

BIM Supporting the Development of Multitasks Related with the Structural Project

Alcnia Zita Sampaio^{1,2*} , Augusto Martins Gomes^{1,2} , Paulo Manuel Sequeira¹,
Gonalo Ferreira Azevedo¹

¹Department of Civil Engineering, University of Lisbon, Lisbon, Portugal

²CERIS—Civil Engineering Research and Innovation for Sustainability, Lisbon, Portugal

Email: *zita.sampaio@tecnico.ulisboa.pt, augusto.gomes@tecnico.ulisboa.pt, p.manuel.sequeira@tecnico.ulisboa.pt, goncalofazevedo@tecnico.ulisboa.pt

How to cite this paper: Sampaio, A.Z., Gomes, A.M., Sequeira, P.M. and Azevedo, G.F. (2023) BIM Supporting the Development of Multitasks Related with the Structural Project. *Journal of Software Engineering and Applications*, 16, 397-419. <https://doi.org/10.4236/jsea.2023.168020>

Received: June 15, 2023

Accepted: August 26, 2023

Published: August 29, 2023

Copyright © 2023 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Building Information Modelling (BIM) is a methodology focused on the centralization and sharing of the project information among all professionals involved, supported on the generation and manipulation of a three-dimensional (3D) digital BIM model. This methodology allows a close collaboration between the architect and the structural engineer and an adequate manipulation of the structural BIM model database, on the definition of multitasks. The collaboration allowed between all disciplines, avoid the detection of conflicts and data omission after in the construction place. Two BIM structural design cases were developed, using Revit as the modelling system and Robot as the structural software. Concerning the structural project the interoperability capacity between the software is still a limitation that engineers must be warned of. In the present study, the benefits and limitations identified within the communication and integration of distinct disciplines and on the development of most frequent multitasks normally related with a structural project, were considered.

Keywords

BIM, Structural Project, Communication, Integration, Interoperability, Multitasks

1. Introduction

The fundamental concept of the Building Information Modelling (BIM) methodology, refers to a hierarchical system of building components in the composition of a digital model, allowing to centralize all data that is generated along the development of a global project of a building or infrastructure [1]. The elaboration

tion of a building project using the available BIM software, involving all disciplines and the required associated tasks, is provided in the form of a digital parametric model. The generated BIM model contains naturally all the relevant geometric details, but also several data associated to the applied material, such as density or elasticity modulus. BIM model offers a complete, updated, and accessible database, allowing the data sharing between partners and phases, encompassing all stages of the life cycle of a building [2].

Considering that BIM is relatively recent, the existing software is not yet fully interoperable, and presents some limitations. In this sense, this paper aims to analyze the technological advances that have been achieved lately, and identifying appropriate strategies for performing different tasks within the structural design process. In order to control, organize and supervise the integration of all process, in a global project, a BIM manager is currently required [3] [4].

As interoperability is an inevitable step that must be taken and analyzed with care in project design offices, the present study aims to contribute to the investigation of the methodology implementation, in order to promote BIM adoption in the specific domain of structural design [5]. In this context, the interoperability is the main problem that must be understood and the present study contributes to clarify the most recurrent limitations and indicates amended strategies [6] [7].

The BIM-based programs available allow the creation of a reliable three-dimensional (3D) representation of the building, including the various specialties that make up a project, and supporting an improvement in the coordination and compatibility of phases. In recent decades, there has been a significant increase in the adoption of BIM methodology, from different areas of the construction industry, due, in part, to the improvement of programs, but also to the confirmation of its benefits in real cases.

The research presents the capacity of BIM methodology of using the database of the BIM model to achieve several types of tasks that normally are associated to the structural design. For that, the research is supported on several steps:

- First, the **collaboration** between the architectural and the structural professionals;
- Second the **transfer** of the created structural model to the dimensioning software;
- Next, the results of the analyses, including the reinforcements obtain, were **transposed** to the initial BIM model, in order to obtain a complete structural project;
- Finally, the **manipulation** of the final structural model in order to obtain the necessary drawings, tables or cost estimation and to perform the conflict analysis and the construction planning.

However, in construction enterprises the changing of traditional working methods to the new methodology, requires a high initial cost investment in training and software. Considering that BIM is relatively recent, the programs

are not yet fully prepared, and present some limitations. In this sense, this paper aims to analyze the technological advances that have been achieved, identifying appropriate strategies for performing different tasks associated with the design of structures.

To illustrate the necessary steps on the development of the structural design, two case studies were selected: the first project is focused on the collaboration between the architecture and the structural disciplines [8] [9]; the second case is oriented to manipulation of a BIM model database, on the definition of multi-tasks [10] [11]. In addition, in both cases, the interoperability capacity was intensely studied, allowing to identify the main problems and to perform adequate strategic resolutions. Thus, the main objective of the work is to analyze, through two practical cases, the implementation of the BIM methodology in structural design, complemented with the extraction of information supporting the development of a diverse type of tasks:

- Evaluating the efficiency of the **BIM tools** used on the elaboration of distinct phases of the structural design process (conception, analysis and structural reinforcements);
- Exploring the various applications that the **BIM model database** can support related to different dimensions of the methodology (coordination, drawing production, construction planning, risk analyses, estimation costs, and sustainability simulation).

2. Case Study: Architecture and Structure

The first case study is a single-family house, located in the archipelago of the Azores, Portugal [8]. The process of creating the architecture design, admitted several alternative options, and all changes were first performed over the BIM architectural model, that was frequently adjusted, and after the required amendment were considered on the structural model.

The process of creating the architecture design admitted several alternative options, providing an interesting illustration of how BIM model constitutes an adequate work-base and understanding of coordination between the activities of the architect and the structural engineer. The BIM manager coordinates all delivery processes, made in both transfer directions, following all steps of the model growing and admitting several changes along its progression. The experts involved, using BIM software, and controlled by the manager, easily follow the adaptation studies applied over both disciplines.

2.1. Geometric Model

An architectural initial BIM model was first created. After a first suited structural component was defined confined to the architectural constraints. To initialize the architectural model, a set of technical drawing were inserted in the modeling software Revit (Autodesk) serving as the base of working (**Figure 1**).

The preliminary **architectural** BIM model was provided by the architectural

(Autodesk) software. The modelling process in Revit is very intuitive, supported by the interactive interfaces of the distinct **structural families** of **parametric objects** available in the system. Then, the first elements to be modelled are the columns, and sequentially the beams, walls, and slabs. The foundations are modelled after the definition of columns and retaining walls. The user selects an element of the desired family and adjusts the dimensions of its cross section or thickness as designed. The modelling of some elements, such as corner columns, inverted beams, slabs, and sloped roof elements, displayed some complexity and limitations, mainly regarding the compatibility of geometric and analytical models. As all elements belongs to **structural families of objects**, the geometric modelling is accompanied by the correspondent analytical model representation.

2.2. Alternative Solutions

The proposed structural solution consists essentially of a reinforced concrete beam structure, formed by columns, beams, walls and slabs, and a complementary mixed structural system, formed by frames and walls. The project under analysis was submitted to changes made in the architecture design, while the structural model was being developed, forcing a series of adaptations over the structural solution (**Figure 2**):

- An **architectural change** refers to a new placement of a window on the 2nd floor, requiring a redefinition of the cross-section dimensions of the upper beam;
- Other **amendment** consists on the removal of two columns on the 1st floor, creating a contiguous span in almost the entire front of the main body of the building.

These changes were performed in a closer collaboration between the architect and the structural engineer, supported on the creation and manipulation of both disciplines worked out over a centralized BIM model. The use of the BIM model to assist the 3D visualization of the project, improved the communication between both offices. The final structural solution was the result of a series of adaptations, made over the initial pre-dimensioning proposal (**Figure 3**).

Several meetings were scheduled supported on the visualization of the BIM model, in order to better understand the requirements and the exigencies involved. Along the process, distinct adjustments to the architecture were made followed by a new suited structural model. In all adjustments, the BIM manger coordinated the delivery of the architectural and structural models between the

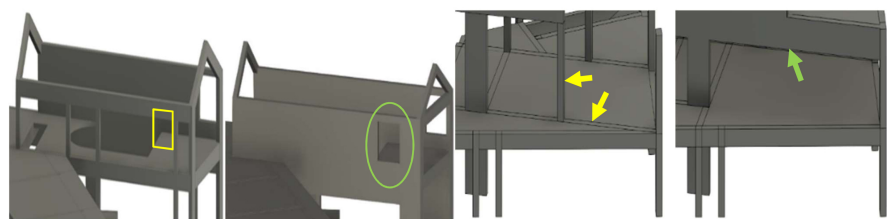


Figure 2. Structural solution before and after the amendments.



Figure 3. The final structural BIM model created in Revit.

respective professionals. The collaboration establishes between the experts, in architecture and structure, was greatly improved, when compared to a paper-based design, as the communication was supported in a BIM model.

2.3. Analytical Model

The geometric modelling process is accompanied by the visualization of the correspondent analytical model. The errors of inconsistency are checked over the analytical model. The analytical model is automatically generated by the software, allowing an easy detection of errors along the definition and adjustment of the structural solution. The inconsistencies of the nodes position, must be amended accordingly. This kind of errors can occur when, for example, the geometric limits of the elements do not coincide with the analytical limits or by failures in the program to detect where the analytical connection of the element should be made consistent.

The images inserted in **Figure 4** illustrate an example of a geometric error, as the limits of the elements do not coincide with the analytical limits. An adjustment of the nodes was then considered.

Some tools facilitate the detection of problems in the analytical model. A visual filter was applied, in the present case, allowing the user to quickly identify disconnected nodes by changing their color to a distinct one.

2.4. Structural Analysis

Once the modelling of the structure has been completed and the consistency of the analytical model has been checked, the model is transferred to the calculation program, the Robot, in order to perform the structural analysis. The Revit/Robot data transfer of the BIM model, was carried out using a plug-in, through the direct integration option, allowing the rapid two-way transfer of information. No errors were detected when performing the transfer, although some flaws were identified later in the analytical model because some slab nodes were poorly connected in Revit (**Figure 5**).

BIM manager control the options for transferring the correct material and properties and updating elements like foundations. The first selected options were *Send model* and *Update model*, and later to transfer the results obtained in

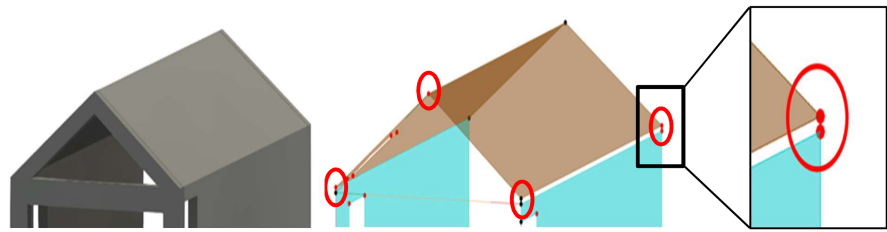


Figure 4. Physical model of the roof and disconnected nodes in the analytical model.

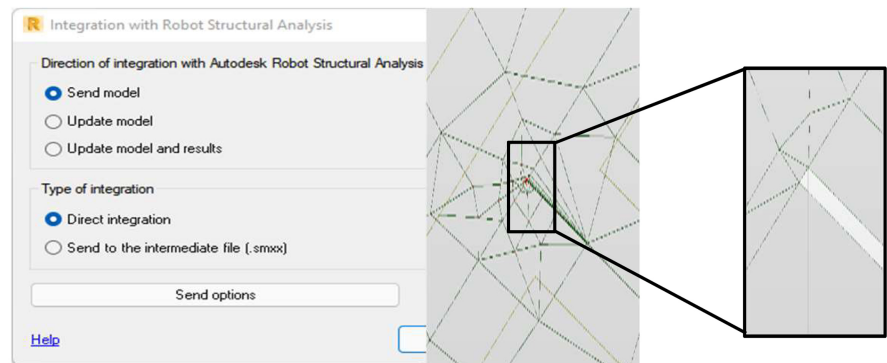


Figure 5. Direct integration option and incoherent zone in the finite element mesh.

the structural analysis to Revit, the option *Update model and results*, was selected. In Robot the loads and combination of loads were applied and the structural analyses was realized (**Figure 6**). For the determination of the seismic action, using the analysis mode parameter, the modal value was first changed to seismic, allowing the selection of the most relevant vibration modes for the seismic analysis, that are associated to a higher percentage of mass participation.

Also supervised by the BIM manger, other transfer process was realized. The calculated reinforcements for each structural component were transferred to the initial software, the Revit, in order to complete the initial structural model. In this step, the interoperability capacity in the way Robot/Revit was evaluated. The interoperability capacity between both software was analyzed. Several inconsistencies were detected and the required adjustments were performed [9]. The interoperability level in a structural design is currently still a limitation. So, it was found that the information transferred in Robot/Revit direction still presents several flaws. All the problems were corrected in order to obtain an accurate and complete structural model. In it, the BIM manager coordinates all process. For that, knowledge about the structural software available and the interoperability level capacity of the systems used, is required as BIM manager skills.

The loads considered for the dead loads, were the self-weight, that is automatically defined and applied by the calculation program, plus the remaining loads, such as partition walls and floor coverings. The applied live loads were defined according to the Portuguese norm, NP EN 1991-1-1, classifying the case study in category A with the type of use “Domestic and residential activities”. After the definition of dead and live loads, the seismic action was considered through a

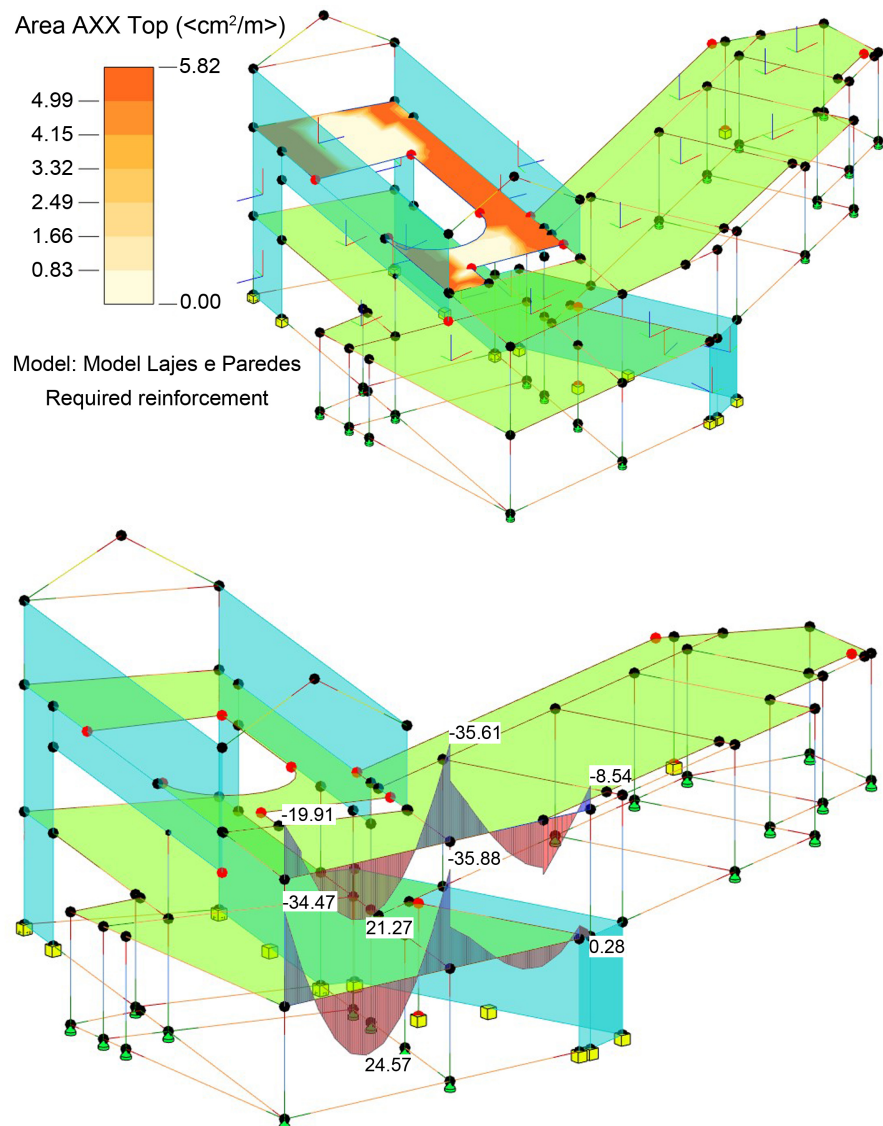


Figure 6. Results of the structural analyses worked out in Robot.

modal analysis by response spectrum since the building has an irregular geometry and is in a high seismicity zone. Then, the structural analysis was performed.

The applied loads were defined according to the Portuguese norm, NP EN 1991-1-1. Then, the structural analysis was performed. Robot provides diagrams of efforts, reactions, deformations, and effort maps, among other options (Figure 7).

2.5. Interoperability Capacity

Based on the results of efforts, Robot automatically calculates the necessary reinforcement areas, satisfying the requirements established in the Eurocodes 2 e 8. The software generates the reinforcement detailing over each structural element that can be represented as technical drawings and as 3D geometric model. The interoperability capability between Revit and Robot, regarding the reverse

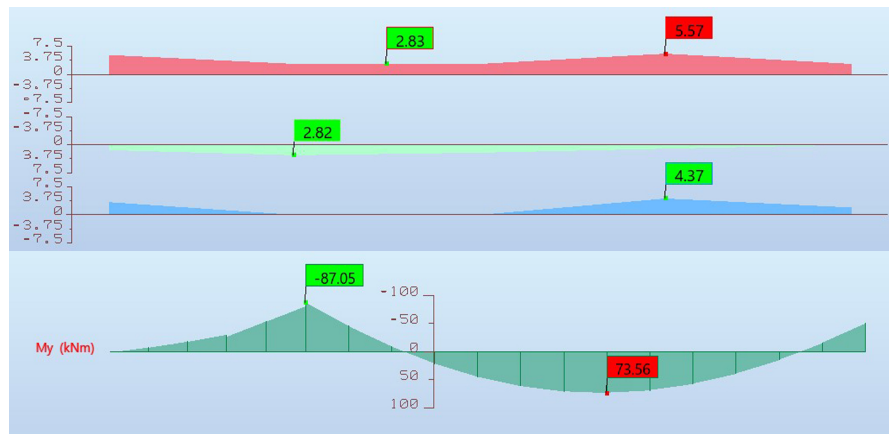


Figure 7. Individual analysis of a beam and my moment.

transfer process, Robot/Revit, was evaluated (**Figure 8**):

- The **foundation** reinforcement is correctly performed if the exact foundations geometry was previously defined in Revit. However, in some situations the reinforcement has a skewed orientation in relation to the footings;
- Analyzing the **transfer** of the columns, no problems were identified. However, the software showed some difficulties in locating the geometry position of the beams and their orientation. Additionally, some beam stirrups were represented out of the element, and the justification is that, since Robot does not consider eccentricities, the software considered larger spans than those defined in Revit.

Despite the steps integration, demonstrating the ability to centralize the results of the structural analysis in Revit, this process still has several errors. There were some difficulties trying to transfer the results. The only solution found was to perform the update of the model, in a selective way by elements, beams and columns and by groups of elements, such as slabs and walls. This procedure led to better transfer results.

3. Case Study: Multitasks in Structural Design

The second selected building concerns a four-storey residential building located in Lisbon [11]. The established structural solution is a reinforced concrete frame. The structural BIM model was generated based on the available set of drawings of floor plants, sections cuts and details of the structure.

3.1. Geometric Model

The modelling software used was also Revit. Revit software includes a structural menu with a wide variety of parametric objects representative of the most frequent structural components, facilitating the modelling process of the required structural solution. In addition, the values of the mechanical properties of the materials, Concrete C30/37 and Steel A500 NR SD, were introduced with their correct values, as they are later used in the structural analyses (**Table 1**).

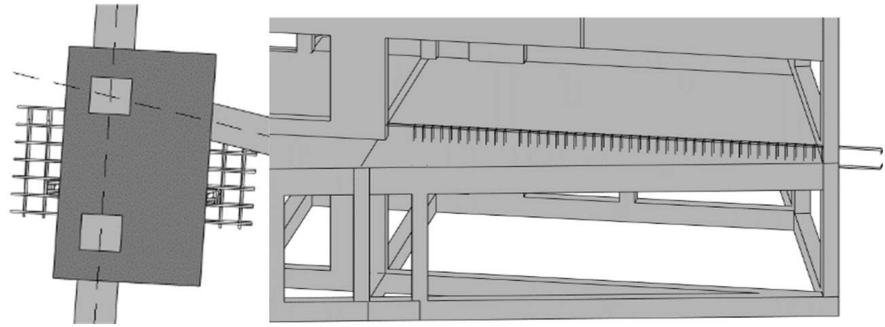


Figure 8. Errors in reinforcements in foundations and beam elements.

Table 1. Properties of design materials.

Materials		Proprieties			
Concrete C30/37	fck (MPa)	fcd (MPa)	fctm (MPa)	Ecm (GPa)	γ_c (kN/m ³)
	30	20	2.9	33	25
Steel A500 NR SD	fyk (MPa)	fyd (MPa)	Es (GPa)	γ_s (kN/m ³)	
	500	435	200	78	

The modelling process of the structural solution is then initialized. A floor solution is defined based on the size of the spans between the columns and the presence or absence of beams (**Figure 9**).

The beams and columns were adequately positioned according to the grids outlined. The modelling system allows to replicate the modelled elements from one floor to the others, speeding up all process. Since the upper floors were similar, this feature was used, replicating the structural elements from the level 0 to the other 3 floors. In addition, the building presents a stair column and an elevator core (**Figure 10**):

- The **stair** element was first modelled only as an architectural element and therefore it cannot be associated with an analytical element or modelled with reinforcements. To solve this problem, the stair was created as a sloped floor element, which belongs to a structural category. Thus, as it was modelled as a structural element of the category slab, with the geometry of the stair, later it would be possible to insert reinforcement in it;
- The **elevator core** is composed of three structural walls with 25 cm thickness and the wall with openings with 25 cm.

All the elements were pre-sizing, were the thickness of the slabs, the cross-section dimensions of the beams and the columns, and finally the dimensions of the foundation elements, were established (**Figure 11**).

The project browser, associated to the model, presents an organised directory in order to support collaboration and coordination, avoiding inconsistencies between disciplines or tasks. The project represented in a BIM model form, can be easily examined simplifying the detection of inconsistencies, regarding the

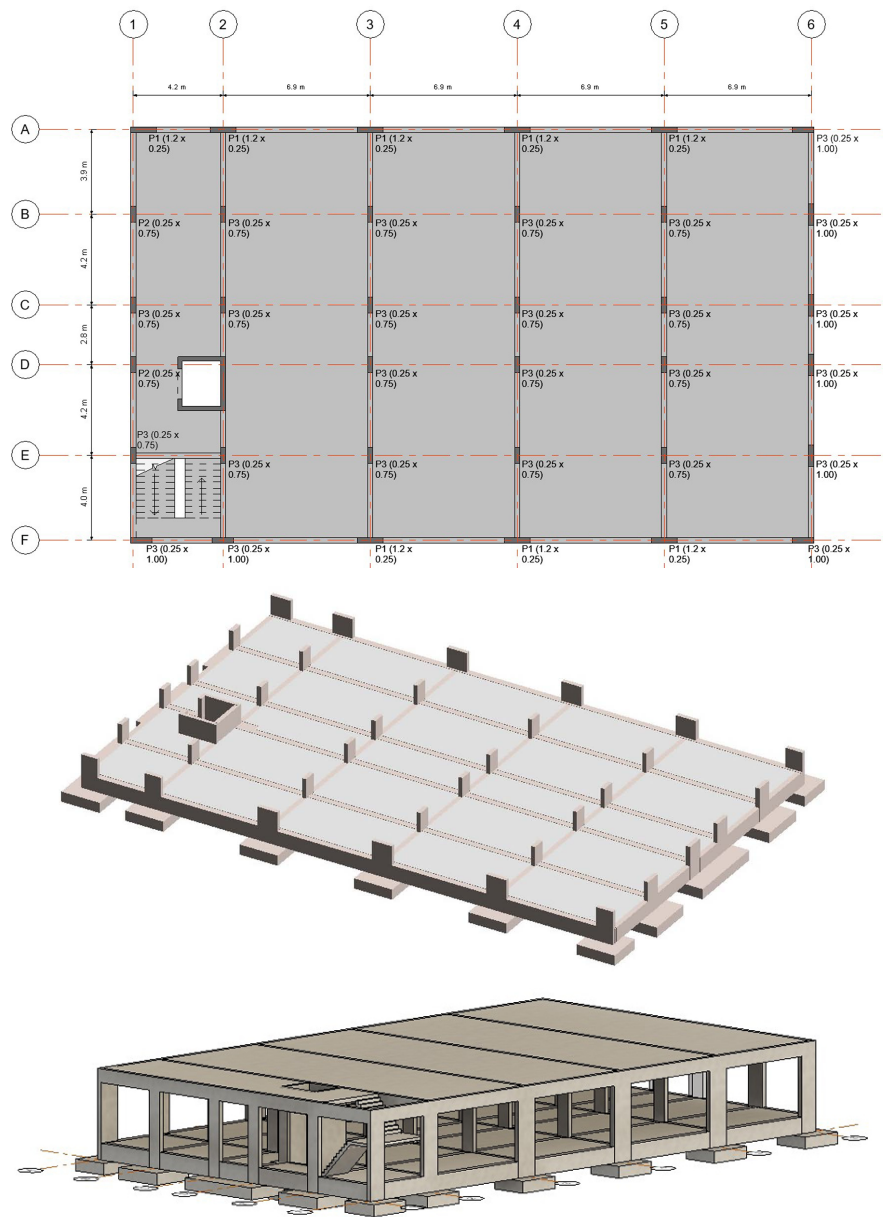


Figure 9. Plant of level 1 and models of the foundations and of the first level.

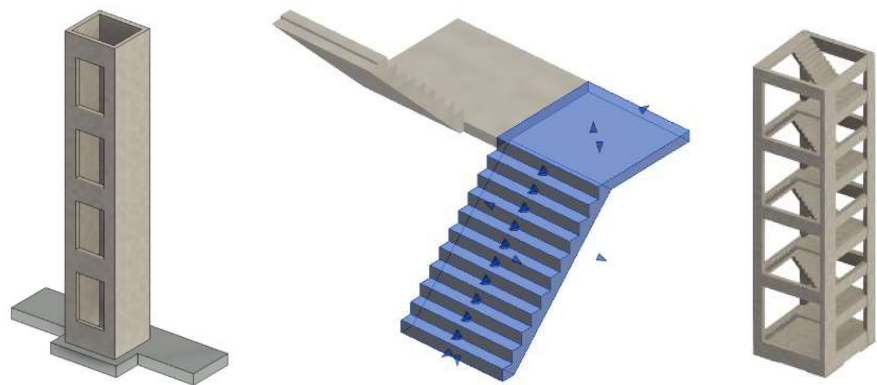


Figure 10. Model of the elevators core and of the stars.

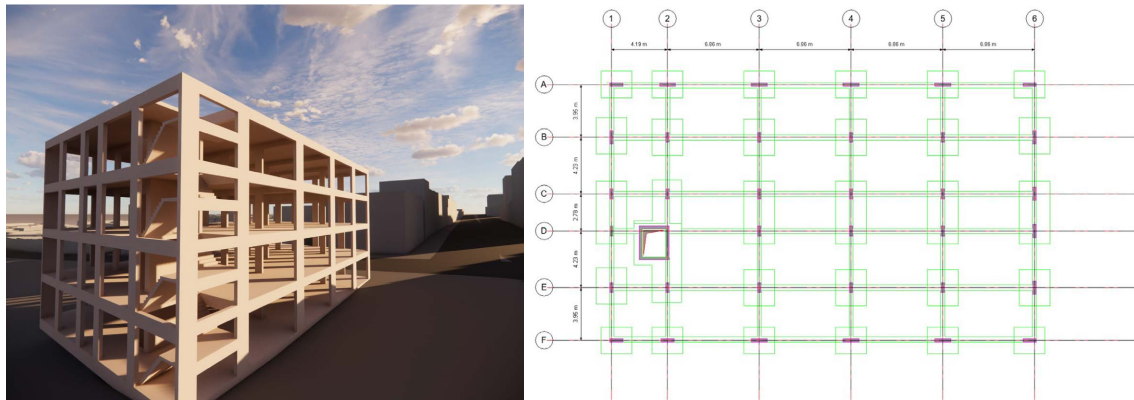


Figure 11. A realistic image of the structural project and the foundation plant.

type of information associated with each object.

3.2. Analytical Model

After completing the physical modelling of the structural solution, Revit enables the automatic generation of the respective analytical model (**Figure 12**). Each physical structural objects have attributes associated with finite elements (FEM) and physical properties. Despite the analytical model being generated automatically, the engineer needs to carefully check its consistency. Revit allows manual adjustment, where a node of the analytical model is dragged from one position to other, independently of its representation in the model.

Through the observation of the global analytical model, some inconsistencies were identified. Therefore, the required adjustments were made, before doing the transposition of the analytical model to the structural analyses software (**Figure 13**):

- The analytical **beams** were slopped positioned towards the orthogonal axis, since the analytical representation of the column was located at its geometric centre, which does not coincide with the intersection of the axis of the beams;
- Thus, the **column** was positioned on the desired reference line by modifying the *Base* and *Top Alignment* in the analytical alignment function concerning the analytical column elements;
- The ground floor was modelled as a **slab** element. However, this element does not have a resistant function supporting the stresses to which the structure is subjected. Thus, in the correspondent parametric object the characteristic *Structural* was removed. Whenever, it is not possible to adjust the analytical element through its properties, Revit allows manual adjustment, where a node of the analytical model is dragged from one position to other, independently of the physical representation in the model (**Figure 14**).
- In Revit, the analytical representation of the **foundations** corresponds to nodes, which are converted, in Robot, into a clamped support. However, if boundary conditions are applied in Revit, Robot assumes that information. In this case a pinned support was applied at the base of the columns (**Figure 14**);

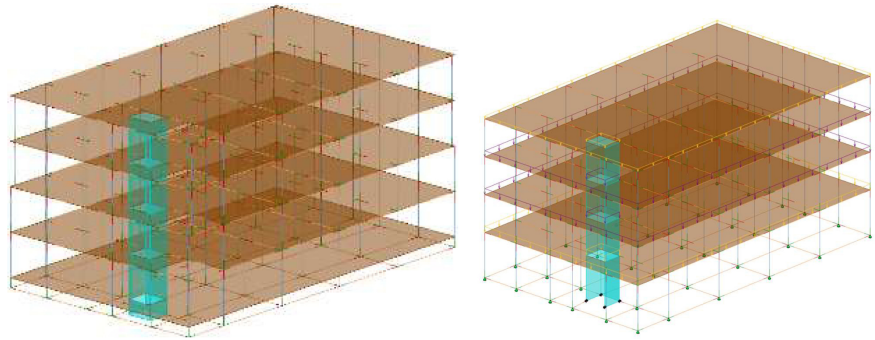


Figure 12. Automatic generation of analytical model with adjustments.

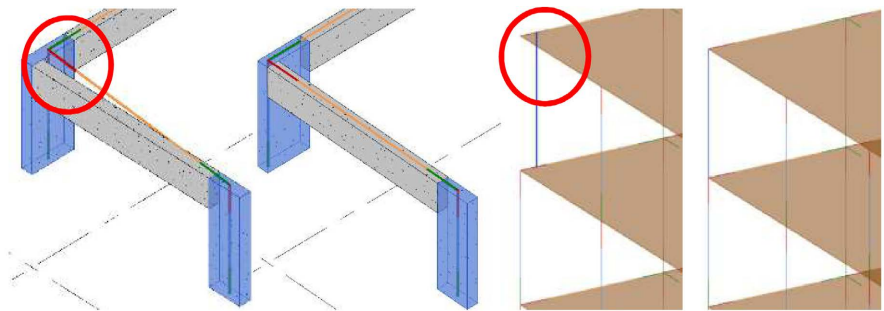


Figure 13. Adjustment of a beam in the analytical model.

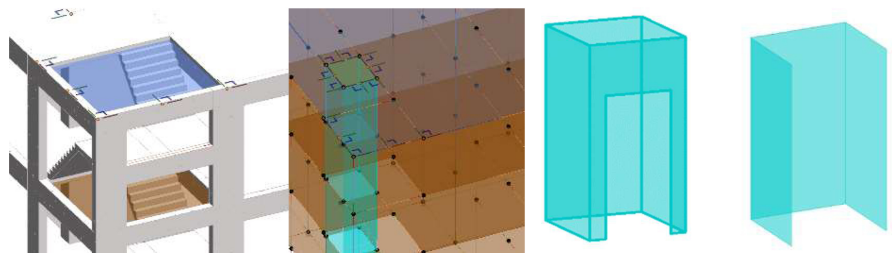


Figure 14. Manual adjustment of the analytical model concerning the stairs and the elevator core.

The base foundation of the **core walls** is located at a lower level of the beam elements. Because the analytical model is a simplification of the reality, the base level of the shell has changed, but they are positioned at the same level. It is possible to make this kind of modification to the properties of the analytical walls by placing the base extension at the level of the foundations (**Figure 15**).

Once the adjustments have been completed, Revit includes a function that allows to check the geometric consistency over the analytical model.

3.3. Structural Analysis

Again the Revit model is transferred to Robot. In Robot, after a consistency check of the transposed model, it was verified that most of the data was transferred correctly, except the value of the spring stiffness of the elastic support, which present an incorrect situation. Robot can automatically generate the combinations of loads and apply them effectively. The application of the standard

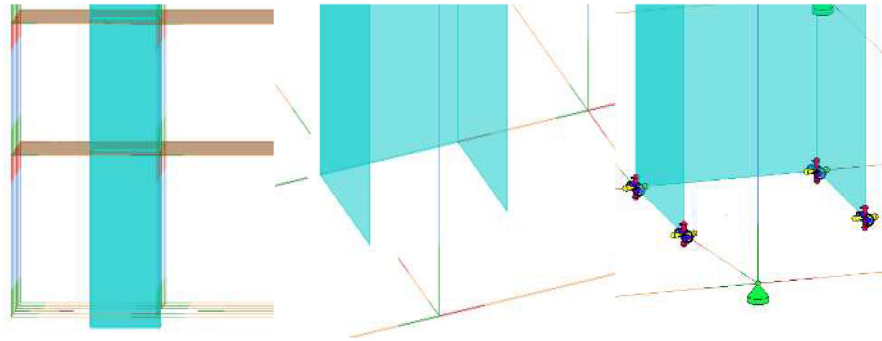


Figure 15. Irregular position of the analytical wall and beams connection to the wall.

loads over the structure, as well the loads combinations, were made in Robot. Robot can automatically generate the combinations of loads and apply them effectively (Table 2). The analyses results verify the Ultimate Limit State (ULS) and the Service Limit State (SLS).

The applications of the standard loads over the structure, as well the loads combinations, were made in Robot. The analyses results verify the Ultimate Limit State (ULS) and the Service Limit State (SLS).

3.4. Reinforcement Detailing

As mentioned, Robot allows an automatic calculation of the reinforcement according to the Portuguese standard following the Eurocodes 2 and 8. In the determination of the provided reinforcement, several parameters were manipulated in order to obtain an adequate solution, accordingly to the engineer knowledge and experience. The safety of each resistant element was verify.

The software presents a possible solution, but the engineer must conceive properly the most adequate bars distribution. When the reinforcement is calculated, the Robot displays the solution, representing the reinforcement's distribution as plant drawings, but also as a 3D model (Figure 16).

3.5. Software Interoperability

After the reinforcement work is completed, it is possible to update the initial Revit model, with the reinforcement details (Figure 17):

- Concerning **slabs** it is possible to build an effective reinforcement solution in Robot. However, only the diagrams of forces can be transferred from Robot to Revit. The required reinforcement must be defined after in Revit. The interoperability capacity is inefficient in this step;
- In the case of the **beams**, the transfer process is the most efficient. Namely, concerning the transfer of the reinforcements of single multi-span beam;
- Regarding **columns** and **foundations** either the interoperability or the automatic calculation are both done with correction.

As some reinforcements were not transfer in efficient way, Revit includes a plugin that allows to complement all the structural model, with the required

Table 2. Loads combinations.

Combinations	Name	Combination type	Case nature	Definition
4 (C)	ULS	ULS	structural	$(1 + 3) \times 1.35 + 2 \times 1.50$
5 (C)	SLS-QP	SLS-QPR	structural	$(1 + 3) \times 1.00 + 2 \times 0.30$
6 (C)	RARA	SLS	structural	$(1 + 3 + 2) \times 1.00$
12 (C) (CQC)	$1 \times 0.3 \times Y$	ULS	seismic	$8 \times 1.00 + 9 \times 0.30$
13 (C) (CQC)	$1 \times (-0.3) \times Y$	ULS	seismic	$8 \times 1.00 + 9 \times (-0.30)$
14 (C) (CQC)	$0.3 \times 1 \times Y$	ULS	seismic	$8 \times 0.30 + 9 \times 1.00$
15 (C) (CQC)	$0.3 \times (-1) \times Y$	ULS	seismic	$8 \times 0.30 + 9 \times (-1.00)$

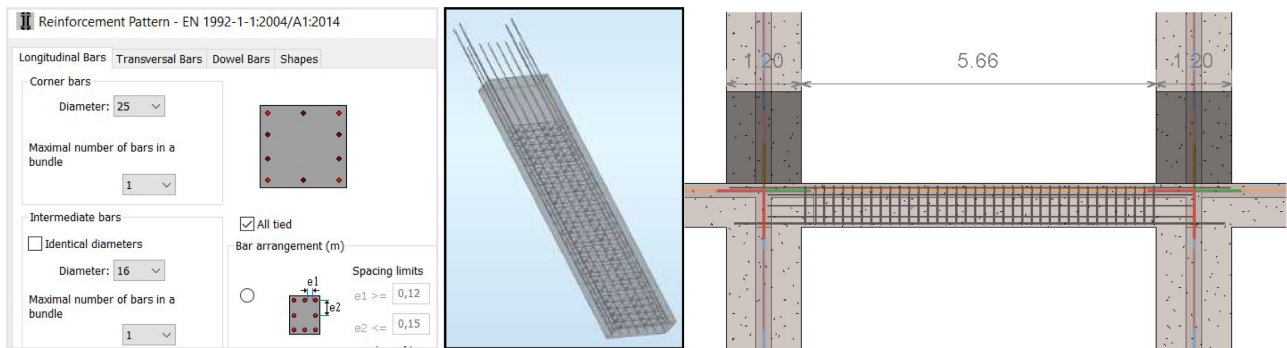


Figure 16. Reinforcements in a column and a beam.

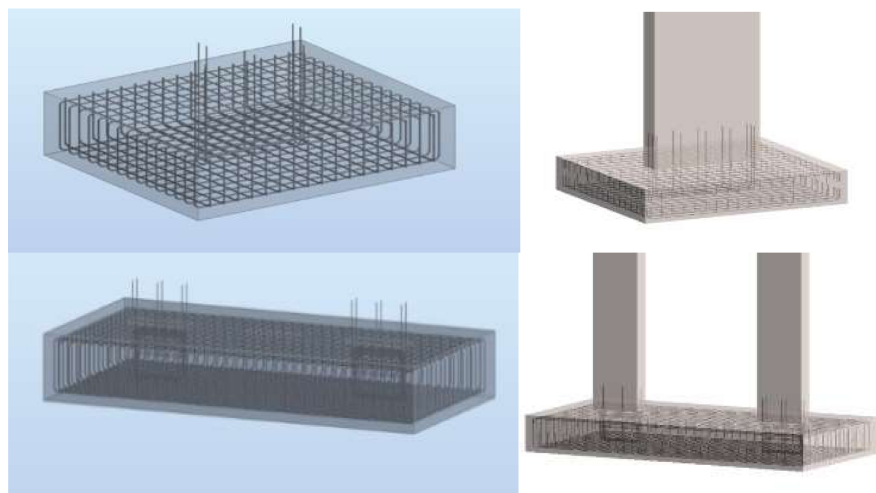


Figure 17. Interoperability between Revit and Robot.

reinforcements. The Rebar modelling interface allows advantages such as obtaining the reinforcement details with automatic identification and accurate immediate quantity take-off (Figure 18).

So, despite the constant effort in research, carried out in academic and business environments, the persistent limitation of interoperability in some of the tasks that require model transfer, in the pursuit of the development of different stages of the project, the technology market still does not provide a completely

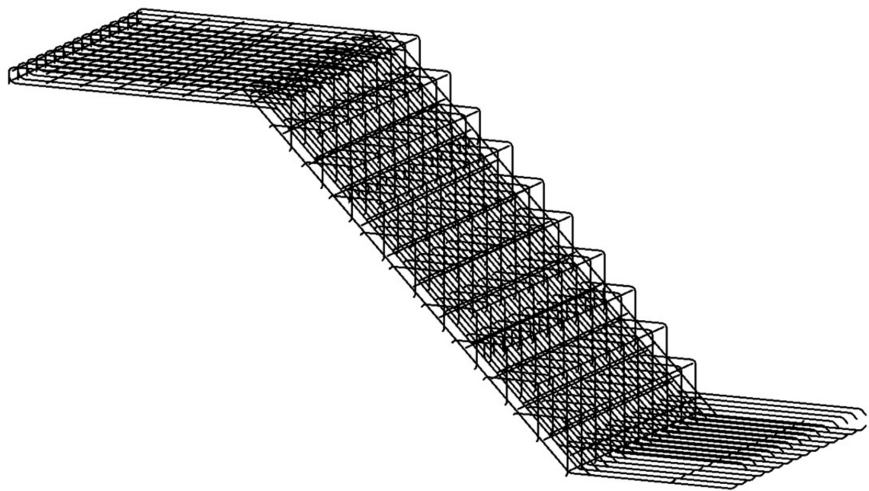
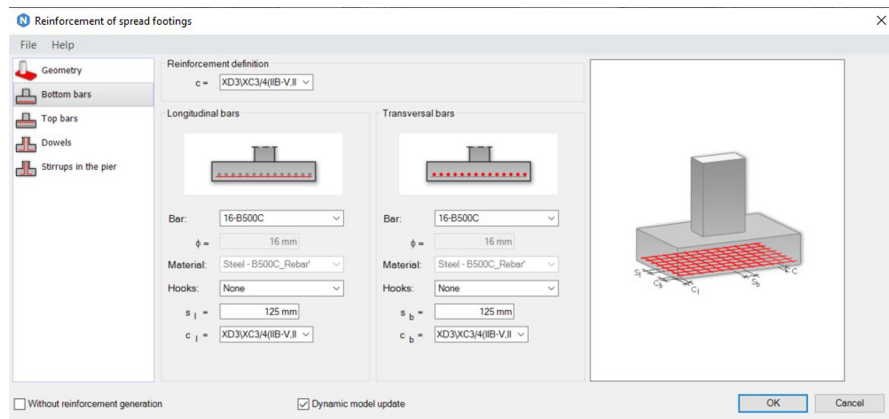


Figure 18. Reinforcements modelling interface concerning the foundations and the stair element.

effective solution, negatively affecting its implementation [12]. This makes interoperability the main practical barrier to successful BIM adoption in the industry [13].

4. Management of the BIM Model

As mentioned, BIM supports the elaboration of a wide range of applications that satisfy different objectives based on the project information contained in the model database. These tasks correspond to the distinct BIM dimensions that are frequently designed as nD BIM [14]:

- **3D BIM** represents the set of 3D parametric objects referring to all the specialties (geometry, spatial inter-relation, and physical properties of the materials);
- **4D BIM** is concerned with the planning of the construction process associating the model to the critical path chain established in each case;
- **5D BIM** is related to the project estimation costs supported by the automatic quantity take-off of materials and components;
- **6D BIM** supports the performance of sustainability studies, namely the si-

mulation of the energy consumption or the CO₂ emissions;

- **7D BIM** is considered in the management and maintenance of the building during its period of use.
- **8D BIM** is associated to the safety risks during the construction work supporting to set up preventive action plans.

Revit provides several options for programming how information is displayed by changing or creating families, allowing for adjustments to aspects related to text, color, thickness, etc. It also allows for more advanced capabilities through programming in Dynamo, a graphical programming platform directly accessible through Revit. However, these features require a high level of user experience.

Analyzing the current state of Revit software, it is noteworthy the ease in creating plans, elevations, and sections, compared to traditional methods, but in the detailing of drawn parts, for the nomenclatures to be according to the desired by the user, it is necessary a high spending of time. However, within a design office, this work should be developed, because the routines and the automation programs to support graphic representation are reusable and adaptable to each project.

4.1. Coordination and Collaboration

Revit saves the information about the results of the diagrams of forces, displacements and the required reinforcement area of each element from the calculation performed in Robot. The ability to centralise information is quite helpful when, in a reinforcement modelling or design review process, the engineer wants to consult the data of the structural analysis.

The great advantage of BIM programs compared to CAD tools is that all sections, plans and details can be generated automatically, from the most actualized model, and there are no inconsistencies between drawings. Formatting drawings is a task that causes a decrease in productivity, as it still requires a repetitive work (Figure 19).

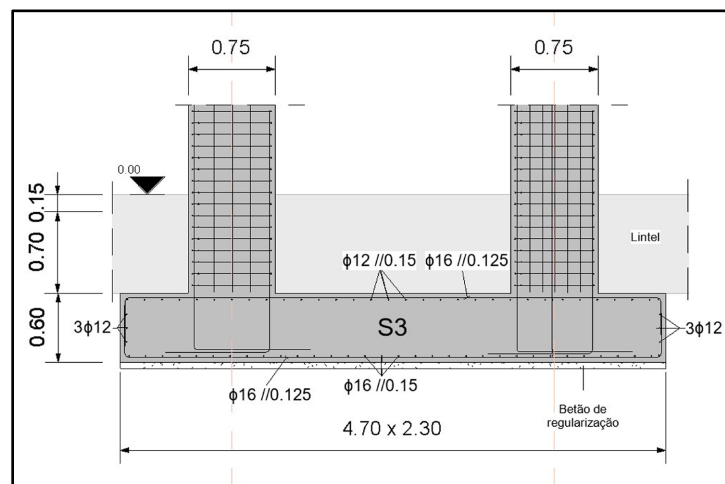


Figure 19. Detailing of a continuous foundation before and after text marks application.

One of the most used applications, concerning the coordination of a project, is the software capacity to detect conflicts between specialities, in an automatic way [15]. This adaptation is extremely relevant since it is not possible to spot inconsistencies in the project so quickly, that would otherwise only identified and resolved on site [16]. Revit allows the user to check interference in the project itself through the Interference Check feature (Figure 20).

4.2. 4D and 8D Dimension of BIM

Associating the time factor to sets of objects of the model, it is possible to simulate the construction phase, supporting the construction planning establishment [17]. The model that links the components of the model to time periods related to construction activities, is referred as a 4D model (Figure 21).

The simulated representation of the construction assists also the risk assessment that the worker may experience, as it allows to identify the situations in the construction site that require special attention in terms of precautions. This other activity, supported also on the BIM model, is mentioned as an 8D model.

4.3. 5D Dimension

The estimating cost activity, concerning the structural project, was also carried out, operating over the BIM model, by associating a unit cost to each material or object (Figure 22). This functionality is crucial when comparing technical-economic studies of alternative solutions.

4.4. 6D Dimension

A sixth dimension can be included in the project, by attributing the information of the amount of CO₂ incorporated in each element (Figure 23). Through the analyses of the schedules, it is possible to estimate the quantity of carbon emissions

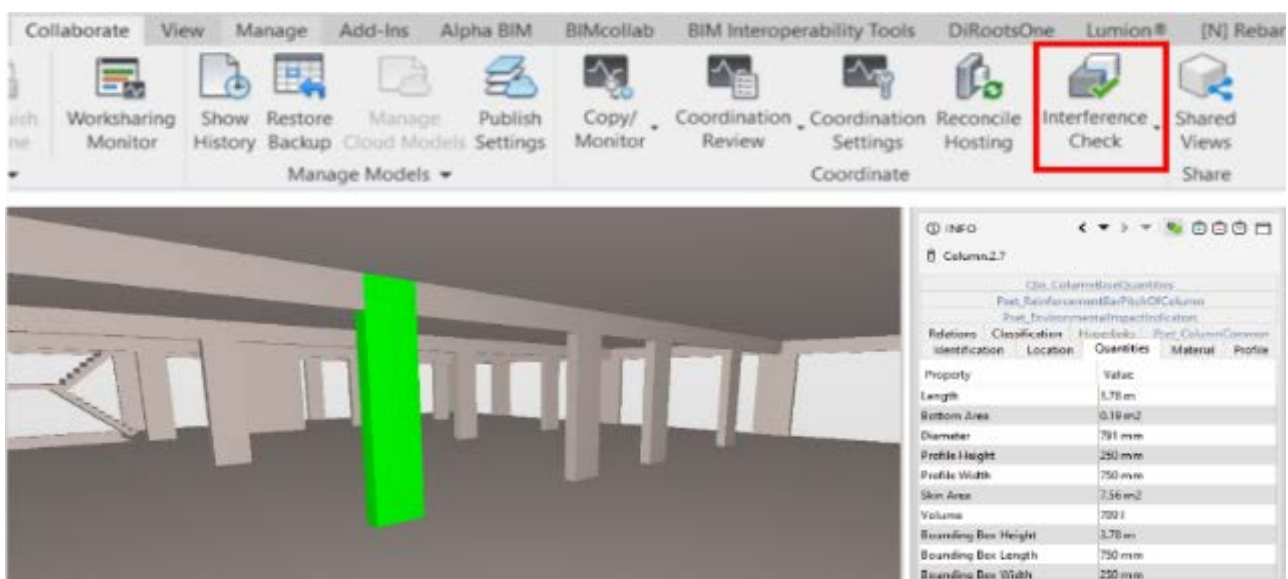


Figure 20. Interference check applied in the intersection of beams and columns.

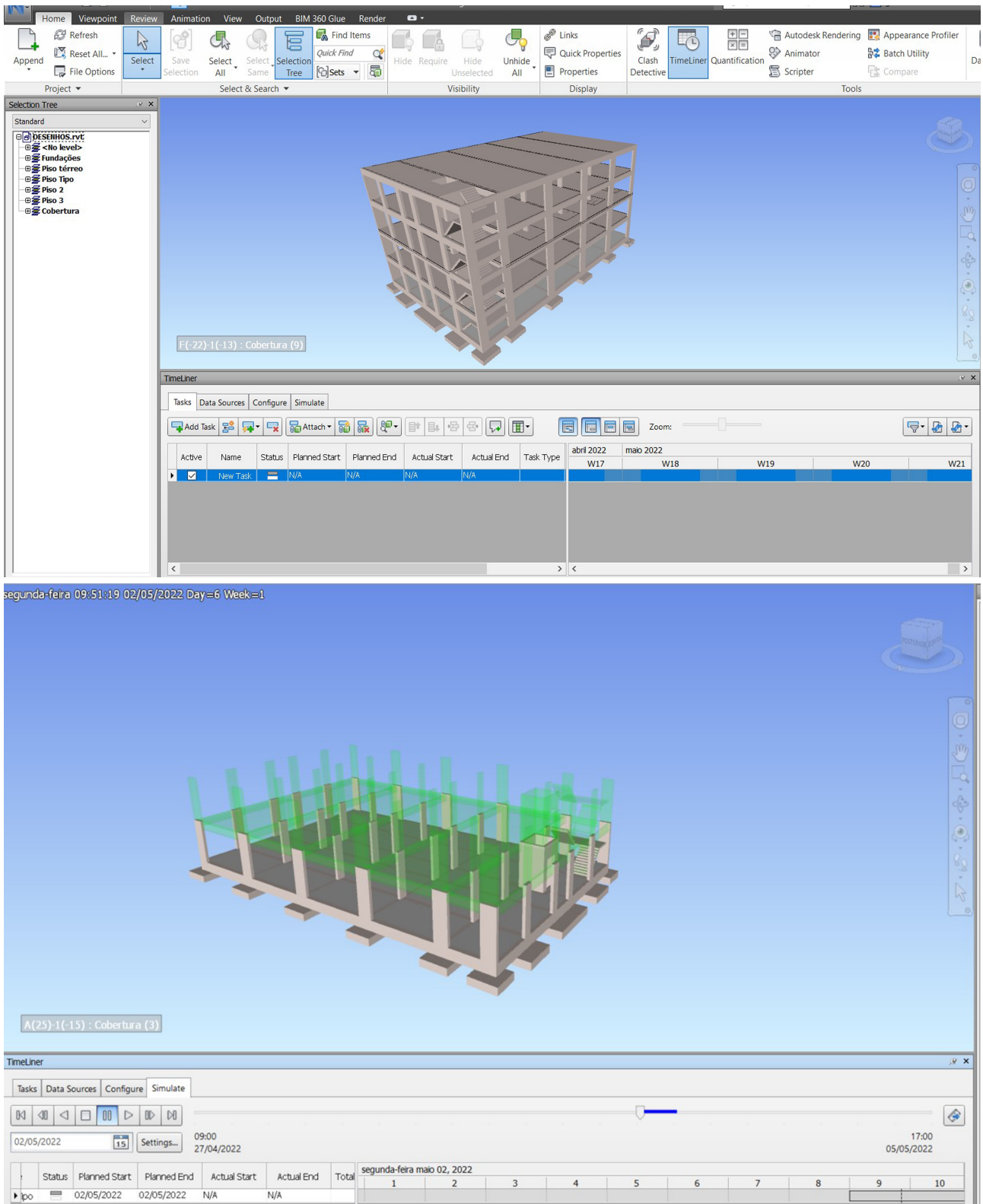


Figure 21. The Navisworks timeliner and images of the construction process.

of each material used in the structure, supporting the decision making of the solution.

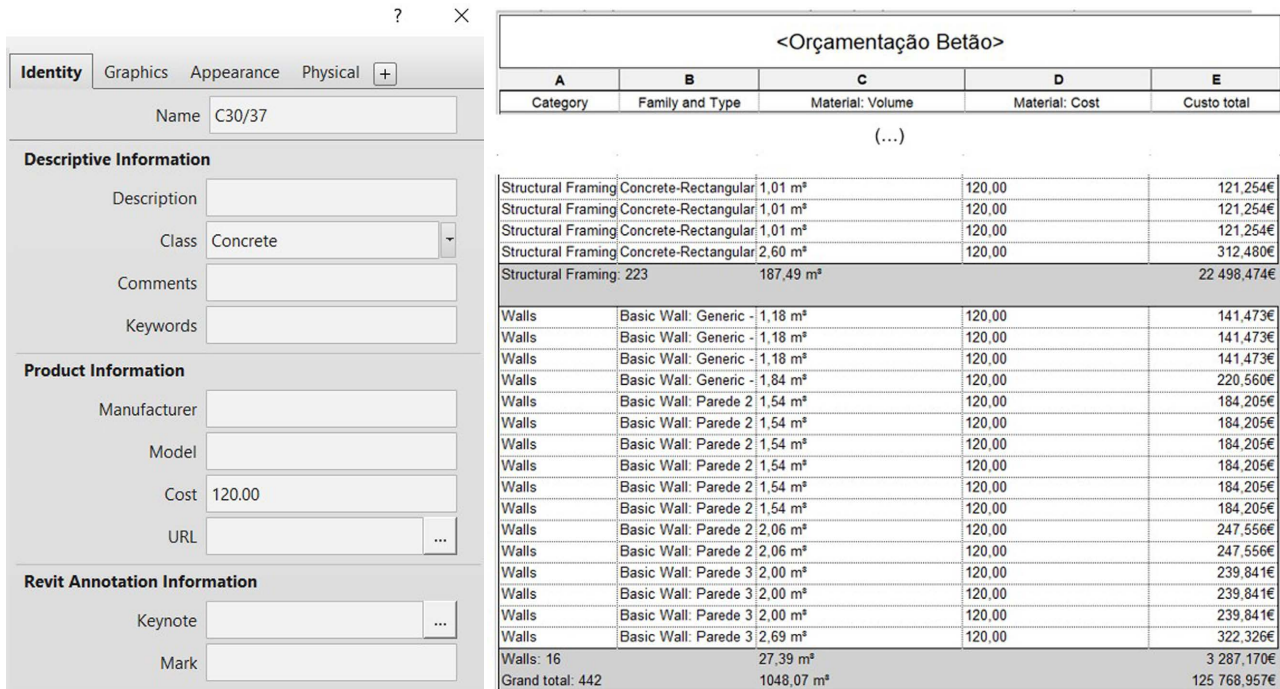


Figure 22. Quantity take-off of concrete.

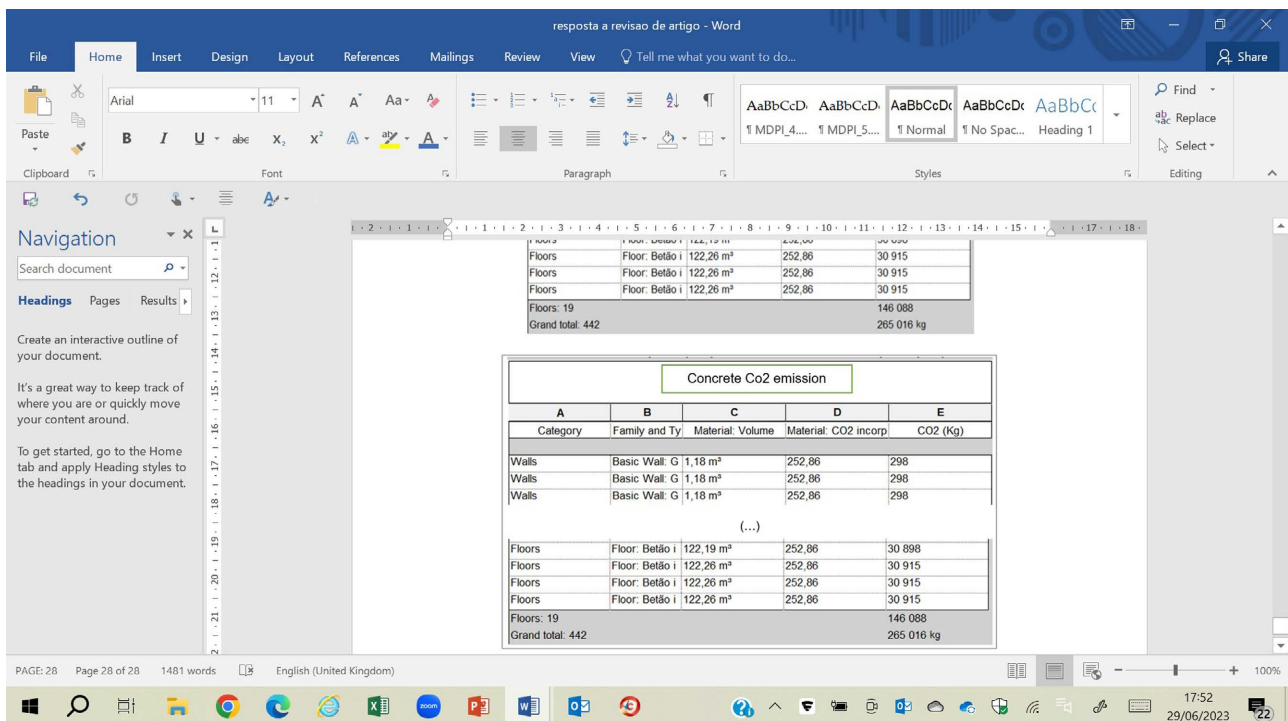


Figure 23. Quantity of CO₂ emissions associated to concrete elements of the structure.

5. Conclusions

The technological advances associated with the BIM methodology have been showing benefits in productivity and construction quality. This study aimed to analyse the benefits of using BIM methodology in the execution of a structural

design, as well as the limitations related to interoperability between Revit and Robot software, and the individual limitations of each program.

The main benefits are focused essentially on aspects related to the correct functionality, speed, and simplicity in the execution of some processes. In addition, the limitations that were found, are mainly related with the analytical model that is not yet completely independent from the physical one, the automatic design does not yet allow a solution to be developed with the desired integration and efficiency and the interoperability capacity that is still limited and may not provide engineers with the necessary confidence.

Despite some limitations, there is, however, some optimism in the adoption of BIM in structural design, either due to competition need in a global world, or because the new generation of engineers is culturally more technological. Technological innovation is growing exponentially and it is necessary that the industry is aware and open-minded in the search for solutions in order to achieve a more efficient and better-quality construction.

Acknowledge

This work is funded by national funds through FCT—Foundation for Science and Technology, I.P., under the research centre CERIS—Civil Engineering Research and Innovation for Sustainability, Lisbon, Portugal

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Succar, B. (2008) Building Information Modelling Framework: A Research and Delivery Foundation for Industry Stakeholders. *Automation in Construction*, **18**, 357-375. <https://doi.org/10.1016/j.autcon.2008.10.003>
- [2] Sacks, R., Eastman, C.M., Lee, G. and Teicholz, P.M. (2018) BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers. 3rd Edition, Wiley, Hoboken. <https://doi.org/10.1002/9781119287568>
- [3] Sampaio, A.Z. (2017) BIM as a Computer-Aided Design Methodology in Civil Engineering. *Journal of Software Engineering and Applications*, **10**, 194-210. <https://doi.org/10.4236/jsea.2017.102012>
- [4] Sampaio, A.Z. (2021) Maturity of BIM Implementation in Construction Industry: Governmental Policies. *International Journal of Engineering Trends and Technology*, **69**, 92-100. <https://doi.org/10.14445/22315381/IJETT-V69I7P214>
- [5] Ren, R., Zhang, J. and Dib, H.N. (2018) BIM Interoperability for Structure Analysis. *Proceedings of ASCE-Construction Research Congress 2018*, ASCE Construction Research Congress, New Orleans, 470-479. <https://ascelibrary.org/doi/abs/10.1061/9780784481264.046>
- [6] Shehzad, H.M.F., Ibrahim, R.B., Yusof, A.F. and Khaidzir, K.A.M. (2019) Building Information Modelling: Factors Affecting the Adoption in the AEC Industry. 2019

- 6th International Conference on Research and Innovation in Information Systems (ICRIIS), Johor Bahru, 2-3 December 2019, 1-6.
<https://doi.org/10.1109/ICRIIS48246.2019.9073581>
- [7] Shirowzhan, S., Sepasgozar, S.M.E., Edwards, D.J., Li, H. and Wang, C. (2020) BIM Compatibility and Its Differentiation with Interoperability Challenges as an Innovation Factor. *Automation in Construction*, **112**, Article ID: 103086.
<https://doi.org/10.1016/j.autcon.2020.103086>
- [8] Sequeira, P. (2022) Analysis of BIM Technology Capabilities in the Generation of 4D Models. Master's Thesis, University of Lisbon, Lisbon.
- [9] Sampaio, A.Z., Sequeira, P., Gomes, A.M. and Sanchez-Lite, A. (2023) BIM Methodology in Structural Design: A Practical Case of Collaboration, Coordination, and Integration. *Buildings*, **13**, Article 31. <https://doi.org/10.3390/buildings13010031>
- [10] Azevedo, G. (2022) Implementation of the BIM Methodology in the Project of Structures: Adaptation of Procedures and Information Management. Master's Thesis, University of Lisbon, Lisbon.
- [11] Gomes, A.M., Sampaio, A.Z., Azevedo, G. and Sanchez-Lite, A. (2023) BIM in Structural Project: Interoperability Analyses and Data Management. *Applied Science*, **12**, Article 8814. <https://doi.org/10.3390/app12178814>
- [12] COBIM Finland (2012) Common BIM Requirements 2012—Series 5—Structural Design.
https://asiakas.kotisivukone.com/files/en.buildingsmart.kotisivukone.com/COBIM2_012/cobim_12_bim_fm_v1.pdf
- [13] Boukara, A. and Aziz, N. (2015) A Brief Introduction to Building Information Modeling (BIM) and Its Interoperability with TRNSYS. *Journal of Renewable Energy and Sustainable Development*, **1**, 126-130.
<https://doi.org/10.21622/resd.2015.01.1.126>
- [14] Sampaio, A.Z. (2022) BIM Academic Training Course to Enhance Construction Professional's Skills. *Technical and Vocational Education and Training*, In Ye, J.-H. and Jiang, M., Eds., IntechOpen, Budapest.
<https://doi.org/10.5772/intechopen.105221>
- [15] Wong, J.K.W. and Zhou, J. (2015) Enhancing Environmental Sustainability over Building Life Cycles through Green BIM: A Review. *Automation in Construction*, **57**, 156-165. <https://doi.org/10.1016/j.autcon.2015.06.003>
- [16] Aksenova, G., Kiviniemi, A., Kocaturk, T. and Lejeune, A. (2018) From Finnish AEC Knowledge Ecosystem to Business Ecosystem: Lessons Learned from the National Deployment of BIM. *Construction Management and Economics*, **37**, 317-335.
<https://doi.org/10.1080/01446193.2018.1481985>
- [17] Khudhair, A., Li, H., Ren, G. and Liu, S. (2021) Towards Future BIM Technology Innovations: A Bibliometric Analysis of the Literature. *Applied Sciences*, **11**, Article 1232. <https://doi.org/10.3390/app11031232>