fact of the structural
elements available in Revit Structure are equally parametric objects, it was necessary to characterize them setting its parameters before the construction of the Revit structural model (Figure 4.1, left).

![Figure 4.1 - Revit structural model (left) and Revit analytical model (right).](image)

The Revit structural model, constituted only by structural objects and alignments (grids), is transferred to SAP2000 through CSIXRevit 2013 plug-in, also provided by CSI. When the model is imported into SAP2000, there is a correspondence between the section type designation of the bar elements and the SAP2000 database (.PRO files) [11]. Therefore, it was necessary to modify these files in order to contain the section type designations corresponding to those importing into SAP2000. This operation is performed through the VBA programming macro contained in the proper.xls Excel file, supplied by CSI [W3]. The import interface of Revit structural model (left) and the final result of the SAP2000 model imported (right) are shown in Figure 4.2. As can be seen, this model needs to be completed so as to be identical to that determined by the traditional method (Figure 3.1, right).

![Figure 4.2 - Import interface of Revit structural model (left) and imported SAP2000 model (right)](image)

Although this information workflow cannot be described as the ideal methodology, taking into account constraints that condition the efficiency of BIM model, it has significant advantages compared with the traditional process. Therefore, it was possible to illustrate what at the moment is transverse to the AEC industry, an evolution from the traditional process towards the BIM methodology.
In conclusion, the main **advantages** are listed:

- Decrease of the amount of errors and inconsistencies in the structural design;
- Decrease of the total project duration;
- Increase of the overall efficiency.

As well as the **limitations** encountered in this process:

- Unidirectional information workflow (updates not supported);
- Limitations on the type of elements transferred;
- Difficulty in transposing slabs openings;
- Inability to transfer alignments (*grids*);
- Failure to recognize the constraints of foundations.

5. Information workflow between Revit and Robot

This chapter analyzes the ability of interoperability between Revit and *Robot Structural Analysis Professional 2013* (Robot) software. Initially, the Revit structural model, created in the previous chapter, was exported to Robot. Here is performed the analysis and stress calculation of the structure and the reinforcement design. Then, the detail drawings are exported to *AutoCAD Structural Detailing 2013* (ASD) software with the aim of improving its definition realized in Robot. Both software products also belong to *Autodesk*, therefore is expected that the results, in terms of interoperability capacity, to be quite acceptable. The data transfer between Revit and Robot facilitates the coordination of geometric information (architectural model, structural model, etc.) with analytical information. The Revit structural model (Figure 4.1, left) created associates the geometric component of the structural elements (slabs, columns, etc.) to an analytical model (Figure 4.1, right), information that is incorporated into Robot in order to perform the stress analysis and the structural design [12].

The data workflow between Revit and Robot can be performed in both directions, allowing multiple iterations and updates, although a few parametric objects cannot be transferred with an acceptable effectiveness. However, in this aspect, there is a great improvement compared to the previous workflow [12] [W4]. Before exporting the analytical model is necessary to proceed to its validation, to which Revit has specific tools, in terms of static coherence between the various elements, in particular, their connections and boundary conditions [W5]. After the validation of the analytical model, proceeds to the export through the *Integration with Robot Structural Analysis Extension*, taking into account the definition of the given options: the type of load, *load case*, which accounts for the self-weight; the degrees of freedom of the bar elements; the used materials; among others. After defining the load combinations, the stiffness of the bar elements, and finite element meshes, are determined the stresses in the structure. During the progression of the project, and taking into account possible divergences in the collaboration of several teams, it is necessary to consider an appropriate organization with an appropriate hierarchical structure for decisions regarding the management of BIM model [12]. The Robot structural model (Figure 5.1) continues to be organized and constituted on an ongoing process of information workflow between Revit and Robot.
The next step was to determine the amounts of steel that verifies the safety of the calculated elements. The *Reinforcement of RC Elements* tool, existing in Robot, performs the calculation of the necessary amount of steel based on the considered regulation (EC2 e EC8), and also generates the detail drawings of concrete reinforcement elements. This tool, despite the necessary cautious in its use, can be considered a support tool of the BIM process. Essentially, it is responsible for creating new information from existing one, helping to enrich and facilitate the management and execution of the project. This information besides the graphical component, based on the detail drawings (Figure 5.2), also contemplates a descriptive component which stores all the design information of each structural element.

Due to the fact of detail drawings created in Robot, in some cases, do not fulfill the user requirements, it was found another more interactive and versatile manner to define them. The objective is to give him more control in the options taken regarding the detail drawings. Accordingly to
this, these drawings were exported to ASD (Figure 5.3 ) and de necessary adjustments were made in order to complete them.

Based on the tests performed, it has been found that the inclusion of ASD in the data workflow between systems contributes to an improvement in the overall quality of graphical information, due the high degree of customization given to the user. However, in this study, it was inconclusive which choice is more fast and effective for the development of this task, given that much will depend on the desired end goal for the layout of each concrete element. Since the time factor is an important variable to consider in a project, use the drawings made in Robot may prove to be decisive. Ultimately, the dimension of the project, the type of structural elements and the professionals themselves will affect this selection. We conclude by comparing this information workflow with the previous, that the advantages checked there, were overcome with enhanced quality and efficiency levels, and the limitations were globally suppressed.

6. Conclusions

The focus of this work consisted basically in the comparison between the traditional process of the structural design execution and the one recommended by BIM methodology. Three different approaches for implementing structural design were analyzed:

- Traditional process (without information transfer, no data workflow);
- BIM with data workflow between Revit and SAP2000;
- BIM with data workflow between Revit, Robot and ASD.

It was possible to determine the advantages and limitations of BIM methodology over the traditional process in this project phase. Additionally, with the characterization of two different information workflows - resorting to the use of different platforms and tools – was verified the existence of deficiencies at interoperability level in BIM methodology. Consequently, there still is a long road
ahead in order to obtain an efficient interoperability between the currently existent software on the
market. The traditional process has obvious deficiencies and disadvantages identified in the tests
realized, especially with respect to the data workflow between Revit, robot and ASD:

- Semi-manual coordination of structural and architecture models;
- Manual coordination of model changes;
- Manual construction of detail drawings of the reinforced concrete elements;
- Manual Obtaining of quantity takeoff and cost estimating.

Regarding the BIM methodologies analyzed, were observed significant differences in the
achievement of the proposed objectives. A unidirectional link between Revit and SAP2000 revealed
some disabilities that affect the efficiency and overall quality of the project, namely, the inability to
update the BIM model with the design information and the own effectiveness of this information
transposition. On the contrary, the link with Robot supports bidirectional workflow, the update of the
BIM model information, and the transposition of parametric objects was performed with a high degree
of effectiveness. This difference in the interoperability quality is justified mainly by the fact that these
software products are developed by the same manufacturer. From the results of the work carried out,
it can be concluded that, the BIM workflow of information more recommended consists in:

- Modeling of the structural elements and analytical model configuration in Revit;
- Definition of actions, calculation and stress analysis, and structural elements design in
  Robot;
- Finally, drawing detailing and composition of steel and concrete quantity takeoff in ASD.

With the selection of SAP2000 software - data workflow with visible deficiencies - was
demonstrated the occurrence of several difficulties in the implementation of BIM methodology in
certain cases, within the AEC industry. Therefore, it is important to manage the level of expectations
created among all stakeholders in order to decrease the amount of dropouts in early stages of the BIM
methodology adoption.

It can be concluded that a major contribution of BIM methodology lies in the automation of
performed tasks, which, in the traditional process, are executed manually increasing considerably the
quantity of errors and project inconsistencies. Direct and immediate consequences are the reduction
of the time variable associated to the design phase and the increased of its quality. This brings the
decrease of the enterprise total cost, becoming the sector more competitive and transparent. It is an
important conclusion to the extent that BIM methodology besides contributes to improving the
effectiveness of the AEC industry, provides the increasing of their efficiency levels.

7. References


