BIM METHODOLOGY APPLIED TO THE STRUCTURES PROJECT

Reconversion of a Heritage Building

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ABSTRACT

The Building Information Modeling (BIM) concept is based on the development of a centralized digital model of all building information in a more integrated and optimized way, based heavily upon parametric modeling and data storage capacity. Although the basic BIM tools, in current use, are more geared towards new construction, they have led to the application of BIM in support of the conservation of historical properties and, subsequently, to their rehabilitation. In developing a BIM project, several design analysis and dimensioning programs are utilized to integrate the different areas of construction. As such, exchange standards are used to guarantee the transfer of digital data from the project.

In the context of the present work, the conversion of a building of great patrimonial value is proposed, along with the alteration of the internal organization of its compartmentalization. The proposed remodeling involves an architectural study that leads to the establishment of a project. The primary objective of the project is to design and analyze a structural solution of a composite slab, using patterns of digital data exchange between BIM based programs. The project aims to drive the implementation of BIM methodology in construction projects of heritage buildings in Portugal, both through the development of libraries for families of certain intelligent objects, and strategies to overcome the inherent limitations of the degree of interoperability found in the case of study.

Keywords: BIM, HBIM, Parametric Objects, BIM Interoperability, Composite Slab, Structures, Project

1. INTRODUCTION

Currently, one of the most relevant topics among specialists in the field of Architecture, Engineering and Construction (AEC) is the evolution of tools for the development of projects that incorporate greater automation and reduce the work for these professionals. As such, the concept of Building Information Modeling (BIM) is introduced, a methodology that allows for the elaboration of projects in a more integrated and optimized way than the traditional one, leading to more efficiency and encouraging the collaboration of all professionals. The methodology is based on the development of a three-dimensional model on the fully parameterized BIM platform, with enough aggregate intelligence that all participants can take advantage of the integrated information throughout the life cycle of a building. The idea of building only one physical asset is outdated and begets the need for a digital information model that can not only accompany the design and construction phases, but also the operation and maintenance, allowing all those involved in the labor to work with updated and readily available data.

Over the past few years, increasing emphasis has been placed on maintaining the cultural identify of each region of Portugal, ensuring that its national history is not forgotten. The adoption of digital technology methods has led to an increase in the useful life of buildings or historic areas, guaranteeing their functionality and rehabilitation, as well as maintaining the testimony left.

The purpose of this work is to encourage the use of the BIM methodology in structural projects for the recovery of properties with patrimonial value in Portugal. By analyzing the degree of existing interoperability, this work reveals the advantages and limitations of interchange standards when transporting a composite structure of steel and concrete. The work intends to further the understanding of how the BIM concept can contribute to the construction sector, through the establishment of its own conservation methodologies while always respecting the properties' cultural trait.

2. BUILDING INFORMATION MODELING (BIM)

Construction is considered one of the sectors with the highest consumption of human and material resources, contributing heavily to the economy in each country. The industry started implementing the BIM methodology at the beginning of the XXI century, with the objective of anticipating decisions and minimizing errors. The methodology was based on the generation of a representative 3D digital model of the project, and on the easy extraction of data for its application in several tasks inherent to the project (Eastman *et al.*, 2008). The BIM concept creates an interconnection between the various areas that intervene in the construction of an edifice (Building), in the transfer of data (Information) and in the creation of an organized virtual model (Modeling) (Azhar *et. al.*, 2012).

In a BIM environment, the building is virtually modeled using parametric objects representative of the components used in the real construction, allowing architects and engineers to develop the projects with a strong visual support of the three-dimensional and realistic aspect of the construction (3D model). The information generated in the elaboration process is stored in a database organized in a hierarchical way, allowing for the definition of activity schedules (4D model), cost estimation (5D model), energy analysis simulation (6D model) and equipment maintenance plans (7D model) (Sampaio and Araújo, 2019). The BIM model is also capable of predicting possible risks in the model and, thus, ensures the safety of workers on site (8D model), and identifies potential waste that may affect their productivity and efficiency (9D model). The ultimate goal of the application of the BIM methodology is its industrialization in the construction sector, through the introduction of new technologies led by its digitization (10D model) (Darós, 2019) (Figure 1).

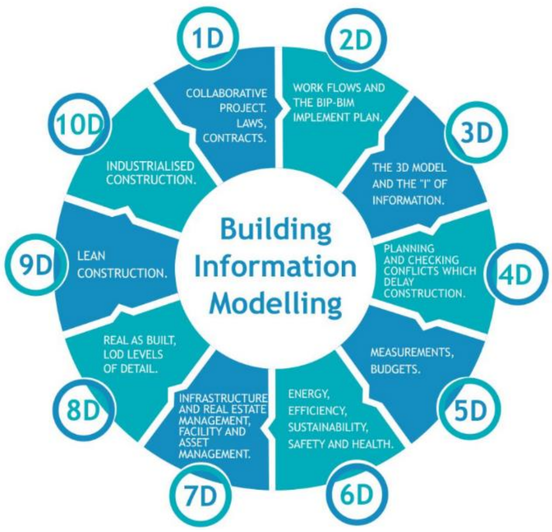


Figure 1: Building Standards (CentreLine Studio, [s.d.]).

The implementation of BIM in the construction sector has led to an improvement in product quality and control of time and cost in construction projects, supporting the coordination and transfer of the digital project and the planning and monitoring of the construction process on site (Grabowski, 2010). The European Commission (2017) states that the European market was valued at 1.8 billion euros in 2016 and foresees an increase of 13% in 2023, reaching 2.1 billion euros with the integration of the BIM methodology in construction projects.

In Portugal, the implementation of BIM is still incipient, but a relevant project has been developed by the "*Comissão Técnica CTº197*" with the aim of regulating BIM activity at a national level (Aguiar Costa, 2020). It is important to raise the market's awareness of the benefits of BIM for the construction sector in Portugal and create communication channels that provide real examples and testimonies to all professionals of the emergence of BIM adoption.

2.1. INTEROPERABILITY

The three-dimensional models of a building need to be shared between all stakeholders in the project. It is therefore necessary to ensure an adequate degree of interoperability between the BIM systems through the use of interchange standards. This guarantees the sharing of data through the entire life cycle of the building between the various software and digital platforms, allowing for the maintenance of an accurate and always updated model and avoiding the reinsertion of data and significant data losses (Queiróz *et. al.* 2019).

2.2. HBIM

The Heritage/Historic Building Information Modeling (HBIM) concept makes it possible to adopt specific methods of conservation and preservation of cultural real estate, guaranteeing an exact and precise model with architectural and structural quality. The objective of HBIM is, therefore, to obtain intelligent models of existing buildings, through the creation of specific parametric objects that contain information of any type, which can be updated, replaced and added. The idea of creating a three-dimensional model that stores all types of information in its database - from schematics to technical drawings, photographs or even documentation of archives – is fundamental for conservation or structural rehabilitation projects, a target of great interest in the present work (Castellano-Román and Pinto-Puerto, 2019).

3. CASE STUDY – BUILDING OF A GREAT PATRIMONIAL VALUE

The maintenance of buildings of historical and architectural value requires expenses that can constitute a significant liability for the private owner. The strategy for the conservation of historical buildings often consists of a remodel that is fragmented into individual housing plots, while preserving the building's identity. The selected case study is the "*Casal de S. José*" mansion, located in Campo Grande, Lisbon, which was built in the early XX century (Figure 2).

Figure 2: Main (1924) and Posterior (1952) Facades (AML, 2019).

The building consists of a ground floor, an elevated floor and an attic with a mansard roof. The project plan has "U" geometry and its height is defined by a variable ceiling height of 2.85 *m* on the ground floor, 3.25 *m* on the raised floor and 2.65 *m* in the mansard area of the attic.

3.1. RECONVERSION PROJECT

Within the scope of this work, it is proposed to convert the building into four apartments, types T2 and T3, and the attic space for storage in accordance with current regulations. Of particular import will be maintaining a large part of the historical main facade. The intended remodeling began with an initial collection of documents requested from the city archive. Next, a detailed architectural survey and visual inspection of the state of conservation were carried out, leading to the establishment of options for minimally resistant and intrusive solutions.

The architectural intervention study was carried out on the correct representation of the mansion and the conversions drawings were created with the identification of elements to be demolished (yellow), to be built (red) and to be replaced (green) for the different floors (Figure 3).

Figure 3: Demolition and constructions plans.

The most relevant structural intervention corresponds to the replacement of the wooden floor of the raised floor, which hardly satisfies the necessary resistance to support the new distribution of interior walls, in ceramic masonry, and the coating of the wet areas, with hydraulic tiles, which impose a weight increase.

4. BIM MODELING OF THE BUILDING

The BIM process is mainly aimed at supporting the development of new building projects, and object libraries support this type of construction. However, in the context of HBIM, cultural heritage is characterized by its complex and inhomogeneous morphology, which contradicts the standardized procedures of BIM. The present study required the development of a library of its own parametric objects for a correct representation of the mansion, accomplished through drawings from the city's archives and a sufficiently detailed survey on the spot.

The model is thus created in such a way as to accurately represent the stonework details of windows, doors and friezes on the façade as well as the supporting walls on which the decorative elements are applied. All other façade walls and interior partition walls of the new apartments are also modeled, as well as the floors and the roof (Figure 4).

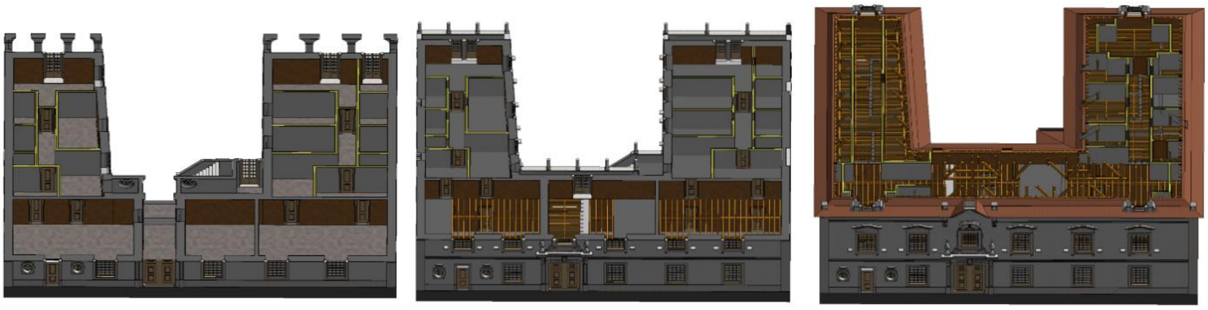


Figure 4: ***Casal S.José's*** **parametric model.**

The complexity of the modeling of all families of objects was immense, as it was stipulated that the representation in BIM should be carried out with high rigor. The use of the modeling capabilities allowed by the software was laborious, but they proved to be sufficient to achieve the intended objective. However, and as a result, the mansion's individuality has been preserved, allowing the model to be used in the future for the further conservation of its heritage and cultural value. This framework demonstrates that it is possible, through tools provided by the software, to protect the architectural heritage left by ancestors that describe our history and in doing so realizes the goal of the HBIM methodology.

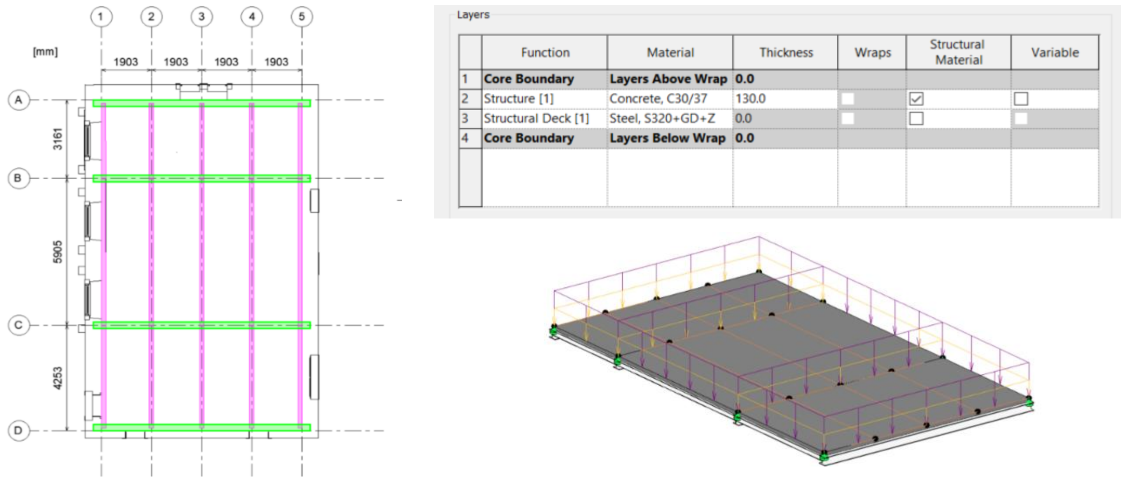
5. STRUCTURAL REHABILITATION

The basis of the BIM methodology, as the main support system for the project, consists of its ability to integrate a large amount of data, which can be shared with all members of the Architecture, Engineering and Construction (AEC) sector. BIM software specialists work daily to overcome the barrier that separates the various sectors of the AEC and, thus, allow for good communication and an appropriate exchange of information between the various software used (Gayer, Ap and Asce, 2009).

In addition to the BIM model of the structure of the existing building, the interoperability of the tools used in the modeling and design of a composite slab was evaluated, which replaces the wooden floors of the building's side wings. This solution involved a pre-dimensioning, which started with the parameterization of structural model in *Revit 2019*.

The steel – concrete composite slab consists of rolled or built-up structural steel beams and cast in-situ concrete floors connected together using shear connectors in such a manner that they would act monolithically. Composite floors using profiled steel sheeting became popular in high rise office buildings. Composite deck slabs are particularly competitive where the concrete floor has to be completed quickly and where medium level of fire protection to steel work is sufficient. These are resistant in the direction of the ribs of the profiled sheet decking, and for this reason, it can be analyzed as reinforced slab in one direction (Calado and Santos, 2013). In this way, it was decided to support the sheets on the *HE160B* (purple), with the ribs perpendicular to them, which in turn unload on *HE280B* main beams (green) and, later, on the masonry walls, as observed in the Figure 5.

The secondary beams are simply supported on the main beams, as well as the main ones on the masonry walls. In this way, it is possible to take advantage of the partial connection, which can only be used for positive moments and aims to reduce the compression force of the concrete flange and, consequently, the resistant moment, by reducing the number of shear connectors. The actions, combinations and support conditions were also modeled in the *Revit* environment (Figure 5).



	Function	Material	Thickness	Wraps	Structural Material	Variable
1	**Core Boundary**	**Layers Above Wrap**	**0.0**			
2	Structure [1]	Concrete, C30/37	130.0	☐	☑	☐
3	Structural Deck [1]	Steel, S320+GD+Z	0.0	☐	☐	☐
4	**Core Boundary**	**Layers Below Wrap**	**0.0**			

Figure 5: Composite slab parametrization.

5.1. REVIT TO ETABS

The *Industry Foundation Classes* (IFC) standard was used to transport the model to *ETABS 2018* and, thus, perform the structural analysis of the composite beams, which is permitted by the shear studs.

The digital data export process proved to be inefficient as neither the grid, the support conditions or the arrangement of the structural elements were exported, demonstrating an inadequate degree of interoperability. However, to avoid completely discarding the process, some of the conditions in the *Revit* parameterized model were adapted and changed. The transfer was then repeated by matching the geometric lines of the steel beams with their analytical lines, changing the spatial position of the two main alignments of the structure design plan for the coordinate point (0;0), and by saving the grid in *.dxf* format. With these changes, the position of the model and the grid were successfully exported (Figure 6).

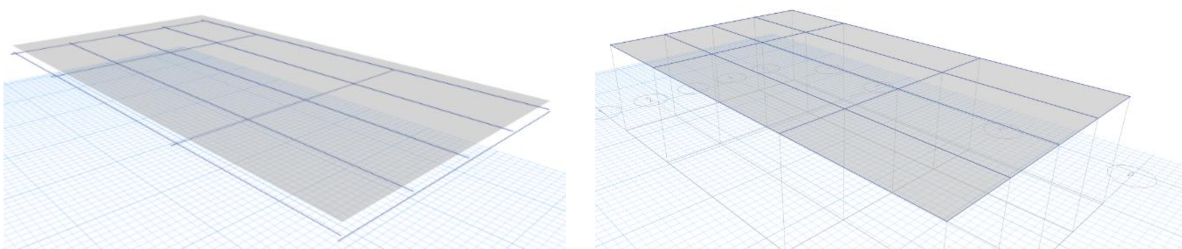


Figure 6: Composite slab transposition to *ETABS*: 1st Attempt and 2nd Attempt.

When analyzing the model in detail, other errors were found in the structures, namely in the physical properties of the materials, in the support conditions, in the slab geometry, on the rotating positioning of the *HE280B* main beams and in the actions on the structure. As such, it was necessary to reconfigure all the parameters of the structure in order to be able to properly analyze the structural solution.

In the analysis carried out on the composite beams, the minimum number of shear studs needed to verify the safety of the structure was determined, as well as the degree of shear connection, the design values of the shear resistance of a single connector, the compressive force in the concrete flange, the resistance shear and the resistance moment of a composite section. This allowed for the design of a favorable solution for the case study.

5.2. REVIT TO ROBOT STRUCTURAL ANALYSIS

The *Robot Structural Analysis* software has a strong link to *Revit*, since they belong to the same supplier (*Autodesk*). Exporting the model is therefore an almost immediate process, guaranteed by an extension incorporated into the *Revit* work environment.

Unlike *ETABS*, *Robot Structural Analysis* was able to properly export the spatial position, the geometric and physical properties of the steel profiles, as well as the support conditions and actions and combinations of the structural model. However, similarly to the previous A&D software, the program did not transfer the geometric and physical properties of the composite floor, generating instead a generic slab. For this reason, an additional step was necessary to replace this slab with *claddings*, define the direction of the load parallel to the main beams and associate the proper weight of the composite floor (Figure 7).

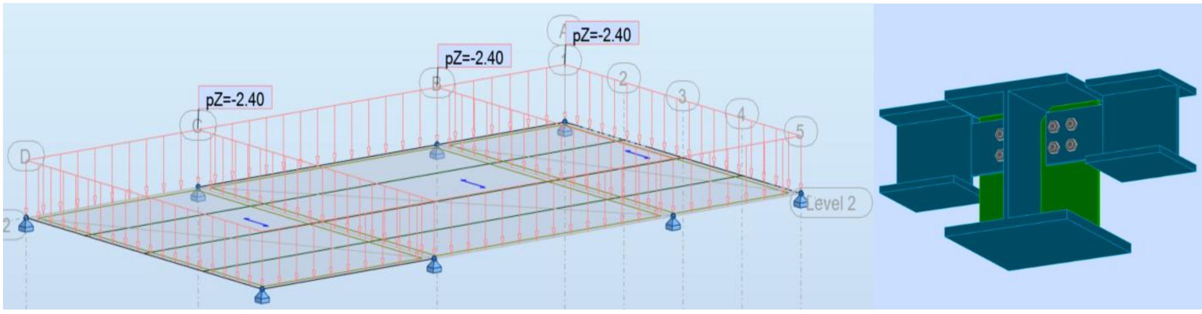


Figure 7: Composite Slab model in Robot Structural Analysis and steel connection between beams.

The steel connection between the main beams and the secondary beams is achieved by extending the core of the secondary beam, connected by *4M12 Cl10.9* screws to a transverse reinforcement placed on the main beam. In this sense, only the shear force is passed to the main beam. The A&D software allows the security check of steel connections to be carried out, providing the designer with a report of all results and a spatial (Figure 7) and 2D view of the connection geometry.

5.3. PARAMETRIC MODELING OF THE COMPOSITE SLAB

The reverse process of exporting the structural solution to *Revit* was ineffective. The geometry of the composite floor and the shear connectors from *ETABS* were not transferred, as well as the steel connection resulting from *Robot Structural Analysis*. On the other hand, *Revit* admits that the profiled sheet is continuously distributed throughout the structure, with no discontinuity in the main beams, leading to inconsistency in the design drawings associated with this structure.

It is foreseen in the present work that the composite floor is composed of three sections of profiled sheet. The lower edges of the sheets, corresponding to the ends of these sections, rest on the main beams, causing the section to end and another to start in the exact symmetrical position to the geometric axis of the main beam, giving rise to a fictitious concrete block between the two sections.

As a consequence of the model inconsistencies, a methodology was adopted to solve these limitations, through the modeling of *In-Place* objects of the profiled steel sheeting and the concrete layer, and by the introduction of the shear connectors in the respective positions (Figure 8).

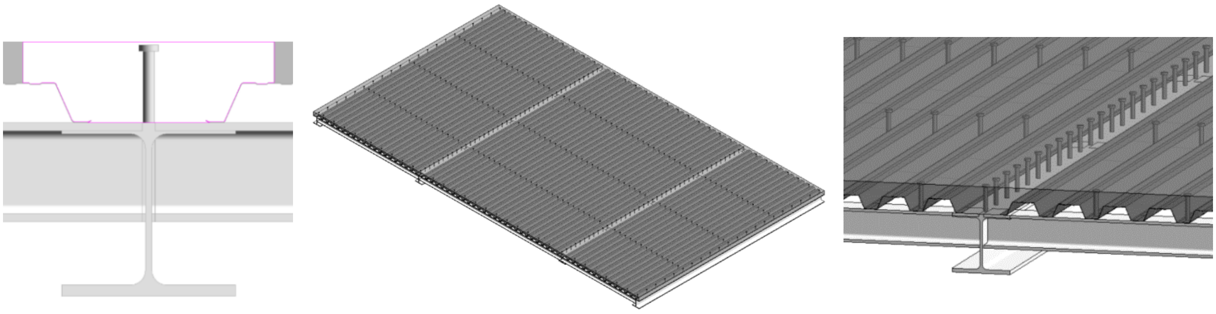


Figure 8: Modeling of the profiled steel sheeting, concrete layer and shear connectors.

Regarding the steel connections established between the secondary beams and the main beams, it was not possible to transfer the connection geometry. However, the *Robot Structural Analysis* software provides the structural designer with CAD drawings of the connection, which were later inserted in the drawings project technicians.

6. DOCUMENTATION ARCHIVE

All graphic and written documentation of the city's archive, as well as of the project photographs must be stored for later consultations, not only to support the technicians involved, but to provide the bases to support the decision of alternative solutions. In this way, all the professionals will be able to develop their work based on BIM methodology, allowing good communication and an appropriate exchange of information between the various sectors of the AEC. The BIM software, in addition to allowing 3D visualization, cuts and elevations of the entire project, also allows the creation of schematic drawings of the project in due detail, so that they can be used on site (Figure 9).

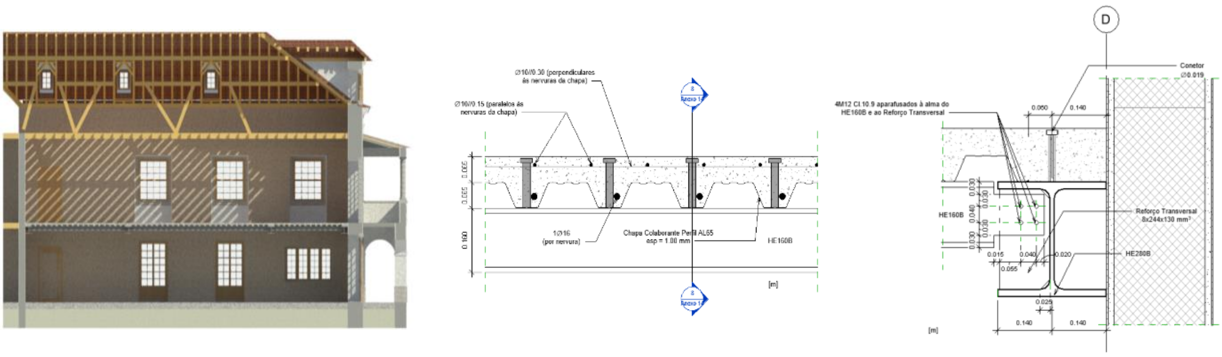


Figure 9: Cut and schematic drawings of the composite slab.

7. CONCLUSIONS

In the present work it was possible to demonstrate the advantages and limitations of the BIM methodology applied to the architectural and structural design of buildings of great patrimonial value in Portugal. The knowledge of the functionalities of the BIM methodology contributed to the development of specific methodologies for parameterizing libraries of families of intelligent objects. Although these were created exclusively for the case study, they can also be changed according to their parameters and, thus, adapted to other similar projects.

From another perspective, the degree of interoperability between the BIM programs, used in the process of analyzing the composite slab solution, contributed equally to a growing understanding of the limitations that the interchange standards still present and what strategies to address to overcome these obstacles.

The degree of interoperability between the *Revit 2019* and *ETABS 2018* software, using IFC format, concludes that the additional changes before and after the export of the model, required a significant conservation strategy for the modeled elements, so much so that it was decided to cut the link between the programs in the export process from *ETABS* to *Revit*. The issue of ineffective interoperability can be justified by the compatibility of program versions. This outcome results in a missed opportunity for process improvements and productivity gains for the structural engineer who struggles to justify the expenses of implementing BIM.

From another point of view, the *Robot Structural Analysis 2019* software was used for the analysis and design of the steel connections established between the steel beams. The degree of interoperability of this program is more efficient, since it allowed the export of all the geometric and physical aspects of the constituent elements of the model parameterized in *Revit*, through an extension. However, the export of the composite floor was also not carried out successfully, and it was necessary to generate a *cladding* element to simulate the load distributed towards the ribs of the composite slab.

Regardless of the capabilities that *Revit* provides to the structural designer in the modeling of a composite slab, the geometric layout of the element is not consistent with what was intended in the work. Therefore, it was decided to parameterize this solution in order to ensure that technical drawings removed from the model were consistent.

BIM is a methodology that is not free of errors, many of the limitations analyzed rise from the fact that it is still a recent methodology. Software, plug-ins and libraries are still growing, and companies, manufacturers, and designers are adapting to this methodology, investing in learning and changing working methods. Interoperability, albeit limited, continues to result in a degree of improvement in the construction process, the maintenance of technical resources, the coordination of documents and the development of project opportunities.

8. REFERENCES

AGUIAR COSTA, A., 2020 – **Visão Construção 2020 – ONS/IST: Digitalização da Indústria da Construção**, http://www.ct197.pt/index.php/homepage/visao-ct197.

AML, 2019 – **16682**, Arquivo Municipal de Lisboa, Lisboa, Portugal.

AZHAR, S.; KHALFAN, M.; MAQSOOD, T., 2012 – **Building Information Modeling (BIM): Now and beyond**, Australasian Journal of Construction Economics and Building, Australian Institute of Quantify Surveyors, Australia, ISSN: 18379133, DOI: 10.5130/ajceb.v12i4.3032.

CALADO, L.; SANTOS, J., 2013 – **Estruturas Mistas de Aço e Betão**, 2ºEdição ed., Universidade de Lisboa, Instituto Superior Técnico, Lisboa, Portugal.

CASTELLANO-ROMÁN, M.; PINTO-PUERTO, F., 2019 – **Dimensions and Levels of Knowledge in Heritage Building Information Modelling, HBIM: The model of the Charterhouse of Jerez (Cádiz, Spain),** Volume 14, Elsevier Ltd, Cádiz, Spain, ISSN: 22120548, DOI: 10.1016/j.daach.2019.e00110.

CENTRELINE STUDIO, [s.d.] - **BIM Standards**, https://centrelinestudio.com/bim-standards/.

DARÓS, J., 2019 – **Building Information Modeling, D's do BIM**, Utilizando BIM, https://utilizandobim.com/blog/category/building-information-modeling/.

EASTMAN, C.; TEICHOLZ, P.; SACKS, R.; LISTON, K., 2008 – **BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors**, John Wiley & Sons, Inc., Hoboken, New Jersey, ISBN: 978-0-470-18528-5.

EUROPEAN COMMISSION, 2019 – **European Construction Sector Observatory – Trend Paper – Building Information Modelling in the EU construction sector**, European Commission, https://ec.europa.eu/docsroom/documents/34518.

GAYER, A., 2009 - **BIM Power: Interoperability**, STRUCTURE magazine, http://www.buildingsmart.com/bim.

GRABOWSKI, R., 2010 - **CAD & BIM - Is There A Free Pass?**, a Report on GRAPHISOFT ArchiCAD's DWG Workflow, upFront.eZine Publishing, Ltd., ISBN: 9781926897158.

QUEIRÓZ, G.; GRIGOLETTI, G.; SANTOS, J., 2019 – **Interoperabilidade entre os programas AutoDesk Revit e EnergyPlus para simulação térmica de edificações**, PARC Pesquisa em Arquitetura e Construção, Campinas, SP, v. 10, p. e019005, jan. 2019. ISSN 1980-6809.

SAMPAIO, A. Z.; ARAÚJO, L. – **BIM concept: Generation of parametric objects of composed walls**, CMN 2019 - Congress on Numerical Methods in Engineering, Guimarães, Portugal, July 1-3, 2019, ISBN: 978-989-5449-60-6, PP. 894-903.