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Compatibility of design through BIM methodology
Compatibilidad de proyectos mediante metodología BIM

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Abstract

Buildings composed of several projects are generally designed by different professionals. In this way, the risk of interference between them at the time of execution is great. This fact damages the progress of the work, generating rework, increased cost, time and even post-work anomalies. The objective of this article is to analyze the BIM methodology for carrying out project compatibility. The projects were prepared from models created in Autodesk Revit 2021 and an interference check was carried out in Autodesk Navisworks 2021. For the compatibility of projects, an interference detection matrix was used based on "GuBIMclass v.1.2". Several interferences were identified between the different projects. By making projects compatible, it is possible to identify interferences between elements and make changes before the execution phase, which helps to reduce projects that waste time and money, in addition to avoiding possible anomalies. BIM technology is a fundamental training process, fundamental for the implementation and advancement of civil construction, in engineering and civil construction courses.

***Keywords**: BIM; Design compatibility; buildings; civil construction; classification system.*

Resumen

Los edificios se componen de varios proyectos en general elaborados por diferentes profesionales. De esta forma, el riesgo de interferencia entre ellos en el momento de la ejecución es grande. Este hecho perjudica el avance de la obra, generando retrabajos, incremento de costos, tiempos e incluso patologías. El objetivo de este artículo es analizar la metodología BIM para realizar la compatibilidad de proyectos. Los proyectos se prepararon en Autodesk Revit 2021 y la verificación de interferencias se realizó en Autodesk Navisworks 2021. Para la compatibilidad de proyectos se utilizó una matriz de detección de interferencias, basada en el modelo "GuBIMclass v.1.2". Se identificaron varias interferencias entre los diferentes proyectos. Al compatibilizar proyectos, es posible identificar interferencias entre elementos y realizar cambios antes de la fase de ejecución, lo que ayuda a reducir pérdidas de tiempo y dinero, además de evitar posibles anomalías. La tecnología BIM es revolucionaria, sin embargo, no es un proceso sencillo y familiar entre los profesionales, por lo que existe la necesidad de una mayor inversión en formación profesional por parte de las empresas, la implementación en cursos de ingeniería y arquitectura, son fundamentales para el avance de la construcción civil.

Palabras clave: BIM; Compatibilidad de proyectos; edificios; construcción civil; sistema de clasificación.

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1. Introduction

The sector of civil construction is very important to the Brazilian economy, once it moves the market in big proportions, impacting on Gross Domestic Product of the country. Besides economic issues, it is the civil construction sector responsible for the country's development, especially on what refers to the infrastructure, building roads, constructions, bridges, railways, among other fundamental constructions to the development of the society.

Despite the significant importance, the civil construction sector needs a constant evolution, adopting as an ally the innovation and methodologies that collaborate to a quality service and efficiency. The lack of technical capacitation and improvement of productive methodologies leads to several problems and improvements of productive methodologies, resulting in many problematics in the civil construction that leads to a higher consumption of inputs, generation of waste, awful quality services, the arise of pathologic anomalies, and consequently a higher financial prejudice.

It is known that in any process, planning is a fundamental phase, and it is not different in civil construction. In the process of elaborating projects of an enterprise it is essential, nowadays, to use technologies to accelerate and produce a service of quality. The buildings, for example, need a series of projects, among them the architectural, structural, electrical installations, hydrosanitary installations, logical networks, etc. These projects, usually made by different professionals, can interfere with each other, if a compatibility methodology is not adopted. The use of the Building Information Modelling (BIM) methodology, stands out because of the advantage of working in an interoperable way, and automate, with a few clicks, the verification of interferences, lowering time and minimizing risks.

Due to what was exposed, this research seeks to analyze and comprehend the compatibility of the projects with BIM technology, evidencing the benefits of this technology in comparison with the traditional ones, through clear demonstrations of projects. Although this methodology still needs more propagation and use on enterprises and educational institutions to become better known such as CAD, it has gained space and has shown very promising results. So, explaining about the use of the BIM technology, it is essential for engineers, architects and constructors to identify its importance and try to use it to improve the quality of the civil construction market.

2. Building Information Modeling

BIM, initials to Building Information Modeling, it has to do with a digital concept of the characteristics that composes the building in the purpose of integrate information, in other words, a tool of many projects of a building, elaborated in a virtual model and compatibilized of a particular building to be built. This is a concept that emerged with Charles Eastman in American Institute of Architects, but the terminology BIM has been used since December of 1992, and its dissemination followed the advances of computing technology (Cardoso, 2022).

"When implemented properly, BIM facilitates the building project process more integrated, which results in buildings with better quality with lower costs and deadlines." (Eastman et al., 2014).

Aligned with (Ferreira, 2007) this technology has devices capable of generating information and archives that have higher elaboration, both in cost and accuracy of projects. Besides being applied in many phases of building, as for examples: in the architectural project, structural project, electrical project, hydraulic project, planning and the budget of the construction.

BIM have all the construction's information, where it can take out cuts, insights, and documents about the project, besides of being able to be simultaneously feed by all the people involved in the project, which differs from the traditional way, where each person involved works individually, in a bureaucratic environment, repassing between a designer and another (Sena, 2012).

BIM is a tool, used in the compatibility of projects, in other words, a model that includes all the projects involved in a building, such as architectonic, structural, electric, and hydrosanitary, therefore prevents these problems from reaching the work (Aleixo and Junio, 2019).

Although it shows many advantages that leads to a greater economy, less time used, higher quality and even less generation of waste, the using of BIM methodology can also show some disadvantages, and in this case, refers to the fact that it has a high acquisition cost, besides needing manpower training.

It should be noted that considering the importance of the civil construction industry, and the advantages showed by the use of the BIM technology, it was published by the federal government the Decree 10.306/2020, establishing the gradual using of BIM in it directs or indirect execution of works and engineering services performed by the organs and the federal public administrations entities (BRASIL, 2020). In its 4th article, the decree deals with the gradual implementation of BIM, divided in three phases, those being:

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I - First phase - from January 1st of 2021, BIM should be used in the development of architectural and engineering projects, referring to new buildings, extensions or rehabilitations, when considered a high relevance to the dissemination of BIM.
II - Second phase - from January 1st of 2024, BIM should be used in the direct or indirect execution of architectural projects, engineering and works management, referring to new buildings, reconstructions, extensions or rehabilitations when considered a high relevance to the dissemination of BIM.
III - Third phase: from January 1st of 2028, BIM should be used in the development of architectural and engineering projects, referring to new buildings, extensions or rehabilitations, when considered medium or high relevance to the dissemination of BIM.

3. Compatibility of Projects

Compatibility of projects is defined as an interaction between the different kinds of projects of a building, as an architectonic, structural, hydrossanitary, electric, and others. The purpose of this interaction is to identify the interferences between them, and minimize the execution impacts. By compatibility of the projects, the interferences among the constructive elements are eliminated or minimized, the project is adjusted and consequently lowers the re-work of execution, the waste of material and time (Monteiro et al., 2017).

The compatibility of projects refers to the process that aims to detect interferences and mistakes of a certain building project during the conception phase, before the execution phase, whereas in this phase can have delays and unpredictable costs, and by making the compatibility of projects these problems are avoided. In the traditional model, this compatibility is manual, in general overlapping the 2D projects and searching by naked eye possible interferences. However, accomplishing a compatibility of projects on BIM, the verification is automatized, which consequently becomes more reliable, and the incompatibilities are found, even the less obvious ones (Gomez and Caixeta, 2020).

The Autodesk Navisworks software is a tool capable of verifying these problems, through resources as Clash Detective, generating reports that detect all the verifications and the interferences between the projects. So, the responsible designer is able to correct the errors even in the project phase, and afterwards make a new compatibility, until the bugs are fixed, or irrelevant.

When it comes to the traditional model of projecting, where the drawing has only two dimensions, are verified many limitations, between them, the low consistency among the information, such as in the plant as in the cuts, besides being verified bugs between the projects, may causing delays, unexpectable costs, low efficiency in the production, and even lawsuits due to these problems (Eastman et al., 2014).

This process of project compatibility is made through a overlapping from the various projects (architectonic, structural, electric, hydraulic, and others) of a building, and constitutes as the best approaching turned to the problem solving referred to the projects fragmentations, and that reduce or eliminate the main problems found, in the middle of them: the physical interferences, re-work, waste of materials and time, loss of resources and functionalities caused by the incompatibilities. In BIM modeling, this project compatibility with the overlapping of all them in one only model, results in a digital construction of the building, including the constructive systems and stages, leading to a control over the building, knowing all the parameters involved in its conception, such s the adopted solutions (Pinto, 2019).

In accordance with (Goes, 2011) the project compatibility has a great relevance, since it is one of the the main activities when projecting certain building, interfering directly in the final quality, through reducing of re-work, waste of time and materials, among others, where BIM presented itself as a fundamental tool in this compatibility becoming the project process successful.

3.1 Method used

Aiming a verification of the project compatibility with BIM technology, seeking to evidence the benefits of it, it was used a research methodology in order to validate this compatibility, including the interoperability of softwares, where it was used Revit 2021 and Navisworks 2021

The scope of this research is about a fictional residential project of two pavings, where the architectonic, structural and their complements (electric and hydrossanitary), was modeled through the Autodesk Revit 2021 software, aiming a more complete visualization through three-dimensionality. The compatibility of these projects was made in the Autodesk Navisworks 2021 software.

In most cases the projects are made by different professionals which increases even more the incompatibility risks. However, for this research the projects were made by the authors together, in a collaborative manner, although it is possible to analyze some project bugs caused by some interference.

3.2 Modeling Projects in Revit

First, we sought to model the architectural project in Revit 2021, aiming to build a virtual and three-dimensional model of the building, which included not only the 3D model, but also information on its elements for analysis of interferences and thus actually carrying out the BIM methodology **(***Figure 1)*

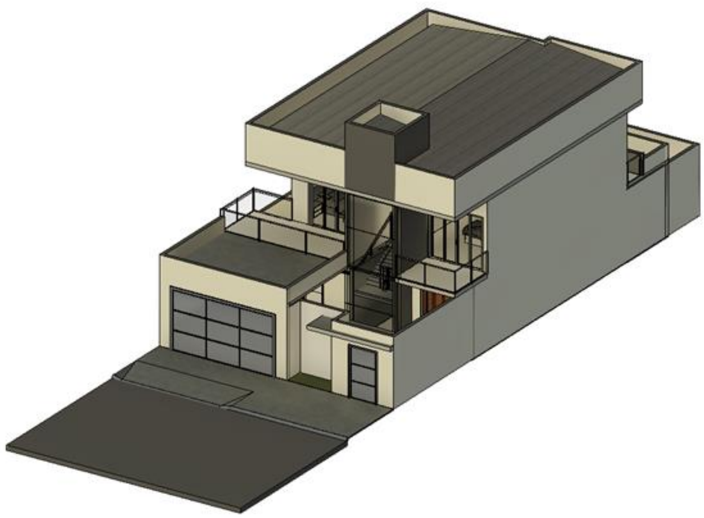

***Figure 1**. Shows the architectural design adopted*

After the architectural project was completed, the structural and complementary project began, where this architectural project was used as a "link" in Revit to start the others. This is a process that was adopted with the intention of performing similarly between different offices and adopting different templates for each discipline.

Regarding the structural project, the modeling started from the insertion of the column, followed by the beams and slabs. And similar to what was done in the architectural project, after inserting the elements, it was necessary to perform a compatibility within Revit itself, aiming at an analysis of the elements to identify whether they pass through inappropriate places, such as column in frames, or even in the middle of some environment. The 3D structural project is shown in (Figure 2).

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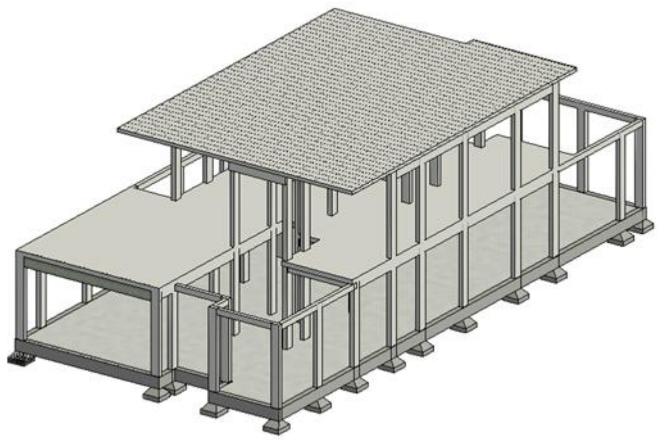

Figure 2. Visualization of the 3D structural project in Revit.architecture project in Revit.fine aggregate analysis.

At the beginning of the hydrosanitary project, it was noticed the need to create a shaft, or vertical opening in the wall, for access and downfall of most of the pipes, to avoid possible incompatibilities with other projects. After verifying inconsistencies and adjusting, the hydrosanitary project was as shown in (Figure 3).

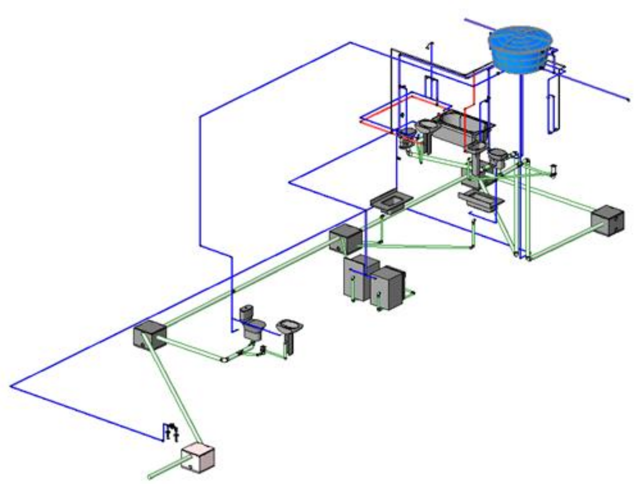

***Figure 3**. View of the 3D hydrosanitary project in Revit*

In the electrical project, care was taken with the conduits, in order to avoid passing them through column, beams and close to the hydraulic pipes. Thus, having done each project collaboratively allowed a more concise verification of inconsistencies. This sequence is generally not adopted in most companies, in short, all projects are elaborated from the architectural point of view, without verification of the others and, in general, by different professionals/teams. The electrical project is shown in (Figure 4).

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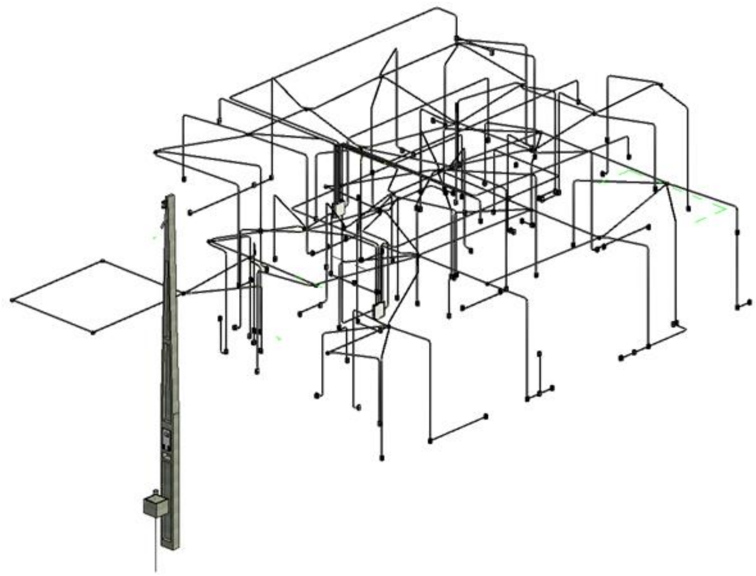

Figure 4. *Visualization of the 3D electrical project in Revit.*

3.3 Creation of the interference matrix

For interference detection, it is extremely important to have a predefined matrix called the Interference Matrix (Clash Matrix), because through the defined nomenclatures, it is easier to filter better results.

Although this matrix is extremely important, there is still no specifically Brazilian interference detection matrix, a fact that ends up leading offices in Brazil to adopt its methodology. In this sense, as a basic parameter, "GuBIMclass v.1.2, created by GuBIMCat in July 2017", was used, which refers to a Spanish classification system.

There are other classification systems, such as the Uniformat of the AIA and the GSA (American Institute of of Architects and General Services Administration) from the USA; Uniclass and Uniclass 2015 from the UK NBS (National Building Specification); Omniclass by CSI (Construction specifications Institute) of the USA. However, it was decided to adopt the GuBIMclass due to the already familiarity of the group members with this classification system.

GuBIMClass is a system for classifying construction elements according to their function. Thus, it contemplates the constructive elements on the ground of the building (equipment, infrastructure and installations) carried out by a GuBIMCat working group linked to infraestruturas.cat.

The objective in the development of the GuBIMClass system was to create a classification system that mainly satisfies the needs of the construction industry in Spain, although, of course, this does not mean that the system cannot be used in other countries where its use is considered convenient. The interference detection matrix created based on the GuBIMClass is presented in (Table 1). It is possible to observe that each element of the matrix contains an identification code, in order to differentiate the type of element, thus, each code of its respective element was inserted in projects according to their discipline in Revit.

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Table 1. *Interference detection matrix*

Clash Matrix			Architecture						Structure						Electric					Hydrosanitary			
			40.10.10.10	40.20.20.20	30.20.10.10	40.20.10.10	40.10.10.40	40.10.10.40	20.10.10.20	20.10.30.10	20.20.10.10	20.20.20.20	20.20.20.10	20.20.20.30	50.60.30.10	50.60.30.40	50.60.50.10	50.60.10.10	50.60.40.10	50.70.30.10	50.10.20.10	50.10.10.20	50.10.20.20
			Wall	Floors	Roofing	Ceiling	Doors	Windowns	Foundation	Wall Structure	Column	Beams	Slabs	Steel Structure	Trays	Conduits	Fixtures	Panels	Sockets/Switches	Tubes/Fittings	Valves/Registers	Equipment	Sanitary
Architecture	40.10.10.10	Wall																					
	40.20.20.20	Floors																					
	30.20.10.10	Roofing																					
	40.20.10.10	Ceiling																					
	40.10.10.40	Doors																					
	40.10.10.40	Windowns																					
Structure	20.10.10.20	Foundation																					
	20.10.30.10	Wall Structure																					
	20.20.10.10	Column																					
	20.20.20.20	Beams																					
	20.20.20.10	Slabs																					
	20.20.20.30	Steel Structure																					
Eletric	50.60.30.10	Trays																					
	50.60.30.40	Conduits																					
	50.60.50.10	Fixtures																					
	50.60.10.10	Panels																					
	50.60.40.10	Sockets/Switches																					
Hydrosanitary	50.70.30.10	Tubes/Fittings																					
	50.10.20.10	Valves/Registers																					
	50.10.10.20	Equipment																					
	50.10.20.20	Sanitary																					

Fonte: Adapted form GuBIMClass v.1.2 (2017).

In order for each element to be recognized according to its respective code, it was necessary to create a "project parameter" within Revit, as shown in (Figure 5). The term adopted to represent this parameter was Nomenclature + the type of element to which the code is intended.

With this parameter, it is possible to use it to determine the filtering of elements in Navisworks and thus carry out the compatibility in a consistent and contained way. After the parameter is created, when selecting the element in question, and going to "edit type", the nomenclature of the element will appear in the text parameter, being exactly the parameter that was created. In this field, the code of the existing element in the interference detection matrix was inserted.

(Figure 6) shows this example for the case of beams. As can be seen, the code "20.20.20.20" is used, and when doing this whole procedure for all the beams present in the project, they are recognized through this code, facilitating the analysis of interferences.

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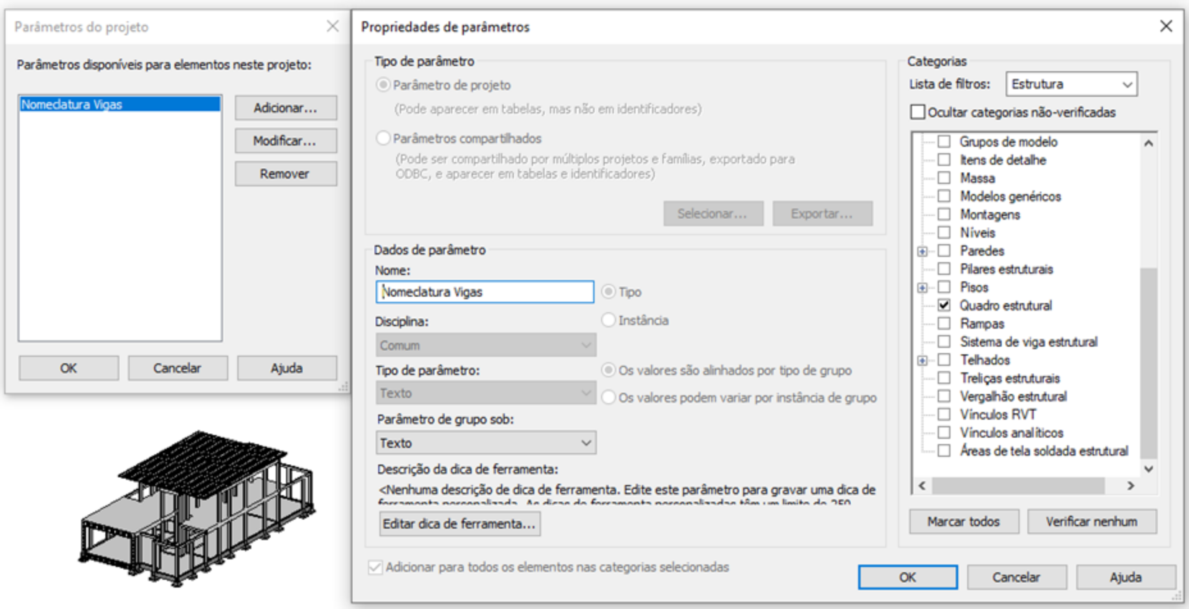

Figure 5. *Creation of parameters of the project in Revit.*

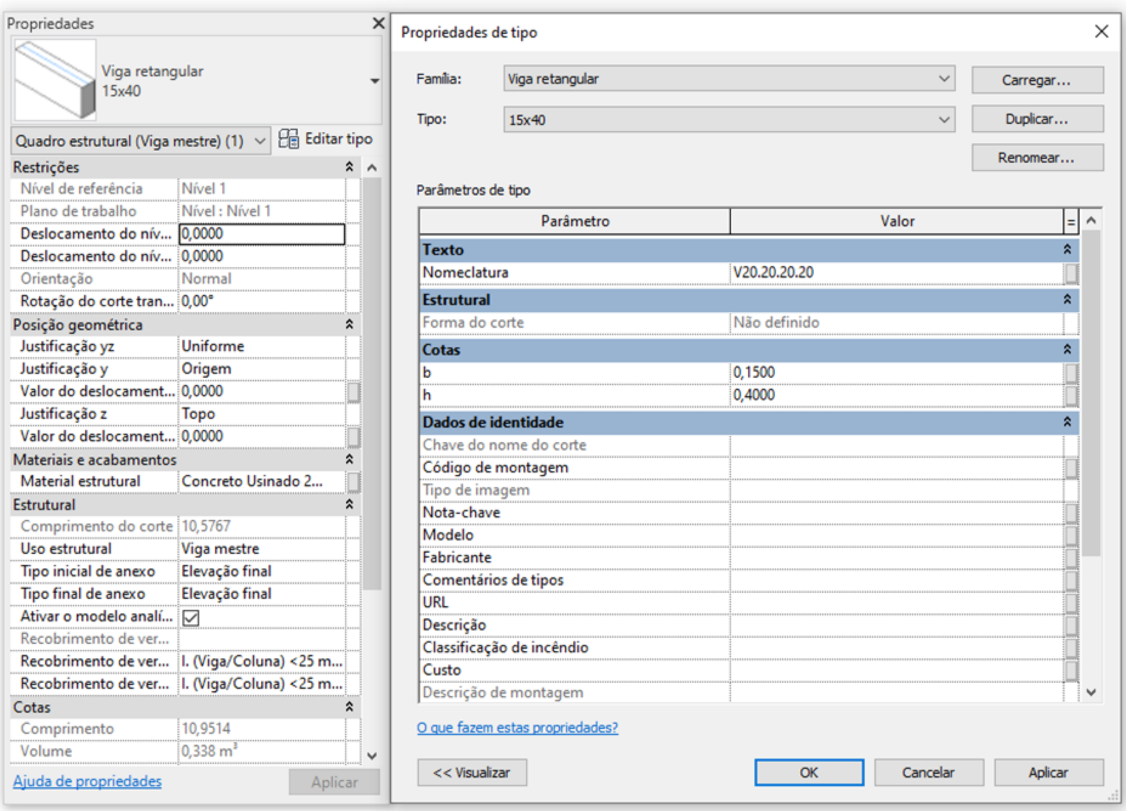

Figure 6. *Insertion of the naming of beams in Revit.*

3.4 *Compatibility of projects in Navisworks 2021*

The entire process carried out previously has the main objective of facilitating the identification of elements and generating better information management of the different elements of projects, also facilitating the filtering of elements for the verification of interferences.

The linking of projects in Navisworks was made directly with the Revit format file (.rvt), although the option for .ifc are also accepted, the possibility of linking the .rvt allows changes to be made in Revit and, when saved, can be updated in Navisworks without the need for a new link and the reduction of loss in interoperability. However, to avoid errors, the versions of the programs must have the same year, that is, (Revit 2021) and (Navisworks, 2021.

After linking all projects in Navisworks, filtering (sets) was performed using the " find items ". For this research, 8 sets were created, including column, beams, conduits, frames, windows, doors, roof and hydrosanitary equipment (toilets, sinks, etc.), as shown in (Figure 7).

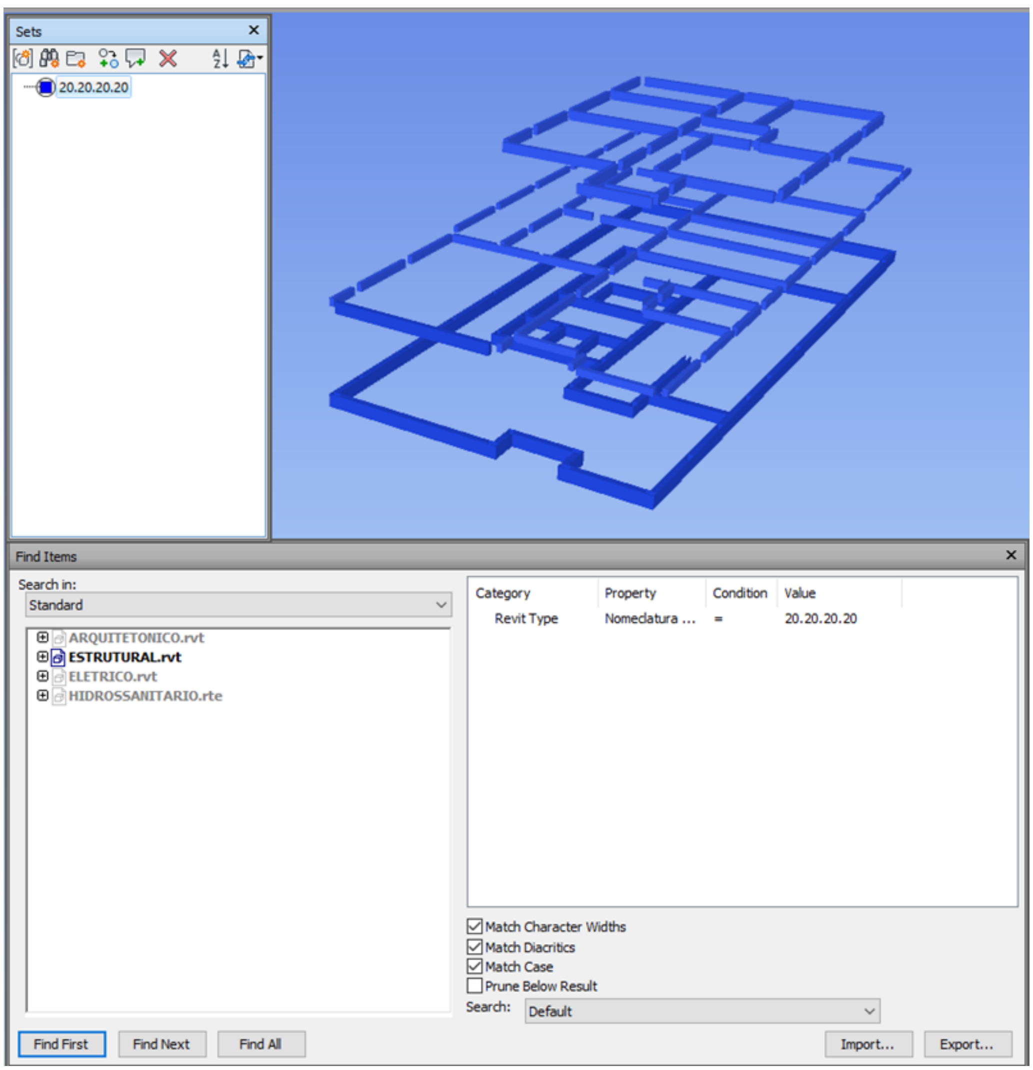

Figure 7. *Generation of element filtering according to nomenclature in Navisworks.*

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After creating them, the tool "Clash Detective" or interference detection was used. Through this, it is possible to carry out the verification of interference between the elements in an automated way, in other words, with just one click and some informed parameters. Altogether l, six checks (crossings) of different elements were made for this research, namely: column x windows; column x conduits; Hydraulic pipes x Electrical panels; Conduits x windows; Beams x pipes; Conduits x ports.

From this, after identifying all interferences, attributing comments and designating the person responsible for verifying the necessary corrections, these can be reported in HTML form, with illustration with images and comments, so that they can be resolved through compatibility of projects, before the work is actually carried out. The different checks carried out are presented as shown in (Figure 8).

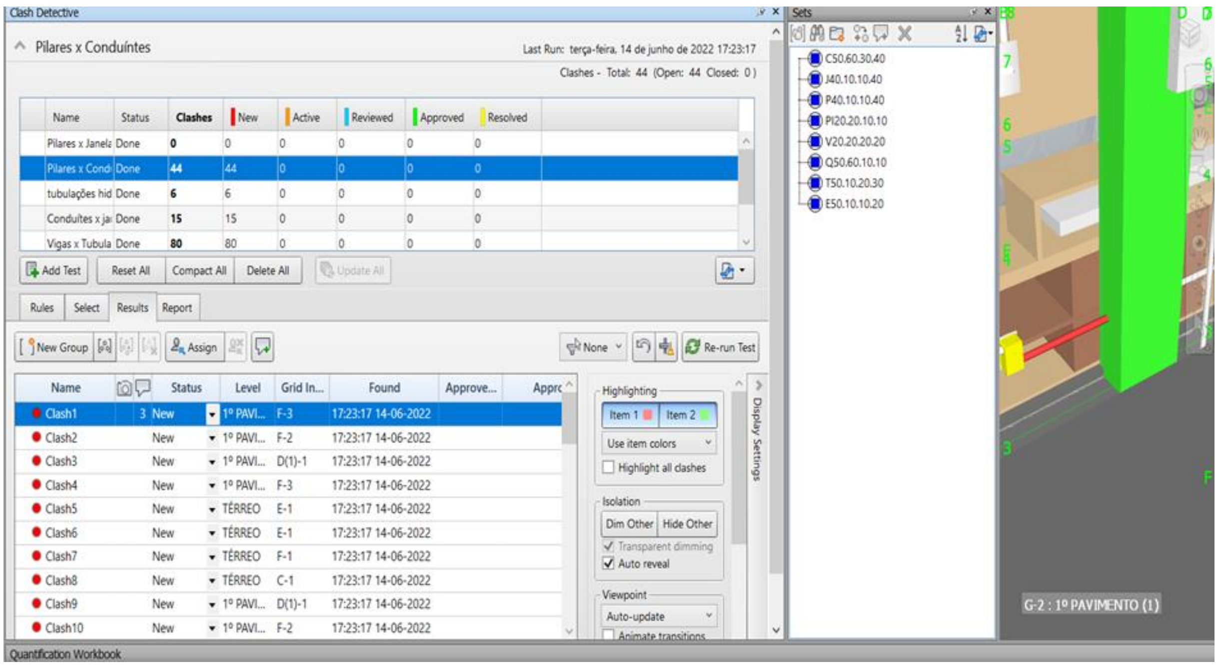

Figure 8. *Automated clash detection of designs in Navisworks*

4. Results and Discussions

Based on the informed methodology with regard to project modeling, creation of an interference detection matrix and project compatibility, considerable results were obtained.

As mentioned, six verifications were carried out between different elements, four obtained interferences, even though each project was carried out in collaboration between the authors, which points to the significant importance of BIM technology in the compatibility of projects both for collaborative teams, and especially for offices that work in isolation.

In (Table 2), there is a summary of the results regarding the interferences obtained.

Table 2. *Summary of interferences found*

Name	Interferences
Column x Windows	0
Column x Conduits	44
Hydraulic pipes x Electrical panels	6
Conduits x Windows	15
Beams x Pipes	80
Conduits x Doors	0

As shown in (Table 2), it is possible to notice some intersections that obtained no interference, but others that obtained expressive values, as is the case of column x conduits and beams x pipes. In this way, aiming at a synthesis of the results, only one of each will be illustrated.

Another possible point to observe is that there were no conflicts between column x windows, and this may be due to greater ease in checking the draftsman between one project and another.

Between column x conduits, 44 interferences were obtained, which can be classified with high relevance, since it is a large expressive amount. Some anomalies can be caused, such as leaks, loss of column section and resistance, etc. In some cases, in the execution of the work, rework and even damage to the structure can be generated. This is, therefore, an unacceptable situation from a structural point of view, which could seriously compromise the resistance capacity of the element.

In accordance with (ABNT NBR 5410, 2004) and (ABNT NBR 15465, 2020), conduits must follow some basic criteria for installation, obeying minimum dimensions, in addition to the fact that they cannot be embedded in beams, column, as well as not can pass through hollow elements. Thus, the interference between column and conduit is a failure that, in addition to going against Brazilian civil construction regulations, also causes problems in the execution of the work

It should be noted that there was greater care on the part of the designer in passing the conduits, and yet there were a large number of inconsistencies. This points to the significant importance of BIM technology in project compatibility.
In the image these interferences between column and conduit occurred as shown in (Figure 9).

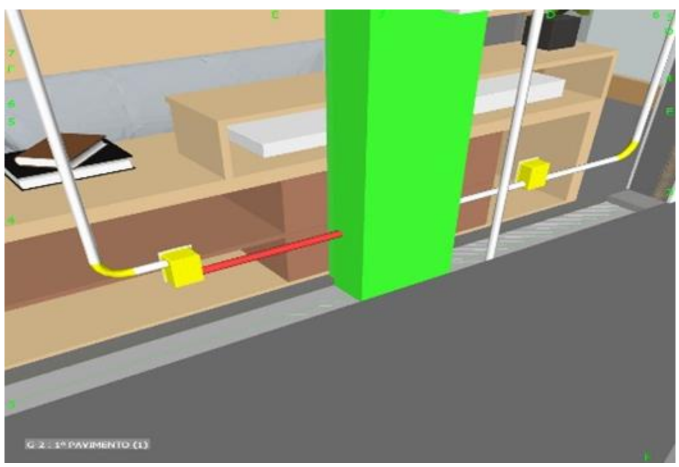

Figure 9. *Interference between column and conduit*

In addition to the column and conduits, inconsistencies were also found between the hydraulic pipes and electrical panels, where there were 6 in total. Considering ABNT NBR 5140 (2004), which deals with low voltage electrical installations, they must be avoided being close to water.

This verified interference between the hydraulic pipes and the electrical switchboards is evidenced in (Figure 10), and from that it is possible to make changes in the project, in order to adapt the project to the regulations.

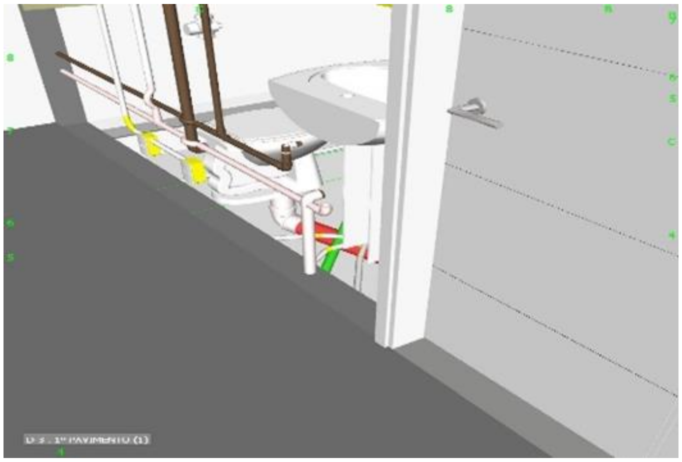

Figure 10. *Interference of hydraulic pipes near electrical switchboards*

Still with regard to the problems observed between the electrical project and the other projects, 15 inconsistencies were identified between conduits and windows, and none between conduits and doors. If there is no meticulous observation when passing the electrical wiring, it is common to pass unnoticed in the eyes of the designer, elements such as windows and doors, generating this problem, where, as well as the others previously explained, if you reach the execution phase of the work, generates rework and various losses. This interference between conduits and windows is demonstrated in (Figure 11).

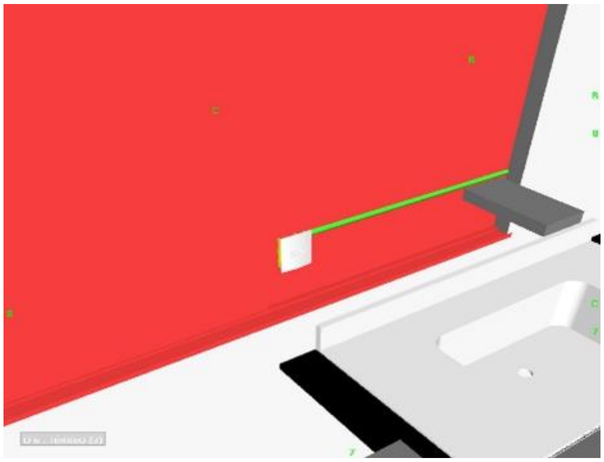

Figure 11. *Interference of conduits with windows*

Besides the inconsistencies generated, a large amount between beams and pipes was observed. When it comes to projects, a very common situation is to verify pipes of the hydrosanitary project crossing beams, requiring the execution of a hole in the beam, a fact not foreseen in the structural project. This is an occurrence that may seriously compromise the resistance capacity of the element, since the beam was not designed for this, which demands that the beam project be redone, considering the hole, or the hydrosanitary project be redone with the change of the location of the pipes.

This is a very serious interference, considering that the beam is a structural element, and is obviously fundamental for the safety of the building. This occurrence can lead to improvisations in the work, if they are not resolved in the design and compatibility phase, which leads to loss of quality.

The interference of pipes with beams can be observed as shown in (Figure 12).

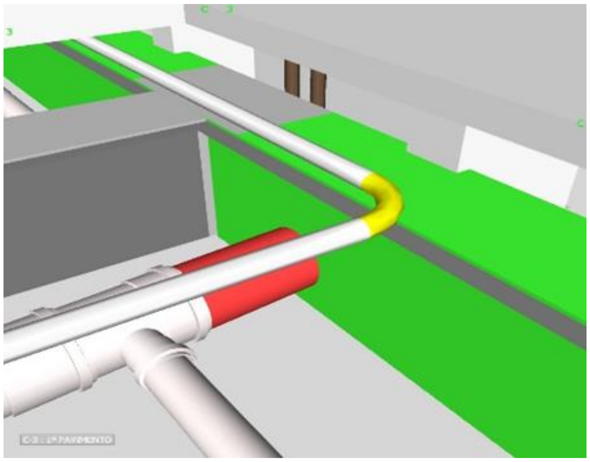

Figure 12. Interference of pipes with beams

According to Gomes and Caixeta (2020), by making it compatible with BIM, greater project quality is guaranteed, and normally most of the interferences found can be corrected without the need to resize the elements, which guarantees a gain in time, more detailed projects, and consequently an execution of work without the occurrence of interferences that compromise its functioning and quality.

Still (Gomes and Caixeta, 2020) for the authors, the manipulation of the tool in a trivial way, does not guarantee satisfactory results, requiring a choice of correct parameters and an effective investigation of all intercurrences found.

The observed data referring to the analyzed residential building indicate that even irrelevant conflicts are likely to occur. Even when there is only one designer responsible or a collaborative team for all projects, it is possible for mistakes to happen. Therefore, adequate training and adoption of this methodology will guarantee a considerable gain in the quality of projects.

5. Final Considerations

This research aimed to verify the compatibility of projects through the BIM methodology. In this way, it was possible to verify the importance of using it to improve the quality of projects, avoiding errors commonly apparent only in the execution of the work.

An obvious point is that the use of this methodology significantly contributes to the identification and remedying of interferences between projects before the execution of the work, facilitating the verification of interferences, whether simple or complex, which makes the process reliable and even necessary. The adoption of this methodology helps to identify inconsistencies that are difficult to identify, but which, when taken to the work, cause problems of great proportions, generating rework, economic losses, lower quality of the work, in addition to delays.

It should be noted that although BIM technology is revolutionary and guarantees the verification of simple and complex failures, it does not have a simple process, in addition to not working alone, demanding that the user/professional in charge has knowledge of the use of the tool and knows how to select the correct parameters. In this sense, it points to a greater need for improvement of civil construction professionals, so that they are trained already with the performance within the tool, not only in the traditional way, and even after training, the professional must seek constant knowledge, especially when considering that the software is constantly being updated and improved.

In Brazil, it is still very common to use the traditional design model in offices and undergraduate courses, where it is done in a two-dimensional model, usually CAD technology. It is important that educational institutions, in particular, train their teachers and students to deal with these technologies, every day we see their advancement, the use of innovative technologies and methodologies becomes a necessity in an extremely competitive world that needs to be sustainable. The waste of materials, labor, time, poor information management, etc. can be avoided or minimized with the advancement and use of these technologies and methodologies.

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In the civil construction market, construction companies and enterprises can invest in team training using BIM, demanding an investment that, although high, contributes significantly to reduce failures, execution errors, rework, and even quality. of a building.

Another point to highlight is the need for a Brazilian classification system that can guide professionals and standardize the nomenclature adopted. A BIM standard for design compatibility can be adopted as future work.

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