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BIM methodology, a new approach - case study of structural elements creation

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Abstract

BIM methodology has gained great importance in the construction industry. This methodology introduces noteworthy changes in the way as building design, construction and maintenance are traditionally managed.
This paper explores and evaluates the advantages and disadvantages of BIM methodology application on the preparation, revision and coordination of designs, as well as the analysis of the computational tools available. Using the Revit software a building (laundry of a hospital) was modeled in BIM based in the design drawings carried out by using the traditional methods in CAD 2D.

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1. Introduction

BIM (Building Information Modeling) methodology intents the integration of all phases of the construction process, i.e. the integration and promotion of collaborative work by all the design disciplines involved in the design phase. Besides, it is supported by three-dimensional visualization applications. The great potential of BIM concept is also in standardization of information, being supported, among others, by the standardization of methods to perform the objects modeling process. Based on this, potential improvements in the preparation, coordination and revision of design documents, and management and maintenance of the built environment might be markedly valuable [1].

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Thus, a research work under a master's thesis [2] was carried out in order to clarify the concept of modeling rules and levels of development, when the development and management of a design is proposed using BIM methodology. Assuming as a starting point the design documents prepared by the traditional method (CAD 2D drawings), the structural design and several design disciplines were modelled according to BIM methodology, in order to (i) assess the ability of communicate and exchange information between the project carried out by the different design disciplines as well as to assess the ability of aggregation and management of all information related with the project (with special attention to the structural design) in a single BIM model; (ii) identify where the conception of modeled object is desirable in order to be later used in the development of other projects, increasing therefore the productivity; (iii) identify and assess cases where the application of BIM methodology has high advantages in relation to traditional methods of elaboration and management of projects, in particular to perform the measurements and the design review. This paper will focus on the point (ii) including the conception of structural elements (e.g. lightened fungiform slabs and capitals) not provided on the software libraries.

2. BIM - Building Information Modeling

The BIM concept has assumed different definitions and its use in mass has generated discussions about the validity of the term and even about its applicability. Under this document, it is considered BIM as a digital presentation of the physical and functional characteristics of a building. As such, this digital presentation serves as a shared knowledge resource for information about the construction, allowing the creation of a reliable basis for decisions during its life-cycle, from design to end of service life/demolition. BIM can also be understood broadly as a way to create and use digital models and collaborative processes between related enterprises in order to promote the added value of the models [3]. This means that BIM is the shared digital representation based on open standards for interoperability. This interoperability should include all the relationships and inheritances of each of the components of the construction described in the model – making it an intelligent BIM model [4].

Through this methodology, it can be digitally constructed one or more accurate virtual models of a construction whether it is a building or an infrastructure. These models support the project in its conception phases, allowing improved analysis and control of processes. When completed, these models generated shall contain the geometry and the data required to support the entire construction process, manufacturing and activities through which the construction is carried out [5, 6].

It can be therefore said that BIM is an intelligent model because the information can be introduced in a three-dimensional virtual model. A part of this information can have a physical nature, as it will contain data on the nature of an object, such as its geometry/dimension, its location in relation to other objects, the amount of objects and other parametric information about the object itself. For example, considering the object "wall", the parameter information of the object itself refers to what distinguishes a specific component of another identical. In fact, the walls have common qualities but each may have different characteristics such as its dimensions, location, type of material (concrete, wood, among others.), supplier information, costs, durability, etc.. Every aspect of this type of information can be programmed into the object so that it represents exactly what the design requires [4].

This model includes both graphic information (drawings – Fig. 1a)) and non-graphic information (specifications, schedules and other data – Fig. 1.b)), and modeling allows both a data management which serves as support for future creation and coordinated use of this information [6].

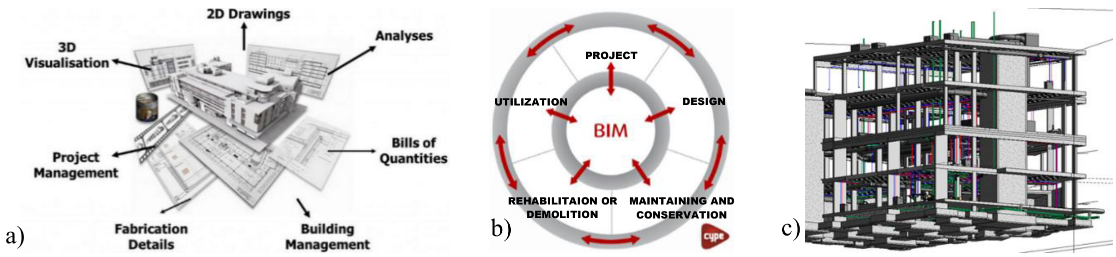

Fig. 1. (a) Smart model [7]; (b) Model BIM life cycle of a building [8]; (c) Model BIM with different specialties modeled active [2].

The main feature of BIM is the 3D modeling system accompanied by management mechanisms, and the introduction of sharing procedures and data exchange over the life of the building. In fact, the end result desired is a model that contains a three-dimensional image in real time, where each object holds actual and updated physical data.

2.1. Information exchange between specialties in Revit

When BIM is used, and in order to enhance advantages, effective communication is crucial between all disciplines. To overcome this problem, Revit software incorporates in the Suite Revit application platform, the Revit Architecture, Revit Structure and Revit MEP which are applications oriented to disciplines such as architecture, structures, facilities, equipment and water and wastewater systems, HVAC installations and electricity, respectively. The basis of the program is the same, only tools and features are changed to allow easier modeling of the different construction objects from the various disciplines.

Stating that appropriate tools and features are provided to different design disciplines in a single and common BIM platform, these various project elements created in the respective modules can be more easily fully compatible with the rest, allowing collaborative work, improved visibility into the information sharing process and synchronization of Revit models without requiring any kind of conversion [9].

The cooperation between disciplines can be performed on Revit by using the tool 'Coordination'. With this tool, amendments may be easily proposed between disciplines avoiding conflicts and architectural constraints.

In order to streamline the analysis of the various design disciplines when integrated with others, filter options are available to the various 2D and 3D views allowing to show only the relevant information, otherwise all information would be observed together. Fig. 1c) presents the design of foundations and structures, facilities, equipment and water and wastewater systems, HVAC installations and electricity active at the same time.

2.2. Extensions and Revit Supplements

In Revit software there are add-on menus that add capabilities and functionalities to the software. Extensions are different from supplements in that the extensions are fully developed and supplied by Autodesk, while supplements are produced and provided by other companies working in partnership with Autodesk to facilitate the modeling of their products. For example, for Revit Structure, the provided extensions are the following [6]:

• Modeling: addition of some tools and capabilities that can facilitate / streamline the modeling process. For example, a feature that allows the creation of a BIM model by introducing data in Excel sheets, or other feature to automate the definition of structural lines in plan and elevation, eliminating the need of introducing them individually.

• Analysis: provides calculation possibilities for structural elements pre-design in a first approximation to the structure to be modeled.

• Reinforcement: allows the automated modeling of reinforcement in concrete elements.

• AutoCAD Structural detailing: allows communication with the AutoCAD Structural Detailing.

• Steel Connections: allows the modeling process of the metal links, although it is still currently limited to only two types of connections, its use is still extremely limited.

• Bridges: introduces modeling capabilities and functionalities aimed for the construction entities - bridges.

With regard to supplements, these can be divided into two distinct groups. The first addresses to applications that introduce new modeling tools in Revit, for instance, the IDAT (developed by the company IDAT) aimed for the design of prefabricated concrete structures or the SDS/2 Connect (developed by the company SDS/2) introducing modeling capabilities for metallic bonds. The second group addresses to applications that allow or optimize the exchange of information between Revit and other external software to Autodesk, for instance, the supplement 'BIMLink' that allows interoperability between Revit and Microsoft Excel sheets, conversion supplements that foster the interoperability of the structural model of Revit and structural calculation programs as STAAD.pro or RAM Structural System (from Bentley) [10]. There are also supplements for interoperability between different modeling programs that optimize the ability to communicate among them (already possible through the IFC standard format), as for example between Revit Structure and Tekla Structures and Revit Structure and Graitec Advance [11].

2.3. IFC format

To encourage interoperability between BIM applications from several companies it was created the IFC format, specified and developed by buildingSMART. The IFC format is a repository of data for open building semantic information object, including geometry, properties and relationships to facilitate [12]: (i) the interdisciplinary coordination during the construction of the information models, including design disciplines as architecture, structural or services, as well as during the construction phase; (ii) the data sharing and exchange between IFC applications; (iii) the transference and reuse of data for analysis and other further tasks.

The IFC initiative began in 1994 when Autodesk started to develop a set of C ++ classes that could support the development of integrated applications. Twelve other American companies have joined the initiative, initially defined as the Alliance for Interoperability. In 1997, the name was changed to International Alliance for Interoperability due to the integration of more international companies. This new alliance was reconstituted as a non-profit organization with the goal of developing the IFC as a neutral product for the architectural, engineering and construction industry. The designation of this initiative was again changed to buildingSMART in 2005 [12].

In 1997 it was launched the first version of the IFC format. Over the years, the IFC format has been improved and new versions have been released. The improvements are based not only on the optimization of the various features previously supported by the format, but also in increasing the variety of information supported. As an example, just after the IFC 2x2 version it was possible to transfer structural designs, once BIM modules applications dedicated to the structure design have arisen later. However, only in the latest release, IFC 2x4, it became possible, for example, transfer via IFC modeled reinforcement on construction elements, such as walls or slabs [9, 13].

3. Case study

The present case study was focused on modeling with the BIM methodology the laundry building of the Funchal main hospital (Portugal). The modeling was done based on the drawings from different design disciplines, such as foundations and structures, installations of equipment and water and wastewater systems, equipment, heating, ventilation and air conditioning (HVAC) and facilities, equipment and electrical systems – which were prepared using “traditional” methods, namely 2D CAD drawings and written specifications.

3.1. Implementation of BIM on foundations and structures project

Revit Structure is a modeling software that integrates a geometrical model of various materials with an editable and independent analytical model. The Revit Structure includes a single model for structural analysis and documentation, construction documents and detailing structures. Moreover, the various features allow Revit Structure to [15]: allocate construction documentation to each object; generate structural details; support multiple data formats; perform multi-material modeling; use parametric structural components; develop collaborative work; and set interoperation with Autodesk Revit Architecture and Autodesk Revit MEP.

It is also important to note that the Revit platform has two partitions name, 'Revit Project' and 'Revit Families'. Revit Project is addressed to the modeling of the project itself, and Revit Families wherein the creation of new BIM objects is possible – for example, change the physical characteristics and the default extrusion of the selected pillar in Fig. 2 – initially not available in Project Revit, which become usable in modeling and can be used on the modeling process on other designs. Revit also has a second tool for creating new objects, which is in the Revit Project itself with the name 'model in place' where the modeled object can only be used in the current model.

Revit divides the various design disciplines by category. Therefore, it recognizes structural elements modeled as a structural element referring to the category of foundations and structural design. Consequently, it is necessary to define their structural properties (Fig. 2(b)). In Revit Structure, the modeled elements are usually automatically considered to be structural, but one can make changes – those changes can also be set by the architect when using Revit Architecture.

Note that when a particular structural element is defined as a concrete element, then it is also possible the modeling of reinforcement, the definition of the intended coverage values, as well as the possibility of activating the analytical model of that element (Fig. 2(b)). It is noted that the existence of an analytical model representative of the respective structural physical element that is indispensable for this structural element is transferable to calculation programs – for example, the Robot Structural Analysis.

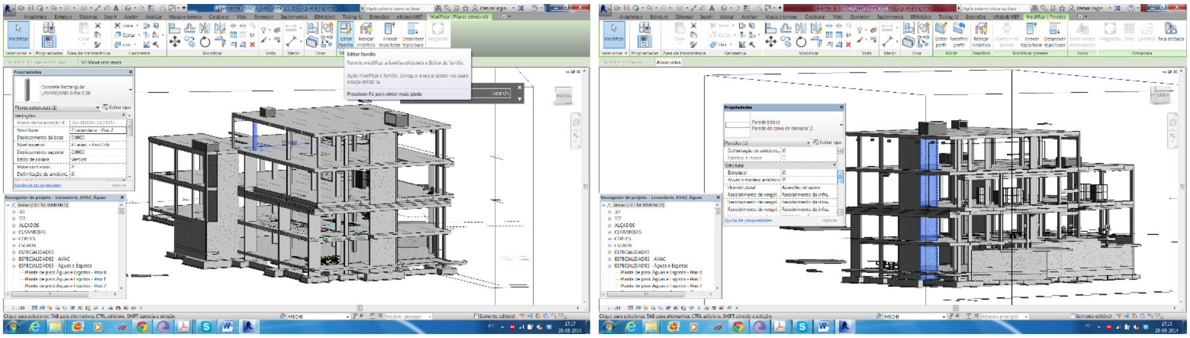

Fig. 2. (a) Option View edit family for the element 'pillar' (left); (b) Properties selected of the selected structural wall [2].

The creation of objects in BIM involves not only geometric characteristics but mainly physical ones. In fact, to these objects are associated, among other information, the types of materials. Revit, already contains a list of materials in its database, nevertheless the addition and customization of new materials and respective physical and non-physical characteristics is possible. Thus, they may be stored for future use in another Revit design and to characterize the objects to be compatible with other software, for example using IFC format. It is noted that physical properties that may be introduced can include, the concrete compressive strength, elastic modulus, shear modulus, thermal expansion coefficient and weight per unit volume.

3.2. Ability to create new BIM objects

The importance of a geometric model with high quality in BIM may require the development of new objects, capable of translating intended construction element sand that once created can be used on other projects. In Revit, as already mentioned, for this purpose there is 'Revit Families' or in the construction 'Revit Project' tool 'model in place' (if is not to be used in other designs).

Within Revit Families, there are several menus for the conception of different types of objects. There are menus dedicated to architectural, structural, mechanical construction elements as well as menus for with generic capabilities.

In this case study, there was the need to model a module of lightened flat slabs (in this document referred to 'blocão'). Thus, for the conception of the object 'blocão' the structural partition was used because 'blocão' was a structural element. The following steps were completed: (i) creating the object, a new family; (ii) choose metric generic model; (iii) reference design with two lines that represent the reference planes for the implementation of the element; (iv) create the concrete 'blocão' drawing with contours in plan and making its extrusion; (v) create the void of 'blocão' by drawing the outlines of void in plant and making a void extrusion; (vi) carry out the parameterization of the object to setting the properties of 'blocão' parameters, (vii) define the material of 'blocão'; (viii) create a slab where the family is inserted ('blocão'); (ix) insert the component in the respective slab; (x) carrying the family ('blocão'); (xi) Finally, select the object and enter the 'blocão' in the slab without forgetting to assign the correct parameters to 'blocão' (Fig. 3(a)). More detailed information on the creation of this object can be found in Reference [2] where each step is accompanied by images.

Apart from 'blocão' in this study, there was also a need to model the capitals – an object not included in Revit. With regard to the lack of objects (capitals), it can be performed in two different ways: (i) cheating the software with the elaboration of a beam (or pillar) to the desired dimensions (size of capital) – problem: difficulty of crossing the slab reinforcement in the capital; (ii) performing a slab inside another, by using the tool ‘split’ (Fig. 3(b)), in order to quantify the volume of concrete of the capital or of the slab (otherwise Revit counts twice the volume intersection slab / capital) – problem: the slab reinforcement must be manually extended into the capital. By default the software believes that when we have two contiguous slabs, the reinforcement of each slab is stopped at the end of the respective slab, so the slab reinforcement has to be manually ‘extended’ into the capital.

In this case study, we opted for the second option, the realization of capitals being executed through the following steps: (i) create the slab and give the name of ‘capital’; (ii) create the capital; (iii) split the elements (so that there is no overlap of concrete); (iv) create the capital with reinforcement in the same way as the slab; and finally, (iv) extend the reinforcement of the slab for the capital. Like the ‘blocão’ object, more detailed information (with pictures) on the conception of this object can be found in Reference [2].

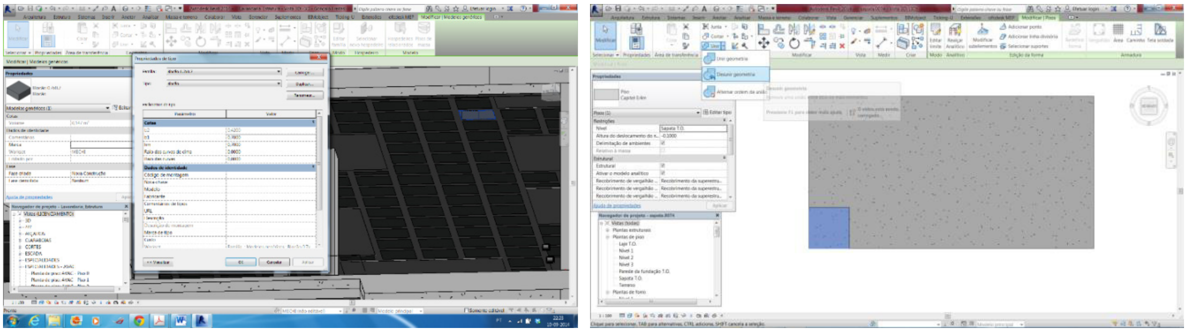

Fig. 3. (a) View ‘blocão’ inserted in the respective structure and parameters; (b) Split Capital from slab [2].

It should be noted that new families can be saved and re-introduced in different projects where its use is required. Thus, the user can create his own library with new elements (saving time for future projects). Note that an important factor for productivity in BIM is the existence of a good library to save time in any discipline / application Revit (Architecture, Structural, MEP).

3.3. Reinforcements

As a BIM component, it is also possible structural detail of reinforcement, namely in corners of a designed structures. The level of detail made possible by 2D and 3D visualization of reinforcement in the model allows careful consideration of the reinforcement solutions to be adopted. Moreover, there is a tool to assist space between the reinforcement bar in order to avoid duplication and conflicts. It should be noted that Revit has tools designed to overlay the detection of bars. For the modulation of the reinforcement in the structure using BIM, there are two possible methods, their applicability depending on the structural element concerned:

• Model the reinforcement directly on the structural elements: This reinforcement modeling mode is possible at any concrete structural element. In this modeling method reinforcement bars are placed directly on the concrete elements, being possible to choose the precise positioning required for each bar. This is the process that allows greater customization, being the best solution for structural elements with more unusual geometries and more complex reinforcement solutions. In structural elements such as floor slabs and walls, it is possible to define reinforcement meshes. This modeling method is time consuming and somewhat automated, although not specifically versatile and complex. Currently, this was the way used to model the reinforcement of the concrete stairs on the analyzed building.

• Model using the extension 'Reinforcement' in Revit Structure to the reinforcement. With this extension it is possible to model the various structural reinforcement in concrete elements: distributed in foundations, walls, beams, columns. Allows the modeling of reinforcement that occurs through the number, diameter of the bars, spacing values and coverage. However, its use is limited by the geometrical shapes of the elements included in Revit library, for example, it considers only beams and rectangular and circular or rectangular pillars walls. It does not fit nor is fitted for stairs and walls with round parts.

The modeling of all equipment in the BIM model structures project could result in a lengthy process, especially when the number of structural elements under conventional geometries and / or less frequent reinforcement solutions are dominant. In areas where there is a high number of reinforcement bars of different structural elements, so that they can get the desired combination with no overlaps, it might be necessary to 'extend' some bars manually. The process becomes particularly lengthy because the definition of the desired trajectories for the bar is still somewhat an intuitive process and difficult to define.

According Tarrafa, PGD [9], reinforcement modeling process is not practical enough to easily convert traditional CAD methods to BIM. In fact, reinforcement details in a CAD 2D process is considerably faster. However, it is noted that despite being a lengthy process, by modeling in BIM it is automatically possible to assist budgeting processes, facilitate work in the analysis of reinforcement solutions through complete drawings.

3.4. Measurements, quantities and costs

The BIM methodology is effective on supporting an automated budgeting way to obtain data for measurements, quantities and costs, for example the pillars. In Revit, these data are presented in tables that can contain various measurement parameters (length, area, volume, cost) and qualification (description, comments, company name producer, element name), where identically can be created new parameters. The BIM methodology also allows employees to evaluate the project effectively to several economically structural options, facilitating and also streamlining the correction of budgeting due to last minute changes proposed to the initial project, which is necessary only for that update the model with the desired modifications.

Despite the high accuracy afforded by BIM in Revit unaware of the possibility of the user to change the order of priority assigned by the measurements that the various structural elements, leading to obtain measurements and quantities that do not respect the recommendations of LNEC [15] which are used in Portugal. Comparing some considerations assumed by Revit, with LNEC measurement standards the following is noted:

- Revit considers that the height of the pillars goes from the base of the slab (beam or capital), other than recommended by the measurement rules of LNEC – the heights will be determined between the upper faces of the slabs or concrete beams.
- Revit considers that the height of the wall will only go to the base slab, different measurement rules recommended by LNEC - the heights are determined from the upper faces of the slabs or concrete beams.
- Similarly in Revit, the volume of the beam that is embedded in the slab is included in the slab measuring unlike the standards recommended by measuring LNEC – measuring the volume embedded in the thickness of the slabs shall be included in the measurement of the concrete beams or lintels.
- From the recommendations of LNEC measuring the reinforcement will be held in kg - in Revit the reinforcement is measured in volume [cm^3] (however, this difference can be easily solved, being only needed to multiply by the density of steel (0.007850 kg/cm^3 to obtain the weight of the reinforcement in kg).

4. Final notes

During the elaboration of this work it was found that due to the amount of information to be inserted into Revit, to produce a project that uses BIM methodologies, the time consumed is considerably higher in the early stages than in the later stages.

The application of BIM methodology requires high demands for computers, i.e., a large RAM capacity, as when performing a reinforcement extending through modeling 'Reinforcement' can take several minutes.

In the design of foundations and structures, lack of libraries made it necessary to create objects ('blocões' and 'capitals'). The reinforcement of the stairs and the reinforcement between 'blocões' were modeled directly on the elements; there is no extension available in Revit.

BIM is a powerful methodology that is confirmed in automating processes due to the parameterization capabilities of BIM objects and the ability to obtain directly from the BIM model measurements, quantities and costs. However, despite Revit supports the automatic preparation of the measurements, it is necessary to adapt the software to the measuring rules currently applied in Portugal - for example, allowing the user to set the order of priority assigned to the construction elements in terms of measurements.

Acknowledgements

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