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JAIME ROMERO AND MIGUEL GUTIÉRREZ

Analysis of information exchange between structural design and Revit using IFC

ABSTRACT

The construction industry faces difficulties in transferring information between different software. Engineers and architects use specialized software, but sharing their progress is challenging due to exchange file format issues. BIM (Building Information Modeling) relies on the Industry Foundation Classes (IFC) as the primary format for information transfer, but it suffers from information loss during exchange.

To address this problem, a study was conducted to test the transfer of information between four different software tools used for structural analysis and design (SAP2000, Abaqus, CYPECAD, Rhino3d), and Revit. A simple model was created using each software and IFC files were exported to other software. Then the information loss was analyzed. It was also evaluated how every program performed in terms of ease of usage, possible data formats, quality of the exported element, and adaptability.

The results indicate that information loss occurred when using IFC as a transfer tool, resulting in missing elements and scale inconsistencies in the structural design programs, and the loss of all types of calculations in Revit. It was also concluded that SAP2000 was the program best suited for our test.

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Keywords: Structural, Revit, IFC, data exchange, automation.

Image created with Adobe Firefly

1 Introduction

Professionals and researchers in the construction industry recognized that one of the primary challenges facing this field is the automation of processes. A construction project typically comprises distinct phases, including planning, manufacturing, assembly, and operation. In this particular paper, we will concentrate our efforts on the planning and design phase. This phase involves various disciplines, such as architectural and structural design, and our research paper primarily focuses on the exchange of information between these two fields.

Architects and structural engineers, both use a variety of software to make their designs and calculations. There are several software manufacturers that offer their own products, and each one of these products brings its own specifications. Usually, this implies that every software uses its own file format. At the moment, at which this research paper is being written, the standard information exchange format file is IFC. Industry foundation classes (IFC) is the main file format used in the construction industry in particular in Building information modeling (BIM) programs such as Revit [1]. An IFC file will contain information related to the building model, such as spatial elements, materials, and shapes [2][3]. This format has the advantage that it is a neutral platform, it can be opened in any BIM software [4].

Within the overarching goal of streamlining the information exchange processes between structural design and architectural software within a BIM framework [5], architectural software solutions have evolved to incorporate modules for assigning crucial structural characteristics, such as loads and boundary conditions. This holds the potential to significantly expedite the design process if data exchange can be relied upon. In an ideal scenario, an IFC file could serve as a comprehensive starting point for structural design, with just a designer's validation needed. Likewise, achieving seamless and dependable geometry exchange between

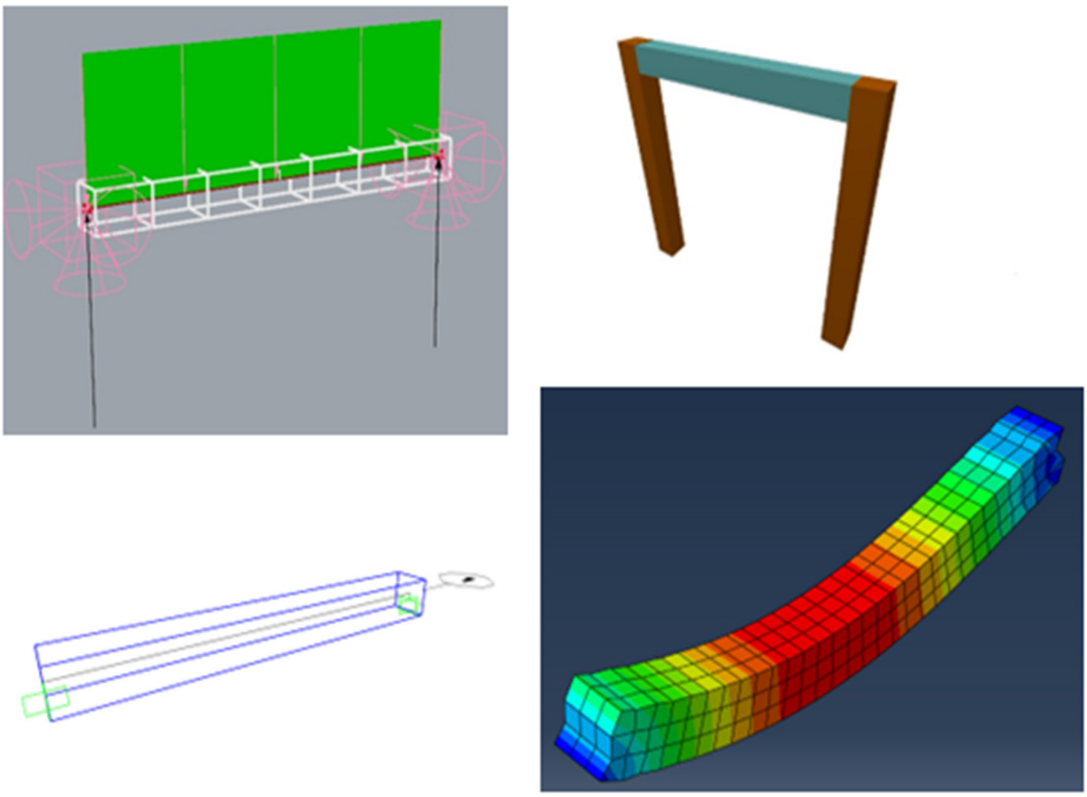

Fig. 1. Sample 3D models (from left to right Rhino3d, CYPECAD, SAP2000, Abaqus).

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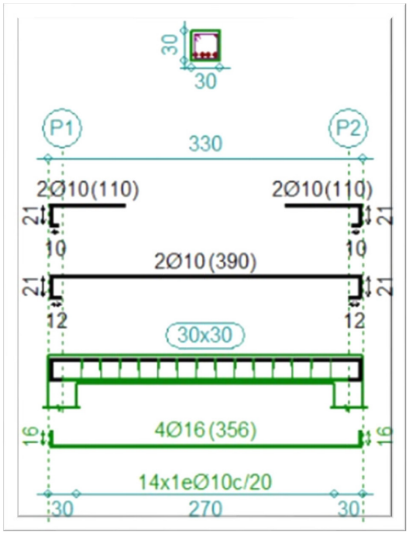

Fig. 2. Reinforcements on CYPECAD.

software like Revit and structural design tools is paramount for facilitating efficient design adjustments and reiterations. This synergy not only accelerates workflows but also ensures a higher level of accuracy and consistency, ultimately contributing to the creation of safe and efficient structures in the realm of modern construction.

1.1 Existing solutions

Robot Structural Analysis Professional is structural load analysis software that can be integrated with Revit, allowing data exchange between both programs [6]. The data transfer is made using the Autodesk desktop app and the common file format between both programs is SMXX. This format type is specific to Autodesk products and especially to Revit. With robot structural IFC file format could be avoided. This could mean that information between Revit and the structural design program is not lost, but we will not test this in this paper.

Another important trend solution is the utilization of IFCopenshell, an open-source software library designed for the manipulation of IFC files according to the specific requirements of structural software [7] . This approach involves the development of code to configure the IFC file, ensuring that the resulting exchange file is perfectly legible and compatible with both architectural and structural software. IFCopenshell presents a promising pathway toward achieving reliable data exchange, streamlining the collaborative design process, and fostering a more efficient and error-free construction industry.

2 Methodology

We conducted interviews with two professionals in the construction industry. One of the interviewees was a civil engineer who utilizes structural design software, while the other was an expert in charge of drafting plans using Revit. Both professionals shared their feedback, stating that when they receive an IFC file from another program, there is

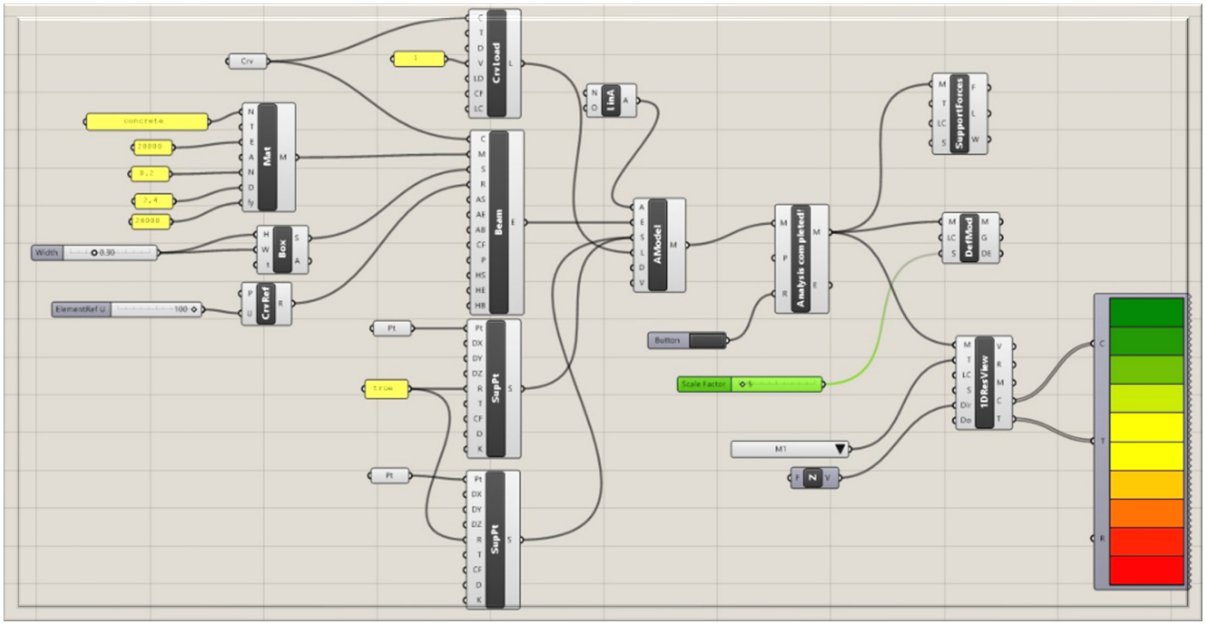

Fig. 3. Grasshopper script.

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often a loss of information, and it is more efficient to recreate the design from scratch. As a result, we decided to create a sample model on four different structural design programs (CYPECAD, Abaqus, SAP2000, and Rhino3D) and on Revit, and then export each model using the IFC file format. Next, we tested the ability to open the models created on a structural design program in Revit and vice versa. The interviews also allow us to have an idea to what the obtained results will look like. This will allow us to see if the loss of information is made by the exchange or by a misuse of the software.

2.1 Sample

We decided to create a uniform sample model in each program, taking into consideration any limitations each program might have. Our goal was to make each model as similar as possible. The agreed-upon sample model consisted of a 3-meter-long beam embedded at both ends, with a cross-section of 30 by 30 cm and a uniform load of 1 kN/m distributed along its length. If feasible, we aimed to add reinforcement of four 16 mm bars and 10mm stirrups spaced 20mm apart.

2.2 CYPECAD

CYPECAD is a structural design software widely used in the construction industry, particularly in Spain and Latin America [8]. For the purpose of our theoretical analysis, CYPECAD presented some limitations. The program requires the creation of at least two floors and must adhere to the laws and regulations of a specific country. In our case, we added two columns and placed the 30 by 30 cm beam between them, ensuring that the model adhered to Spanish regulations.
Once the model is completed, CYPECAD calculates the reinforcements needed. We changed them so they are closer to how we defined the model. We then exported the model into IFC format to be opened in Revit. Exporting in CYPECAD can be done easily and it even asks for the IFC version.

2.3 Rhino3D

Rhino3d is a 3D modeling software and grasshopper is visual programing tool that allows us to interact with the 3D model. Usually is not used for structural design, although it is commonly used for parametric design [9][10][11]. We can use plugins in grasshopper to add this functionality. For our test we used a plugin called kiwi3D for the structural calculations. Using Rhino3D, we decided to not add any reinforcements as this will overcomplicate the code. Once the script was done, we used another plugin called “BIM GEOMGYM IFC”, which allows to import and export IFC files.

2.4 SAP2000

SAP2000 is a comprehensive structural analysis and design software developed by Computers and Structures, Inc. (CSI). It is widely used in the construction industry, particularly in the United States, where it is recognized as one of the leading tools for building design. The software is well suited for the building industry because it makes it easy to model structures and perform various types of analysis.
One of the key features of SAP2000 is its user-friendly interface, which makes it accessible to engineers and designers with varying levels of experience. To use the software, you first define the materials and cross sections for your structure. Then you can create a grid and draw elements, such as beams and columns, that make up your structure. The next step is to set boundary conditions and loads, such as wind, earthquake, and gravity loads, that will act on your structure. Finally, you can perform the calculation to determine the response of your structure to the applied loads.

2.5 Abaqus

Abaqus is a finite analysis program used for composite elements and 3D printing elements. This program is rarely use in the construction industry and is the only one without any type of IFC support. For the modeling process in Abaqus is necessary to follow different steps because this software works through a special flow in which you have to define multiples environments for

Property	Rhino/ Grasshopper	ABAQUS	SAP2000	CYPECAD	Revit
Geometry	✓	Partial	✓	✓	✓
Material	x	x	x	x	x
Load	x	x	x	x	x
Boundary conditions	x	x	x	x	x
Reinforcement	x	x	x	x	x

Table 1. Quality of exported element per software.

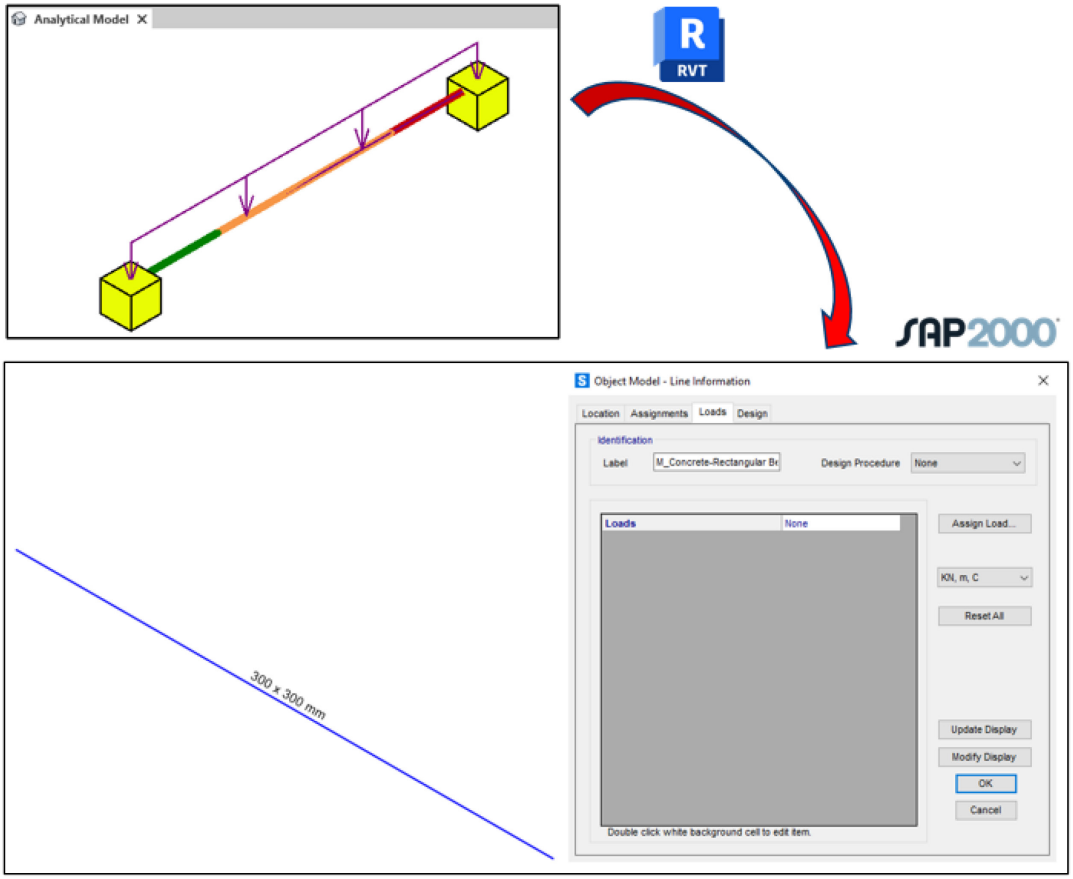

Fig. 4. Exported element from Revit to SAP2000.

each necessary components of the model. The model made in Abaqus follows the sample conditions. Abaqus does not support IFC file format, either for import or export. In order to enable exportation to Revit, the Abaqus file was accessed through Autodesk Fusion360, and underwent a conversion process to a format compatible with Revit.

2.6 Revit

Revit is Building Information Modelling (BIM) program used in the construction industry all around the world. One of the main advantages of Revit is the use of elements parametric families, which allows to make changes and updates on the project with efficiency. Once we use IFC to import and export from Revit, we will check two things: do the elements obtained in Revit belong to a parametric family? do the resulting model in the software have the characteristics defined in Revit?

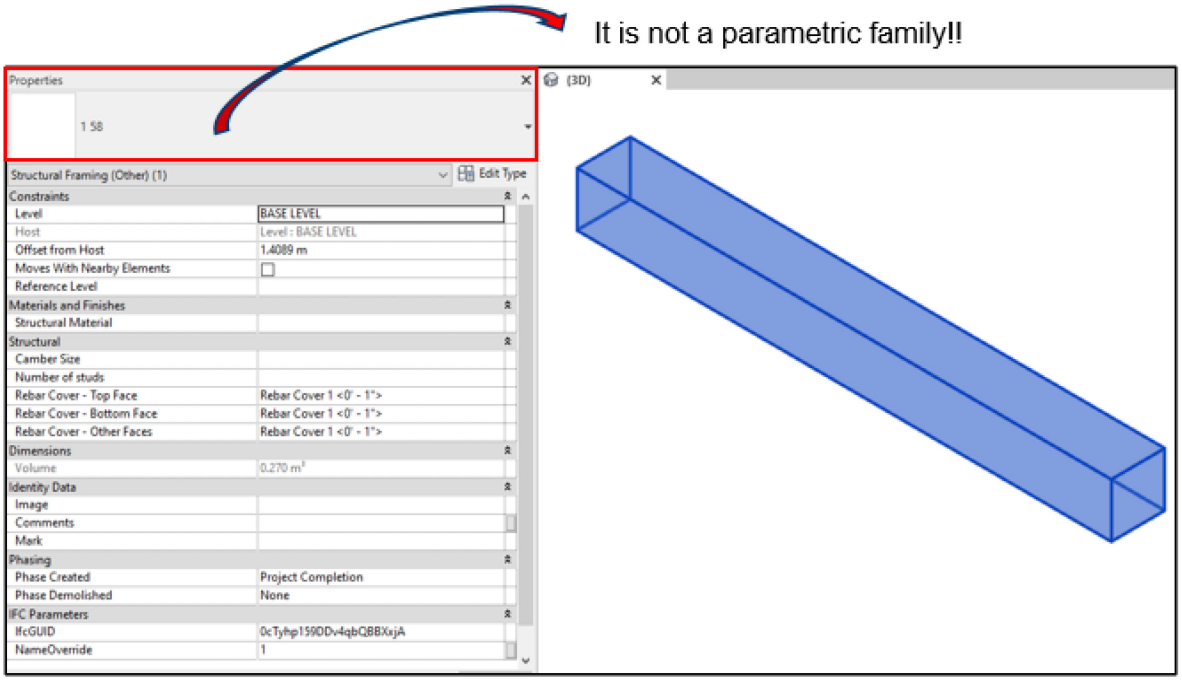

Fig. 5. Exported element from CYPECAD to Revit.

3 Results

From the previously described methodology, different qualitative and quantitative results were obtained. To analyze these results a valuation matrix was created, to allow a more objective evaluation of the findings. Four evaluation criteria were defined: usage (complexity of the exchange process), possible data formats (handling IFC format or another common format), quality of the exported element (accuracy of the process), and adaptability (plugins offer or another tool that allows the exchange). Each item received a different importance percentage according to its relevance for the overall exchange process.

3.1 Matrix components

The quality of the exported element was defined as the most important criterion for the evaluation matrix, analyzing the properties of the element that was obtained at the end of the import process in both Revit and design programs. The properties analyzed were: geometry, material, load, boundary conditions, and reinforcement.
Analyzing the elements obtained in Revit, it was possible to establish that there is an important loss of information. Of the parameters defined in table 1, the only one that managed to be efficiently transported was the geometry. In this case, the length of the beam and its cross-section were correctly identified and assigned by Revit. In all other cases, the defined properties were lost.
Figure 4 shows the result of exporting the element defined in Revit to the structural design software SAP2000 using the IFC exchange format. It can be seen in the software image that the element has the correct geometry but has no load assigned. Also, the boundary conditions, the reinforcement, and the material defined in Revit are lost during the process.

Figure 5 displays the subsequent workflow: a structural component made in CYPECAD and conveyed as an IFC file to Revit. The outcome produced in Revit is an element where solely the geometry matches the CYPECAD definition. Furthermore, Revit automatically designates a family referred to as "1 58", resulting in a reduction in the worth of the imported object [12].
The default family assigned by Revit is hard to parameterize, which decreases the value of the sample and the overall exchange procedure. In summary, one of Revit's advantages as a tool for constructing models and blueprints is the utilization of parameterizable families, which gets

compromised during the exchange process. The export and import capability using various file types was the second most important criterion established. In this aspect, besides the number of formats, their validity and relatively common use within the construction industry were taken into account. For instance, the Rhino/Grasshopper software enables users to work with a significantly large number of file types. However, it should be noted these programs are utilized in a wide range of applications, so not all of these options are pertinent to the present investigation.

Finally, two more standards were defined for the matrix, the usage and the adaptability of the programs. The first is purely subjective and was evaluated based on our experience as users during the investigation. Table 3 shows the resulting matrix, where it is evident that the only program with an outstanding rating on this topic was SAP2000, due to its practicality when importing. For the other applications, considerably more search time was spent in completing the task. It is important to measure this software management procedure since automation and reproducibility of processes within the world of construction and design are very essential.

Adaptability tries to measure the trend of manufacturers to connect its product with the BIM technology, Revit in this case. Along with the development of the research were found different tools that evidence or not that tendency. For Rhino were found several plugins which accomplish the task, also for SAP2000 a special complement for Revit came into the picture. CYPECAD has a tool that allows checking updates in the model you are working on but not something for the exchange process. In the last position, Abaqus got the worst value here because it was not identified anything for the software. he results show parity between the qualification obtained for Rhino, CYPECAD, and SAP2000, the latter being the one that achieved the best percentage. Contrary to the above, it is established that ABAQUS obtained the worst rating, being isolated from the others.

Considering the criteria employed to evaluate the programs, it was determined that the usage, availability of formats, and quality of exported elements showed consistent results. Out of these attributes, three software

Software	Export	Import
Rhino/Grasshopper	3DM, 3DS, 3MF, SAT, AI, AMF, DWG, DXF, DAE, CD, X, EMF, GF, PM, KMZ, GTS, IGS, IWO, UDO, FBX, OBJ, CSV, X_T, PDF, PLY, TXT, POV, RAW, RIB, SVG, SKP, SLC, STP, STEP, STL, VDA, WRL, VRML, GDF, WMF, X3DV, XAML, XGL, ZPR, IFC(PLUGIN).	3DM, RWS, 3DS, 3MF, AI, AMF, DWG, DXF, X, E57, DST, EXP, EPS, OFF, GF, GFT, GH, GHX, GTS, IFC, IFCZIP, IGS, IGES, IWO, GGN, FBX, SCN, OBJ, IV, PDF.PLY.ASC.CSV.TXT.XYZ.CGO_ASCII, CGO, ASCI, PTS, RAW, M, SVG, SKP, SLC, SLDPRT, SLDASM, STP, STEP, STL, VDA, WRL, VRML, GDF, ZPR.
ABAQUS	SAT, IGS, STP, WRL, WRZ, 3DXML, OBJ.	SAT, IGS, IGES, STEP, STP, DXF, SLDPRT, SLDASM.
SAP2000	XML, STEP, IFC, IGS, DAT, EXR, MDB, S2K, F2K, DXF, FWP, SSI.	XML, STEP, IFC, IGS, DAT, EXR, MDB, S2K, DXF, FWP.
CYPECAD	4, IFC2X3, C3E, DXF, DWG.	XML, STEP, IFC, IGS, DAT, EXR, MDB, S2K, DXF, FWP.
REVIT	DWG, DXF, DGN, SAT, STL, PDF, FBX, GBXML, IFC.	IFC, IFCXML, IFCZIP.

Table 2. Possible data formats per software.

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Criteria	Rhino/ Grasshopper	ABAQUS	SAP2000	CYPECAD
Usage (15%)	2	2	4	2
Possible data formats (25%)	4.5	3	4	4
Quality of the exported element (50%)	3	1	3	3
Adaptability (20%)	5	2	4	3
Result	3.43	1.75	3.50	3.10

Table 3. Evaluation matrix.

received the same or pretty similar score, with only one deviation in each case. On the other hand, the adaptability component showed the highest level of variation, with each program receiving a unique rating. This can be seen in the accompanying graph.

4 Discussion

The research question was properly answered: although today IFC is the most common format to exchange models between the structural and the architectural disciplines it is clear exists inefficiency in the process. In this chapter, we are going to discuss the reasons for this response.

4.1 Improvement opportunities

Improving the workflow between structural design software and Revit (BIM) presents a significant opportunity. Our research highlights that the current process results in a significant loss of information, indicating its inefficiency. This loss is particularly concerning given that only the geometry is transferred, and the parametric family properties that add value in Revit are missing. These findings prompt an important question: is it worthwhile to engage in this exchange process when most of the information will be lost? To shed light on this, we conducted interviews with professionals, including the structural engineer and the BIM modeler. Our interviews revealed that the current process using IFC is limited to geometry, consistent with our research. Additionally, the methodology is highly inefficient, and the process is primarily used to import information from other disciplines for interference checking and reference. This highlights a clear lack of automation, as the information acquired through this process cannot be used as a starting point for modeling.

In this same sense, the possibilities of automation that are seen by us, as well as by our interviewees, are great. The advantages offered an efficient flow of information between the parties would have is attractive, we must not lose sight of the fact that depending on the size of the project, the information flows in both directions can be overwhelming. A small change, the need for alternatives, and unforeseen conditions are some of the reasons why an appropriate flow of data would mean considerable savings in work that translates into time and money.

It is important to emphasize that it is not about eliminating necessary processes, nor about a single professional being in charge of managing all the software ignoring all the knowledge that is required to make use of this type of specialized tools. It is clear that engineers and architects specialized in their disciplines are needed to use wisely the programs, however, the professionals consulted, as well as ourselves as engineers who have made use of these tools, identified the need to work on the efficient exchange of information that allows optimizing workflow. As mentioned in the results obtained for the adaptability criterion, it can be interpreted as a sign that companies are seeking to automate the flow of data between disciplines with the development of plugins. Although some of these add-ons were tested, there are limitations, such as the need for additional payments to have them. In this same sense, versions, and configurations must be consistent in order to make correct use of

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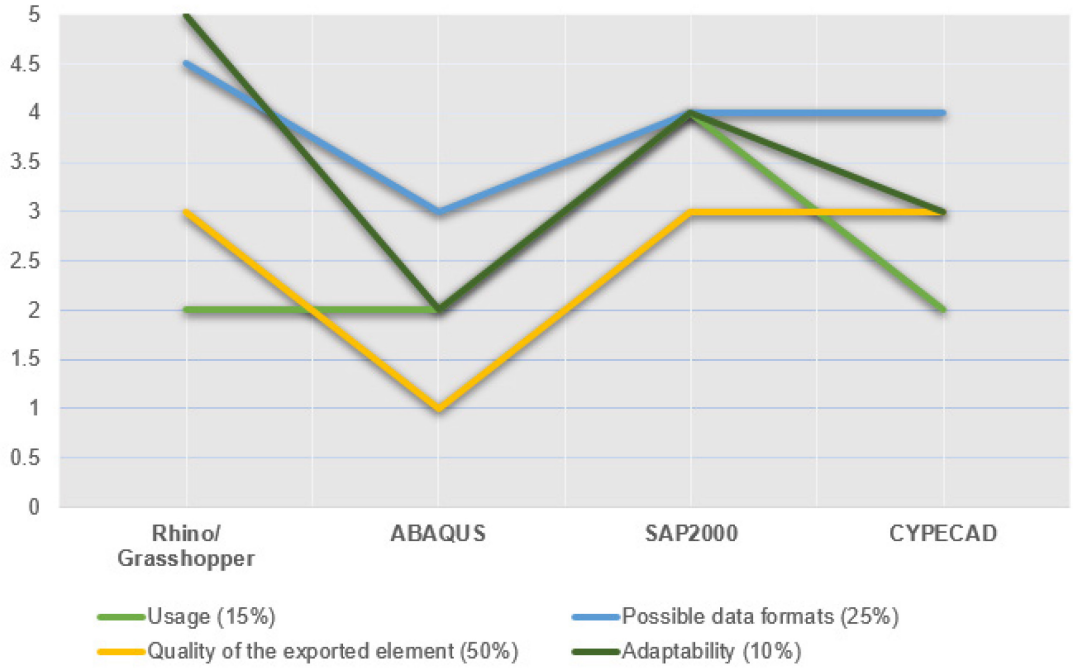

Fig. 6. Variability of indicators per software.

these specific exchange formats. The results suggest a wide scope for improvement in the field, and the companies are currently pursuing this path. As it was commented at the beginning of the document, the potential for improvement in the design flow between software from the same vendor, such as Robot Structural and Revit, suggests that similar investigations could be conducted to explore the exchange format used there. This concept could be expanded to solve the issues found with the IFC format.

4.2 Software results

ABAQUS obtained the worst rating according to the parameters established in this research, which means that in terms of examining the ease and tendency of the analyzed software to interact with Revit, it was not efficient. This may rely on the basis that it is software for Finite Element Method analysis, and its use is not for specific building design and construction purposes but more for investigation and detailed estimation of particular elements.

Consistent with the results obtained for Abaqus, it can be said in general terms that SAP2000 and CYPECAD performed well, being programs specialized in the structural design of buildings, where the exchange of models with the architectural branch is done regularly.

Finally, rhino/grasshopper presented a surprising performance. It is well known that these powerful tools have gained acceptance as software to automate processes within engineering, due to the ease of visual programming and adaptability to different fields. Thus, our results direct us in that sense, since despite not being a software specialized in structural design, it performed at the same level as the others.

5 Conclusion

After conducting extensive tests with specialized structural design software such as CYPECAD and SAP2000, alongside the utilization of the 3D modeling software Rhino3D, our findings underscore a significant challenge in the current state of information exchange within the construction industry. Despite our best efforts, our experiments demonstrated that we could only successfully transfer the geometric aspects of structures between these software platforms. Particularly, when attempting to transfer data from ABAQUS, a less common yet specialized analysis program in the construction field, to Revit, the limitations of the existing exchange processes became all the more evident.

The predominant use of the Industry Foundation Classes (IFC) file format for information sharing revealed its inherent constraint - it primarily handles geometry data, leaving critical structural and design information underutilized. This realization shows us the pressing need for substantial improvements in the data exchange process within the construction industry.
Enhancements in the IFC file format or the creation of more robust and standardized data sharing methodologies are essential to ensure that all pertinent information, beyond mere geometry, can be effectively and reliably communicated between software platforms. Addressing these challenges head-on promises to streamline construction projects, leading to increased efficiency and productivity in an industry where precision and collaboration are paramount.

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