Addressing Flood Risk Assessment and Heritage Conservation by Integrating HBIM and GIS: The Case Study of Castello del Valentino (Italy)

Addressing Flood Risk Assessment and Heritage Conservation by Integrating HBIM and GIS: The Case Study of Castello del Valentino (Italy)

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Abstract

Climate change and increasingly frequent extreme weather events pose critical threats to cultural heritage, particularly flood-prone historic sites. This study presents an integrated workflow combining Historic Building Information Modelling (HBIM) and Geographic Information Systems (GIS) for flood risk assessment and heritage conservation. The methodology is applied to the Valentino Castle in Turin, a UNESCO-listed site located along the Po River, vulnerable to recurrent flood events. A semantically rich HBIM model was developed from high-resolution point cloud data to document the architectural and material characteristics of the castle. This model was then integrated into a multi-scale 3D GIS environment to simulate various flood scenarios and assess their impact on building elements. The workflow addresses technical challenges such as BIM-GIS interoperability, semantic-geometric translation, and applying Level of Information Need (LOIN) in heritage contexts. The resulting framework allows for detailed, spatially accurate vulnerability assessments and supports decision-making for risk mitigation, preservation planning, and stakeholder communication. While Valentino Castle is the case study for this first methodological validation, the proposed method is scalable and adaptable to other heritage sites. Integrating HBIM and GIS proves to be a valuable tool for protecting cultural assets in the face of climate-induced hazards.

1. Introduction

1.1 Climate Change, Flood Risk and Cultural Heritage

In recent decades, the frequency of extreme weather events, especially stormwater and flooding, has significantly increased, posing significant threats to human life, infrastructure, urban environments, and cultural heritage. Furthermore, the risk of flooding is expected to increase due to climate change and other factors; considering that floods imply significant losses of human life, extensive infrastructure damage, and displacement of communities, disturbing local economies and causing long-term financial hardships (Boudreau et al., 2022; Dottori et al., 2018), strategies for risk mitigation are critical. Indeed, cultural heritage sites are especially at risk, as floodwaters erode foundations, submerge structures, and degrade materials, leading to irreversible damage and, lastly, to the risk of loss of cultural identity (Pickles, 2015). Italy, with its rich cultural heritage, is vulnerable to these events due to the geographical location of these sites and their intrinsic characteristics. Moreover, an aspect that needs to be underlined is that these buildings were built foreseeing a completely different climate and are not designed to be resilient to the effects of climate change. The Castello del Valentino, the case study of this research, was inscribed in the UNESCO World Heritage Site list in 1997. The Castello del Valentino is situated along the Po River and is closely connected to its groundwater system, making it particularly susceptible to escalating flood risks due to the increasing emergence of extreme weather (see 1.2).
In parallel, the digital transition in the field of built heritage documentation has opened new opportunities for preventive analysis, conservation, and risk communication through 3D environments. Emerging technologies allow heritage managers to monitor, simulate, and assess threats using detailed digital replicas of existing structures, bridging conservation theory with environmental modelling.

1.2 HBIM-GIS for Risk and Conservation

In recent years, Heritage Building Information Modelling (HBIM) has emerged as a crucial tool for studying, preserving, restoring, and creating a 3D archive of historical structures (Murphy et al., 2009). In this research domain, an evolving trend involves integrating the potentialities offered by HBIM with other disciplines to provide comprehensive insights into heritage safeguarding, protection, and conservation. The research presented in this work integrates HBIM and Geographic Information System (GIS) to gain a deeper understanding and improve the management of flood risks affecting cultural heritage sites, using the Castello del Valentino as a case study.

The proposed methodology enables detailed flood simulation scenarios through a multi-scale 3D GIS environment, enriched with semantically meaningful HBIM data that reflects the historic structure's architectural and material features.
The core objective of the research is to propose, evaluate, and validate an HBIM-GIS pipeline that could be replicable in other heritage sites, thereby contributing to protecting and preserving valuable heritages in the face of flood risks. This integration might facilitate multi-scale documentation of heritage assets and their surrounding context, promote multi-disciplinary collaboration and real-time information sharing among stakeholders, and finally enable multi-scale analysis to assess flood impacts at the building element level (Liu et al., 2017; Matrone et al., 2023; Vacca et al., 2018).

The approach also involves interpreting and transforming point cloud datasets into HBIM models, integrating topographical and hydrological data, and using CityGML standards to ensure interoperability between BIM and GIS platforms. While current Flood Risk Management Plans for the Po River Basin offer general assessments of cultural heritage at risk, they lack

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detailed analysis and specific intervention proposals for built heritage at risk, such as the Castello del Valentino. Traditional flood damage assessment methodologies often focus on broad economic losses at community or urban scales, frequently overlooking the specific vulnerabilities of individual building components within historic structures (Amirebrahimi et al., 2016a, 2016b; Kalogeropoulos et al., 2023; Meng et al., 2019). Furthermore, there is a need for more intuitive visual tools, such as 3D visualisations, to enhance public understanding and community involvement in flood risk management for heritage sites. Finally, achieving seamless interoperability between HBIM and GIS data formats, especially for complex historical building models, remains a significant challenge, often resulting in data loss and unsuccessful conversions. By leveraging an integrated HBIM-GIS strategy and addressing issues of semantic translation, spatial referencing, and data generalisation, the proposed workflow offers a robust foundation for risk analysis and communication tailored to heritage buildings. The following sections describe in detail the implementation of this workflow, starting from multi-sensor survey acquisition to flood simulation and heritage-specific visualisation outputs.

1.3 Standards for spatial interoperability: IFC and CityGML

A key challenge in integrating HBIM and GIS lies in the fundamental difference between their data models and exchange standards. Building Information Modelling environments primarily rely on the Industry Foundation Classes (IFC), an open, ISO-standardised schema developed by Buildingsmart to ensure interoperability among AEC software. IFC represents buildings as object-oriented, hierarchical entities with geometric, spatial, and semantic properties[1].

Conversely, GIS platforms use CityGML, an Open Geospatial Consortium (OGC) standard designed to represent 3D city models. CityGML structures information in Levels of Detail (LoDs) and focuses on georeferenced surfaces, topologies, and thematic classes (e.g., buildings, terrain, vegetation)[2].

While IFC is rich in design and construction semantics, it lacks standardized geographic referencing. CityGML, on the other hand, enables multi-scale spatial analysis but is limited in architectural detail and lacks embedded construction semantics. For this reason, integrating HBIM into GIS requires custom workflows to move between these standards.

In the context of flood risk and heritage conservation, the ability to interoperate between IFC and CityGML allows semantic-rich HBIM models to be embedded within urban-scale geodatabases. This enables spatial analysis and simulation while preserving architectural identity. The workflow developed in this research leverages both formats, evaluating the benefits and limitations of each one for cultural heritage protection and management.

1.4 The Case Study: the Valentino Castle

The Castello del Valentino, located along the left bank of the Po River in Turin, is a remarkable example of stratified architectural history. Originally a riverside villa in the 16th century, it was acquired and transformed by Christine of France in the 17th century into a “*maison de plaisance*” inspired by French models, with symmetrical towers, decorative interiors, and formal gardens. The transformation was led by architects Carlo and Amedeo di Castellamonte, resulting in a Baroque structure that still defines the castle’s identity today. Throughout the 18th and 19th centuries, the building underwent multiple functional adaptations, including the use as a military barracks and later as a venue for national exhibitions. Since the early 20th century, it has hosted engineering and architectural education and research activities, and it currently belongs to the Politecnico di Torino. In 1997, it was inscribed in the UNESCO World Heritage Site list as part of the “Residences of the Royal House of Savoy.”

The proximity to the Po River, the presence of underground water channels, and the vulnerability of its historic basement and foundations make the Castello del Valentino an exemplary case for testing integrated HBIM-GIS strategies in flood risk assessment and conservation planning.

In recent flood events such as those in 2000 and 2016, surrounding areas like the Murazzi and Borgo Medievale experienced water levels exceeding 3.5 meters, confirming the hydrogeological vulnerability of this portion of the city. This historical context reinforces the strategic value of using Valentino Castle as a pilot site for assessing and visualizing heritage-related flood risk. Moreover, the castle is not only a built asset but also a node within a wider cultural landscape, which includes the Parco del Valentino and the river system. This makes it particularly suitable for testing multi-scale integration across architectural, urban, and environmental data layers.

2. Methodology and first results

2.1 Methodological workflow

Typically, flood depths exceeding 1 metre above floor level can cause structural damage to buildings, particularly when the buildings are in a poor state of repair and conservation. However, it is uncommon for the structural integrity of a historic building to be compromised under such conditions (Pickles, 2015). In this research, hydrostatic and hydrodynamic flooding actions will not be considered. The primary focus is on low-flow velocity floods, emphasising the impact of flood depth. The study identifies vulnerable elements of Castello del Valentino under various flood scenarios, ass
uming the overall structural stability is maintained.
The proposed methodology follows a structured workflow comprising 3D data acquisition, HBIM modelling, GIS integration, flood simulation, and data interoperability analysis to assess and visualise flood risks (Figure 1) effectively.

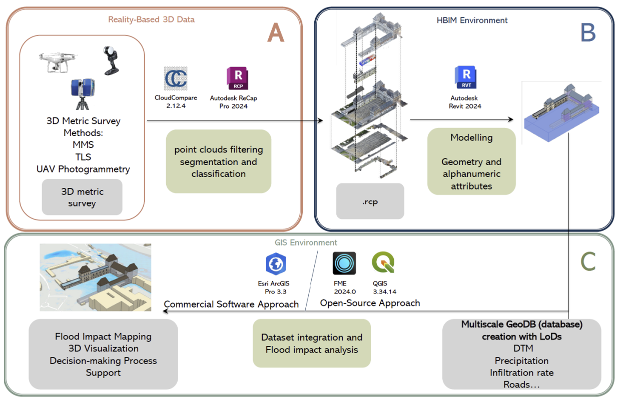

Figure 1. Proposed workflow for Flood Impact Assessment

[1] https://technical.buildingsmart.org/standards/ifc/
[2] https://www.ogc.org/standards/citygml/

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This workflow operates across three integrated environments: 3D reality-based data, HBIM, and GIS. The conversion of point cloud data into semantic HBIM and its subsequent integration with geospatial data aims to produce spatially informed flood simulations.

2.2 The 3D integrated metric survey

The first step consisted of the 3D metric survey representing the foundation of the Scan-to-BIM process (Figure 2). The survey included traditional topographic acquisition (Global Navigation Satellite Systems-GNSS and Total Station techniques), Uncrewed Aerial Vehicle (UAV) photogrammetry, Terrestrial Laser Scanning (TLS), and Mobile Mapping Systems (MMS) with Simultaneous Localisation And Mapping (SLAM) technology to achieve a complete reconstruction of the Castello del Valentino. The different techniques were used to document different areas of the Castello, and a multi-scale and multi-sensor approach was thus implemented. These datasets were acquired and processed by the G4CH Lab, ensuring full coverage of both interior and exterior environments. More specifically, using a DJI Phantom 4 Pro (1-inch CMOS sensor and 20 effective megapixels), UAV-based photogrammetry was conducted for the exterior and surrounding areas. The courtyard was scanned using TLS, employing a FARO Focus X330 (scanning rate ranging up to 976,000 points per second, ranging error ± 2 mm). The basement was surveyed using a STONEX X120GO mobile scanner with SLAM technology (6mm relative accuracy). This combination allowed for accurate surface reconstruction despite accessibility constraints, varying lighting, and different terrain conditions (Remondino et al., 2022).

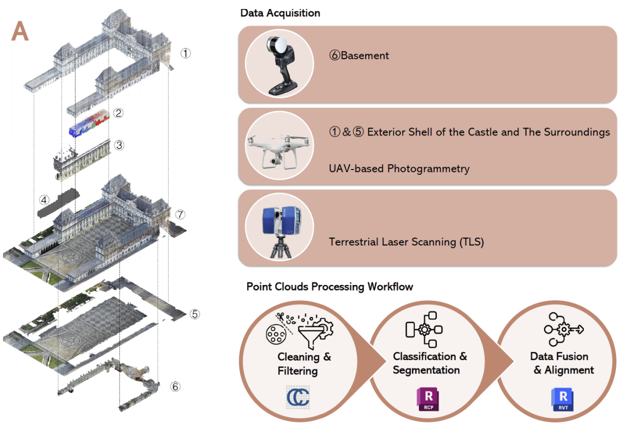

Figure 2. Data acquisition and processing workflow.

The data from the different techniques were processed following standard and consolidated approaches, and the use of topographic measures allowed for ensuring the metric control over the process. In a second phase, the data were then further processed in different steps before moving to the modelling phase. These steps included: cleaning, filtering, segmentation, classification, and data fusion. These operations were achieved using Autodesk ReCap Pro 2024[3] and the opensource solution CloudCompare[4]. Statistical Outlier Removal (SOR) tool was applied in CloudCompare to automatically reduce the noise of the point clouds as a preliminary step. Additionally, manual classification, cleaning and segmentation were carried out for TLS, UAV and MMS datasets to ensure consistency.

For the UAV dataset, a simple automatic classification was adopted to extract the Digital Terrain Model (DTM) using Autodesk ReCap. After the cleaning of the dataset, the UAV point cloud of the overall castle was imported into Autodesk ReCap, which implements an automatic ground classification function to identify and classify the ground surface. The automatic classification successfully extracted most of the ground surface-related points, although some were misclassified and later manually corrected.

After saving the point cloud in .rcp format, in recap, and picking a coordinate point as base-point, the point clouds have been imported in Revit. Point clouds were realigned by roto-translating coordinates to comply with Revit’s spatial range limits. A unified reference point in the courtyard was set as project base point for geo-referencing in Revit and ArcGIS Pro (Figure 3).

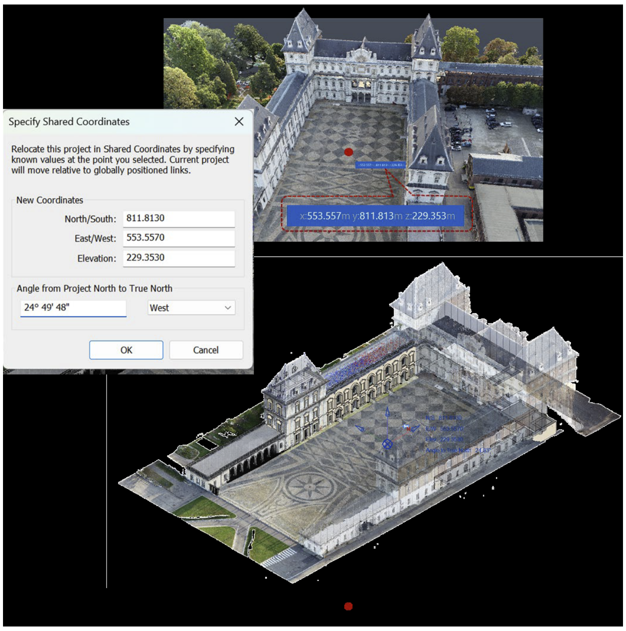

Figure 3. Definition of the Project Base Point.

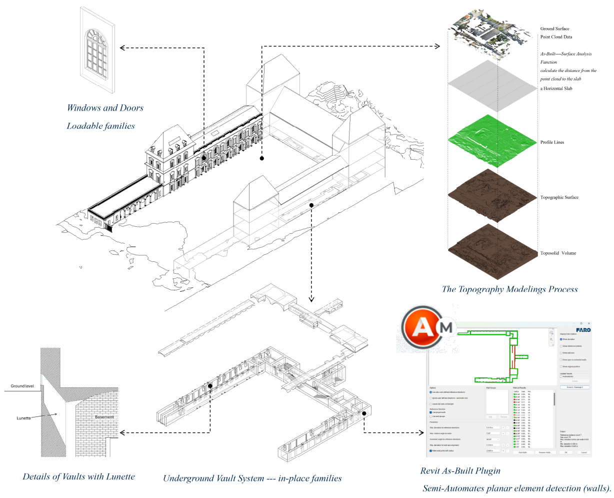

Figure 4. Methodological step of the HBIM process and ground surface extraction.

[3] https://www.autodesk.com/eu/products/recap/overview
[4] https://www.danielgm.net/cc/

2.3 HBIM Modelling Strategies for Architectural Heritage

The modelling process starts from the semantically registered and aligned point cloud datasets (WGS1984 UTM 32N). Modelling operations were executed using clipping boxes and visibility filters in Revit to isolate relevant geometry portions. After the processing of the survey data, the next step consisted of the generation of the HBIM model of the Castello del Valentino. It was developed in a BIM environment, thanks to the Autodesk Revit[5] software, leveraging the processed point cloud data as a geometric reference. The modelling adhered to the BIM standard and the Level of Geometry (LOG) 300, balancing detail and efficiency, while a Grade of Accuracy (GOA) 200 was applied to complex decorative elements to simplify geometries without compromising historical integrity (Banfi, 2016, 2019).

The modelling process followed a Scan-to-HBIM approach structured in thematic layers (structural, spatial, material, and risk-related), supporting multiscale analysis of the building.
This level of modelling was selected to ensure adequate detail for simulation and conservation analysis, while avoiding excessive file weight and geometric complexity. The GOA 200 standard allowed for the abstraction of highly decorated components, preserving their volumetric essence without redundant complexity (Banfi et al., 2017).

The balance between Level of Geometry and Grade of Accuracy was defined according to the conservation priorities: main structural elements (LOG 300), decorative vaults and niches (GOA 200), and light wells/ventilation devices were simplified for hydrodynamic simulation.

A key aspect of the HBIM model was the semantic classification of building elements, which followed Italian regulations (UNI 10838:1999 and UNI 8290:1981) to ensure standardized representation. Furthermore, Revit shared parameters were employed to integrate alphanumeric attributes related to materials, existing decay, potential flood damage types, and remedial precautions. Each Revit family was enriched with parameters such as: material type, porosity index (where applicable), visible deterioration, and exposure to previous water infiltration, all relevant for flood risk scenarios. To accurately model complex architectural features such as vaults, lunettes, staircases, doors, and windows, a combination of in-place families and loadable families was utilized, drawing upon references from historical construction manuals (Previtali & Banfi, 2018).

In particular, staircases were reconstructed using a combination of horizontal slicing from the TLS point cloud and vertical section profiles (Figure 5), while windows and doors were modelled from MMS-derived ortho-projections to maximize precision in confined basement areas (Figure 6). In the basement, geometries were simplified using in-place components with embedded voids to simulate light wells and air channels – critical paths for water infiltration observed in recent flood events.

Figure 5. Point Cloud Section of Staircase (it is possible to notice the difference in radiometry due to light conditions).

Figure 6. Examples of Door Types and Orthogonal Point Cloud Images (Top), Different Doors families (bottom).

The HBIM model was validated through surface analysis tools in the software FARO *As-Built for Revit*[6], comparing the generated geometry with the point cloud data. The validation process included deviation heat maps to identify critical mismatches over 5 mm between model surfaces and point cloud geometry. Most surfaces remained within ±3 mm, confirming model accuracy and suitability for downstream integration (Figure 7).

[5] https://www.autodesk.com/eu/products/revit/overview

[6] https://www.faro.com/en/Products/Software/As-BuiltTM-Software

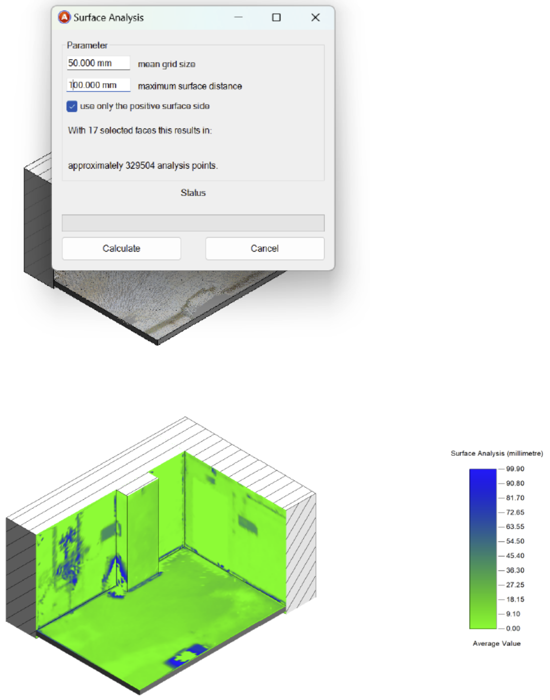

Figure 7. Model validation via FARO As-Built tool for Revit.

The finalized HBIM model was exported in Industry Foundation Classes (IFC) format for interoperability and Revit (.rvt) format for direct integration into GIS environments.

2.4 GIS Modelling and Flood Simulation

The following methodological phase included the multi-scale 3D GIS development and the geodatabase (geoDB) design. The HBIM model was integrated into a multi-scale 3D GIS project using ArcGIS Pro by ESRI[7] to assess flood risk in a geospatial context. The GIS environment incorporated geospatial datasets obtained from Geoportale Piemonte (BDTRE)[8], structured at different Levels of Detail (LoDs), from the CityGML standard, to support multi-scale analysis and visualization. This approach allowed the overlay of HBIM-derived building components with regional datasets, including hydrography, DTM, and administrative units. The 3D GIS was structured following a vertical LoD logic (LoD0–LoD3) to ensure consistent resolution across scales.

The geoDB includes: Digital Terrain Models (DTM) at 1-meter resolution, derived from Airborne LiDAR scanning; Rainfall data from Arpa Piemonte, providing meteorological information; Hydrological datasets, including watercourse morphology and flood-prone areas; and 3D representations of surrounding buildings, categorized into residential, industrial, and service structures. The HBIM model was georeferenced within the GIS environment to ensure accurate alignment with external datasets, enabling spatial analysis and flood simulations.

The georeferencing process used the project base point within Revit and EPSG:32632 (WGS 1984 UTM Zone 32N) in ArcGIS Pro, ensuring spatial coherence with regional GIS layers. A multi-scale LoD framework enabled vertical interoperability between the detailed HBIM and urban context data. The flood simulation was conducted in ArcGIS Pro using the Simulation toolset, which employs shallow water equations to model water flow dynamics. The simulation assessed the potential impact of extreme rainfall events on Castello del Valentino by incorporating historical and predictive hydrological data (Figure 8).

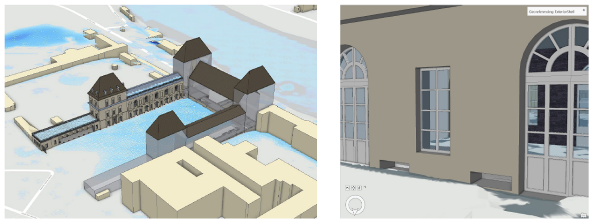

Figure 8. 3D visualization of a simulated intense rainfall event. 200-year return period, ten minutes after precipitation began

Key simulation parameters included: Return periods of 10, 50, and 200 years, based on rainfall data from Arpa Piemonte; High-accuracy 0.1m cell size for detailed flood modelling; and ground infiltration rates derived from regional hydrological and geological data, with evaporation effects excluded. A specific focus was placed on basement flooding, analyzing how rainwater could infiltrate through light wells and ventilation openings. The simulation outputs included water depth, absolute height, and velocity at different time intervals, generating 3D flood progression visualizations to facilitate interpretation. Post-processing included flood raster overlays on the georeferenced HBIM, producing damage prediction maps at the element level, and supporting preventive conservation actions in vulnerable zones.

However, limitations were acknowledged in ArcGIS’s ability to represent complex hydrodynamic phenomena, such as river dynamics and vegetation interactions. Advanced simulations involving river–building interaction, turbulence, and vegetation drag are not yet supported in the current ArcGIS simulation toolset, suggesting future use of dedicated hydrodynamic software (e.g. HEC-RAS or InfoWorks ICM) for more detailed modelling and the involvement of domain experts for more accurate simulations.

2.5 HBIM–GIS Data Interoperability

A challenging aspect of the research involved ensuring data interoperability between the HBIM model (IFC format) and the GIS environment, allowing seamless integration for spatial analysis and flood risk assessment. Both commercial (ArcGIS Pro 3.3) and open-source (FME 2024.0) tools were tested to evaluate the most effective workflows for data exchange while maintaining geometric accuracy, semantic consistency, and analytical functionality.

Interoperability challenges stem from the fundamental differences in data models: BIM uses object-oriented representations (e.g., IfcWall), while GIS uses topological geometry and attributes linked to spatial features (Donkers et al., 2016).

The primary objective was to convert IFC data into CityGML (versions 2.0 and earlier) to support detailed 3D GIS projects. Custom workflows were developed in FME to transform building elements such as IfcWindow, IfcWall, IfcSlab, and

[7] https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview
[8] https://geoportale.igr.piemonte.it/cms/

IfcRoof into CityGML MultiSurface geometries, ensuring compatibility with geospatial applications. The conversion workflow included three main custom transformers: *ConvertGeometry*, *GetGrandParentID* and *CityGMLGeometrySetter* (Figure 9).

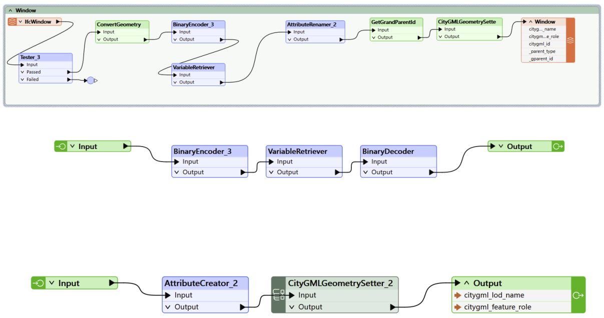

Figure 9 (a, b, c). Workflow for Converting "IfcWindow" to CityGML, GetGrandParentID custom transformer and CityGMLGeometrySetter Transformer.

The workflow included transformers such as IFCPropertyExtractor, GeometryCoercer, and CityGMLGeometrySetter, which assigned LOD names and semantic roles. However, this process has proven to be challenging in handling complex solid geometries, often leading to data loss or conversion errors. The CityGMLGeometrySetter transformer was applied to define Levels of Detail names and feature roles to address these issues, improving data structure and readability within GIS platforms. Geometries such as vaults and stairs were particularly problematic during conversion due to their non-planar and non-manifold surfaces.

Despite the benefits of lighter CityGML files, their visualization in QGIS[9] proved problematic, affecting their usability for detailed analysis. Attribute hierarchies from IFC were often flattened or lost in QGIS, reducing the semantic richness of the model.
Additionally, the open-source workflow tested an FME workspace published on GitHub but found it failed to support complex geometries like vaulted or sculpted elements (Figure 10).

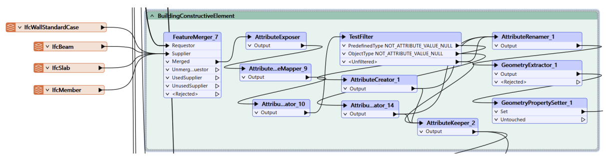

Figure 10. FME workspace on GitHub; does not convert complex geometries.

As an alternative, the research explored the direct import of .rvt (Revit) files into ArcGIS Pro, providing a more stable spatial analysis and visualization solution. Unlike the CityGML approach, this method preserved the full spatial structure, attributes, and geometry, making it a more efficient and reliable option for integrating HBIM data into GIS. Hence, the study highlights opportunities and limitations in HBIM-GIS interoperability by comparing these approaches (Figure 11). The CityGML conversion output, visualized in FZK Viewer, highlights how geometric simplification affects the appearance of architectural elements and causes loss of semantic hierarch (Figure 12).

[9] https://qgis.org/

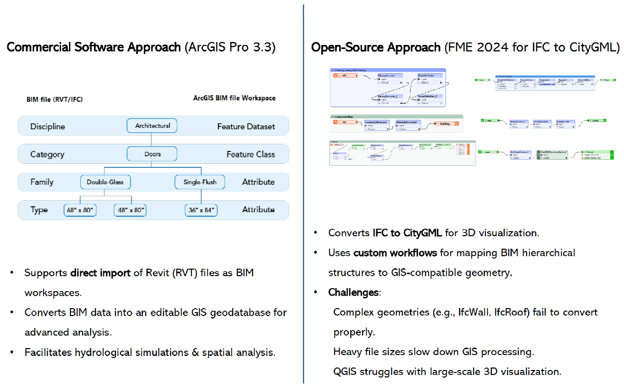

Figure 11. Comparison of commercial and opensource approach for multis ale GeoDB creation.

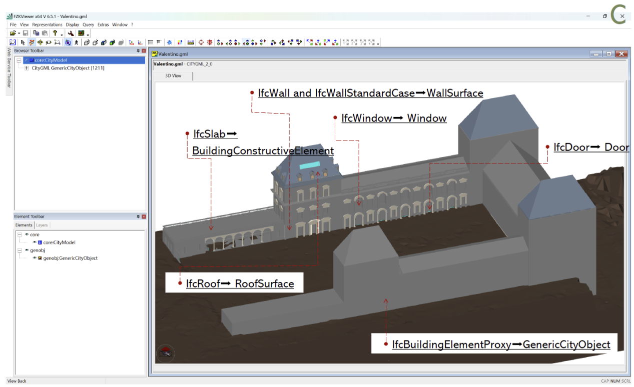

Figure 12. Output of CityGML file in FZK viewer.

Despite the overall interoperability potential between IFC and CityGML, several practical limitations emerged during the implementation phase. In particular, as mentioned before, the conversion of complex architectural elements such as vaults, curved walls, and staircases often resulted in geometry simplification or data loss. This was especially evident using open-source tools like FME, where non-manifold surfaces and non-planar geometries triggered errors or resulted in malformed outputs. Furthermore, semantic flattening during the transformation process —i.e., the loss of object hierarchies and relationships between building components— led to a loss of attribute hierarchy, compromising the model's descriptive richness when visualized in GIS environments such as QGIS.
Additionally, CityGML's rigid schema and limited support for rich construction semantics make it challenging to preserve IFC-based object definitions (e.g., IfcWall, IfcSlab) during conversion. These limitations currently affect the maturity of BIM–GIS workflows for operational heritage risk management, particularly when detailed building components and heritage-specific attributes are required for downstream analysis or stakeholder communication. Moreover, these issues are more evident by increasing the level of detail and the scale of representation.

3. Final results

As discussed in the above paragraph, while IFC-to-CityGML conversion enhances data portability, it requires further refinement to overcome geometric conversion challenges. On the other hand, the direct use of .rvt files in ArcGIS Pro offers a practical and stable alternative, particularly for heritage conservation and flood risk assessment, ensuring that complex building elements retain their integrity within GIS-based simulations and analyses.

3.1 Hazard Mapping and 3D Visualization

The final step involved generating flood impact maps and 3D visualizations within the GIS environment to assess potential damage and facilitate risk communication. The simulation results were overlaid onto the HBIM model, allowing the identification of vulnerable building elements and estimating structural risks. 3D visualization tools enabled immersive exploration of flood progression, providing insights into how water would accumulate in and around the castle.

Specifically, the visualization outputs included water depth maps, voxel-based time-evolving surfaces, and building element status layers (e.g., basement walls marked for intervention). The integration of these simulation layers with the semantically enriched HBIM enabled targeted conservation strategies, as it was possible to associate flood intensity with specific materials and conditions extracted from the Revit model. This step is particularly relevant to support stakeholders such as conservators, civil protection authorities, and local governments in planning response and adaptation measures (Kalogeropoulos et al., 2023). In addition, using 3D tools helps bridge the gap between technical experts and the public, enhancing awareness and community involvement through accessible digital content and scenario-based risk communication.

Thanks to the involvement of stakeholders, it could be possible to prioritize inspection and conservation efforts based on simulated water depth thresholds in sensitive building zones, and to integrate simulation results into preventive action plans and funding proposals for resilience improvement.

Furthermore, preliminary steps were taken to define a future WebGIS-based interface (currently under development) that could host the 3D simulation layers, allowing stakeholders, with a user-friendly tool, to interactively explore risk scenarios, access associated metadata, and download reports. This would support decision-making processes by providing both spatial and semantic context in a user-friendly environment. Such developments aim to bridge the current gap between technical output and actionable information for heritage professionals, institutions, and policymakers.

It is important to acknowledge that the current simulation approach, based on ArcGIS Pro's built-in tools, simplifies the hydrological modeling by focusing mainly on flood depth. While suitable for initial scenario visualization, it does not consider dynamic flow parameters such as velocity, hydrostatic pressure, or infiltration processes. Future improvements should involve the integration of advanced hydraulic modeling tools (e.g., HEC-RAS, InfoWorks ICM) to represent more accurately the interaction between floodwater and the built heritage environment. This step would significantly increase the physical realism of the analysis and its value for risk mitigation planning. Moreover, the researchers will also contact and consult experts in risk scenarios, geographers, and hydrologists.

4. Conclusions and discussions

This integrated HBIM-GIS methodology presents a comprehensive, multi-scale approach to flood risk assessment and heritage conservation. By leveraging HBIM for detailed architectural modelling and GIS for environmental analysis, this workflow enables a more accurate prediction of flood impact, supports decision-making for preservation, and enhances resilience planning for historic sites. The Castello del Valentino served as a relevant pilot site due to its documented flood exposure and architectural complexity, which made it ideal for testing interoperability and multi-scale analysis.

Despite different challenges, the integrated HBIM-GIS framework proposed in this study demonstrates its potential as a valuable approach for enhancing flood risk assessment and management for cultural heritage at a detailed component level.

As mentioned before, the Castello del Valentino was a relevant pilot site due to its documented flood exposure and architectural complexity. The 3D visualization capabilities of the integrated environment significantly improve communication and understanding of flood risks among diverse stakeholders, including heritage managers, policymakers, and the public, fostering greater engagement in conservation efforts. The use of time-sequenced simulation outputs and immersive visualization scenes supported intuitive interpretation, even for non-technical users. The ability to assess potential flood damage at the building element level can contribute to more accurate estimations of restoration costs and facilitate improved insurance risk valuation and coverage planning for historic properties. Such detailed assessments could also support emergency response prioritization and pre-event mitigation strategies, especially in UNESCO-designated sites (Kalogeropoulos et al., 2023; Meng et al., 2019). Moreover, the visual outputs generated from flood analyses serve as an effective medium for communicating risks to stakeholders, including conservationists, urban planners, and policymakers. Future research should address the identified limitations by exploring advanced techniques for BIM-GIS interoperability, particularly for complex geometries, and by integrating more sophisticated hydrodynamic flood modelling tools through interdisciplinary collaborations. The inclusion of open standards like CityGML 3.0 and integration with advanced solvers such as HEC-RAS or InfoWorks ICM could enhance the representation of water dynamics and vegetation interaction (Gröger et al., 2021; Donkers et al., 2016). Furthermore, access to higher-resolution and more accurate geospatial data is essential for refining the analysis and ensuring the robustness of the proposed framework. Future perspectives could also include the webGIS publication for implementing a user-friendly app useful for different stakeholders. Such platforms could allow real-time access to simulation results, exploration of risk scenarios, and contribute to participatory conservation planning.

Finally, this work originates from an outstanding Master’s thesis project, which demonstrated both technical rigor and innovative vision. Although the study was initially conducted in an academic framework, it lays the foundation for further applied research and development. Given the increasing frequency and severity of flood events due to climate change, the proposed methodology is highly relevant and timely.

The integration of semantically rich 3D models with GIS environments and the publication of these results through a web-based 3D GIS platform would significantly support local administrations, municipalities, and heritage site managers. In particular, institutions such as the Politecnico di Torino—being both the academic partner and a current user of the Castello del Valentino—could benefit from a predictive tool that enhances awareness of flood hazards and supports the planning of effective preventive actions. By enabling proactive risk communication and data-driven decision-making, such digital platforms represent a strategic asset for the long-term conservation of vulnerable heritage assets.

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