A VULNERABILITY-ORIENTED 3D GEODATABASE SUPPORTING SEISMIC PREVENTION IN HISTORICAL CENTRES

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Abstract: *Historic urban centres are particularly vulnerable to seismic risk because of their complexity and fragility. Their safety affects entire communities, and their preservation as cultural assets is in charge and under interest of policies at various levels, from local to international. For this reason, a geographical multi-scale point of view for the analyses is increasingly favoured in the perspective of the scientific literature and, specifically, in Italian regulation policies. In this sense, advanced geomatics techniques can help to provide tools supporting data collection and storage, multi-scale seismic vulnerability assessment, and decision-making, especially in emergency situations and in places particularly affected by natural disasters. The proposed approach aims to implement a multiscale 3D geodatabase to support conservation strategies and risk assessment scenarios by developing a vulnerability-oriented GIS/HBIM integration in an urban 3D geodatabase, based on multiscale data derived from urban cartography and 3D mapping. To achieve that, geometric and semantic information on historic buildings and structural data were integrated for seismic vulnerability assessment, focusing on churches as particularly widespread and vulnerable assets. Special attention was paid to harmonizing the work with Italian legislation and the INSPIRE-based semantic (the Directive for Infrastructure for spatial information in Europe), so that the database can be as useful to seismic assessment as possible and at the same time the most shareable. In this framework, the area of study is connected to the territories affected by the 2016 earthquake in the centre of Italy. Particularly, the historical urban centre of Norcia and Campi di Norcia hamlet, with the church of Sant'Andrea in Campi di Norcia are the two cases connected with the double scale analysis, which are the urban and the architectural ones. The research is aimed at creating a user-oriented webGIS solution enriched by the object-based 3D GIS data and HBIM models, for the purposes of public sharing and use that will help all risk-related users as experts involved in emergency rescue activities and in cultural heritage preservation, for preventive seismic risk assessment and planning of restoration projects by predicting future scenarios.*

1. Introduction

The complexity of urban centres is due to a multi-layered structure, that has to be analysed by a multi-scale approach. Increasingly, city databases are being developed to integrate different types of information and enable numerous analyses, including predictive ones. In addition to being characterized by complexity, urban centres are also characterized by fragility related to historic buildings. In this sense, it is a priority for stakeholders to preserve cultural heritage from the risks that may affect it; especially seismic risk, which most afflicts historic centres and particularly historic churches. It is, therefore, necessary to develop advanced approaches for the creation of databases that integrate different types of information according to different layers, at different scales, from building scale to territorial scale. Various approaches to documenting damage and structural strength have been investigated in the literature concerning the creation of 3D models of urban centres, highlighting the effectiveness of Geomatics tools. Typically, digital and spatial data are used, such as for example, emergency mapping, onsite image datasets, direct measurements through onsite inspections, data sheet reports, and more recently digital remote sensing models based on imaging and range sensors, such as drone-based photogrammetry models (Fernandez Galarreta et al., 2015; Grazzini et al., 2020; Romis et al., 2021). Recently, some studies have also focused on the validation of rapid mapping, UAV and MMS based techniques; this method is effective in containing the cost and time of in-situ surveying, which is very useful in the context of documentation in emergency situations (Sammartano, 2018). All collected data can be stored in 3D Geographic Information System (GIS) models to manage urban emergency response at the building scale (Zlatanova, 2008) and analyze seismic vulnerability at the urban scale (Colucci et al., 2018; Redweik et al., 2017).

The challenge for geomatics research is to create a 3D geodatabase based on geographical scale 3DGIS that can arrange multiple scales simultaneously. This infrastructure should be capable of integrating both building-scale and urban heritage 3D models. The models can then be visualized and stored as boundary representations (B-rep), which are generated based on the complexity of the surfaces. These surfaces can be created using either parametric or non-parametric approaches, and can be embedded within heritage building information models, also known as HBIM (Banfi, 2017; Murphy et al., 2013). This work investigated the possibility of creating a 3D HBIM-GIS-based database for storing, representing and analysing highly detailed geometric and semantic information for seismic vulnerability assessment at different scales. It is imperative that these models can be integrated and accessible to all stakeholders in the management and protection of cultural heritage (CH), for scientific analysis by experts and implementation of policies by governments aimed at the management of resources for the implementation of structural reinforcement interventions spread throughout the territory. In this regard, the European Parliament has established INSPIRE (INfrastructure for SPatial InfoRmation in Europe) (INSPIRE, 2013 & 2014), transposed by the governments of European states, with the aim of making georeferenced information homogeneous and shareable within the European Union for the implementation of policies or activities that may have an impact on the environment.

Currently, a great deal of interest regarding numerous fields of application that pertain to urban spatial and constructed legacy knowledge exist. These fields necessitate the representation and exchange of 3D metric data and digital models within geographic information platforms (Volk et al., 2014). In such circumstances, the importance of 3D geodatabases cannot be overstated. By including multiple dimensions, these databases represent information models that are exceedingly detailed and abundant in information, across all spatial dimensions and temporal periods. This is intended for the direct immersion of expert users who participate in the policies processes. The goal for this research was to approach the topic of HBIM-GIS integration for the implementation of a 3D geodatabase for seismic vulnerability assessment (Sammartano et al., 2023), starting from a crucial knowledge phase of the building, schematic but critically well-founded, that would be applicable, in a territorial perspective, to the churches system subject to seismic hazards. In fact, the directive (DPCM 2011) mandates the evaluation of a safety assessment of historical masonry buildings, considering the vast number of assets distributed throughout the Italian territory, and with appropriate solutions over time. Additionally, the PCM directive provide a simplified model for estimating the vulnerability index of historical masonry churches. This is achieved by analyzing macro elements, parts of the building that represent autonomous behaviour in relation to the structure. Based on the use of the rapid assessment method, it becomes possible to establish a robust multi-scale geographical database, that serves as a framework for organizing the planning of future projects of intervention, providing an opportunity to improve a workflow for creating an informative 3DGIS model. This model encompasses the entire process from 3D multi-sensor clouds to structured models that have pertinent data embedded for seismic vulnerability evaluation. Additionally, this study enriches the GIS-HBIM-implemented model by a WebGIS interface that enables the interpretation of vulnerability and risk of churches on a geographical scale. In accordance with the LoD (level of detail in the CityGML domain) and LOD (level of development in the IFC domain), this work establishes multi-scale models and relevant information for vulnerability assessment, determination of vulnerability index, and identification of damage mechanisms under Italian legislation.

1.1. Seismic risk management in Italy: a spotlight on churches

Given the context of the Italian landscape, it is important to acknowledge its susceptibility to seismic activity. Moreover, this region has recently experienced catastrophic seismic events (Stewart et al., 2018) that have caused permanent harm to our cultural and historical heritage, especially masonry churches because of their structural weaknesses and collapse mechanism predictable for the architectural elements (Lagomarsino & Podestà, 2004a, 2004b; *NIKER*, 2010). This is increasingly under the attention of prevention policies.

Since churches need special attention, the directive of Prime Minister’s Office (PCM) directive of 9/02/2011 (DPCM 2011), https://www.gazzettaufficiale.it/eli/id/2011/02/26/11A02374/sg, accessed on 27 January 2023), which is referred to in this issue, outlines the steps that lead to the implementation of a seismic prevention plan. Religious heritage has been highlighted by recent national funding initiatives such as the PNRR plan. This has led to a renewed interest in church buildings as a type of historical structure that is widespread and vulnerable to seismic hazards. The 07/06/2022 decree of the Ministry of Culture allocates extraordinary funds for the fulfillment of conservation and restoration projects devoted to church buildings in the national territory (PNRR-M1C3, DM 145-07/06/2022)[1].

The seismic prevention program is regulated, as well-known, by the Italian Directive, which clearly outlines the boundaries and procedures for its implementation. The directive approach, based on a series of knowledge phases (Livelli di Conoscenza, LC) associated to the three levels of evaluation (Livelli di Valutazione LV), consists of various modules and analytical steps leading to the complete assimilation of knowledge. Each step (LV1, LV2, LV3) as three levels of increasing completeness, require specific documentation methods that can be integrated and boosted with a geographical scale perspective, as suggested in this study. In fact, the program's vulnerability does not completely take into account the availability of a 3D information system, which could have been beneficial. The directive modules (Table 1) are divided into two categories of autonomous and complementary data sheets, representing differing levels of comprehension. To achieve the survey objectives, contextual parameters, and resource availability, various directive module forms must be completed and compiled to form the cognitive project. For instance, A and B pertain to asset identification, while C and D relate to the structure's components.

Table 1. *Interpretation of the Directive Modules from Italian regulation (DPCM 09/02/2011) content according to LoD and LOD of multi-scale models BIM-GIS*

LoD/LOD	Directive Tasks	Description
LoD 0	A	Building identification (cartography, cadastre)—2D
	B	Criticality factors of the building in relation to the territorial context
LoD 1/ LOD 100	A	Building identification (cartography, cadastre)—3D
	B	Criticality factors of the building in relation to the territorial context
LoD 2/ LOD 200	E	Geometric survey—3D
	F	Former restoration actions—4D
	LV1	Parameters resulting from the LV1 assessment relating to the macro-elements
	LV2	Parameters resulting from the LV2 assessment relating to the macro-elements
LoD 3,4/ LOD 300/400	C	Element's morphology—3D
	D	State of conservation of elements—3D
	F	Former restoration actions—4D
	G	Historical investigation—4D
	H	Diagnostic investigation—4D
	LV2	Parameters resulting from the LV2 assessment relating to the elements
	LV3	Parameters resulting from the LV3 assessment relating to the elements

There are several methods utilized to carry out a vulnerability assessment, each with varying levels of complexity and speed. Simplified models are employed in some cases, while other approaches involve more intricate and comprehensive evaluations (Benedetti et al., 1988). For example, the present study examines a simplified model of church territorial scale seismic risk analysis by calculating a vulnerability index (iv) obtained in LV1 through the identification of church macro elements and the analysis of the related earthquake safeguards and vulnerability indicators. In addition, at each scale that in the information system perspective we indicated using LoD and LOD, accordingly to the BIM-GIS standards, the modules specified in the directive for collecting information, which is useful for assessing the seismic vulnerability of a church, have been progressively implemented (Table 1).

[1] DM n. 455 del 7 giugno 2022, ministero della Cultura, misura M1C3, Cultura 4.0, l'Investimento 2.4.–Sicurezza sismica nei luoghi di culto, restauro del patrimonio Fec e siti di ricovero per le opere d'arte–Recovery Art. https://www.beniculturali.it/comunicato/assegnazione-delle-risorse-a-valere-sul-pnrr-assegnazione-delle-risorse-per-la-sicurezza-sismica-nei-luoghi-di-culto-e-il-restauro-del-patrimonio-fondo-edifici-di-culto-fec-rigenerazione-di-piccoli-siti-culturali-patrimonio-religioso-e-rurale, accessed on 05/10/2023

1.2. The case study from the 2016 centre Italy earthquake survey

The research focused on two case studies in urban centres in central Italy, affected by the violent earthquake that hit those areas in 2016. The survey operations were carried out by the Geomatics group of the Polytechnic University of Turin, focusing many urban centres (Spanò ed., 2018) with the purpose to test 3D mapping techniques in the emergency context. The 3D metric survey was based on a topographic survey with GNSS and traditional methods and was developed with integrated aerial and terrestrial techniques for the realization of multi-scale and multi-content models, with a view also to the validation of rapid mapping procedures in these contexts.

The geodatabase was populated with some churches in central Italy, in the areas affected by the 2016 earthquake. In particular, the modelling of Sant' Andrea in Campi di Norcia is developed, for the interesting damage mechanisms that have been triggered, and the historical centre of Norcia for the cultural interest and at the same time the exposure to seismic risk. The city of Norcia is located in the heart of the Apennine region (600m asl) in which the continental tectonic plates meet determining the high seismic risk. Firstly, Roman and then Longboard city, Norcia was a free municipality during the XIII and XIV cent. when the city constructed respectively the city wall and the imposing basilica of San Benedetto and San Francesco. After many disastrous earthquakes (the major ones in 1328, 1703, 1730 and 1859), the latter (10/30/2016 with a magnitude of 6.5) is infamous for destroying the San Benedetto Basilica together with the main other churches of the city. The Sant'Andrea Church in Campi di Norcia is a masonry church, medium in size, dating from the 14th century. The church consists of a hall divided by a colonnade into two vaulted naves, a porch in front, and a bell tower at the back. Today it is partially collapsed following the seismic events that hit central Italy in 2016 with a magnitude above 5 and, on October 30, 2016, with an epicentre 4 km northeast of Norcia.

(a) (b)

Figure 1. (a) Sant'Andrea church in Campi and (b) the 3D point cloud view of the Norcia historical centre, with San Benedetto church, left and Castellina, right, both following the 2016 earthquake events

2. Material and Methods for the 3D geodatabase

The presented approach is based on the knowledge developed in 3D geodatabases for generating 3D city models and develops originating a 3DGIS environment where HBIM models at diverse scales can be incorporated, visualized, queried and analysed. The entire process validated in this study pays special attention to historic churches, as it is considered a priority for resource management related to CH conservation. The metric survey is based on the rapid mapping method, which is crucial in containing costs and time, especially when operating in emergency situations as may occur in these cases. The 3D metric survey allows the collection of geometric and morphological information about urban spaces, buildings and the architectural elements of built heritage, as well as clues about damage, which are useful for vulnerability assessment. The techniques used are UAV (Unmanned Aerial Vehicle) photogrammetry, terrestrial scanning also based on MMS (Mobile Mapping System).

Point clouds, generated by 3D metric surveying, are a substantial basis in database generation. Their processing begins with segmentation and optimization for automatic or semi-automatic classification of terrain, buildings, vegetation and if possible, roads. In the research literature, many efforts are dedicated to automatize or develop semi-automatic strategy to speed up the as-built modelling devoted to higher LoD/LOD development. Knowledge-based approaches combined with algorithms capable of clustering clouds(Treccani et al., 2022), development of machine and deep learning tools (Matrone et al., 2020), sometimes also exploiting the ontological conceptualization approach to describe and identify city objects (Colucci et al., 2021), and finally also the exploitation of VPL (Visual Programming Language) (Roman et al., 2023)are focused to decrease the time-consuming phase of HBIM modelling. In this study, major attention was placed on the modeling phase, for the definition of different levels of detail and granularity to be stored in the spatial database. In this regard, different strategies were developed for the model at the urban scale, compared to the model at the scale of the building, the masonry church. However, in both cases modeling was based on an HBIM approach, integrating IFC and CityGML standards. Meanwhile, the management phase of information enriching models was supported using visual programming diagrams developed using Dynamo for Revit (Avena et al., 2021). This whole phase was approached in implementation of the PCM Italian directive. In the end, a consistent and versatile solution is proposed for the creation of the 3D geodatabase in an HBIM-GIS environment. The fruition is proposed through the use of a web GIS platform, complete with AMS interfaces as successfully used in other applications. (Meschini et al., 2022)

(a) (b)

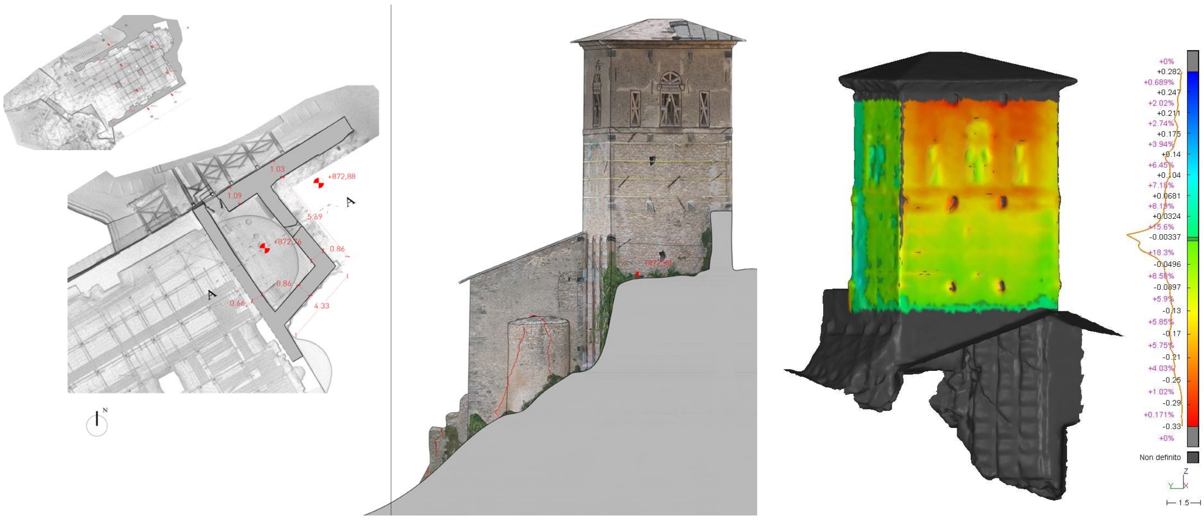
Figure 2. (a) Point cloud processed from UAV survey of Castellina palace in Norcia (b) 3D integrated mesh model of Sant'Andrea Church in Campi after the 2016 earthquake events.

2.1. Integrated rapid mapping approach supporting damage mapping and seismic vulnerability assessment from 2016 earthquake: lesson learnt

The effectiveness of integrated rapid mapping approaches in seismic damages context has been largely studied, together with satellite and aerial data, especially for the more recent introduction of oblique imagery (Voigt et al., 2011) and UAV photogrammetry (Duarte et al., 2017), integrated with ground-based technologies as portable SLAM-based scanners (Sammartano, 2018). The winning approach is based on the compactness and portability and/or manoeuvrability of digital devices, and it optimally ensure completeness of point cloud related to intrados and extrados, and topological accuracy among surfaces and 3D elements with a specific spatial configuration. The advantages are not only limited to the analytical phases of the results. In fact, these solutions work successfully primarily on the acquisition phases, and they minimize or completely avoid the operator's permanence on site, lowering exposure to risk. In seismic vulnerability assessment phases, the visual inspection related to expeditious LV1 stage as the directive indicates, despite largely based on a long-time know-how factor, can largely benefits from the versatility of 2D/3D metric products. Thus, the contribution of 3D documentation is very relevant, especially in these preliminary stages supported by rapid mapping, where analyses are here based on:

- 3D models and images visualization and damage detection
- Geometry inspection and deformation analysis, not only presence/absence, but also magnitude of: verticality, planarity, out of plumb, slanting, overturning, etc…;
- Monitoring of the evolution of deformations and damages by analysing and comparing different measurements datasets, from a multi-temporal and multi-scale point of view;

- Definition of 3D volumes based on multi-source data-fusion (LiDAR, photogrammetry, thermic data, IR mapping, sensors, etc…) for analysis aimed at the identification of the elements that give emphasis to the architectural system and the conditions of equilibrium.



(a) (b) (c)

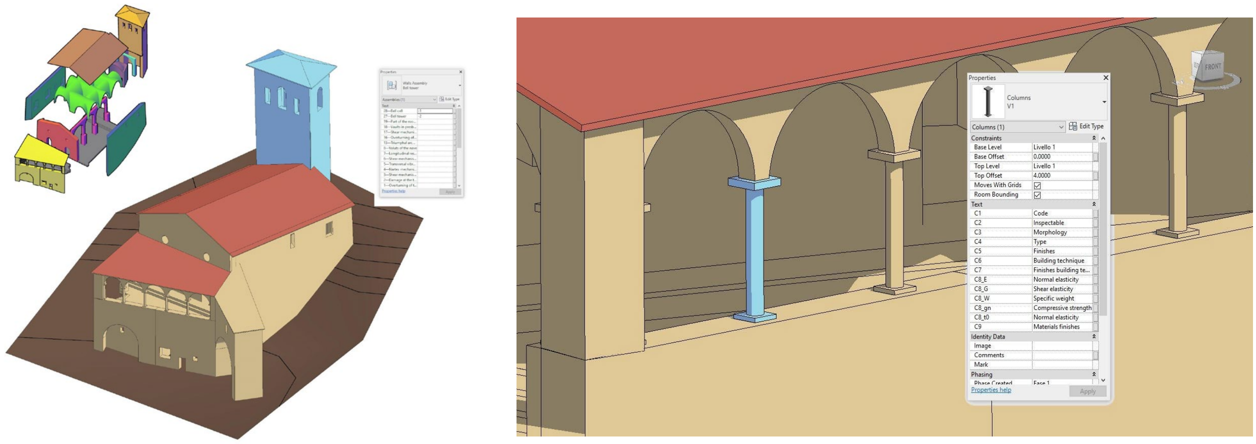
Figure 3. Examples of 3D metric data supporting geometric model and anomalies analysis: (a) the church plan, derived from integrated LiDAR and UAV data, (b) 3D photogrammetric model indicating the masonries cracks, highlighted from the UAV images point of view, (c) off-lead of the bell tower underlined in red colours from the deviation map from a verticality analysis.

2.2. HBIM Modeling, from Point Clouds to Structured Models for the Macro–Elements Analysis

The starting data for the structuring of a semantically enriched 3D models for the construction of the 3D geodatabase is the optimized point cloud data. In the specific, segmentation plays a crucial role in the morphological and functional modelling, oriented to the structural analysis. It is necessary to consider that these operations are more complex when applied on historical centres and historic buildings, compared to modern buildings. The analysis by macro-elements and related damage mechanisms can be supported using a complete and accurate 3D geometric model. The goal is to translate pure geometric data (point clouds, meshes) into volumetric elements that represent macro-elements (facade, bell tower, vaults, etc.) and enriched with all the semantic information that allows the analysis of earthquake principals and vulnerability indicators. According to the logic of BIM models, the 3D model is developed in a multi-scale perspective, integrating details derived from high-scale point cloud surveys, corresponding to both volumetric elements and higher construction details.

Point cloud-based modeling operations are carried out according to the approach widely used in the literature, called *reverse modeling*: the procedure operates through sections of the point cloud, approximating surfaces according to the as-built generative process. H-BIM models are characterized by more complex elements to be modeled as-built according to parametric approach. Therefore, some more regular elements, such as the porch columns, were generated as parametric BIM elements based on lower grade of generation (Banfi, 2017). In others cases, such as the vaults, were modelled based on GOG9 and GOG10 as objects integrating NURBS surfaces. Finally, all elements topologically connected were grouped according to different groups in the macro-elements' hierarchy. In this occurrence, the model representing the pre-earthquake conformation was integrated using archival drawings and previous surveys. It is important to remember that it is always preferable to define time phases and proceed with modeling by sticking to the data for a particular phase. Once the parametric modeling phase is completed, the BIM model can be further enriched with semantic information according to Table 1. Existing datasets can be entered semi-automatically using Dynamo.

The HBIM model is a object-based spatial database and can be organized in relation to directive, and can be enriched with semantic information for building vulnerability analyses, for defining vulnerability indices of individual macro-elements, for leading more in-depth analyses now possible due to the geometrically complexity and semantic richness. Finally, the 3D geodatabase can now be shared with experts for planning and designing interventions to reduce seismic risk.



(a) (b)

Figure 4. (a) The church 3D models: macro-element LOD 200 (b) element LOD 300, with association of semantic data and results of the analysis that can be consulted and queried

3. Urban scale HBIM modelling oriented to LoDs

The debate on the integration of geographical models of urban spaces with building-scale models obtained through the BIM strategy arose early (Isikdag & Zlatanova, 2009), immediately after the first publication in 2008 of the City GML standard which regulates the geometric and semantic contents of city representation data model, enabling storage and sharing of 3D digital urban objects. (CityGML - City Geography Markup Language http://www.opengeospatial.org/standards/citygml, published by the Open Geospatial Consortium (OGC).

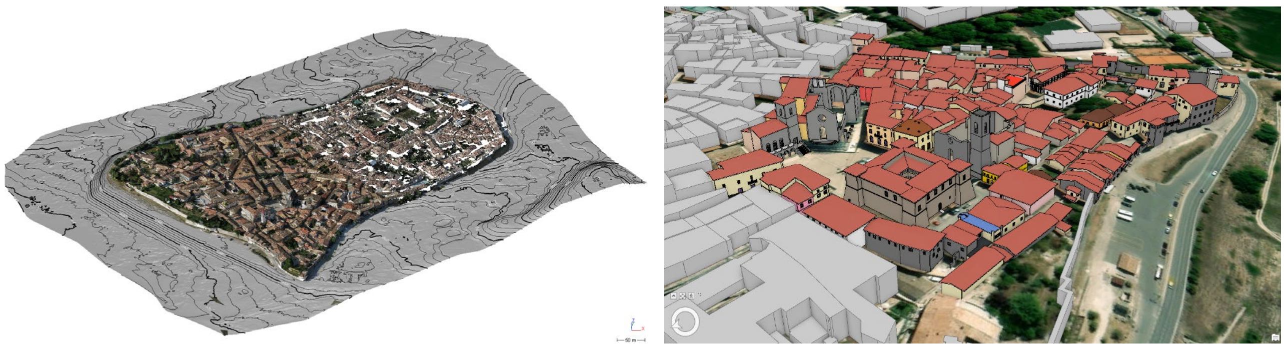
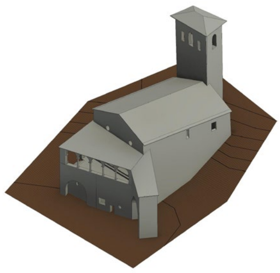
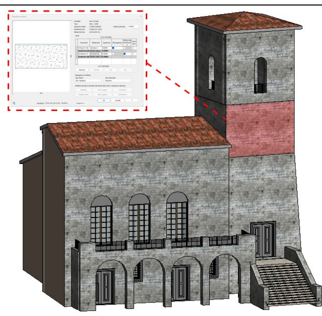


Figure 5. (a) LoD 1 3D model of the historical centre of Norcia after segmentation and classification phases. (b) Multiscale modelling: 3D view (LoD 1 and LoD 3) of the “red area” of historical centre of Norcia.

While information modeling at the building scale and based on the IFC standard (Industry Foundation Classes) (https://www.buildingsmart.org/standards/bsi-standards/) has expanded to include the historical building heritage, involving the so-called as-built modeling which originates from point clouds and structures the model through the HBIM paradigm, studies have multiplied both to adapt the complexity of the cultural heritage to the parametric approach (Brumana et al., 2019; Murphy et al., 2013), and to reflect on a comparison of the semantic and geometric descriptions of objects to allow interoperability between the two standards. (Xu et al., 2014). Having ascertained the mutual advantage and enrichment that derives from the integration of systems that aim respectively at the geographical/urban scale and that of the building and its parts, it is necessary to clarify that the standards and their use have undergone an evolution. The City GML has always aimed to represent the 3D objects of the city according to different levels of detail (LoD), which over time have gone from 4 to an articulation in 16 (Biljecki et al., 2016). The OGC released version 3.0 of the City GML open standard in 2021 which allows to encode data in GML and JSON or database schemas. Additional benefits that in this research are particularly interesting, include a better integration with BIM, consisting in the ability to represent interior spaces in different levels of detail (LoD),

Table 2. The table show a comparison between LOD CityGML and IFC standard, through the correspondence of modelling approach and model visualization levels

	Modeling approach *based on algorithms (segmentation/ classification/labeling)*	***CityGML 2.0***	***IFC Elements***	***Model Visualization***
LOD 0	*CSF (Terrain)*	*LoD 0*	*IfcSite*	
LOD 100	*CSF (Buildings)*	*LoD 1 (AbstractBuilding)*	*IfcMass*	
LOD 200	*RANSAC/As-built modeling*	*LoD 2 (RoofSurface class BuildingInstallation class WallSurface)*	*IfcRoof-IfcWall*	
LOD 300	*As-built modeling*	*LoD 3 Opening: Door/Window BuildingInstallation*	*IfcDoor-IfcWindow-IfcStair*	
LOD 400	*As-built modeling*	*LoD 4 InteriorWallSurface*	*Stratigraphy elements*	

As regards the IFC standard, the LOD indicate the level of development, combining the level of Geometry and the Level of information (pertaining the non-graphical information), but recently a new parameter LOIN (level of information needed) has been introduced (Di Giuda, 2019) that assume a great importance when the building is subject to maintenance, refurbishment and restoration after the construction (also vulnerability assessment procedures oriented to structural reinforcement).

The previous Table 2 synthetizes the extensive analysis and 3D modelling compliant with the two standards which is just referred in (Avena et al., 2021; Sammartano et al., 2023). The second column is crucial from the geomatic point of view: in the first levels, at the scale of the territory and the city, the segmentation of the point clouds necessary to transform an unstructured model such as clouds into a semantic modeling as required by the two standards has used supervised segmentation algorithms for example to transform the DSM into DTM, or to identify the road surrounding the historic centre of Norcia, derived from the ancient moat close to the city walls. The third and fourth columns demonstrate how the strategy followed not only responds to compliance with the standards but also to the multi-scale approach for documenting the buildings damage as required by the directive.

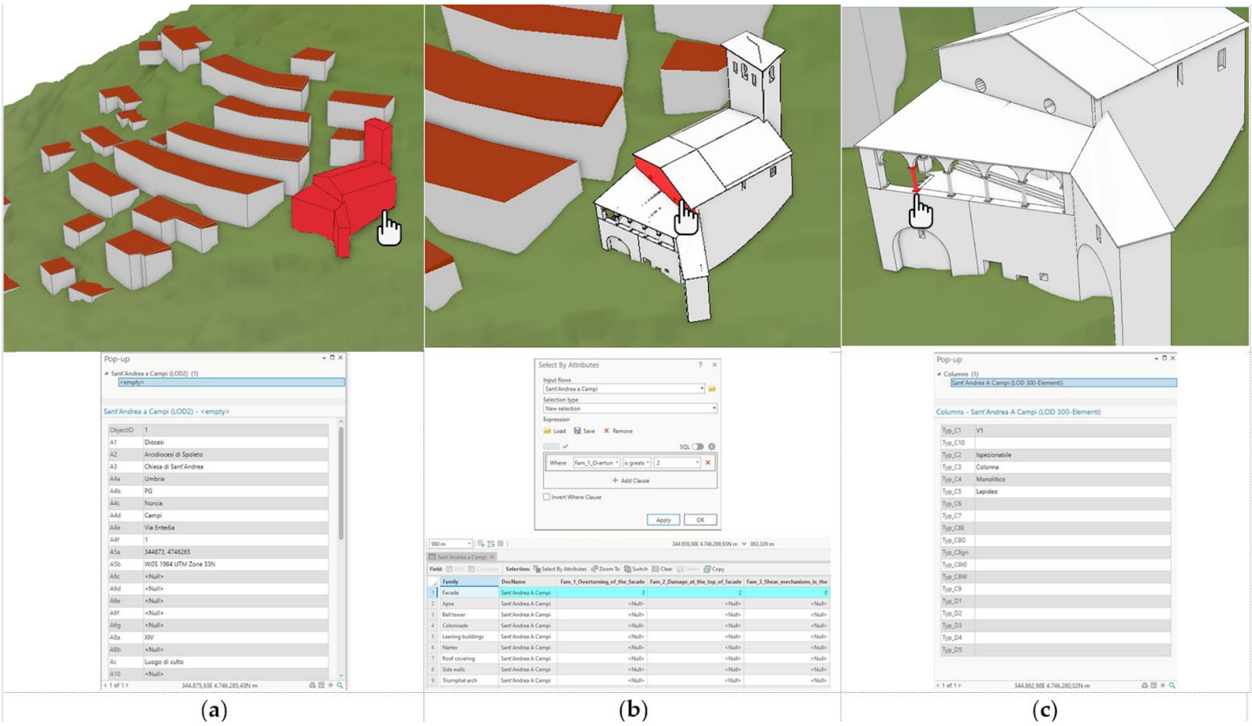


Figure 6. The 3DGIS of Campi di Norcia, from LOD2 (a), LOD3 modeling of macro-elements (b) and LOD4, with the elements modelling, and it is visible the information associated, as damage mechanism information associated to the macro-elements, and with C and D information. (Sammartano et al., 2023)

4. Discussion & conclusions

The User-based fruition Improvement of the Multi-Scale 3D Geodatabase

The sharing and dissemination steps are crucial part of the 3D geodatabase implementation, in relation to the finalization of the methodology itself. It is the phase that can allows the research validation and corroborate its purposes and the legitimacy and effectiveness of the semantic content. Nowadays WebGIS and AMS (Application Management Systems) platforms allow the user interaction with the 3D model objects and connected information. In this case the ERSI ArcGIS Pro platform was exploited, both the desktop version of Geodatabase and webGIS sharing interface (Figure 7), where the 3D objects, based on different developed LODs, can be visualized, navigated and queried, according to the semantic hierarchy and semantic content derived from vulnerability analysis results. These objects can be originated both with GIS-based approach from numerical cartography, and integrated with ones from BIM-based approach, importing, managing, and storing **.IFC* BIM models in GIS, including **.rvt* Revit files.

The successful steps of the 3D geodatabase implementation are, synthetically: a 3D multiscale information structuring according to the macro-elements and elements, function of the Directive orientation; the possibility to perform analysis of phenomena using a geographical scale approach, according to the Directive modules and according to the level of evaluation; the applicability of dashboard interfaces for information querying. Bottlenecks that can be underlined consist mainly in the3D modelling and generation phase, related to the still weak availability of automated tools facilitating the macro-elements modeling and also the time-consuming implementation of semantic information on 3D geodatabase.

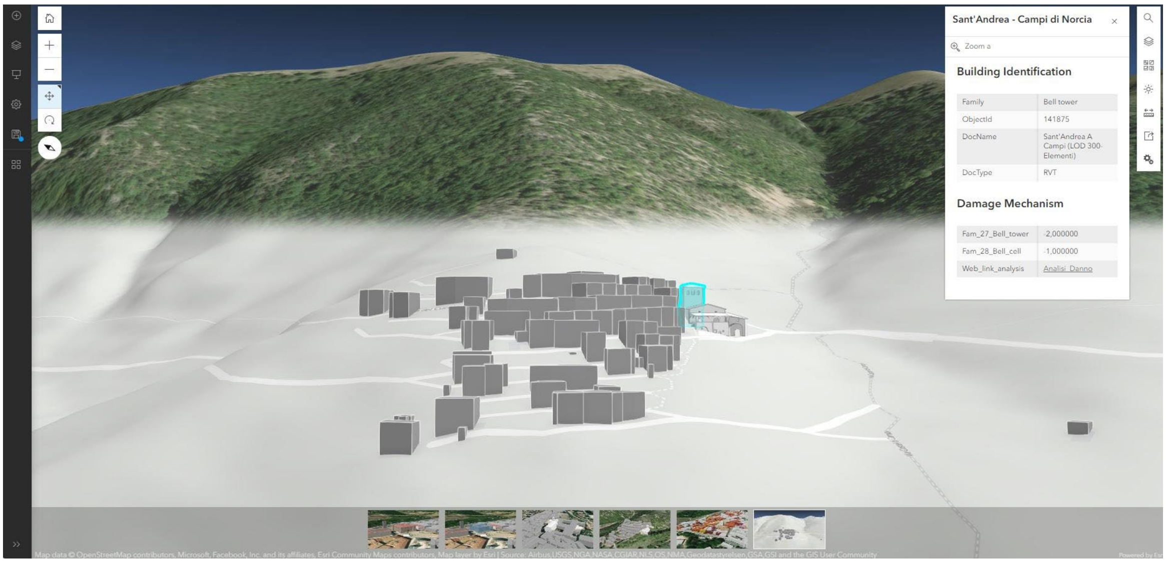


Figure 7. The WebGIS interface view, navigating on the sample dataset of Campi di Norcia. In lower bar, the navigation on the multiple urban contexts modelled for the research purposes.

In this framework, the 3D geosciences-based digital documentation method proposed in this study provides a improved critical perspective for building knowledge about the security levels of churches. In this study, a wide-ranging documentation approach based on 3D geodatabases is proposed to answer policy queries in terms of multi-scale knowledge, policy module and assessment step levels. Therefore, the availability of rapid mapping and low-cost 3D surveys, as well as their suitability for identifying and sizing macro-elements, is an interesting area for methodological and holistic comparisons. The interest in this strategy comes from its potential if we consider the analysis of the vulnerability of single structure, using geospatial science methods, in conjunction with its territory and other protected buildings, as a geographical scale phenomena indeed.

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