

BIM-GIS INTEGRATION THROUGH OPEN TOOLS

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Abstract

The implementation of effective workflows based on a fully open BIM-GIS (Building Information Modelling-Geographic Information Systems) integration is still an unsolved topic. This is mainly due to the lack of freely available BIM authoring tools, as well as to still unfixed interoperability issues between software. In this context, this paper proposes a new methodology to effectively integrate BIM and GIS without using commercial tools and proprietary formats. The proposed workflow is enabled by the use of the add-on “BlenderBIM” for the free software “Blender”, which allows to manage IFC (Industry Foundation Classes) models by updating non-geometric information through “.csv” files. Moreover, “.csv” files are also assumed as the main information exchange vehicle between BIM and GIS. The method is finally validated through an illustrative case study.

Introduction

Currently, the management of large building stocks is one of the most challenging activities which copes with many heterogeneous aspects and issues. In such a framework, the paper proposes a methodology capable of integrating different but strongly complementary tools, data, and information for a multiscale approach. It shows the first results of an ongoing research focused on the integration of BIM and GIS environments by taking advantage of open-source tools and non-proprietary data exchange formats. It is worth specifying that the herein proposed experimentation is part of a wider research concerning the implementation of an effective BIM-GIS integration in support of facility management of large building stocks (Congiu et al., 2024). However, the BIM-GIS workflow proposed in (Congiu et al., 2024) took advantage of open-source tools except for the BIM authoring. In this context, this contribution preliminarily attempts to replace the commercial BIM authoring in the original workflow (Congiu et al., 2024) by introducing BlenderBIM (*BlenderBIM Add-On*, n.d.) (an open-source BIM tool which is still in an unripe maturity level but really promising) and testing it through a simple abstract case study. In contrast to what has been mainly proposed in the literature concerning BIM-GIS integration so far, the methodology presented in this paper does not aim at transferring BIM data to the GIS platform. This unusual choice relies on the belief that it would be more advantageous to not wholly transfer integral BIM models into a GIS system firstly to prevent information redundancies and wastes, by keeping well distinct the two informative systems, as they have distinct purposes. Moreover, in the perspective of implementing an effective BIM-GIS integration to manage large building stocks,

transferring into GIS a considerable amount of integral BIM models it would make GIS projects too large and extremely difficult to be managed. For this reason, only some necessary information (selected based on the specific application field of the BIM-GIS integration) to be handled at an urban scale should be considered to be shared between the two information systems. The work thus focuses on a bidirectional integration between the two informative systems, by linking them and allowing for an easy switch from one system database to the other. The experimental phase, reported in the final part of the paper, focuses on the validation process of the methodology developed by applying the proposed methodology to an illustrative case study.

Literature review

Open BIM workflows: use of the IFC

In accordance with the buildingSMART International definition, openBIM is intended as a collaborative vendor-neutral process, which has to ensure good interoperability, the use of open standards and workflows, reliability of data exchange flows, flexibility, collaboration and sustainability (buildingSMART International, n.d.). It is also worth remarking that the non-profit organization buildingSMART International is responsible for creating and adopting open international standards such as IFC (Industry Foundation Classes), bSDD (buildingSMART Data Dictionary), and BCF (BIM Collaboration Format) to promote a common language in data exchange. In particular, the IFC schema is a standardized, ISO-recognized (ISO 16739-1:2018), data model that codifies the identity, semantics, objects, related attribute and processes (buildingSMART International, n.d.). The IFC schema is currently used as an exchange data format. Some interoperability issues are therefore due to the fact that IFC is not treated as a native way of recording data created by specific BIM applications (Malewczyk, 2022). Unlike other BIM authoring tools, Malewczyk showed how the open-source add-on BlenderBIM for Blender (*Blender 4.0*, n.d.; *BlenderBIM Add-On*, n.d.) works as a true IFC authoring tool, thus minimizing the risk of data loss related to forced data conversions.

In this context, it is worth mentioning a comprehensive literature review on the openBIM domain, workflows, standards, software platforms, and tools, provided by Jiang et al. as an outcome of an accurate investigation of the most accredited databases (e.g. Scopus, Web of Science, Science Direct etc) (Jiang et al., 2019). Their study supplies indeed a detailed understanding of the progress status of OpenBIM research by also discussing

the actual research gaps, including still unfixed critical issues in integrated BIM-GIS applications.

BIM-GIS integrated systems

Geospatial data in building planning and management play a very important role both because of their ability to integrate objects in a spatial context and to simplify all those operations involving a huge amount of information and data related to objects and to the territory in which these objects are located. Among geospatial data tools, Geographic Information Systems (GIS) play an important role, mainly due to their ability to perform spatial analysis and complex queries (Satria & Castro, 2016). In all cases where GIS involved a large building stock, the most crucial issue to be faced was to manage the huge amount of data and information that a building stock brings with itself. In the management of such data, a significant contribution has been made by BIM-GIS integration. GIS and BIM share similar features as they both manage spatial information but at different scales. Moretti et al. explored the combination of BIM and GIS and proposed a GeoBIM approach intended to improve digital Asset Management (AM), by especially focusing on outdoor and indoor condition assessment of the built environment. More specifically, Moretti et al. presented a GeoBIM model of the university Leonardo Campus of the Politecnico di Milano (Milan, Italy), by importing IFC models into a GIS environment in a 3D spatial data format by taking advantage of a specific commercial tool (FME workbench) (Moretti et al., 2021). Similarly, Sammartano et al. worked on a 3D City Model of Turin (Italy) to develop a digital twin of the city by taking advantage of a BIM-GIS integration with ArcGIS Pro (Sammartano et al., 2021a). Recently, Facility Management (FM) research is involving integrated BIM-GIS systems. FM is increasingly focused on finding solutions and tools to work at different scales more efficiently, from component, room, or building scale to spatial, regional, or national (Vankova et al., 2021). By way of example, Kang et Hong advanced a proposal of a software architecture based on an effective BIM-GIS integration using IFC and CityGML schemas, to specifically support FM (Kang & Hong, 2015). Vacca et al. showed the results of a research

concerning the integration between BIM and 3D GIS, applied to a housing project in the city of Cagliari (Italy) (Vacca et al., 2018). Mangia et al. provided a comprehensive study, based on the analysis of the literature, concerning BIM-GIS integrated systems for managing large building stocks (Mangia et al., 2022). Meschini et al. focused their research on the development of an Asset Management System (ASM) for university building stocks by combining BIM and GIS with cognitive digital twins (Meschini, Accardo, et al., 2022; Meschini, Pellegrini, et al., 2022). Other interesting applications of GIS-BIM integration systems refer to the management of infrastructures such as highways (Zhao et al., 2019), airports (D’Amico et al., 2020), or railways. Wang et al. introduced a comprehensive study on the progress status of the research on BIM-GIS integration and its applications, by specifically underlining some still unsolved critical issues related to one-way IFC-to-CityGML conversion (Wang et al., 2019). The potential of BIM-GIS integration in several application fields was investigated by Liu et al. through an extensive state-of-the-art review (Liu et al., 2017). The research of Liu et al. revealed still unfixed issues related to information loss or corruption in data exchange, but also the potential of semantic web technologies as promising integration solution. Concluding, it can be stated that BIM-GIS integration still needs to be enhanced in terms of software interoperability, data exchange accuracy and use of open-source tools and datasets.

Methods and tools

In light of what has emerged from the literature review, it can be stated that although some available commercial tools allow to transfer BIM models into GIS maps by taking advantage of IFC-to-CityGML conversion (Sammartano et al., 2021b), a lack of BIM-GIS integrated workflows uniquely based on open-source tools is still noticeable. This evidence then motivated the present research which is focused on developing a new BIM-GIS integrated workflow by only taking advantage of open-source tools, add-ons and non-proprietary data formats (see Figure 1).

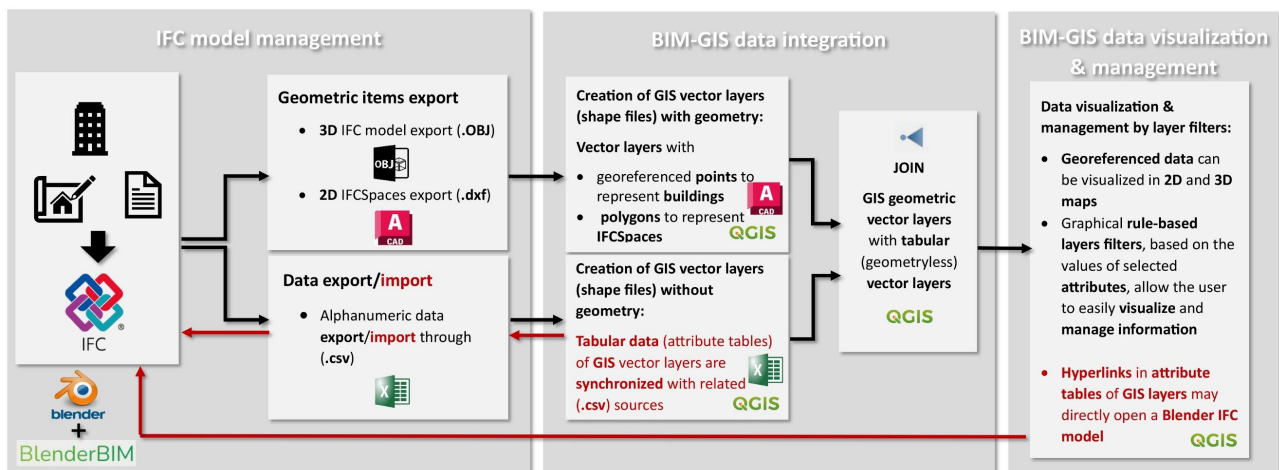


Figure 1. BIM-GIS integration workflow through open-source tools

It is also worth remarking that the proposed workflow is aimed at implementing an effective two-way integration between the two informative systems, by properly relating them and allowing for an easy switch from one system to the other, without transferring whole BIM databases into GIS maps. In this configuration, users can easily find the information which they require in the BIM model, at the scale of the specific building, and in the GIS model, at the scale of the large stock to which the specific building belongs. Moreover, the link between BIM and GIS models ensures that all the information, stored without copies or redundancies, is always updated and consequently reliable.

IFC model management through BlenderBIM

BlenderBIM (*BlenderBIM Add-On*, n.d.) is an add-on for the free but advanced modelling and rendering software Blender (*Blender 4.0*, n.d.). BlenderBIM provides an open-source IFC authoring platform which combines common abilities of modelling with additional scheduling, costing, simulating, and coordinating features. Blender and BlenderBIM add-on, unlike other BIM authoring programs, do not take advantage of object-oriented modelling tools. Blender tools allow the designer to create geometries whereas the BlenderBIM add-on allows the user to assign IfcClasses and related property sets to the modelled objects. BlenderBIM takes use of the IFC schema to classify geometries (Malewczyk, 2022). As shown in Figure 2, BlenderBIM easily allows a qualified user to model, edit and manage any sort of IFC object, as well as to manage IFC models deriving from a third BIM authoring tool. Therefore, BlenderBIM modelling is not object-oriented but rather IFC based. Elements classification and attributes are compliant with IFC standard, provided that a proper IFC class is assigned to each object. It can be therefore stated that, differing from other BIM authoring tools which use IFC standard to simply exchange data, BlenderBIM takes advantage of IFC as a native way to record information about the model (Malewczyk, 2022). As it is not among the goals of this research to transfer whole BIM models into GIS systems, the proposed workflow simply considers exporting IfcSpaces polygons as geometric items through the open-source add-on “ezdxf exporter”. The latter enables to export some selected IFC geometries to “.dxf” (Drawing Exchange Format) by properly setting custom properties of the exported layers. The choice of importing into GIS only BIM objects with simple geometry (*i.e.* IfcSpaces) is consistent with the aim of preliminarily testing the two-way effectiveness of the proposed BIM-GIS workflow on a simple dataset. In addition, IfcSpaces are suitable to be imported into a GIS environment as they can provide a proper .dxf geometric data source for a GIS shape file. The “.dxf” format is therefore assumed as the main exchange data vehicle between BIM and GIS for geometric entities. Moreover, the “Quality and Coordination” dialogue box of BlenderBIM provides a powerful “IFC-CSV Import/ Export panel” which enables two-way alphanumeric data exchange between the IFC model and “.csv” spreadsheets. This is the core of the proposed methodology as this BlenderBIM functionality

allows to export IFC alphanumeric data to a “.csv” tabular form, as well as to directly update information stored in an IFC model by reimporting updated “.csv” tabular data back, provided that specific IFC selection queries are properly set up through specific panels (“Add Search Group” and “Add CSV Attribute”). It can be stated that the IFC model is the main repository of information in the proposed workflow. CSV files are used instead as main information exchange vehicle between BIM and GIS for non-geometric data.

BIM-GIS data integration

The aforementioned datasets (*i.e.* geometric and semantic IFC data) are then imported and managed through the open-source GIS software QGIS (Quantum Geographic Information System) (*QGIS*, n.d.). QGIS enables to develop a suitable GIS environment to handle spatial data. Both 2D and 3D georeferenced maps can be easily built by taking advantage of freely available raster and vector layers (provided that also elevation values are included in attributes), such as the following:

1. DTM (Digital Terrain Model) raster layer adopted as DEM (Digital Elevation Model) source for the terrain elevation (freely available for Sardinia Italian region (*SardegnaGeoportale – Aree tematiche*, n.d.))
2. orthophoto of the area
3. vector shape file of volumetric units of buildings from a geo-topographic database (GTDB) 1:2000, freely available for Sardinia Italian region (*SardegnaGeoportale – Aree tematiche*, n.d.).

2D and 3D queryable maps with basic topographic contents provide a suitable GIS-based environment to be efficiently integrated and linked with additional geometric and non-geometric information extracted from BIM models. As previously anticipated, the proposed BIM-GIS integration requires a clear distinction between geometric items and respective semantic attributes to be exported from BIM models to be transferred to the GIS environment. This clear separation is made necessary by the need to export selected geometric items to a “.dxf” format, which is suitable for generating GIS shape files but which, however, also involves the loss of most of information associated with the exported objects. Fortunately, non-geometric data associated with the selected IFC objects can be exported, in a tabular form, to a specific structured “.csv” file, which can supply a suitable data source of a GIS geometryless vector layer in the QGIS scene (by keeping information constantly and mutually synchronized). As shown in the flowchart in Figure 1, semantic alphanumeric information needs to be properly linked to the respective geometric objects in the GIS environment, without losing synchronization with the data source files. This operation is made possible by the QGIS “Joins Properties” layer tab (*QGIS*, n.d.), allowing the user to associate geometric features of the current layer (called “Target layer”) with alphanumeric attributes from a geometryless layer (*i.e.* the “Join layer”). The layer “Joins Properties” functionality requires a “Join field” common to both layers to join, to accurately associate attributes of the “Join layer” with the “Target layer”. In

this regard, the proposed BIM-GIS integration approach provides for the assignment of IFC object names to “.dxf” layers during the related export, in order to create a suitable “join field” to allow subsequent “join” of attributes with the “.csv”-based geometryless layer in the QGIS environment. According to one of the main purposes of this research, in order to improve the bi-directionality on the BIM-GIS integration, the attribute tables of GIS layers may also include URL fields to hold specific hyperlinks to directly access useful additional files, like BIM models (*e.g.* BlenderBIM projects including IFC models).

BIM-GIS data visualization and management

The BIM-GIS workflow herein advanced, takes advantage of QGIS layer display features to enhance data visualization and management of the GeoBIM model. As previously anticipated, only IfcSpace objects have been assumed to be exported from BIM and imported into the GIS environment as 2D vector polygons. The latter may be also displayed on 3D maps as long as the related “height” values are set up as “extrusion” values in the layer 3D view tab. Also building “volume units” of the GTDB layer may be “extruded” on QGIS 3D maps to provide an effective graphical representation of urban contexts. In this regard, in order to make BIM-derived buildings more easily identifiable from the GIS urban context, a detailed 3D representation of that buildings, based on “.OBJ” geometries exported from the IFC authoring (*i.e.* BlenderBIM), may be associated with the related centroids (displayed as vector points in 2D maps) through the layer 3D view tab. In addition, QGIS rule-based filters for vector layers provide a powerful tool to ease data visualization and management in the herein advanced GeoBIM approach. More specifically, QGIS rule-based render options allow to discriminate features of a layer according to their attribute values by assigning them specific rendering settings. Filtering rules can be set up by taking advantage of a powerful SQL (Structured Query Language)-based “Query builder” dialog. In this regard, it is worth remarking the importance of setting up equally-named filters, based on the same rules, in both 2D and 3D view properties of layers, to ensure a perfect correspondence between 2D and 3D visualization of GIS maps. Unfortunately, QGIS does not enable to concurrently activate corresponding 2D and 3D render filters, so that users must therefore pay attention to activate 2D and 3D render options properly.

Workflow validation: a case study

The current section of this paper is aimed at validating the effectiveness of the BIM-GIS workflow, uniquely relying on the use of open-source tools and non-proprietary data formats, by simulating an illustrative example of data exchange, integration, visualization, and management, without employing a real case study. Therefore, as an example, a basic six-room house, developed on a single floor, has been modelled and adopted as an abstract illustrative case study to test the proposed BIM-GIS workflow. At this preliminary stage, the proposed methodology has not been implemented for a specific

application field. For this reason, this work does not focus on specific information requirements nor on precise information sets to be transferred from BIM to GIS, as only some abstract test parameters have been used to validate the two-way effectiveness of the method.

IFC model management through BlenderBIM

A basic BIM model of the adopted application case study, managed through the IFC authoring add-on BlenderBIM, is shown in Figure 2. As highlighted through a specific object selection, the model includes six IfcSpaces, whose attributes are manageable through the “Attributes” sub-panel included in the related “Object Information” tab, available among the BIM setting tabs on the right section of the BlenderBIM Graphical User Interface (GUI). It can be noted that the “Name” attribute provides a univocal numeric code assigned to each IfcSpace, whereas the “LongName” is a textual parameter, conceived to store the space full name commonly including information on space end uses. The “GlobalId” attribute provides instead the 22-character encoded internal ID, which is automatically generated by the software for each IFC element. According to IFC standard, IfcSpaces are characterized by several property sets, among which it is worth mentioning the “Attributes” set (including the fundamental attributes cited above), the “Object Property Sets” (including various properties sub-groups), the “Object Quantity Sets” (containing all relevant parameters for quantity take-off), and so on. In addition to standard IFC attributes, IfcSpaces are herein also equipped with a custom IfcBoolean parameter, named “TestParameter”, specifically created to be edited while performing experimental simulations of data exchange and management to assess strengths and weaknesses of the proposed BIM-GIS integration. In accordance with the proposed methodological workflow (Figure 1), IfcSpaces are exported to “.dxf” subject to properly set layer properties by assigning IfcSpace names to each respective exported layer through “ezdxf_exporter” add-on for Blender (see Figure 3). As far as IfcSpace alphanumeric data are concerned, some selected attributes, quantities and properties, including the aforementioned “TestParameter”, are exported to a “.csv” tabular format (through the specific functionality of BlenderBIM), provided that specific IFC selection queries are defined properly (see Figure 4). It is worth remarking that the BlenderBIM sub-panel “Quality and Coordination” also allow to update the involved IFC data by simply uploading the updated version of the “.csv” file, as long as the same IFC selection queries used to export data are set up (Figure 4). This is fundamental to ensure a real bidirectional integration between BIM and GIS, as it will be shown more clearly at the next validation sections. BIM-GIS data integration

In order to show an application of the proposed workflow, the IFC data extracted from the basic BIM-based model adopted as abstract case study, are properly imported into a GIS map. By way of example, a GIS map composed of a Digital Terrain Model, an orthophoto and the building “volume units” vector layer included in the Geotopographic database (GTDB), all freely available as open

geospatial data for the city of Cagliari, is generated. Thanks to the “elevation” attributes, it has been also possible to implement a 3D view of the map, thus providing both 2D and 3D representations of the urban context. Then, a georeferenced vector layer with

geometric polygons is also added to the map as a shape file, by using the IfcSpaces “.dxf” file as data source. Consistently with the specific “.dxf” export setup herein adopted (described in the previous section), the “Layer” field in the attribute table holds the IfcSpace names.

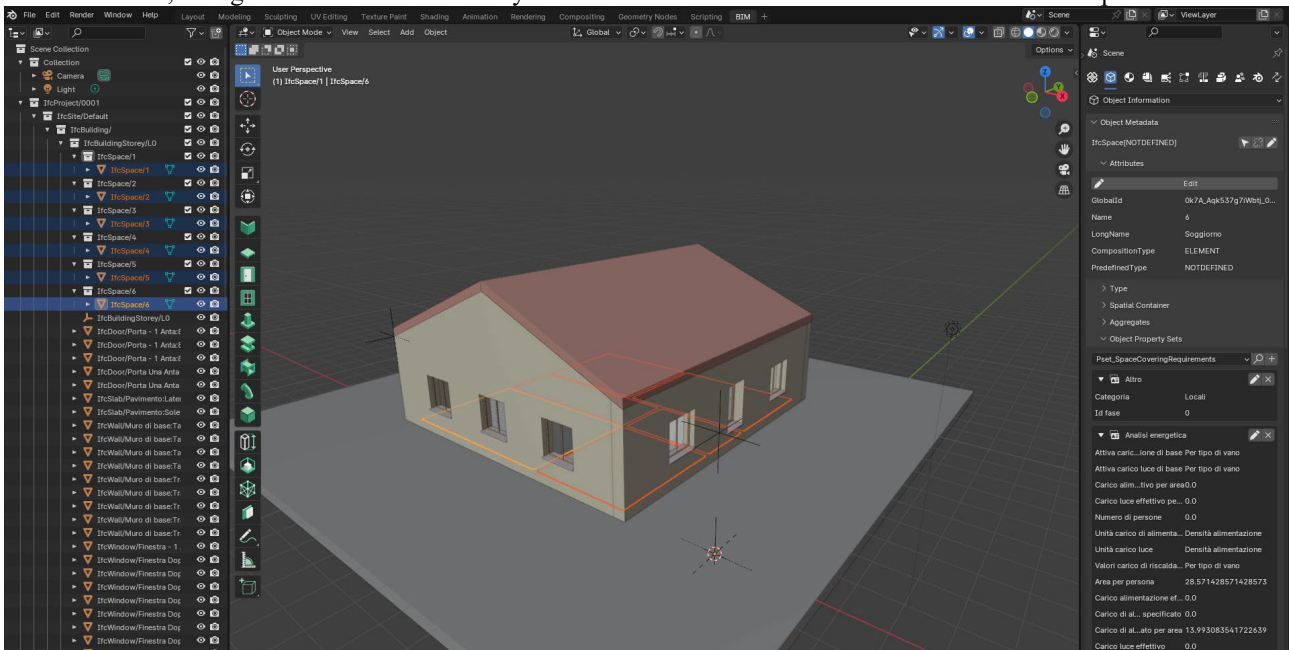


Figure 2: IFC model management through BlenderBIM (the illustrative case study)

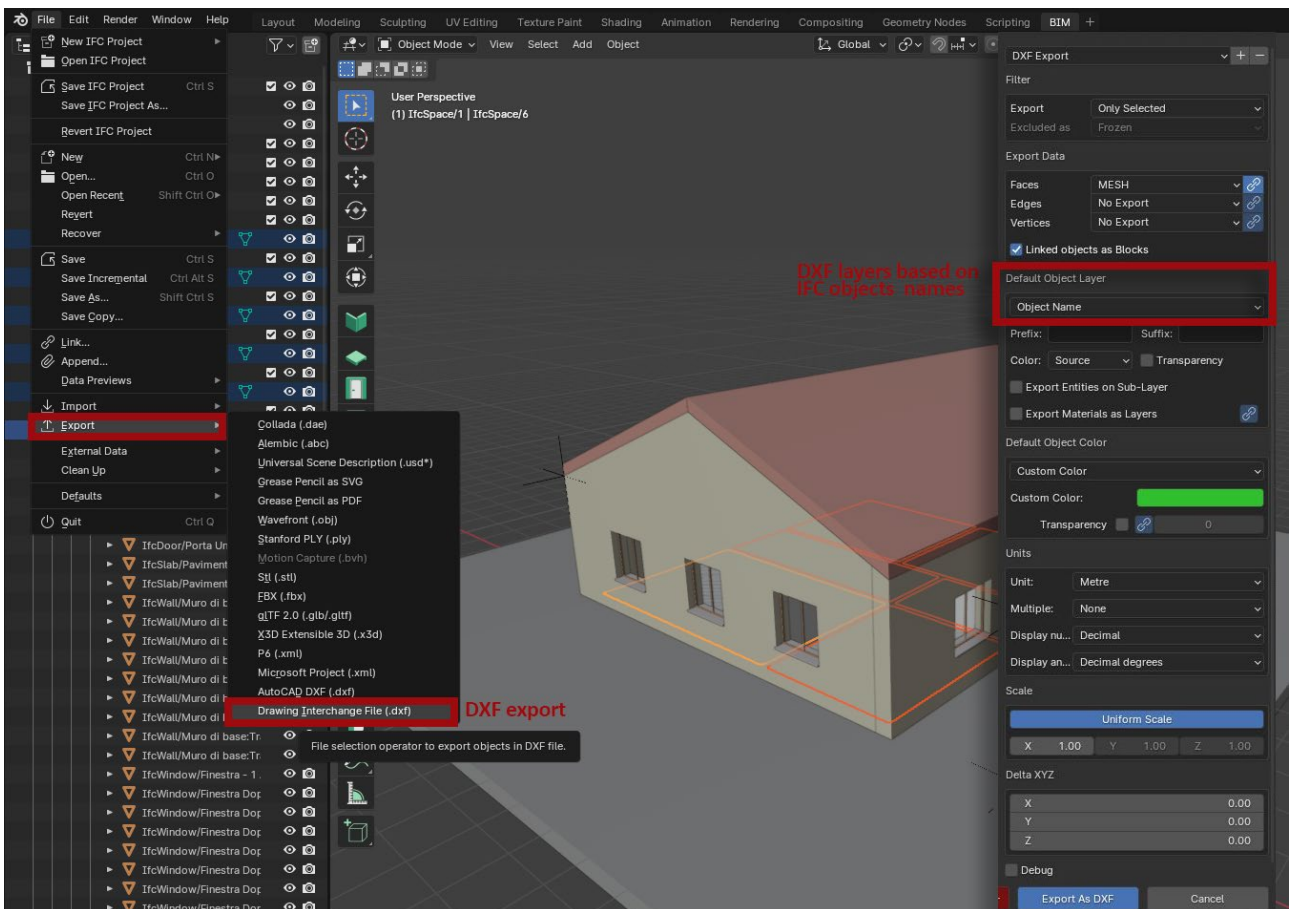


Figure 3: IfcSpaces export to .dxf (settings)

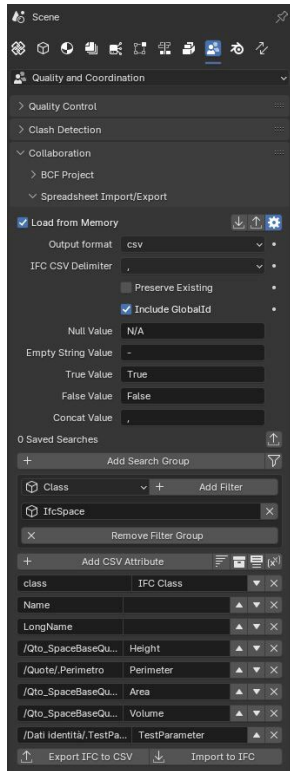


Figure 4: BlenderBIM – Export IFC to CSV and Import CSV to IFC settings for managing IfcSpaces data

The “.csv” table holding the additional alphanumeric IfcSpace data provides instead a suitable data source for a geometryless vector layer. In accordance with the advanced methodological approach, all fields of the csv-layer attribute table have been added to the attribute table of the IfcSpace layer including vector polygons by properly setting “Join Properties” of the “Target layer”. It is extremely important to underline that this operation ensures a join of attribute tables (see Figure 5) of the two involved layers without merging them, so as not to lose synchronization with the “.csv” data source of the geometry-less layer. Moreover, the IfcSpace “Name”, shared by both attribute tables, provided a suitable “Join field” to correctly associate “IfcCSV” data with the respective IfcSpaces. It can be also noted that all attributes derived from the “Join layer” (i.e. the geometry-less csv-layer) are specifically marked with the prefix “IfcCSV_” in order to distinguish them from the layer original attributes instantly (see Figure 5). It should also be

reported a critical issue related to the impossibility to directly edit attributes deriving from the “Join layer” through the attribute table of the “Target layer”. Those attributes can be only managed by editing their original geometry-less layer synchronized with its “.csv” data source. Concluding, a vector layer including a georeferenced point, corresponding to the building footprint centroid, is added to the map, to hold general information about the building. To enhance the bi-directionality of the advanced BIM-GIS integration, the attribute table of the building centroid has been equipped with a special attribute (named “IFC model”) to store an hyperlink (see Figure 6) to directly access the BlenderBIM project (holding the building IFC model).

BIM-GIS data visualization and management

As already declared, the GIS-based open-source tool QGIS is herein also adopted as GeoBIM data visualization and management platform. As far as data visualization is concerned, the IfcSpaces are graphically represented as vector polygons on the 2D map, whereas they are displayed as box objects on the 3D map, as long as the “IfcCSV_Height” attribute is assigned as extrusion value in the layer 3D view tab. Moreover, the building centroid is displayed as a georeferenced point on the map 2D view, whereas a detailed semi-transparent 3D hologram of the IFC model, based on the building “.OBJ” geometry exported from BlenderBIM, is associated as 3D model shape with the point 3D view properties (as shown in Figure 7). The detailed 3D hologram of the building is aimed at making BIM-derived buildings more easily identifiable from the box objects representing the built urban context. In Figure 7 some possible rule-based renderer filters are also shown. In this regard, the first exemplifying layer filters are simply based on the IfcSpace “names”, which are also assigned as labels. The last two display filters, which are activated in Figure 7, are based on the Boolean value of the “IfcCSV_TestParameter”, by assigning the red colour to “False” and the green colour to “True”. It can be also noticed that the respective 2D and 3D layer filters, based on the same display rules, are simultaneously activated. Notwithstanding that the 3D view of the shown GeoBIM model could be beneficial in terms of objects visualization quality, the map 2D view turned out to be more easily accessible, queryable and manageable as informative system.

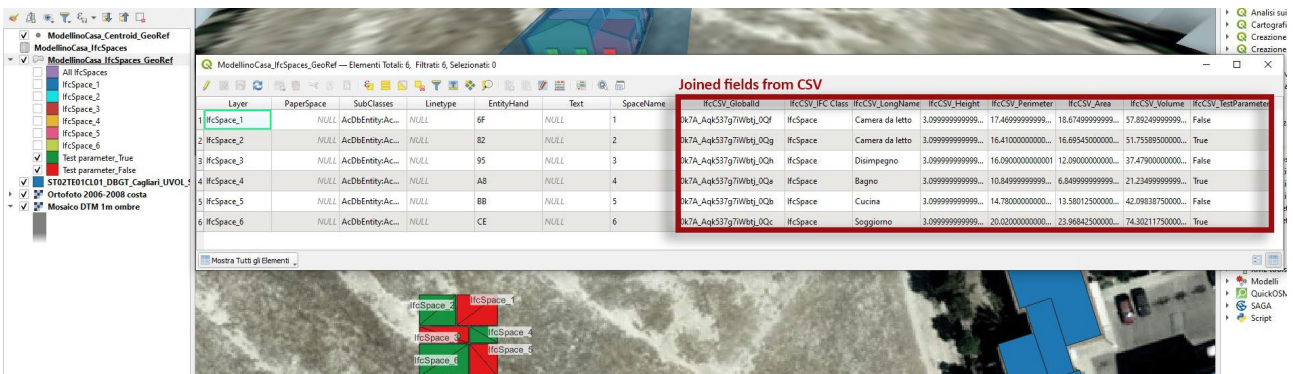


Figure 5: QGIS - Attributes table of the IfcSpaces (.dxf) polygons layer with additional “joined” attributes from .csv tabular data

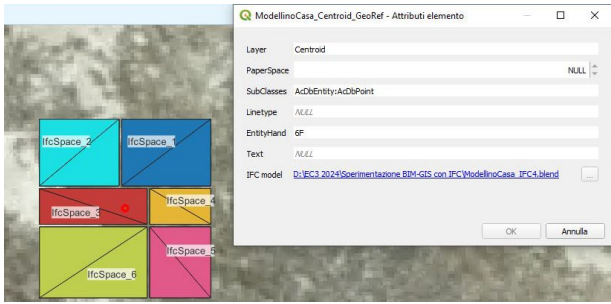


Figure 6: QGIS – IFC model hyperlink attribute

The conducted experimentation was finally concluded by validating the bidirectionality of the proposed BIM-GIS integration by first editing the “TestParameter” value of an IfcSpace on the GIS system and then successfully updating the IFC model by simply reimporting the related “.csv” file automatically updated thanks to data synchronization.

Conclusions

The integration of BIM and GIS methodologies and tools achieves high levels of effectiveness and efficiency in large building stock management. Starting from these premises, this paper shows the results of an ongoing research focused on the development of a methodological framework integrating BIM and GIS environments. The experimental phase conducted on an abstract illustrative case study allows the authors to highlight the strengths and weaknesses of the methodological framework developed. One of its strengths focuses on the exclusive use of open-source tools and open, international standards. This aspect is strictly bound with the important issues of interoperability, customization, verifiability, optimization, and low costs. The proposed methodology involves Blender-BIM, an open-source software that supports BIM approach, QGIS, an open-source software that allows users to manage geospatial information, and open standards like DXF and CSV. The work focuses on a bidirectional integration between the informative tools,

by linking them and allowing for an easy switch from one system database to the other. Despite the benefits that this methodology offers, some potential critical issues have emerged. It is worth underlining the difficulties in data management and visualization through QGIS filters. Users must pay attention to manually activate both 2D and 3D display filters that are not synchronized although they are based on the same rules. Moreover, the 3D view is affected by some annoying selection bugs, which make it difficult to correctly query the 3D map. Another issue is the critical management of the attributes deriving from the “Join layer”. These attributes can be only managed by editing their original geometry-less layer synchronized with its “.csv” data source. Finally, although the proposed workflow still needs to be improved and validated, it could be a solution to overcome some unfixed critical issues still affecting interoperability between commercial tools and enhance collaboration. Future work development will focus on the issues shown above.

Acknowledgments

We acknowledge financial support under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.5 - Call for tender No.3277 published on December 30, 2021 by the Italian Ministry of University and Research (MUR) funded by the European Union – NextGenerationEU. Project Code ECS0000038 – Project Title eINS Ecosystem of Innovation for Next Generation Sardinia – CUP F53C22000430001- Grant Assignment Decree No. 1056 adopted on June 23, 2022 by the Italian Ministry of Ministry of University and Research (MUR). This manuscript reflects only the authors’ views and opinions, neither the European Union nor the European Commission can be considered responsible for them. The research was also funded by “Piano Triennale della ricerca di Sistema del settore elettrico nazionale per il triennio 2022-2024», Progetto 1.5 “Edifici ad alta efficienza per la transizione energetica”.

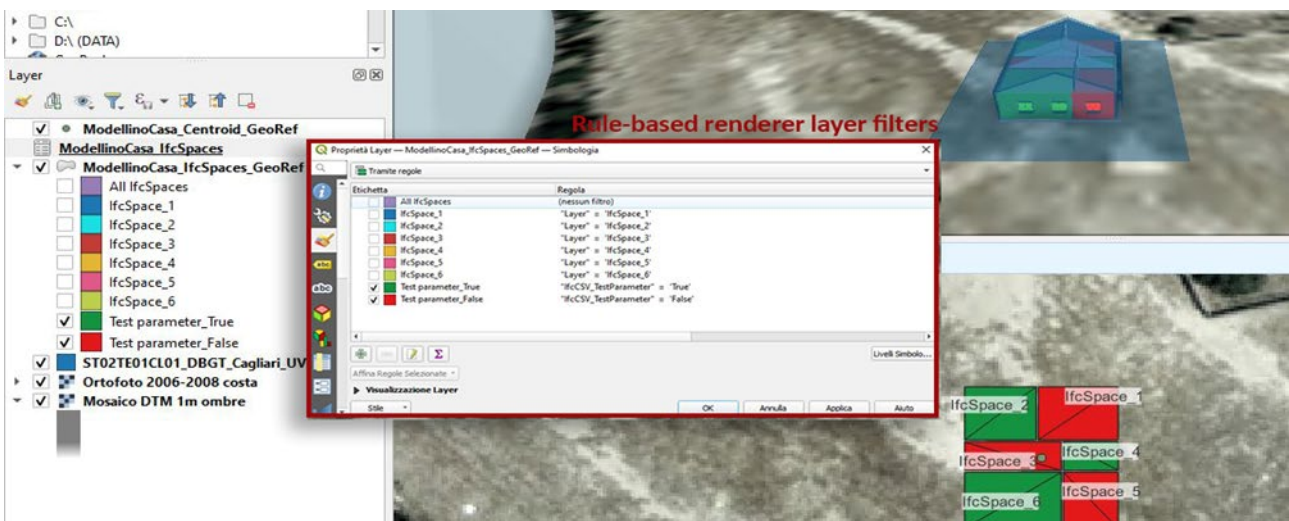


Figure 7: QGIS 2D and 3D maps with activated rule-based filters

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