BIM and Building Heritage Management: Interoperability Issues in Structural Design

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Abstract. The construction sector is one of the most polluting in the world. The increase in sustainability of the sector passes through the management of the existing real estate in terms of renovation and efficiency. The problem is particularly evident in Sardinia Island, owner of a largely obsolete and inefficient real estate stock. In this context, BIM (Building Information Modeling) represents the tool to improve the efficiency and quality of the processes of design, construction and management of public works. However, to date, interoperability between software related to the various process elements - architectural, structural, plant engineering, etc. - does not seem adequate. This paper analyzes the level of interoperability between three software for the creation of the BIM model and a structural modeling and calculation software with reference to a reinforced concrete building representative of the Sardinian real estate stock. The results highlight the critical issues still present in the process of exporting and importing models between the various software, which prevent the full effectiveness of the BIM approach. The implications of these aspects on the construction sector in Sardinia are illustrated and discussed.

Keywords: BIM · structural design · existing buildings · buildings sustainability

1 Introduction

Italy is the first country in Europe for the number of homes per capita. According to national institute of statistics (ISTAT) housing stock data, in Italy there are 599 homes per thousand inhabitants against a European average of 506, and including unused buildings, the total number of buildings or building complexes amounts to 14,515,795 [1, 2]. This primacy highlights the centrality of housing policies in Italy, especially considering the gradual loss of value of the building stock, above all in peripheral areas, since over 70% of buildings are over 40 years old. Much of this heritage shows problems of obsolescence that require structural, functional, typological and technological interventions.

In Sardinia Island, more than 60% of residential properties date back to over 44 years ago, and over 30% of properties for civil use are uninhabited [1]. These properties are often in small towns subject to depopulation or are intended for holiday homes. The interventions on the house for the implementation of the so-called Green Buildings

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Directive [3], which foresees a gradual reduction in energy consumption of residential buildings, will concern two thirds of the houses occupied and built by 1980 on the Island. In view of this, the renovation market currently absorbs approximately 80% of the value of construction production, and represents 64% of the value of regional production, consolidating its relevance in the global insular market and in the regional economy [4].

The old real estate heritage, often in precarious conditions, represents a brake on the transition towards sustainable construction. The renovation and management of this building heritage is one of the great challenges that the construction sector will have to face in the coming years, a complex path that will require innovative solutions and tools, concreteness and feasibility, knowledge and expertise. Buildings cost more than they should to design, build, and maintain, so there needs to be more and better collaboration between the various stakeholders involved in the construction process. In a recent NIST (National Institute of Standards and Technology for the United States) study, lack of interoperability was identified as costing $15.8 billion annually [5]. This aspect can be significantly improved with better information management and a restructuring of management processes to create standard information exchanges between stakeholders.

A tool that can offer a control opportunity for buildings sustainable renovation is Building Information Modeling (BIM), a method for generating and managing information about buildings throughout their life cycle. Based on parametric building modeling technology, BIM uses a relational database combined with a behavioral model to process and represent information about the building in a dynamic way.

When considering structural design, which is a fundamental aspect in the sustainable renovation of existing buildings, it can be noted that this area is lugging in applying the BIM digitalization process due to several factors, including the difficulty of automating processes in which the intervention of the structural engineer is strictly necessary, the schematization of calculation models, the passage of information between architectural, structural, and systems models.

This paper analyzes the problem of BIM interoperability in structural design of existing buildings through the implementation of representative tests and their critical analysis, focusing on the exchange of data between BIM software and structural modeling software. To this end, a sample building, simulating existing reinforced concrete buildings in the Sardinian context, was generated using three different commercial BIM modeling software, then exported and loaded onto a commercial structural modeling software, and the critical issues that emerged in the transition between the two modeling environments were detected and analyzed.

The results obtained allow us to shed light on the state of the art regarding interoperability between architectural and structural models, and to focus on the future steps needed to facilitate the use of BIM in the structural renovation of existing buildings, essential in contexts such as the Sardinian one in which the proper management of the building heritage represents a primary objective towards sustainability.

2 Building Information Modeling (BIM)

The National Building Information Model Standard Project Committee defines BIM as follows: *Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for*

information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition [5].

Declaring the definition in the construction field, Building Information Modeling (BIM) is a process based on intelligent 3D models that provides stakeholders in the sector (architects, engineers, professionals, etc.) with in-depth information and tools to plan, design, construct and manage buildings and infrastructure more efficiently and reduce their overall costs. "Building" refers to the entire life cycle of the structure, including conception, design, construction, functional life, maintenance, renovation and adaptive uses, recycling/disposal, as well as related factors such as investments, risk management, environmental impacts and others. Currently, 10 dimensions of BIM are used (Fig. 1). "Information" refers to the acquisition, use, exchange and creation of information in the form of data, which is the key to the functioning of the system. Relatively recent developments in standardized database schemas have begun to standardize the packaging of information, but further standardized definitions are needed across the various fields related to the construction model for the various functional aspects and participants in the process to work together efficiently. "Modeling" refers to the digital representation of the construction and the management process that revolves around it, meaning that computers can be used to virtually "build" the construction project, visualize and test it, modify it if necessary, and then produce various reports and views for all the phases involved in the process.

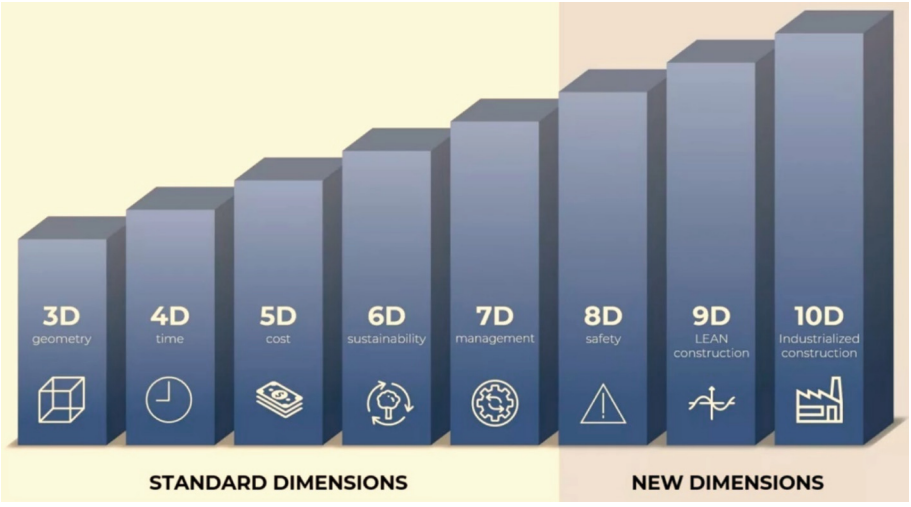


Fig. 1. The 10 dimensions of BIM

BIM therefore offers the possibility of having a virtual dual of the building, allowing the world of construction to be approached from a methodological point of view with all other production sectors and promoting its industrial characterization. The BIM building model, created using entities representing the different building components, can make them relate to each other and integrate them with multiple pieces of information, to allow stakeholders immediate and shared verification of all the choices made. The basis of the

effectiveness of the BIM approach is the concept of interoperability, understood as the possibility of exchanging the data contained in the model between the various software work environments related to the different process elements, allowing all stakeholders involved in the design, construction and management process of a building to collaborate efficiently and without loss of information. BIM interoperability is therefore a fundamental requirement to facilitate and guarantee the exchange of information between the different software platforms used in the life cycle of a building project. Therefore, it is necessary that the flow of information capable of fully describing the production and management process of the structure is defined in a universal "language", i.e. understandable by the various software platforms involved. This can be done by encoding information in standardized formats such as IFC (Industry Foundation Classes) [6], a common exchange format defined at international level and continuously evolving. The IFC data model is intended to describe data from the building and construction industry. The main and most important feature of this format is that it is a neutral and open file type, i.e. not under the control of a group or a single supplier but available to everyone. The IFC model is developed by BuildingSMART [7] (International Alliance for Interoperability, IAI) with the aim of facilitating interoperability between the various disciplines that interact during the design, construction and life of a building (engineering, architecture, construction industry, environmental matters, systems and safety, etc.) by defining a system that can be used and understood by all so as to be able to exchange a single file containing all aspects of the building that can be modified and read with maximum ease, based on the BIM methodology. The IFC data model specification is open and available and has been recognized and registered in the international standard ISO 16739:2013 [8] and subsequent amendments and additions.

2.1 Interoperability in the Field of Structural Design

Interoperability is therefore the passage of information from the central BIM model software to the specific software of a given field, in this case the structural field, and vice versa.

To date, the diffusion of BIM in Italy is mainly concentrated in the architectural design sector, where the solutions are increasingly advanced and sufficiently mature for highly professional use. Only in more recent times have proposals for BIM solutions linked to structural and plant engineering aspects seen the light. The use of BIM in the structural field, and in particular the interoperability between the architectural BIM model and the structural calculation model, is a topic still being explored, which certainly needs to be developed further. The central theme is the different vision of modeling between the architectural field and the structural field: while architectural modeling aims to obtain a model as realistic as possible, structural modeling aims to schematize the structure in simple or simplified elements, such as rods and nodes, for the subsequent structural analysis. At present, a way must be found to contemplate both needs, to improve and make the BIM model of the building increasingly efficient. Further complexities arise when it comes to modeling an existing building, for which a survey phase in the broad sense is necessary to identify the actual state of the construction with the greatest possible precision and reliability, so that the structural model can correctly represent the building to be analyzed and predict realistic collapse mechanisms. Although there are

some specific studies on the subject in the literature [9–14], the issue of interoperability between the BIM model and the structural model is still an open problem that requires considerable in-depth study, especially when modeling concerns existing buildings.

In this context, the present work aims to analyze the interoperability, relating to the structural aspects of an existing building, between the architectural model created in a BIM software environment and the structural model created using software for structural analysis. To this end, the model of a reinforced concrete (RC) building was generated, representative of the large building stock present in Sardinia, using three commercial BIM modeling software. The BIM model was then exported and loaded onto a commercial structural modeling software, and the critical issues that emerged in the transition between the two modeling environments were then detected and analyzed.

In this research, the software chosen for the creation of the BIM model are Autodesk Revit [15], ALLPLAN [16] and ARCHLine [17], while for the structural modelling and analysis the software chosen is Sismicad [18]. The choice fell on these software by reason of their diffusion among workers in the sector.

3 The Building

The reinforced concrete building structure is a two-level frame 2.95 m apart with a foundation level positioned at −1.50 m from the design level (Fig. 2).

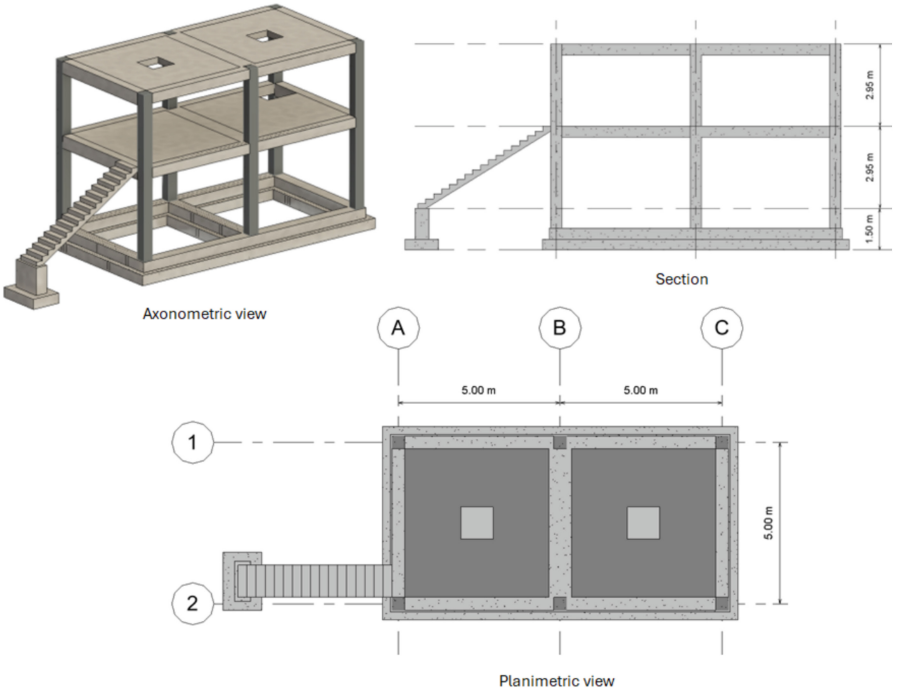


Fig. 2. The reinforced concrete building. Axonometric and planimetric views and section

Each floor frame is made up of six pillars, spaced 5.00 m apart, with a section of 0.40×0.40 m, reinforced with 4 longitudinal bars φ16 mm, stirrups φ8mm every 0.25 mm and a 250 mm concrete cover (Fig. 3a). The longitudinal bars of the pillars extend below the design level to connect with the foundations. There are three types of beams: type 1 beams connecting the pillars along the long sides of the building, type 2 beams connecting the pillars along the external short sides, and type 3 beams connecting the central pillars along the short side. The type 1 beam has dimensions 0.40×0.40 m with 3 φ16mm reinforcing bars in the upper part and 3 in the lower part, the stirrups are φ8mm with variable pitch 0.20 m in the middle and 0.10 m up to 1.5 m from the ends. The type 2 beam has dimensions 0.40×0.50 m and the same reinforcement as beam 1 (Fig. 3b).

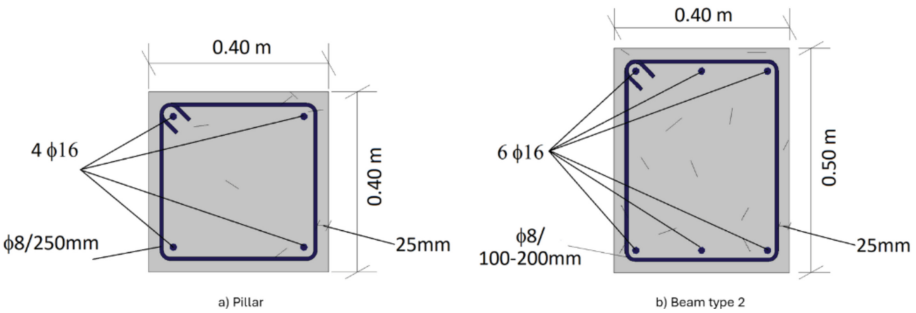


Fig. 3. Pillar (a). Beam of type 2 (b)

The type 3 beam has dimensions 0.70×0.25 m, longitudinal reinforcement made up of 7 φ16mm bars in the upper part and 7 in the lower part, φ8mm stirrups with four arms with pitch 150 mm. The foundation structure is composed of reversed T-beams with a section of 1.00×0.80 m reinforced with 14 longitudinal bars φ16mm divided into two rows of 7 positioned parallel to the design plane, plus 8 bars distributed in the vertical part of the inverted beam, φ8 stirrups with a pitch of 150 mm (Fig. 4).

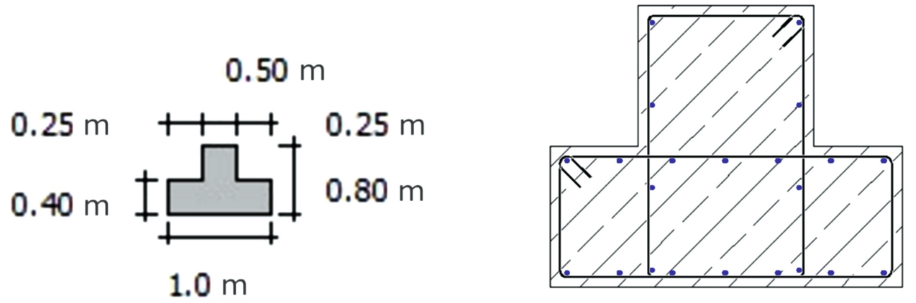


Fig. 4. Foundation beam

The floors of the ground floor are mixed in reinforced concrete with 200 mm hollow cores and 50 mm screed with a total thickness of 250 mm; one of the floors has a hole measuring 1.40×1.40 m. The floors of the upper floor are reinforced concrete slabs with a hole measuring 1.00×1.00 m in the center. The building is equipped with external stairs, 1.00 m wide and with a difference in height of 2.95 m. The stairs consist of a 150 mm thick climbing slab with 17 reinforced concrete steps with a riser of 173.5 mm and a tread of 280 mm. The stairs reinforcement consists of two rows of 10 longitudinal bars φ14mm, adapted to the shape of the ramp and ending in the foundation of the stairs, and a cage of transverse bars φ10mm that continue along the entire slab, while the foundation of the stairs is reinforced with φ8mm stirrups and φ16mm bars (Fig. 5).

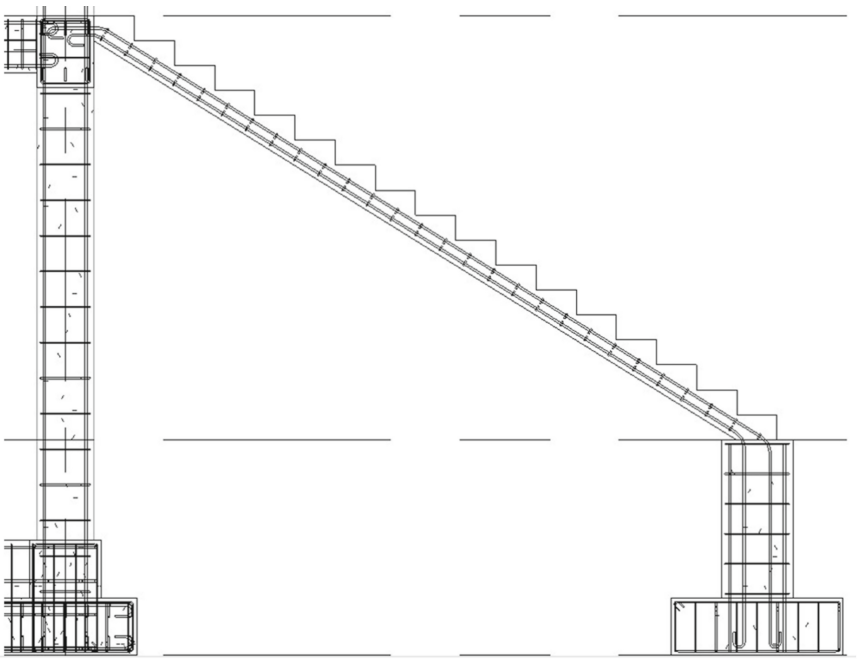


Fig. 5. The stairs reinforcement

4 Methodology

The working methodology is divided into four steps:

- Step 1: creation of the model of the sample building in each of the three BIM software and export of the model in the IFC4 and IFC2x3 formats. The IFC4 format is the most recent, but is not yet supported by several platforms, including Sismicad; the IFC2x3 format is more consolidated, although it has a smaller library than IFC4.

- Step 2: visualization of the exported model using the KITModelViewer software [19], a tool used to visualize semantic data models from the fields of BIM. In addition to the graphical representation, the tool can display properties and relationships between objects and allows various analyses of the data. This visualization tool is very useful in the transition from BIM software to other environment software, such as structural software, to analyze the information contained in the standardized and open data files, evaluate the correctness of the exported model and intervene on the information.
- Step 3: import of the IFC2x3 file into the structural analysis software.
- Step 4: analysis of critical issues related to data export and import.

Figure 6 summarizes the methodological flow.

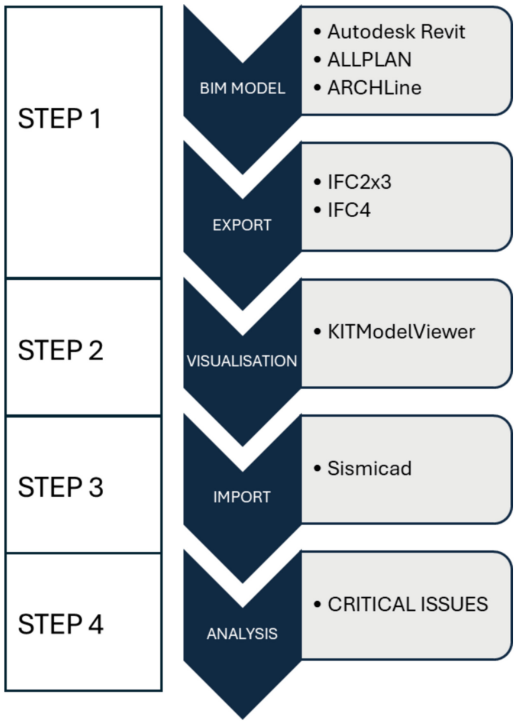


Fig. 6. Methodological flow

5 Results

The results and critical issues encountered in the modeling and data transfer process are reported below.

Figure 7 shows the 3D model created with the three BIM software as exported in the IFC4 format and displayed by KITModelViewer.

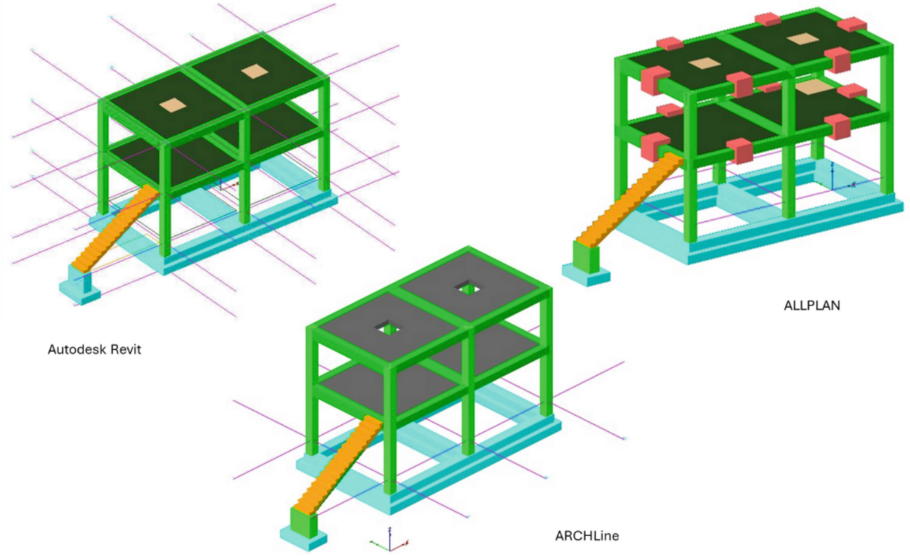


Fig. 7. 3D BIM models

In general, thanks also to the detailed analysis of the various properties of the elements exported in the IFC4 and IFC2x3 formats, omitted for the sake of simplicity, it can be observed that Autodesk Revit exports a greater number of elements than the other two software, ALLPLAN does not export the assignment of objects to work planes and introduces elements not present in the original model, while ARCHLine does not support reinforcements as stand-alone elements.

Analyzing the three IFC2x3 files imported into the structural software Sismicad, it can be observed that, compared to what was detected in the passage through KIT-ModelViewer, there is a further loss of information, as many elements have not been converted, others have been converted incorrectly, and others are not readable by the structural software. Although in many cases the operator can intervene by making corrections directly in the Sismicad environment, this solution represents an additional step that highlights the limits of interoperability between BIM software and structural software, especially considering the simplicity of the modeled building. Figure 8 shows the building models exported from the three BIM software via IFC files and imported into the structural software, while Fig. 9 shows some details of the visualization and layers produced by converting the entities into the structural software.

Therefore, the analysis relating to steps 1 and 2 has allowed us to understand the limits and differences of the BIM formats and software in relation to the IFC file. The analysis relating to steps 2 and 3, on the other hand, is based on importing the IFC2x3 files into the structural software, and has allowed us to observe which elements are recognized and which are not and the degree of adherence of the model imported into Sismicad compared to the models in IFC format, thus understanding the level and limits of interoperability between the various software used.

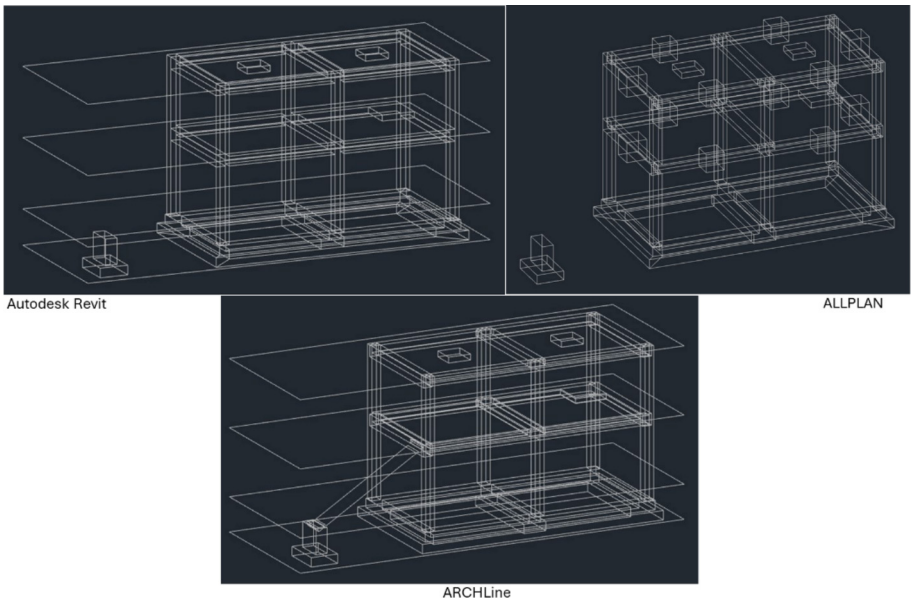


Fig. 8. IFC models imported into Sismicad

Figure 10 summarizes the quality of the model transfer from BIM software to the structural software Sismicad, highlighting the problems encountered element by element.

6 Discussion

From the results previously presented, the following considerations can be drawn.

- The most recent IFC format (IFC4) is not supported by all the software considered in this study, therefore a less recent format (IFC2x3) was chosen, but still suitable for simulation.
- The use of the various software considered was approached from the point of view of a user without specific experience in BIM modeling, so the modeling, export and import options were often kept in the default mode.
- The building chosen as a case study is significant and representative of the real estate heritage of Sardinia but is still a relatively simple building.
- In the export and import phases of the IFC model, some entities are not read, others are not recognized or are recognized only partially, others are inserted even though they are not present in the starting model.
- The major problems are associated with the management of the bars of the reinforced concrete elements.
- The BIM modeling software used in this study manages some types of data differently, therefore the export of such information into the structural software using the IFC file does not occur in a univocal manner.

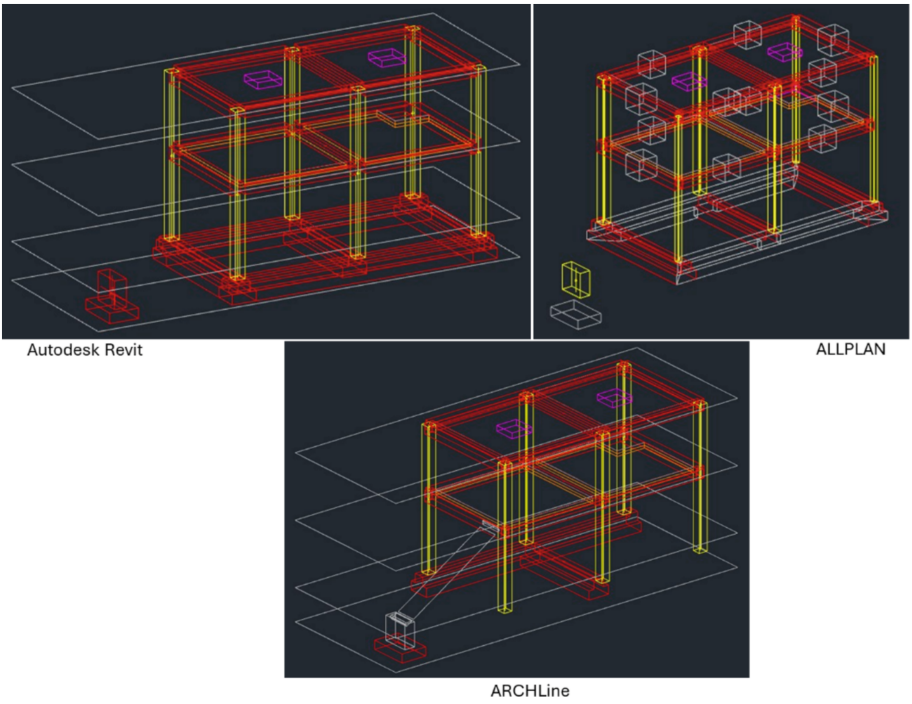
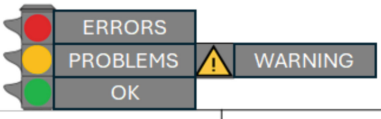


Fig. 9. Details of the imported models



	Autodesk Revit	ALLPLAN	ARCHLine
BEAMS	✓	✓	✓
PILLARS	✓	⚠	O
REINFORCEMENTS	X	X	X
STAIRS	X	X	X
R.C. SLABS	✓	✓	✓
MIXED FLOORS	O	O	O
REVERSED T-BEAMS	O	X	X
FLOOR HOLES	✓	✓	✓

Fig. 10. Quality of the model transfer

In light of these considerations, it can be stated that, in the context of this study, the IFC2x3 format is efficient and allows the transfer from the BIM modeling environment to the structural software of a building model that is consistent with what has been set, unless there are a series of critical issues that can be partially resolved through

additional corrective intervention by the user in the structural software. Therefore, the IFC2x3 format can be useful in the construction phase of the structural model of the building as it reduces the operations compared to the implementation of the model from scratch. However, from the point of view of interoperability, understood as the possibility of building a single file containing all the information of the building in a detailed and unambiguous way and manageable by the different software relating to the various areas of analysis while keeping all the types of data unchanged, the road is still long. The achievement of real interoperability will be linked to the possibility and ability to standardize the coding and interpretation of information in the various areas of design.

While the purpose of this study is to evaluate the level of interoperability in the application of BIM to structural engineering, without going into the merits of the capabilities of the individual software used, it can be asserted that, net of some strengths and weaknesses that each software has, the interoperability problems that emerged are common to the software considered, so that, currently, the choice of the BIM software to be used for a given project will generally depend on various factors, such as the specific needs of the project, the level of complexity, the budget, the expectations, the skills of the user.

6.1 Relevance for the Construction Sector in Sardinia

Interoperability in the structural field, still in its early stages, is just one of the key aspects for the introduction and diffusion of BIM in the design, construction and management of buildings and related services throughout Italy and in Sardinia, which has a real estate portfolio often inefficient and obsolete. It should be emphasized that in Italy, starting from 1 January 2025, contracting authorities and granting bodies must adopt digital construction information management methods and tools for the design and construction of new buildings and for interventions on existing buildings with an estimated cost of more than 2 million euros. Therefore, BIM has become mandatory in public procurement of a certain size, but the transition is hindered by digital gaps and regulatory doubts, highlighting the difficulties in implementing the digital challenge by many contracting authorities, which could fuel speculation to the advantage of a few and generate unnecessary rush to superficial training or merely formal certifications. The ANCI (National Association of Italian Municipalities) has even proposed raising the threshold of mandatory BIM to 4 million euros.

This problem is particularly strong in Sardinia, where contracting authorities are mostly small and could find themselves facing a blockage of procedures due to technical and personnel shortages. The OICE BIM 2023 report [20] highlights how in Italy the geographical distribution by macro-regions adopted for the purposes of analyzing the BIM tenders detected in 2023 sees the Central regions in first place, with 30.5% of the total BIM tenders, the South in second place with 27.9%, the North-East in third place with 18.2%, the North-West in fourth place with 13.0%, while at the lowest level are, as in 2022, the Islands of Sardinia and Sicily with only 10.4% of all BIM tenders. Despite this deficit, it is important to underline that Sardinia is moving to promote the introduction and diffusion of BIM and digitalization in the construction sector. For example, within Iscol@, a program of the Sardinia Regional Authority for the Sardinian school, Axis II “Safety interventions and scheduled maintenance of school buildings”

is included, aimed at making schools more comfortable and safe places by carrying out safety interventions, maintenance and renewal of furnishings and equipment on school buildings. In the Iscol@ tenders, the Sardinia Regional Authority has foreseen the possibility of introducing BIM as a reward element as early as 2017, and has drawn up specific guidelines [21], for use by Local Authorities, to create BIM models of school projects both for the graphic part and for the information part and the database setup. This best practice should be encouraged and transferred to as many project areas as possible, together with the promotion of interoperability in the structural and other technical fields.

7 Conclusions

This paper analyzes the level of interoperability between the software Autodesk Revit, ALLPLAN, ARCHLine, used for the implementation of the BIM model of a building, and the software for structural modeling and calculation Sismicad. The models are visualized with the software KITModel Viewer.

The building considered is a reinforced concrete construction representative of the existing real estate stock of Sardinia.

The applied methodology consists in the implementation of the BIM model in the three dedicated software, in the export of the model using the IFC4 and IFC2x3 formats and in its import into the structural software.

The results highlight the critical issues related to the process of transferring the model from one design environment to another. In particular, it emerges that in the export and import phases of the IFC model some entities are not read, others are not recognized or are recognized only partially, others are inserted even though they are not present in the starting modeling environment. The major problems are associated with the management of the bars of the reinforced concrete elements. Furthermore, it is clear that BIM modeling software manages some types of data differently, therefore the export of such information to the structural software via the IFC file does not occur univocally.

While the purpose of this study is to evaluate the level of interoperability in the application of BIM to structural engineering, without going into the merits of the capabilities of the individual software used, it can be stated that, net of some strengths and weaknesses that each software has, the interoperability issues that emerged are currently common to the software considered. The choice of BIM software to use for a given project will generally depend on various factors, such as the specific needs of the project, the level of complexity, the budget, the expectations, the skills of the user.

These interoperability gaps between BIM software and structural software are representative of the problems that currently prevent the full effectiveness of the BIM approach in the management of the design, construction and management processes of public works. This also has a significant impact in the case of Sardinia, which holds a real estate portfolio that is often inefficient and obsolete and is characterized by generally small contracting authorities that often have to deal with technical deficiencies and inadequate resources.

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