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(Article begins on next page)

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Abstract

The adoption of BIM (Building Information Modelling) for archaeology is limited by different issues inherited by the software, which is usually designed for AEC industry and rarely fits Heritage assets. An unconventional solution could be provided by FOS (Free and Open-Source) software, thanks to source code accessibility and modifications possibilities, by adapting thus the software to specific needs and not the opposite. HBIM (Historic Building Information Modelling) methodology could become a good solution for the documentation and analysis of building archaeology, and FreeCAD software – apart from being a well-known modeller – has the potential to become the proper tool to use, because of its adaptability (overcoming limitations of standard BIM software). This paper is focused on experimentations and adaptations of FreeCAD to building archaeology assets, as a HBIM custom platform for the documentation and analyses, trying to avoid methodological compromises related to commercial BIM software, as well as trying to preserve the original goals of specific research.

Keywords: BUILDING ARCHAEOLOGY; DOCUMENTATION; FREECAD; FOSS; HBIM.

Introduction and objectives

Informative systems and open-access data have experienced a great development in the archaeological panorama especially in order to solve research and methodology-related issues. Specifically, data fragmentation and the difficulty of connecting paper-based to digital information has affected publication and knowledge-sharing steps of excavated sites or surveyed historical buildings for many years.

Historical Building Information Modelling (HBIM) was conceived eleven years ago (Murphy *et al.* 2009), and it has had an enormous importance becoming the subject of researches regarding archaeological fields. This term is referred to the adoption of BIM methodology (informative system created for architecture design) for Cultural Heritage assets, in particular to historical buildings documentation and analyses. In fact, HBIM should be intended as the knowledge management of historical buildings and it takes place in a specific historic moment; by contrast, traditional BIM methodology is intended for new constructions and it takes place at the beginning of the life-cycle of the building (Fassi *et al.* 2013).

This project moved from two starting points, one linked to geomatics and the other to building archaeology: in recent years BIM has rapidly developed thanks to commercial software, and our question is: can we today design a BIM/HBIM system by using exclusively FOSS tools?

In parallel, informative systems have demonstrated their importance for the archaeological field allowing one to keep linked different kinds of data. Is it, therefore, possible to design a proper HBIM solution to specifically address the needs of building archaeology?

Based on these assumptions, this project focuses on experimentations and adaptations of FreeCAD FOS software[1] as an HBIM platform for the documentation and analysis of building archaeology. This unconventional solution was used especially to try to adapt tools, software and workflows to specific needs, by avoiding methodological compromises imposed by commercial BIM software and preserving researches goals (Logothetis *et al.* 2016; Diara *et al.* 2018).

FreeCAD was trialled and validated on the refectory of the medieval Staffarda Abbey, a Cistercian monastery located near Saluzzo in north-west Italy. Knowledge processes on the religious context have generated a large amount of data which needed to be managed in a smart way for achieving a good standard of documentation. For this reason, HBIM was selected as an appropriate methodology and dynamic informative platform.

HBIM and archaeology: short review

HBIM methodology for the archaeological domain is rapidly spreading thanks to its huge potential. This approach involves the representation and reproduction of archaeological sites and monuments, focusing also on semantic knowledge resulting from morphological and conceptual peculiarities, by including the dimension of time (Historic England 2017; Trizio *et al.* 2019; Diara 2020). Although powerful BIM software products such as Autodesk Revit[2] or Graphisoft Archicad[3] were designed for AEC industry, in recent years there have been interesting and well conducted applications of the software to the archaeological domain, in order to document and investigate archaeological and building stratigraphy (Scianna *et al.* 2015; Bosco *et al.* 2019; Trizio *et al.* 2019). Consequently, the time dimension is fundamental in an HBIM project. A very interesting and recent project is focused on the possibility of implementing a Harris' Matrix inside a BIM model by using ontologies (Borin *et al.* 2020). This integration becomes essential for analysing the time dimension of the case study through semantic relations with parametric objects, achieving a relative chronological vision of constructive phases and periods (Trizio *et al.* 2019; Borin *et al.* 2020; Diara *et al.* 2020). Moreover, stratigraphic graphs assume great importance when trying to compare and merge, through a new methodology, 3D data with traditional bidimensional data (Diara 2020).

However, the already mentioned commercial BIM software allows a parametric modelling based on simple and predefined architectural families. This is relevant for the digital reproduction of stratigraphic units related to archaeology or building archaeology, especially since there are no predefined parametric families corresponding to archaeological elements. For this reason, the HBIM design of archaeological sites involves the creation of *ad hoc* families by using parametric modelling tools. During this time-consuming step, important interpretations occur. In fact, shapes related to stratigraphic units or historical architectural elements need to be understood and simplified (and therefore conceptualised) in order to

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[1] https://www.freecadweb.org/ (accessed 30/07/2021). FreeCAD is released with a GNU GPL v2 license.
[2] https://www.autodesk.it/products/revit/overview (accessed 30/07/2021).
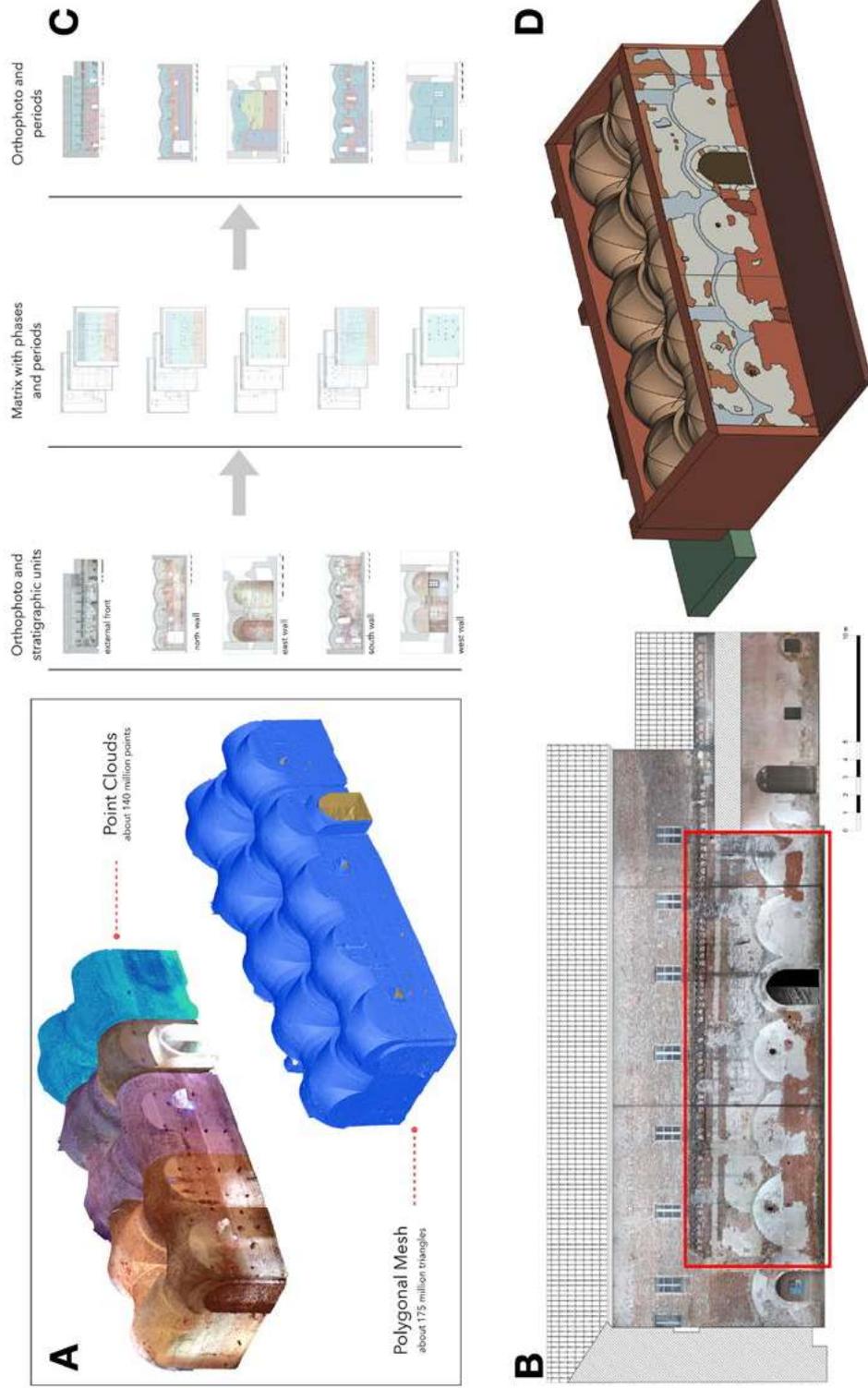[3] https://graphisoft.com/solutions/archicad (accessed 30/07/2021).

Figure 1: Knowledge processes: from metric survey (A) to stratigraphic survey and analysis (B and C), until the parametric model construction (D).

establish physical and semantic relations. However, this operation is not so easy to manage due to the overall complexity of the geometric data and the required level of accuracy (Diara *et al.* 2019; Bosco *et al.* 2019). This difficulty is largely due to modelling tools integrated into the software, and then due to software design. For this reason, unconventional solutions were the focus of different projects aiming at creating and managing *ad hoc* platforms, trying to solve these methodological issues (Logothetis *et al.* 2016; Diara *et al.* 2018; 2020). A branch of these studies is focused on the exploitation of FOS instruments in order to adapt and customize them to archaeological needs, and this paper focuses on this approach.

Starting point: data acquisition

The trial we are about to present was conducted on the refectory of the Staffarda monastery. A previous larger project (Diara 2020), took care of the data acquisition, obtained from metric and stratigraphic surveys of this religious context (Figure 1). The metric survey was carried out using total station for the topographic framework and LiDAR acquisitions of structures, surveyed by using the terrestrial laser scanner (TLS) Faro Focus 3D S120.

On the other hand, the stratigraphic survey has provided a fundamental step in order to achieve historical information from masonries. The refectory of the medieval Staffarda Abbey was chosen as a case-study for the implementation of stratigraphical recording inside the HBIM platform, encoded as semantic historical information: in fact, this building is characterized by the presence of a complex masonry stratigraphy generated between the 12th – 13th centuries and the beginning of the 20th century (Beltramo 2016; Diara 2020).

The stratigraphic survey was performed on the internal walls and on the external façade, facing the cloister of the abbey. It was conducted both on-site and in the laboratory, on 2D CAD projects to achieve a clear stratigraphic analysis on detailed orthophotos. The Harris Matrix was designed to obtain a relative chronology by isolating phases and historical periods.

Briefly, the stratigraphic analysis was crucial for the comprehension of construction and destruction phases and chronological periods. The building of the refectory could be divided into seven chronological periods, the principal being: from the early construction site of the refectory (1160) to the main construction block referred to 1180–1220; from morphological and structural changes after the Battle of Staffarda in 1690, to the maintenance interventions of the 19th – 20th centuries (Beltramo 2016; Diara 2020; Diara *et al.* 2020).

HBIM platform design

FreeCAD is a parametric modeller, integrated by different customizable tools and supported by a large community of users and developers. Moreover FreeCAD, given the premises, could also be used as complete BIM solution, entering the FOSS ecosystem of informative platforms, next to QGIS[4] and MicMac,[5] just to mention the most well-known projects.

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[4] https://www.qgis.org/ (accessed 30/07/2021).
[5] https://micmac.ensg.eu/ (accessed 30/07/2021).

The customization of FreeCAD as a HBIM platform has been the project's focal point, and it was carried out by the implementation of *ad hoc* libraries, workflows, and a proposal of classification.

Initially, a smart integration of fundamental libraries was designed to be included inside the software: IfcOpenShell[6] open library was preferred since it allows managing IFC (Industry Foundation Classes) open format, a necessary requirement for BIM and data exchange. Additional packages and libraries represent a crucial base for the HBIM platform in terms of basic functionalities and specific workflows.

Apart from these additions, FreeCAD was implemented with particular *workbenches* for defining the HBIM platform as well as CAD functionalities: *BIM workbench*[7] played a fundamental role in order to establish all features of Staffarda Abbey and its refectory (including floor levels) and other general attributes related to the main construction site*; Dynamic Data workbench*[8] was included especially for managing parametric objects with dynamic properties; *Reporting workbench*[9] played a key role for the data validation since it allows designing and managing custom SQL (Structured Query Language) queries and the related output. All these additional workbenches were easily downloaded and implemented through the internal *addons manager*.

Despite these implementations, FreeCAD was also modified for IFC classification. These modifications involved the default IFC2X3 schema file located in the root directory of FreeCAD: in addition to default AEC classification the IFC2X3 schema was implemented with a proposal/demonstrative custom classification useful for building archaeology purposes through designed typological sub-divisions of existing default classification. Then, an adequate classification with the actual architectural situation of the refectory were included, such as *ifcVault* (as sub-type of ifcRoof) – *ifcPillar* (as sub-type of ifcColumn) – *ifcUSM* and *ifcUSR* (as sub-type of ifcWall) concerning macro stratigraphy evidence (mostly medieval) related to masonry (USM) and render/plaster (USR), fundamental both for archaeology and restoration purposes.

Model and data management

Despite the possibility of building a high quality 'as-built' model of the refectory, the modelling choice was affected by the intention of a voluntary simplification of the architectural elements. In fact, the HBIM model was conceived not as a *digital twin* of the real architectural context but as a conceptual and simplified representation of reality, as BIM models should be 3D conceptual database-models.

The simplification of architectural elements of the refectory was designed in order to highlight historical information represented by stratigraphic units of masonries, permitting easy handling of the management of essential chronological elements inside FreeCAD (Figure 2). For this reason, the modelling phase of HBIM projects must be principally related to semantic

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[6] http://www.ifcopenshell.org/ (accessed 30/07/2021), LGPL-3.0 License.
[7] https://wiki.freecadweb.org/BIM_Workbench (accessed 30/07/2021).
[8] https://wiki.freecadweb.org/DynamicData_Workbench (accessed 30/07/2021).
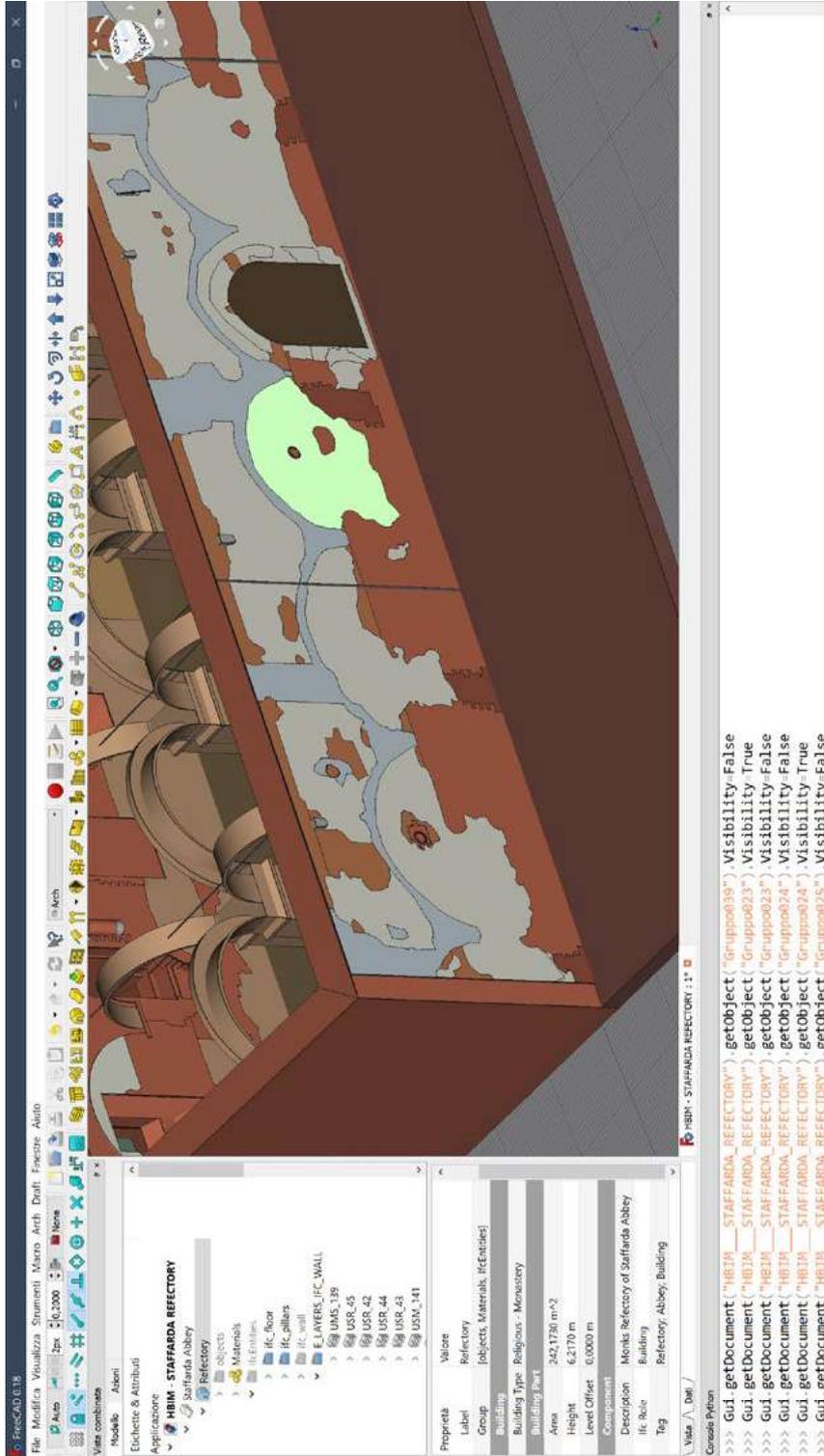[9] https://github.com/furti/FreeCAD-Reporting (accessed 30/07/2021).

Figure 2: FreeCAD platform and parametric model of the refectory with stratigraphic units.

information and how investigate them (Di Stefano *et al.* 2019; Matrone *et al.* 2019; Bruno *et al.* 2019).

The obtained metric data (point clouds) was the skeleton around which the parametric model was created after the extraction of planar sections. Inside FreeCAD, parametric volumes were modelled by extruding surfaces obtained from planar sections shapes. Stratigraphic units were modelled starting from profiles drawn on orthophotos mapped on the model. By using these profiles, flat surfaces were created and extruded as parametric volumes, having a minimum thickness value (e.g. 2 mm – 5 mm).

After volume creation, other metric attributes and information were managed by using the *Dynamic Data workbench* that allows the creation of Python containers for new custom and dynamic metric properties: when a custom property is changed, the related object will automatically and proportionally update. Once architectural elements and stratigraphic units have turned into parametric objects, the *IFC Role/Type* attribute is set for each element. In this regard, the already mentioned proposal classification is followed.

Behind the parametric model, the real actor of the platform is the historical data related to architectural peculiarities of the refectory. The process of knowledge and the stratigraphic analysis is fundamental and propaedeutic for the archaeological data integration into the platform. The attributes menu of IFC objects was correctly implemented with information, such as: *General description* concerning architectural elements and stratigraphic units detected on masonries; *Detailed photos* for each element were included, also concerning iconographic resources; *Material* of each object.

The default material database of FreeCAD was implemented by adding materials related to the refectory; *IFC roles* and architectural classification depending on single elements, including stratigraphic units by using the *ad-hoc* classification prepared during the custom modifications phase; *ID code* by using *Standard Code* text field; Architectural elements and stratigraphic units of the refectory were enriched by alphanumerical identifiers referred to stratigraphic analysis enumeration; *Stratigraphic diagrams* (Harris Matrices) – included to obtain a relative chronology analysing physical relations among stratigraphic units – were included by using the *additions* field (Figure 3); *Chronological periods* were implemented through the *tag* field (alphanumerical value) to include the chronological interpretation carried out with the Harris Matrix. Furthermore, chronological periods were also highlighted directly on parametric objects by the use of different colours. Finally, the integrated DBMS of FreeCAD was used to manage bibliographic resources and other external references concerning the case study. All these collected data relating to the refectory turned out to be crucial for revisions and updates, as well as for overcoming data dislocation.

Platform validation and results

The implementation of historical data inside the platform has proven essential for two reasons. First to create a dynamic informative environment focusing on the refectory and preventing data fragmentation, and, second, for the purpose of managing punctual analysis through custom queries for data validation, revisions and updates.
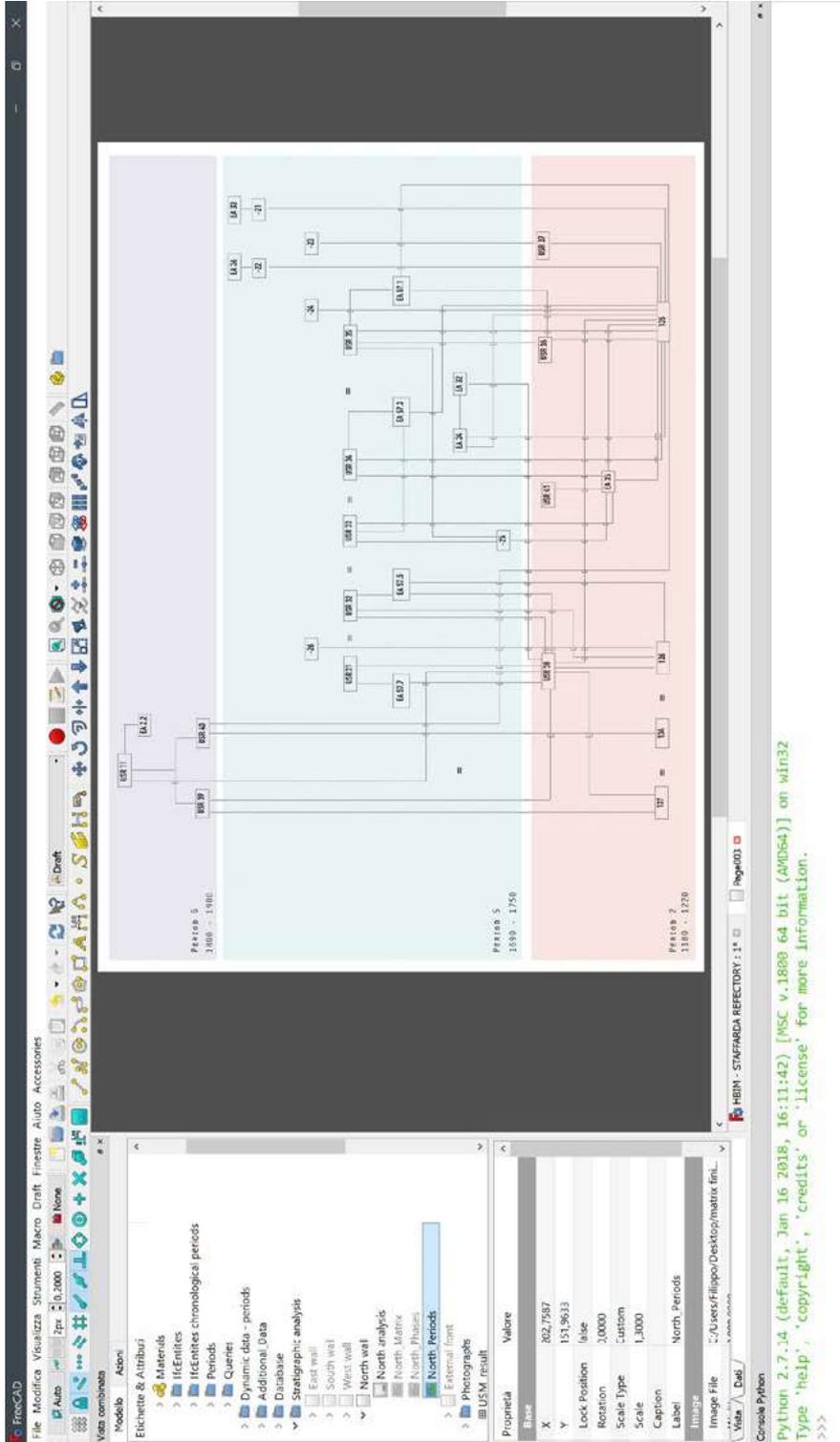
Figure 3: Stratigraphic diagrams implemented as semantic data (Harris Matrix of north wall of the refectory of medieval Staffarda Abbey).

Reporting workbench and *sqlparser* allowed the design and management of custom SQL queries to investigate the object properties of both architectural elements and stratigraphic units.

SELECT SQL queries were performed in two ways. The first is based on the *sqlparser* module, which allows queries to be executed directly on the FreeCAD Python console: the query has to be written on the console after evoking *sqlparser* module and the console returns the result using green-coloured text.

The second method relies on customizable SQL statements of *Reporting workbench.* Following this procedure, *SELECT* queries are set on the configuration window of *Reporting workbench* and saved with custom labels. In this way, the result report is obtained from double clicking on query label and the platform return a datasheet containing the query result (Figure 4). Datasheet reports can be easily exported as CSV files. This method is certainly far more dynamic and user friendly than the previous one, also facilitating data exchange processes among collaborators. Following this procedure, data storage and future analyses on the refectory are correctly ensured, especially for monitoring operations.

SQL queries are performed for investigating IFC types, refectory materials, particular layer identifiers, chronological periods via *tag* field, etc. These queries were designed to investigate stratigraphic units and their properties linked to the parametric model. In this regard, the *SELECT* syntax proved essential for facilitating the semantic selection process. This kind of query and syntax is referred to a standard query language and these queries could also be managed in other informative environments, for example GIS platforms.

Regarding data interoperability, the internal storage of FreeCAD may connect semantic data with external DMBSs and vice-versa. In fact, internal DBMS and resulted CSV from SQL queries can be exported as datasheets manageable, for example, with stand-alone database software (Libre Office Calc, Google Documents, MySQL, etc.). At the same time, external data originally managed with third-party DBMS software can be imported as CSV files into FreeCAD and further enrich the available semantic data set.

FreeCAD proved to be not only a parametric modeller and a BIM/HBIM software but also a dynamic informative platform for metric and historical data collection and validation. Moreover, this custom platform could be exploited by other users and professionals for further studies on Staffarda Abbey as well as exploited for others contexts. FreeCAD modifications and additions were used for external libraries, packages and workbenches, being easy to download and implement. Furthermore, a custom and independent bundle is under development to create a FreeCAD branch based on modifications performed for this project. In this regard, the FreeCAD community will be essential for monitoring the constant development and growth of this software, even for improving this workflow.

Conclusion

This paper was focused on the use of FreeCAD as a valid and efficient BIM/HBIM platform, in addition to being a parametric modeller. This software was customized for adapting particular libraries to building archaeology needs for monitoring and restoration, as well as further analyses. In short, FreeCAD has a huge potential as HBIM platform for building
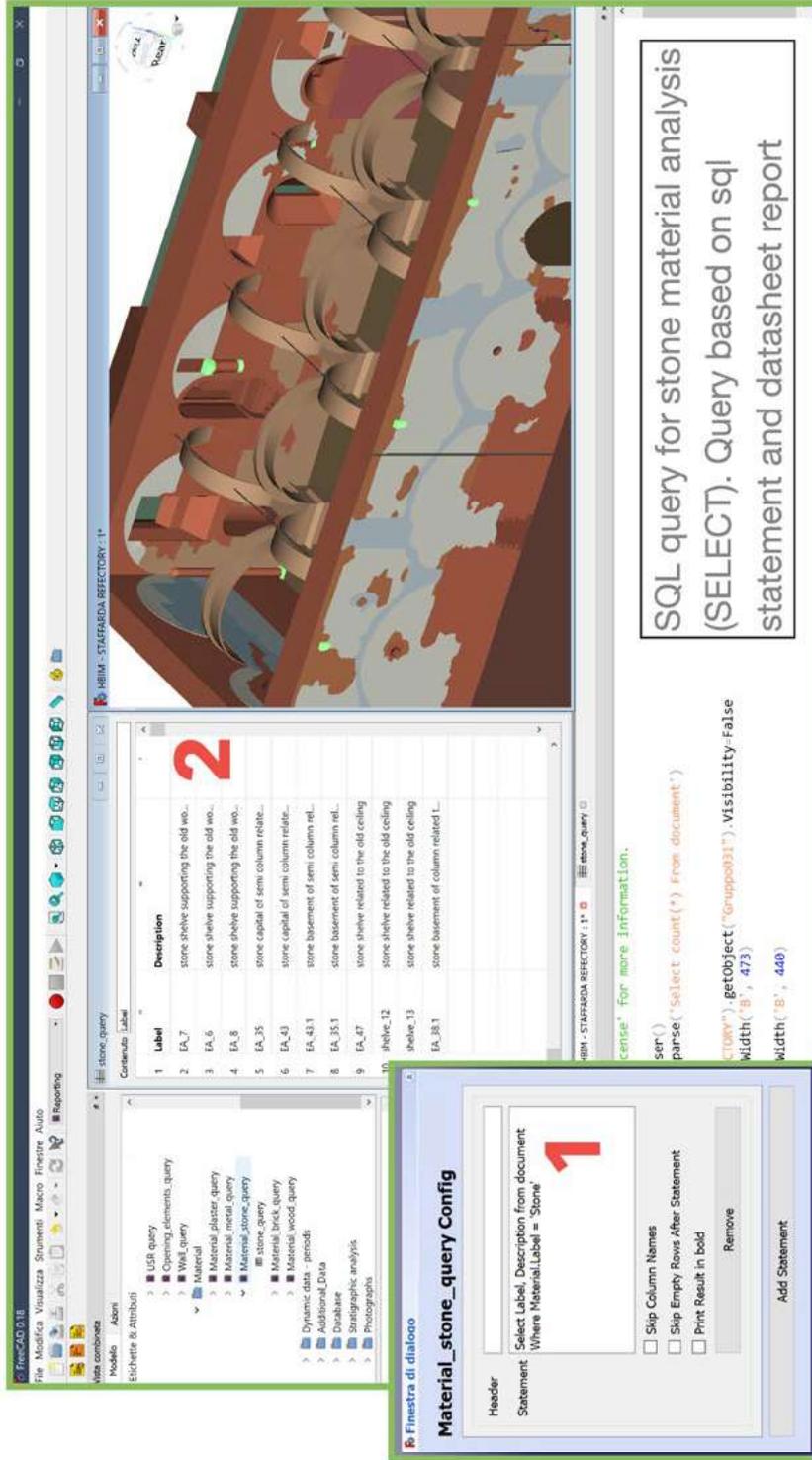
Figure 4. SQL query by using Reporting workbench and statement configuration: selection of stone elements and their description (result on CSV).

archaeology purposes. The integration of stratigraphic analysis has become possible by the new IFC classification proposal, the inclusion of stratigraphic units as parametric objects and the related analysis. As a result, custom SQL queries have proved to be fundamental for investigating and validating archaeological data.

This project has illustrated advantages and innovative points: first of all, the resulting platform was revealed to be a secure environment for collecting and managing different type of data, avoiding 2D and 3D data fragmentation and favouring historical interpretation, as well as maintenance operations. Through source code accessibility, the workflow tried to overcome traditional BIM limitations concerning IFC classification, modelling and implementing tools. But beyond these positive feedbacks, some critical issues also arose. This experimental scan-to-BIM workflow involves different file formats and software. There are risks, too, for data exchange and compatibility, and project stability in general. Moreover, it was a time-consuming workflow: from metric acquisition to parametric modelling, from stratigraphic surveys to stratigraphic analysis of the entire refectory, from FreeCAD implementation to data collecting and querying. Finally, the absence of a standard semantic classification for stratigraphic units was one of the most critical issues faced by the project. This important issue led this research towards a custom (and not perfect) solution to overcome this limitation. Notwithstanding these difficulties, the designed workflow succeeded in solving the goals set in advance, as an operative and custom BIM platform was created for building archaeology purposes via FOS software.

Proceeding in the direction of current informative systems (GIS and BIM) it is possible to ensure data protection and exchange of complex architectural and archaeological contexts, overcoming limitations to do with the juxtaposition of digital analyses and paper-based studies.

The integration of methodologies and tools should become the only procedure to overcome technical and compatibility issues, obtaining a methodological synthesis suitable for Heritage assets documentation and analysis.

However, the documentation and analysis of archaeological and architectural contexts should not be based on predefined methodological and software solutions that are not sufficient warranty of a correct data analysis. Experimenting new ways should always be an available solution to carry out *ad hoc* analyses, adapting techniques to the research, and not the other way around.

The constant increase of technological innovation leads researchers to use specific technologies and geomatics methodologies just because they are new and benchmarking, even if not every solution could be reliable for all disciplines. The HBIM methodology and FOSS adoption have proved to be the best solution for this project – FreeCAD allowing the collection of the refectory data and therefore dynamic revisions and updates – but it may not be the perfect solution for other case-studies. Replicability and feedback from the community should always be a major objective of this kind of applied research.

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