BIM model management in the design of structures

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ABSTRACT

Building Information Modeling (BIM) methodology is now widely used in a large number of sectors linked to the construction industry. This approach allows the increase of efficiency in labor management on the development of design and improves quality of project information. Existing studies show a significant decrease of time effort through use of BIM. The methodology allows the creation of a digital model in which all information linked with the construction is accessible for all stakeholders. Existence of this open digital model significantly improves the detection and solution for errors or conflicts and therefore, reduces costs associated with different stages of the life cycle from the building. The implementation of this methodology is already mandatory in public works from different countries.

The work of this thesis intends to conduct a state of knowledge regarding the BIM technology, mainly focusing on the management of the methodology in the development of the design of structures. The capabilities of these tools are analyzed, applied to the design and an optimized work-flow is presented from the viewpoint of the structural engineer. The level of interoperability is based on the analysis of the quality from the information transposed between software and also from the consistency of the final product. During the process inaccuracies are identified and adjustments are referred in order to optimize the application of BIM methodology in the design of structures.

KEYWORDS: BIM, Structural design, Interoperability, Rebar detailing, Automation in Construction, Information extraction.

1 INTRODUCTION

The Building Information Modelling (BIM) methodology is based on a form of collaborative work involving different stakeholders of the design team from previous study to property management stages. In the process a single model containing all information from the various components is compiled. The model presents organized information which can be shared and accessed during all phases of project design and during the building's life cycle. These BIM capabilities, allow a faster development in the design phase and a great confidence in the results.

This paper selects a case study for the application of BIM methodology and describes the different stages associated with the generation of the BIM model, referring to the architectural and structural components necessary for the structural analysis to be developed.

The BIM software used are referred, and the functionality capabilities for both the modeling and calculation software’s in an integrated guide of action trough the work are studied. The interoperability between software's, in particular as regards the occurrence of errors and the effectiveness, efficiency and quality of information transferred is also analised and evaluated.

2 CONCEPT AND APPLICABILITY OF BIM

2.1 DEFINITION OF BIM

Succar (2009) describes BIM as an interaction of policies, processes and technologies that lead to the establishment of a methodology which allows constant updates of all information inherent to the life cycle of a building. BIM is also considered as an emerging technology that requires a procedural change in the Architecture Industry, Engineering Construction and Operation (AECO).

While BIM definition is not consensual, it can be considered a method that involves the development of the different stages from design and subsequent the building management. In a small scale BIM is also defined only as the use of innovative software with advanced modelling capabilities, where information that supports both the design phase and the whole life cycle of the work can be organized. According to the different definitions, BIM can then be the process, a set of tools developed to support the collaborative process inherent to the methodology and is also the final product. Figure 2.1 illustrates different views of BIM.

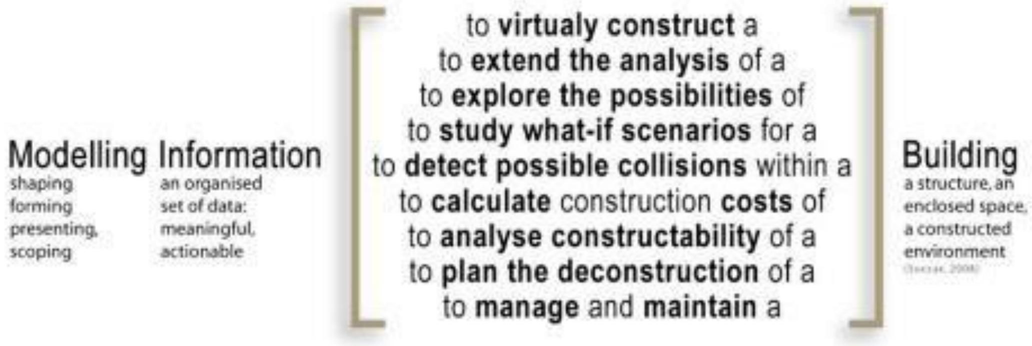

Figure 2.1 - Different definitions of BIM (Succar, 2009).

The BIM concept relates to the beginning of computing in 1960's, the design of two-dimensional layouts in the 1970's and later the spatial modeling in 1980's, referring only to the geometric component without the concept parametric related to the physical properties of elements (Bergin, 2010).

Initially BIM was considered a computer-aided design technology (CAD) associated only to the layout and the spatial geometric modeling (Ford et al., 1995). Thus, in the 80's BIM meant only, the ability to create three-dimensional digital models (3D) representative of a construction. However these models were successively being enriched with additional information organized and incorporated into the model. The current definition of BIM, appears at the beginning of 2000 with the concept of Single Building Models (SBM) applied by CAD software companies such as Autodesk, Graphisoft and Bentley (Smith, Tardif, 2009).

BIM is presently considered to be the standard mode of modeling and representing information in the construction industry. Technological development associated with BIM currently admits a large software integration capability, incorporating different disciplines from the use of parametric objects with a high volume of information.

At the international level, there is a strong adhesion to the BIM methodology both by design and construction companies. More recently, BIM as an organized repository of information has been used in the preparation of various tasks inherent to the construction, such as planning and budgeting. This multi functionality is referred as BIM various nD dimensions (Migilinskas, Ustinovichius, 2013).

2.2 MATURITY LEVELS OF BIM

According to Succar (2009) BIM maturity refers to the quality of information from a BIM model and consequently the ability to perform tasks using the model data. The degree of BIM maturity from a given model, is related to the project development phase. It also depends on the type of information already created and incorporated into the model.

The maturity models are identified by levels associated with specific requirements (Succar, 2009). Literature is not consensual regarding the assessment of BIM maturity and therefore the establishment of levels and their contents. A usual mean to define the maturity levels is the integrated Building Information Modelling (iBIM), which identifies specific targets for the UK construction industry including, technology, standards, practice guidelines, classification and documentation of delivery models (Bew et al., 2008). The objectives to be attained and each identified target are organized in four levels of maturity. Figure 2.2 presents this BIM maturity assessment model.

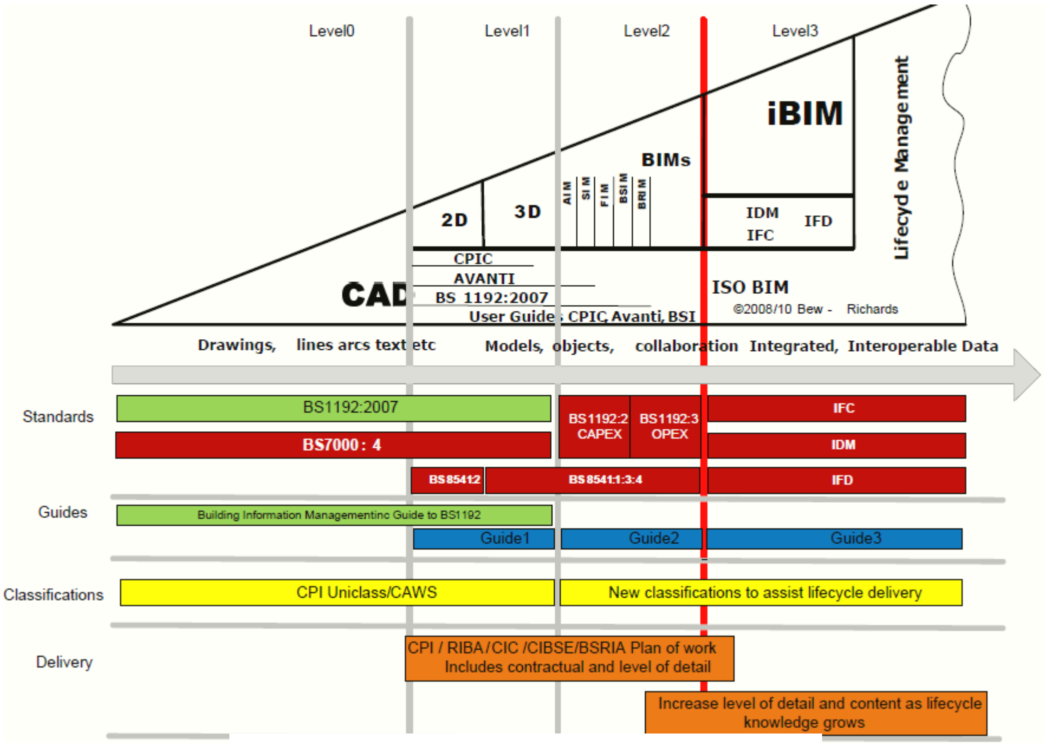

Figure 2.2 – BIM maturity assessment model (BIS, 2011).

As referred each level represents a different degree in the implementation of BIM methodology: Level 0 corresponds essentially to the use of traditional CAD tools; at level 1 there is a greater care in the visualization and manipulation using 3D tools; the actual adoption of BIM occurs from level 2 where the geometric modeling is associated with parametric information; and finally the level 3 corresponds to the full adoption of BIM through existing valences at lower levels, as well as a shared information view, which corresponds to a higher use of interoperability between programs.

2.3 Collaborative process

The project development requires the involvement of different stakeholders. As so it is necessary to coordinate the different information from all the intervenient parts. In a traditional procedure, the coordination task can be complicated, mostly if the project is large and involves many disciplines. In the construction industry, stakeholders represents different experts in their design fields. These different participants also have different motivation and goals to achieve. In addition, specialists may belong to different companies which are temporarily collaborating in the execution of a project, performing only a specific component. In such cases, the collaboration typically involves only a short time relative to the building life cycle or even the design. However the decisions and actions taken by these parties as participants in the project team, have a decisive importance later, both in the design and construction phases, because their actions imposes constraints on the activity and solutions of other participants in the future (Kalay, 2005).

BIM process clearly intends to introduce a high level of collaboration at work. Enabling the use of modeling technologies it is possible to: join all the components; identify the performer for each component; and most importantly analyze mixed or separated parts of the integrated model. BIM modeling is based on parametric objects associating not only the geometry of each element, but a set of information, for instance, materials properties and relation of elements. These features are not possible to consider when drawing CAD models. BIM tools facilitate project management and construction processes, making it possible to update different versions of project components and data, simplifying the coordination of all information involved in the project (Kalay, 2005).

3 ARCHITECTURAL BIM MODEL

The case study used to create the architectural model is a building situated in Rio Maior, Santarém district. The house has three bedrooms, one office, one living room, one kitchen, two toilets, one area for dressing and circulation vestibules. The roof extends over the porch oriented to the south, and is accessible through an extension ladder, placed on the kitchen area.

The selected building is located in a seismic zone with some relevance and admits an average size in plan. The graphic documentation provided regarding the architectural design contains a set of useful information for the development of the model and the subsequent discussion of results.

The creation of the elements in the BIM model correspond the best by those adopted by the architect in the project. However some of these objects have been omitted since they were not related to the paper development. Same decision was made about architectural details as they are not relevant to the present work.

The BIM tool used, Revit 2015 is a very common software in the construction industry, and has advantages to an experienced user in AutoCAD, since both belong to the same company Autodesk, and have similar interfaces. Another important aspect for the Revit selection, is the available interoperability capability with the structural calculation program, Robot Structural Analysis used forward on the work.

The first step in the modeling process is to define the initial settings. Subsequently, it is important to define the work levels. In parametric modeling of vertical elements, identified levels act as lower and upper limits, for which the modeled objects are associated. Throughout the modeling process new levels can be added, simplifying the construction of the model in progress, easing the visualization in each stage. To finalize the modeling preparation phase, it is necessary to implement a grid of auxiliary axes, corresponding to alignments of vertical elements. This grid should be drawn in order to facilitate the insertion of objects in the model.

Been established the bases of modeling, it is then possible to proceed to the creation of the BIM architectural model. This is initiated by the insertion of walls, followed by the placement of windows, doors, flooring, roofing, and also other relevant architectural elements.

The model phase consists in the implementation of parametric objects which can be introduced in a plane or 3D view. The doors and windows used were adapted from existing families in Revit and in accessible libraries found on the Autodesk page. To finalize the model, wall elements were painted respecting the architectural design. Figure 3.2 illustrates different perspectives of the model while being created. Figure 3.1 illustrates a 3D perspective of a view in the architectural model.

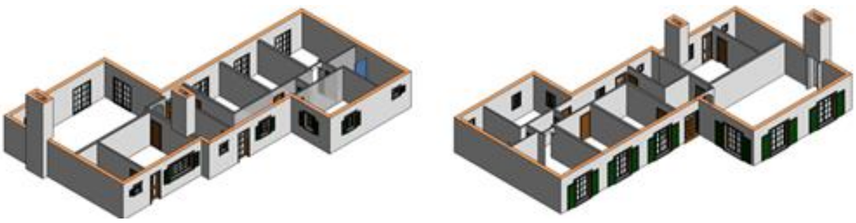

Figure 3.1 - Perspective of the 3D architectural model in construction.

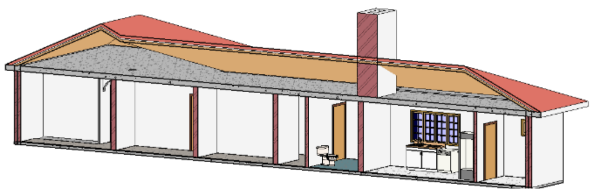

Figure 3.2 – 3D perspective of a view in the architectural model.

4 Structural BIM model

In BIM methodology, the structural solution designed in the preliminary design phase is analyzed on the architectural model. The process of generating a solution is also 3D oriented and allows the engineer to ensure, in a clear way, the architectural conditions that must be respected, avoiding conflicts between the two specialties. Prior to the development of the structural BIM model, it is necessary to consider the design criteria, regulation, materials used, and the type of conditions and restrictions imposed.

Defined a solution and estimated the size of the sections for each element of the structure, a first provisional structural model is then created. Completed the corresponding structural calculation to this model changes can be performed. After the definition of the analytical model by the use of Revit 2015, the information is then exported to the structural calculation program, Robot 2015. After completing the model, stresses and deformations in the elements are evaluated. Subsequently using the BIM components of Robot and Revit the detailing of reinforcement in concrete elements is completed, ending the structural detailing process.

4.1 Model generation

Established the preliminary design of every structural elements, it is then possible to proceed to the creation of the respective preliminary BIM model. The process of modeling involves the definition and insertion of parametric objects in the model, checking for errors and conflicts and preparing the model for exportation. Implementation of columns and the arrangement of beams are made on the adopted grid. The modeling of beams is supported by the attraction capabilities, which easily picks the columns. As for the modeling process Revit makes it quite intuitive. In the case study isolated foundations were admitted. These elements are interconnected by foundation beams, which have the function to assist in the resistance of stresses related to seismic action. All these foundations elements provide a better service behavior of the structure, especially if differential settlements occur. The analytical model should be considered active for all the relevant structural elements. The structural slab is a component that was already modeled on the architectural BIM model. It is only necessary to confirm that the analytical option is checked for this element, so that it is possible to export the information to the structural calculation software. Figure 4.1 represents the structural model created.

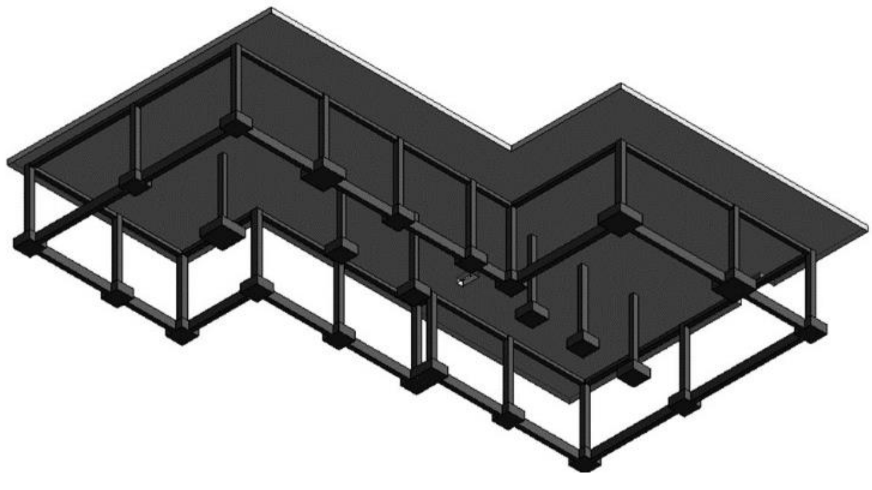

Figure 4.1 – Structural model.

The structural design should also consider the existence of other secondary structural elements which are not exported to the calculation program. Elements like the reinforced rigging on both the ground and porch floors are not subject to a detailed design, but are related to good construction practices. Figure 4.2 represents the structural model with both concrete riggings associated.

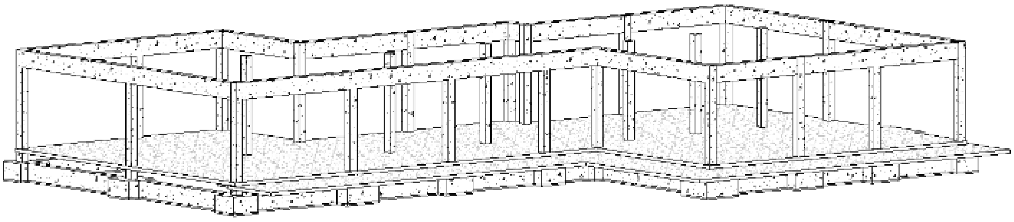

Figure 4.2 – Model including rigging in the ground and porch floors.

4.2 ANALYTICAL MODEL

The created model appears to be constituted by 3D geometric elements, but it is mainly composed of parametric objects with structural identities. The analytical model enables Revit to discretize the individual elements and to obtain a composite representation of elements only at its axis (beams and columns) or mean surface (slab). On this view the designer makes an intuitive visual examination of the elements, and then proceeds to a consistency analysis of the model to be exported. Figure 4.3 illustrates the analytical model.

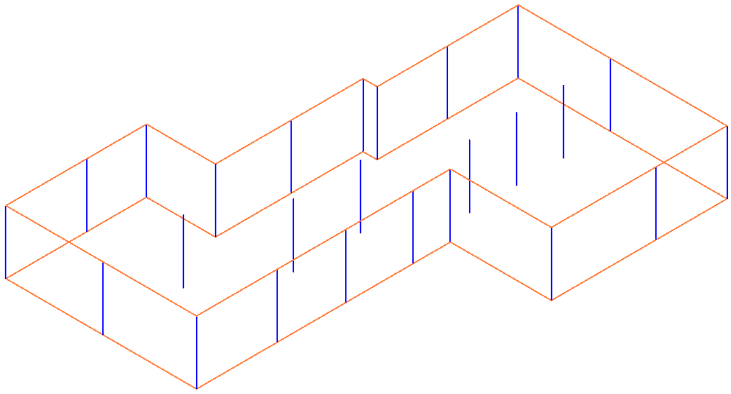

Figure 4.3 - Analytical model.

4.3 REVIT TRANSFER FOR ROBOT

After the verification phase, the model is complete and can be exported to the calculation software. As both, Robot and Revit belong to the Autodesk, the interoperability allows this process to be successful. The transfer to Robot is almost instant. Figure 4.4 shows the model in Robot after integration.

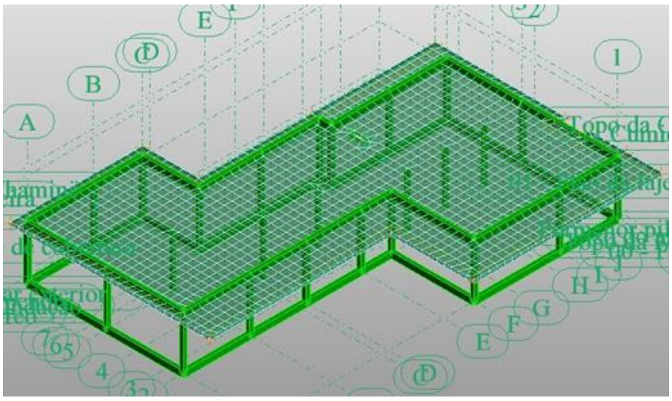

Figure 4.4 – Integrated model into Robot.

5 STRUCTURAL CALCULATION

After the import of the structural model by Robot, again a consistence check is needed. Thereafter, the loads and their combinations are set and then the calculation is carried. Stresses and displacements are determinate in order to validate the geometry of the elements. After this stage, the calculation program allows to carry out the detail of most of the reinforcement of structural elements. Once the detail is complete, it is necessary to send the information created in Robot back to Revit. In the BIM tool the detail is completed and corrections are made in the structural elements not defined in the structural calculation program. Corrections are also required for elements which the information was lost during the exportation process or if a higher level of detail is need.

5.1 Verification of safety and rebar detailing

The automatic calculation process requires, by the user, a constant analysis of the consistency of information in particular by comparing results obtained from the model with simplified methods. As so, a correct understanding of the data involved is always necessary. It is noted that the detailing of structural elements differs between the types of those elements. For slabs, beams and columns, the results in terms of rebar calculation, are satisfactory, but the transposition of this information for Revit is very limited. In this phase the level of interoperability between Robot and Revit is low. For the foundations, Robot only allows to check the forces acting in the supporting nodes. The user must then perform a safety check, by a traditional method, based, however, in the computational model.

To proceed for calculation, the slab was discretized in a reticulated finite element mesh surface, with about 0,50 m from side. Robot can automatically set the value of the reinforcement required for each finite element based on a set of parameters: the method of analysis of the slab; materials; the cover applied, etc. Besides the calculation of the required reinforcement area, Robot also allows to detail the rebar to reinforce the concrete slab. For this, the parameters relating to the spacing and the diameters of the rebar elements are introduced. Robot also models the splices needed for the reinforcement in the slab.

The verification of beams is determined based on the evaluation of the stresses existent on the elements, considering the envelope of different combinations used for actions. The design is made for the most conditioning combination. To find this conditioning combinations, Robot allows to create, for each beam, the envelope of stresses. It is then possible to create rebar detailed solutions, according to the user's instructions and respecting the safety check by the Eurocodes.

For the safety check of columns the normal stresses should be considered. The detailing of reinforcement necessary for the safety check can be conducted by an automatic mode, indicating the spacing between stirrups and by disposing the number of longitudinal bars to be allocated per side, based on the diameters indicated in the calculation options, following an iterative process.

As said before, the foundations were not modeled in the structural calculation program. They were in fact simulated in the model by restrictions imposed on the lower nodes of columns. The foundation beams interconnecting the supports were however modelled. The design for footings is made in relation to the combinations referred. For the foundation beams it is also necessary to analyze the envelope of stresses in order to identify the condition case for each beam. The calculation and reinforcement detailing of foundation beams are carried out similarly as for the upper beams. Figure 5.1 shows an example of the reinforcement of a structural element on Robot, in the case, a foundation beam.

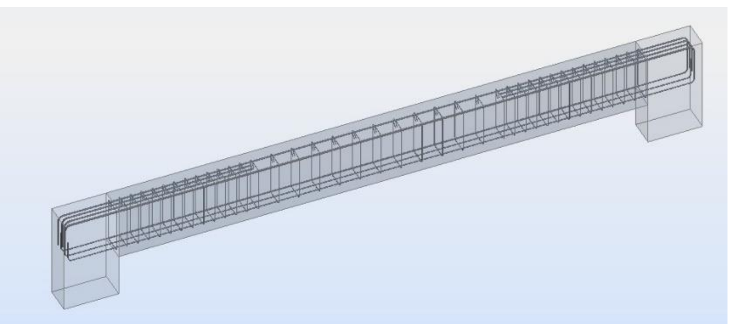

Figure 5.1 – Detail of reinforcement in the foundation beam trough Robot.

6 TRANSPOSITION FROM ROBOT TO REVIT

Following the BIM concept to centralize all the information being cross during the development of the project, data generated in the calculation program must be transferred into the BIM model. One of the great advantages pointed to the adoption of BIM methodology compared to traditional procedures is the automation of processes, taking advantage of parametric information associated with the model, particularly in the detail of rebar, preparation of drawings and maps quantities. After assessing the information collected, the data should be used for generating these essential elements needed for the construction phase.

6.1 EXCHANGE OF REBAR INFORMATION

After the safety check for structural elements and the detailing of rebar it is necessary to transfer all these information back for the BIM model. This process is still very limited as described below.

Regarding the slab, Revit does not recognize the rebar information exported by Robot. It is however possible, to create a *dwg* file in Robot, specifying the detail drawings of reinforcement. This file can then be used as basis for modelling the rebar in Revit, having, however, the modeling to be entirely performed in Revit. It is important that the final BIM model contains all the information of the reinforcement, in order to obtain the necessary drawings to deliver in construction and to perform the quantification of material involved in budgeting tasks and the planning stage.

The transposition process of information related to beam details between the calculation and modeling software admits some degree of integration, however, the results are still not satisfactory. Unknown errors are found in the process and the rebar appears out of place in the BIM software. After founding this errors trough the case study, it was requested support to Autodesk in order to understand the origin and fix it. The explanation provided states that the errors are intrinsic to the still inefficient interoperability between programs. As so there are still many limitations to full integration between Revit and Robot. It becomes then necessary again to set directly in Revit, the rebar on each beam. Even this a duplication of work and an exhaustive procedure, it is facilitated by the use of Revit extensions.

Contrary to what occurs for beams, the exportation of detailed rebar information for columns between Robot and Revit is carried out without any difficulties. For a better detailing, it is possible to create in Revit a specific type of rebar for the columns and change their dimensions and properties, in order to enable the rebar modeling and the respective splices. This takes importance if a higher level of detail is desirable and for the account of material.

For the foundation beams the same problems faced with superior beams occur when exporting detail information about the reinforcement. Observations referred before are identical for these elements. Again it should be considered the correct splices of rebar in the connection between columns and foundations to improve the quality of drawings and the accuracy of the quantification of material, budgeting and work preparation processes.

The detail of footings can also be carried out with support of the extension associated with Revit. Initially it is necessary to set the cover and the diameter of rebar, as the desired spacing to each of the orthogonal directions relative to the upper and lower reinforcement layers. It is also possible to generate constructive stirrups and rebar anchorages for the columns associated with the footings.

6.2 STRUCTURAL MODEL ANALYSIS

The structural model created for the case study was generated in Revit as the safety check was conducted on Robot. The detailing of reinforcement for each structural element, was made both on Robot in a first phase and then completed on Revit. Finally the BIM model contains the information concerning both the architecture and dimensioning components.

Using specific capabilities built in the BIM tool, it is possible to proceed to an analysis of errors and conflicts between the different components of the model. It also possible to generate design drawings to be included to the graphical documentation to be delivered to construction.

The BIM model created also contains detailed information necessary to obtain quantities maps, which can be sorted by the type of material, related to the design of structures. This information is used to estimate the work and the budget as for defining work maps, involving planning tasks, costs and human resources. These steps correspond within the BIM model generation 5D (cost) and 4D (construction planning) dimensions respectively.

As expected, conflicts found in the case of study refered only to collisions between columns and beams with masonry walls due to the occupation of same physical space. This is an error irrelevant from a practical point of view, and type of inconsistency should be ignored. Figure 6.1 illustrates the structural model completed on Revit.

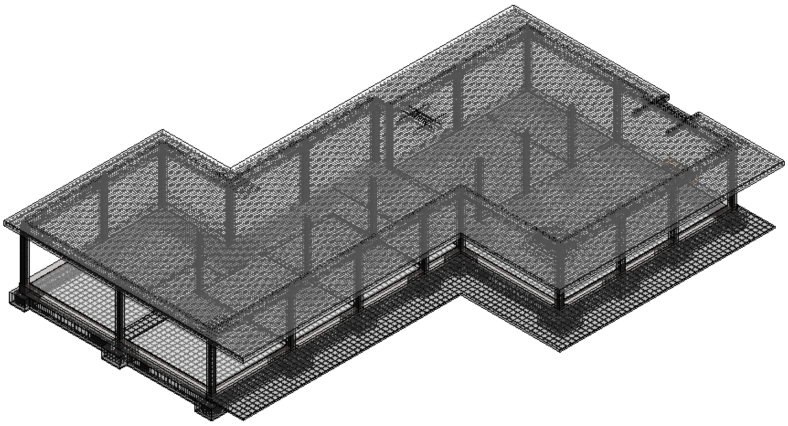

Figure 6.1 – Structural model with reinforcement information

6.3 DETAILED DRAWINGS

The technical drawings shall always be obtained from the updated and checked BIM in order to perform a correct design. Note however, that in result of this automatic approach only some drawings fulfill a determined quality criteria. In the case of the slab, the automated design fails completely this criteria. The alternative passes then to a similar approach to what can be done through CAD. In the absence of an obvious benefit or novelty in the process when comparing to the traditional CAD method, the drawings of the element are not performed in the study. Regarding the drawings, more investment is needed by the Revit manufacturer, particularly, simplifying the representation of elements. Also the software's must be enriched with families associated with the notation of these structural elements, consistent with the practice of other markets, rather than the American one. To do so it would be interesting to establish partnerships with national and European entities.

6.4 QUANTITY MAPS AND BUDGETING

After the model is exported the required analysis is performed, it is then possible to benefit from the parametric dimension associated with the geometry of the modeled elements to obtain maps of quantities. This process carried out in Revit, requires the definition of selection filters. The materials may then be sorted depending on the user definitions. It is also possible to carry out mathematical operations necessary to, for example, quantify the total weight of the rebar in the structure. The maps can be exported to Excel where they can be associate with unit prices for each material, although this process can also be performed on the BIM software. After the process is concluded it is possible to obtain a detailed project budget.

7 CONCLUSIONS

7.1 BIM USING IN THE PERSPECTIVE OF THE STRUCTURAL DESIGN

By the development of the case study, an appropriate procedure for the use of BIM in the preparation of structural design was built and then described. Based on the analysis procedures, involving the generation of the structural model, exporting, using the calculation program, and subsequent, transferring and handling rebar detail in Revit, it is observed that although there a large number of true advantages, there are also numerous technological limitations. In fact the current BIM tools support some tasks, for instance, the collaborative feature for sharing information since BIM models features the information between the different components (architecture, structure, mechanical, electronical and plumbing, etc.). The possibility of transferring information between the modeling and calculation software, as making an analysis of errors and conflicts between components, or the possibility to create quantity maps, automatically, are also important advantages.

It should be noted that the detail of reinforcement developed for the structural elements, is possible by two alternatives; by recourse to the structural calculation software Robot or trough Revit. Both possibilities show different levels of automation and rectifications for the results are commonly necessary due to the inconsistency of data. The drawings were also obtained through both programs, although the quality of those created by structural calculation program is quite low. However, the design *dwg* file regarding the slab can be used in Revit to support the modelling of reinforcement for that element. The drawings obtained by Revit have demonstrated quality for some elements. However the manufacture of the BIM tool, needs yet to cover more content to support the construction details of the European market.

In the development of this work several limitations were also identified, mostly associated with interoperability issues. The design execution speed is related to experience of the use of the technology by the user and also by the level of detail required by the designer. In order to take full advantage of the tool and to optimize the work-flow, it is also necessary to lead with the limitations, seeking alternatives based on the traditional method.

In the design of the reinforcement some errors were identified revealing an ineffective interoperability between programs, although in the case study both software belonged to the same manufacturer. For the detailing of slabs and beams it was necessary to perform a large number of adjustments into the BIM model. Therefore the creation of construction details to associate with the design of structures, based on the interoperability between programs is still limited. Even after the information about rebar was modeled in Revit, it was necessary to complement the drawings by manipulating lines and captions by processes at all similar to those commonly executed on CAD software. Finally it is noted that the biggest drawback of BIM implementation in the project office is the learning time that is required to start the BIM concept approach.

Finally it is important to refer that this work contributed to an increase of knowledge inherent to a methodology of great attractiveness and relevance in the national panorama. This study also systematized the process of structural design. The choices made were justified, and the recommendations that should be adopted were described. The structural model created, was explored on several fronts in order to test and understand the possibilities that the BIM methodology offers, publicizing the real benefits of its use.

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