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Opportunities and challenges of Crowdsourced Indoor Geographic and Semantic Data for Built Heritage

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Abstract

The increasing availability of crowdsourced indoor geographic and semantic data presents both significant opportunities and notable challenges for the documentation and enhancement of built heritage. This work investigates the integration of OpenStreetMap (OSM) and Wikidata as complementary platforms for indoor mapping and semantic enrichment, particularly within the context of cultural heritage. OSM’s collaborative framework, supported by indoor tagging schemas, enables the detailed mapping of interior building elements, points of interest, and artworks, while Wikidata contributes structured, linked semantic information that enhances data interoperability and accessibility. Despite the growing adoption of these platforms, challenges persist in modelling complex indoor environments, achieving data completeness and facilitating user-friendly semantic integration. The proposed methodology demonstrates a flexible workflow for creating interactive 3D virtual tours of cultural buildings, leveraging OSM for spatial data and Wikidata for semantic enrichment. This approach not only supports research and educational applications but also fosters citizen science participation and interoperability with digital tools such as augmented and virtual reality. The findings highlight the transformative potential of open, crowdsourced data in advancing the discoverability, usability, and preservation of cultural heritage, while also identifying areas where further tool development and community engagement are needed to address current limitations.

1. Introduction

Volunteered Geographic Information, particularly OpenStreetMap (OSM), represents a valuable resource for indoor mapping due to its collaborative nature and the growing need for indoor navigation systems (Balducci, 2021). The open-source approach helps overcome data acquisition costs and the lack of support for indoor rendering in many libraries, offering a flexible and accessible solution for visualising indoor geospatial data (Richter et al., 2022). OSM indoor maps can be used for various applications, including floor plans visualisation, security and resource planning, emergency management, and location-based services (Mascitelli et al., 2020). Expanding OSM’s tagging schema to include detailed indoor information allows for a precise representation of building structures, points of interest (POIs), and spatial relationships (Goetz & Zipf, 2011). The adoption of ontologies and indoor-specific data models enhances standardisation and interoperability, improving data quality and reliability (Claridades & Lee, 2020). The integration of Wikidata enhances the accessibility and interconnection of cultural heritage (CH) data by linking geo-information with Semantic Web technologies. Wikidata serves as a collaborative hub, enabling data integration, reuse, and citizen science participation (Danthine et al., 2021). By enriching geospatial data with semantic information from sources like OpenStreetMap, it supports interactive story maps and applications for research and education (Bartalesi et al., 2023, Vega-Gorgojo, 2024). Custom ontologies help ensure that data from different sources can work together smoothly. Moreover, tools like SPARQL queries, while respecting the standards of the World Wide Web Consortium, make it possible to extract specific information (Jang et al., 2024). Indeed, the integration of 3D indoor spatial data into Resource Description Framework – the specific data model supported by SPARQL – allows for querying complex indoor spatial details, including attributes of each space, accessing geometric descriptions, and tracing indoor routes for path planning. Associated REST APIs offer a simpler way for developers to access and use data in external applications and web platforms (Thiery et al., 2021, Fascia et al., 2024), also facilitating the creation of indoor dataset compliant with current standards, such as IndoorGML (Jang et al., 2023). This integration strengthens the discoverability and usability of CH data.
However, the complexity of indoor environments, with their intricate structures and dynamic changes, continues to pose challenges for data modelling and analysis. Indeed, current OSM-based indoor viewers focus on 2D visualisation (Indoorequal, 2025, OpenLevelUp!, 2025) and existing 3D renderers are mostly tailored for simplified outdoor models (F4 Map, 2025, OSM Buildings, 2025), with limited research for complex OSM-derived web-based 3D indoor rendering (Deng et al., 2022). Additionally, integrating Wikidata interactively within this space is challenging, as access often relies on complex SPARQL queries, limiting usability for non-experts (Capodiferro et al., 2024).
In this open data ecosystem, the objective of this work is to provide a flexible methodology that enables a virtual tour experience, starting from a simplified, interactive, 3D digital replica of a cultural building. This replica is based on open geodata from OSM and is enriched with artworks and POIs documented in Wikidata. The work also reflects on the transformative potential of open, crowdsourced data in advancing the cultural heritage sector.

2. The State of Crowd-sourced Indoor Mapping

Although the OSM project was established by Steve Coast in 2004 (Haklay & Weber, 2008), indoor mapping only started to gain the interest of the contributor community ten years later, when discussions began on WikiOSM regarding the need to introduce an open mapping schema for interior public environments. In 2014, the first version of the Simple Indoor Tagging (SIT) scheme was proposed and gradually endorsed by community working groups (WikiOSM, 2025a). Such a schema is conceived to implement operational guidelines for mapping interior portions of built environment through points, ways (lines) and closed ways (polygons), in compliance with the current geometrical primitives for collaborative mapping real-world objects in OSM. Although the schema was never officially adopted, it emerged as the most widely used solution for mapping and tagging indoor spaces in OSM thank to its compatibility with existing data (simplified as nodes, ways, relationships, and semantic tags, combination of *key = value* that associate a meaning to a geometry) and its flexible integration with the Simple 3D Buildings model — the schema adopted by the project for mapping the third dimension of built elements (WikiOSM, 2025b). In particular, SIT addresses the recommended approaches for mapping both POIs (e.g. artworks, shops, and restaurants), intra and inter floors connecting objects (e.g. elevators, doors, and stairs), and the indoor spaces in which they are located (e.g. rooms or areas with specific destination of usage), shaping the practices for the adoption of the de facto tag *indoor=**. Indeed, while for point features it is used mainly as a boolean attribute, for interior environments mapped as lines or polygons it can assume 5 distinct values according to the type of usage and role in the floor plan: *room*, *area*, *wall*, *corridor,* and *level* (Table 1).

The complete mapping of indoor features is supported by the combined editing of connecting elements such as doors (*indoor=door* AND *door=** for opening connecting rooms; *entrance=yes* for building entrance) or windows (*window=**), both modelled as points. Finally, room destinations are defined by adding to the basic indoor tag another one that includes the usage or the role of it: for example, if an indoor room is occupied by a stair, the *stair=yes* tag is added, while if it is part of an art gallery the tag *room=gallery* is specified too.

Indoor value	Geometry	Usage	# object (June 2025)
room	Polygon	A room delimited by permanent walls.	213417
area	Polygon	Subdivision of a room without walls.	19688
wall	Line	Individual (non-passable) wall element.	57364
corridor	Polygon	Connecting the space between different indoor features.	21645
level	Polygon	Identification of the floor level of a building.	5337

Table 1. Documented values of the indoor tag for mapping interior building parts in OSM according to the Simple Indoor Tagging schema.

The usage of the indoor tags is constantly growing in recent years (Figure 1), facilitated by the constant release and update of new tools for the dynamic rendering of OSM data such as F4 Map and OSM Buildings for 3D rendering, OpenLevelUp! for 2D indoor mapping or the promising OpenIndooorMaps beta project for 2D indoor routing (OpenIndoorMaps, 2025). However, its geographical distribution inside the OSM database still highlights the issue of data completeness in some regions of the world (Figure 2). Indeed, Europe and North America, which have the most active OSM communities, have the highest number of indoor mapped features (Schott et al., 2021). Other regions lack this information due to different open data cultures and restrictions. Nevertheless, the OSM dataset remains the only globally available resource for open indoor maps. It offers a flexible and cost-effective solution when other freely accessible alternatives are unavailable.

Artworks can also be mapped as indoor features in OSM. In particular, for the CH field, two special tags exist for mapping artworks: *tourism=artwork* and *exhibit=**, sometimes used in combination. While the first refers to a generic public artwork, the second specifically applies to those that are part of a publicly accessible (with or without a fee) organized exhibition, such as a museum or art gallery (WikiOSM, 2025c). Moreover, objects characterised in one of these two ways can be described in more detail with additional tags regarding the artwork's name, author, direction, date, type and dimensions, which are manually added by users in OSM. Examples of detailed artwork indoor mapping can be found in Louvre (Paris, France), Muhammad Ali Center and Kentucky Science Center (Louiseville, US), North Carolina Maritime Museum (Beaufort, US), Burnaby Village Museum (Burnaby, Canada) and Museo Nacional de Bellas Artes (Buenos Aires, Argentina).

However, a more dynamic approach to retrieving artwork information is represented by the tag *wikidata=**, which allows OSM features to be associated with items in Wikidata. This is the knowledge graph hosted by the Wikimedia Foundation that underlies all its projects, such as Wikipedia and Wikimedia Commons. Using simple requests — for example, via Sophox, the SPARQL query service for OSM — it is possible to retrieve and visualise real-time information and multimedia (e.g. images, video and audio recordings) associated with a given object in Wikidata in custom applications. First proposed in 2013, the *wikidata=** tag is currently de facto (WikiOSM, 2025d). Although it was not approved through the proposal process, it has widespread acceptance among mappers, with 3777298 objects in OSM being tagged with it. Despite its ability to integrate the geospatial component of OSM data with the ontological purpose of Wikidata, this tag is still incomplete, as it is present in just 5.83% of *exhibit=** features and 5.12% of *tourism=artwork* features.

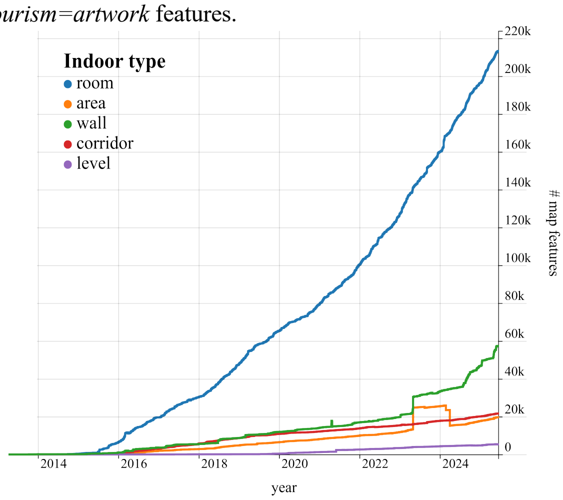

Figure 1. OSM tag history for different combinations of values of *indoor=**, as documented in June 2025.

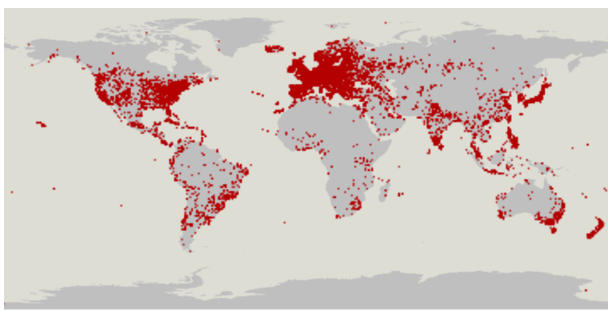

Figure 2. Geographical distribution of the *indoor=** key as documented by the OSM taginfo stats tool in June 2025.

A more detailed overview of the current status of OSM-Wikidata linkage is provided by analysing distinctly the documentation of statues, painting and sculptures in both collaborative projects, evaluating the data completeness of the Wikidata properties *P11693*, which geolocate an entity at OSM-object level through its id, and *P276*, that associate a less-detailed location (e.g. city, museum name, room) to the artwork. The graph in Figure 3 highlights the incompleteness of high-detailed linkage in both projects, despite the generic location properties is widely adopted for statues and sculptures in Wikidata.

The complexity to be addressed in the current indoor POI mapping schema is particularly associated with paintings. This is the typology with the lowest percentage of OSM node property completeness (0.01%), as well as the rarest in the examined OSM *artwork type* values. It represents only 0.94% of global tagged features, whereas statues and sculptures account for 27.77% and 41.87% respectively. This underrepresentation may be explained by several factors. As indoor, wall-mounted objects, paintings often do not possess a permanent physical footprint that lends itself to traditional intuitive geospatial mapping. By contrast, statues and sculptures are usually found in outdoor spaces, where they serve as visible landmarks and are more likely to attract the attention of mappers. Finally, existing geolocating tools are more advanced for outdoor mapping, resulting in less support and mapper engagement for paintings within current mapping workflows for example in GPS denied environments.

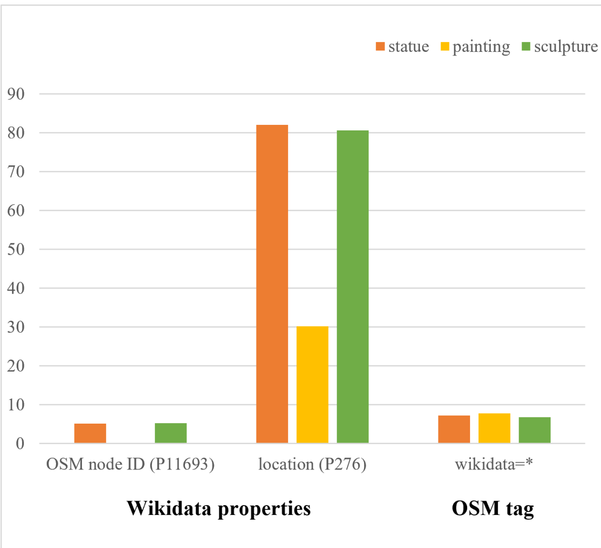

Figure 3. Comparison of the percentage of statues, paintings, and sculptures in Wikidata that are associated with key properties (OSM node ID (*P11693*), location (*P276*)) and linked OpenStreetMap elements (via *wikidata=** tag) as retrieved in June 2025.

However, the ontological structure of Wikidata – capable of tracking multiple changes of location over time – and the constant updating of OSM by a community increasingly focused on micro-mapping cultural elements can help to overcome the current limitations in data completeness. The combination of the two platforms offers a flexible infrastructure for integrating semantic and spatial information, even for complex objects such as paintings. Furthermore, the spread of simplified exploration and editing tools, equipped with more intuitive and engaging graphical interfaces for non-expert users, can encourage greater participation (Figure 4).

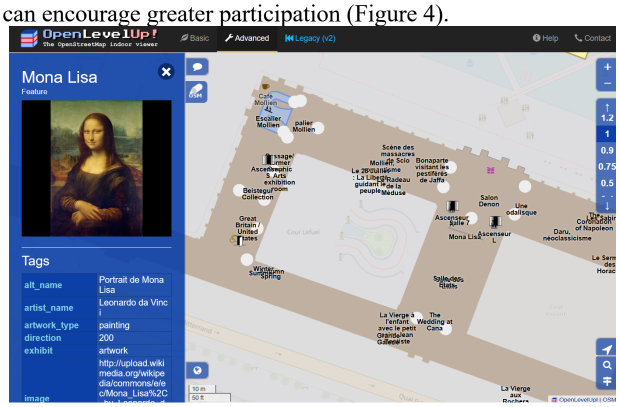

Figure 4. OpenLevelUp! view showing the location of Mona Lisa painting within the Salle des États at the Louvre Museum, Paris. The artwork is represented as a georeferenced point linked to its Wikidata entity in a 2D representation.

Despite current limitations, this integration framework offers key advantages for cultural heritage applications. Moreover, the *wikidata=** tag enables citizen science scalability, allowing crowdsourced corrections and enrichment of georeferenced cultural heritage data. Combined OSM–Wikidata queries support multi-modal discovery or tour path planning, helping users find artworks by both spatial location and semantic properties. The linkage between OSM location-based features and Wikidata entities also facilitates interoperability with digital tools such as Augmented Reality applications, and cultural heritage dashboards, for both research and tourism purposes.

3. Methodology

The proposed approach for testing the Wikidata-OSM integration in a single simple application follows three main steps to develop an interactive 3D virtual tour enriched with linked open data, as illustrated in Figure 5.

During the **data population** and update phase, the existing indoor mapping of the site on OSM is assessed and updated if necessary. As a preliminary step, an overview of the current state of indoor mapping and Wikidata tagging within the OSM ecosystem is provided to contextualise the application. Updating involves adopting a wide variety of techniques with different levels of detail and complexity. Indeed, this can involve in-situ measurements using laser distance meters, scanning and digitising floor plans, and enriching linked Wikidata entities using bulk imports such as QuickStatements, as well as related Wikimedia Commons objects, under relevant copyright and licensing requirements. Indoor mapping is performed in JOSM (Java-based OpenStreetMap editor), which provides a GIS-like user interface and allows for advanced, detailed tagging of map features, as well as visualisation of vector files and georeferencing of rasters for digitisation. For beginner mappers, a more simplified way to contribute is to use indoor-specific browser editors developed by the OSM community, such as OsmInEdit or MapComplete's interior theme editor. The latter provides a particularly user-friendly interface that allows you to seamlessly search for an object in Wikidata and link it to the correct item with a simple click once it has been selected. In all editing environments, indoor rooms and spaces are documented in accordance with the current de facto schema for rooms, walls, doors and indoor features.

The next step is to crowdsource the **processing of geodata** for preparing a 3D virtual tour. The QuickOSM plugin in QGIS is used to extract the indoor OSM-tagged features, ensuring that

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only the necessary elements, such as rooms, walls, doors, and indoor POIs (*indoor=yes* AND *exhibit* not null), are included in the dataset. This simplifies querying elements using an easy-to-use interface that builds queries through the Overpass API. Geometry and topology consistency checks are automatically performed using a PyQGIS script developed within the Model Designer tool. This script detects and corrects common issues such as overlapping geometry or misaligned features, ensuring the dataset is ready for visualisation. Once validated, the data is used to generate and style a 3D scene with the Qgis2threejs plugin. This allows 2D indoor geospatial features to be transformed into interactive 2.5D features, and the resulting scene can be exported as a 3D model in .gltf or .glb formats. This series of processing and export steps ensures the production of simplified geometric output that can be easily rendered using WebGL technologies or game engines.

To prepare for the **deployment of the virtual tour**, the Qgis2threejs output is customised to provide a lightweight yet immersive visualisation of the indoor environment. This output is then enhanced with semantic pop-ups that display information linked to Wikidata (e.g. title, author, image, material, and dimensions), which is defined using JavaScript functions and a Wikidata API request. This establishes a real-time connection to the Wiki knowledge graph, ensuring that any new edits made to the rendered elements on Wikidata are automatically updated in the associated informative pop-up. Finally, the interactive 3D indoor scene is published on the web using GitHub Pages, providing access via a direct link to all users.

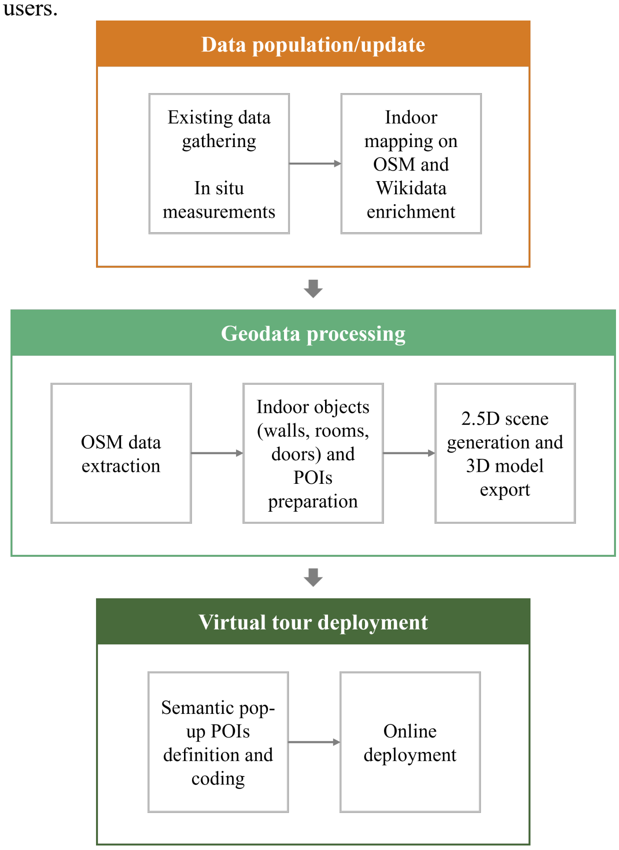

Figure 5. Workflow for creating an interactive virtual tour of a cultural building. The process involves three main stages.

4. Results and Discussion

The described methodology is applied to the case study of the Egyptian Museum; an archaeological museum specialized in Egyptian antiquities located in Torino (Italy). The interior of the multi-story building was first mapped in 2019 with OsmInEdit as part of a local community mapping event called *mapathon*. However, its geometry and tagging have been constantly updated for the following years, as documented in the version tracking of OSM. For this study, the objects were preliminary evaluated and updated in order to check consistency with the SIT schema and last version of approved *wikidata* tags in OSM. An area of particular interest in this museum is represented by the Gallery of Kings located on the ground floor of the site and consisting of two main rooms interconnected by short corridors. This section of the building houses a collection of Egyptian sculptures and statues, the images of which have recently been released under Creative Commons licences as part of a joint project between the museum, Creative Commons Italia, and Wikimedia Italia (Wikimedia Italia, 2023). This has not only enriched the Wikimedia Commons database but also allowed each image to be univocally linked to the corresponding item in Wikidata, thus reconstructing metadata consistent with the museum archive.

Then, querying the OSM database allowed to download such indoor elements in an ordered data structure in QGIS environment where the tagging information can be explored through the attribute tables of each indoor geometry, either rooms or POIs. Table 2 illustrates examples of tag combination for the analysed indoor features.

Element	Key	Value
room	*indoor*	room
	level	0
	room	gallery
	access	customers
	name	Galleria dei Re
	name:en	Gallery of the Kings
	wheelchair	yes
	wikidata	Q115898888
artwork	*exhibit*	artwork
	indoor	yes
	level	0
	material	stone
	artwork_type	statue
	name	Statua di Seti II
	name:en	Statue of Sety II
	wikidata	Q117394566
	direction	120

Table 2. List of common tag combinations for indoor elements in OSM environment. The given examples highlight how tags associated with OSM polygons or nodes can enrich the 2D/3D cartographic representation of a site with useful information for visitors, such as wheelchair accessibility, as well as for researchers interested in adding a spatial dimension to their artwork archives.

The QuickOSM query for the entire museum resulted in the download of 50 rooms and 30 sub-room areas connected by 12 passages defined by 42 doors/openings, mapped according to the OSM indoor schema. Regarding the artworks exhibited in the museum, a total of 58 items were downloaded, including 44 statues, 7 sculptures and 3 murals.

The downloaded data was then processed with the PyQGIS script, resulting in 2 layers of room perimeters with related openings and artworks for each documented level of the building. Accordingly, such layers were styled inside the Qgis2threejs preview 3D viewer, creating distinct outputs for each level of the case study building. A graphical example of output of the process is illustrated in Figure 6, focusing on the ground floor, being the museum level with the highest number of artworks mapped in OSM.

Custom styling – like colours and Z-extrusions for 2.5 D modelling - is then applied to differentiate elements and enhance user navigation within the virtual space. At this point, the plugin allows to export both the underlying files (HTML, CSS, JS scripts) ready to be used for deploying a web page as well as a solid model in glb or gltf whose appearance and geometry depends on the styling and overlaying strategy chosen in the QGIS project and on the settings defined in Qgis2threejs.

The exported code of the viewer was improved with a custom JavaScript function for enabling interactive exploration of Wikidata properties of artworks, dynamically parsed through API (Figure 7). The prototyped example in particular integrates the possibility to visualise with a pop-up a Wikimedia Commons image that a Wikidata user has previously linked to the selected artworks mapped in OpenStreetMap. However, thanks to the population of the *wikidata* tag associated to the given object, any documented Wikidata properties for such linked item could be retrieved and called in the Graphic User Interface of the developed application.

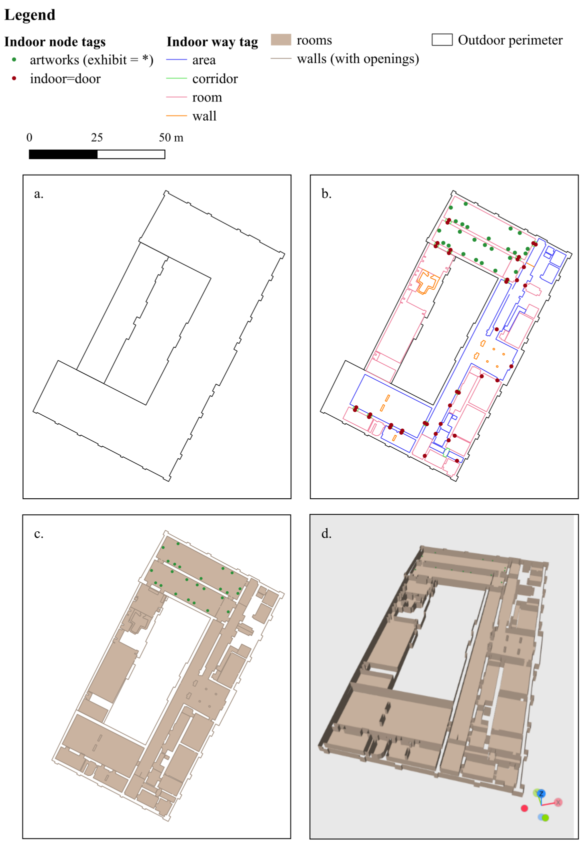

Figure 6. Case studies modelling: (a) building footprints on OSM, (b) on OSM after the update with indoor feature mapping, (c) on QGIS after processing for visualization, d) on qgis2threejs with extruded features.

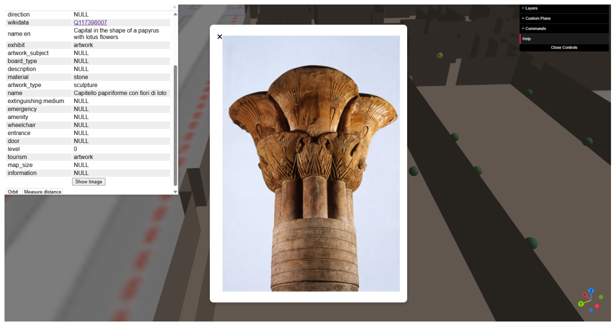

Figure 7. Information pop-up for a given artwork, activated after clicking on the 3D element. It includes tags from OSM and allows dynamic parsing of semantic information from the Wikidata API.

Hosted on GitHub Pages, the developed code is then accessible as the result of a fully open-source pipeline that explores the potential of crowdsourced data gathering in simplified 3D modelling of virtual experience (Figure 8). Unlike existing approaches, this low-coded method provides an interactive 3D representation of indoor spaces while minimizing unnecessary web data requests and avoiding redundant data in the scene. However, it aims also at offering a rapid approach to build a starting point for a more advanced interactive experience that could be further improved with dedicated Three.JS coding.

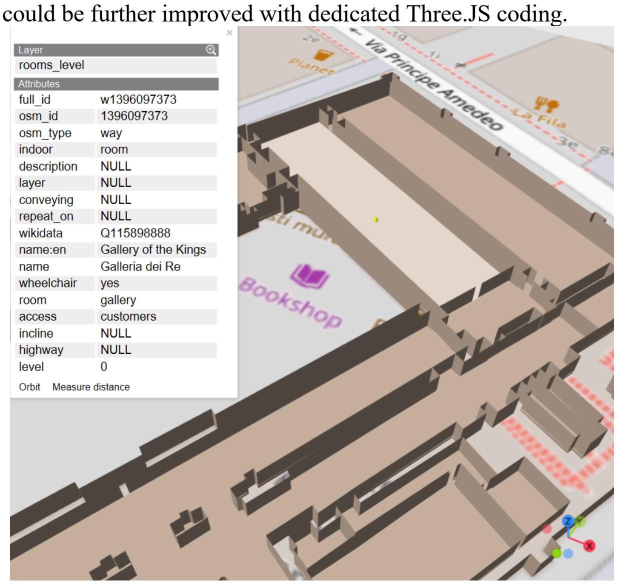

Figure 8. Sidebar displaying details of the explored museum room.

The exported .glb/.gltf model, instead, can be easily imported in more advanced modelling software or game engines for building complex and engaging virtual or augmented reality experiences straight from real-world data, adding animations or physics to the OSM-derived scene (Figure 9). These environments when supporting Wikidata API real-time requests in the scene can represent a gamified digital twinning approach to the CH site exploration built on open data, transparency and community engagement (Luther et al., 2023, Ham & Kim, 2020, Niccolucci & Felicetti, 2024).

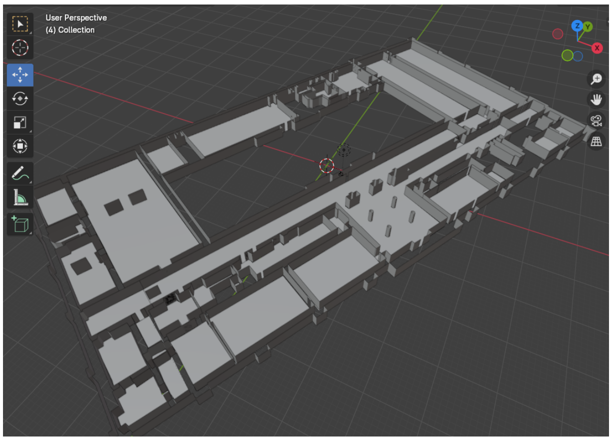

Figure 9. Example of model import in Blender with the ground floor plan data from the case study.

5. Conclusions

The prototype developed in this study provides a straightforward illustration of how open data from Wikidata and OSM can be combined to create an interactive virtual experience in just a few steps. This lightweight and accessible process is especially suitable for small museums and cultural institutions that lack the resources for more complex digitalisation projects. Built entirely on open-source tools, the workflow remains highly adaptable: the resulting virtual environment can be further customised or exported for use in advanced 3D modelling software such as Blender or integrated +more immersive and interactive experiences (Schatten et al., 2020). However, this approach's real strength lies in the way it brings together the spatial detail of OSM and the semantic richness of Wikidata. This integration lays the groundwork for cultural heritage research and interactive engagement with interconnected data. By linking geospatial information with structured semantic knowledge, it becomes possible to reconstruct the physical layout of a site and the evolving history of its documentation. Both OSM and Wikidata maintain transparent records of every edit and change, enabling users to trace the development of a digital object over time, whether that involves updates to its location, attributes, references or licences. That said, one current limitation is the instability of OSM features, which may change geometry over time and therefore lack persistent identifiers or consistent spatial references. This can hinder the long-term reliability of virtual reconstructions. However, this issue can be mitigated by promoting careful mapping practices that are aware of this limitation and aim to maintain stable geometry for key features.

Additionally, as tagging practices in OSM become more comprehensive, the current tendency to simplify geometries can be overcome by leveraging tags commonly used in outdoor 3D building renderings to enrich and make them more detailed. For instance, attributes such as *height=**, *min_height=** or *building:colour=** could provide valuable data to improve the realism and complexity of 3D representations in virtual environments, as demonstrated for outdoor buildings rendering with tools like F4 Map.

Furthermore, using Wikidata's linkage properties ensures that each digital element can be connected to national authoritative catalogues and external databases. This provides an additional layer of reliability and scholarly value, as every item in the virtual tour can be traced back to its original sources and supporting documentation. The open, collaborative nature of both platforms also encourages participation from a wide range of contributors, fostering a richer and more accurate representation of cultural heritage assets while at the same time a greater level of public engagement and heritage awareness.

All the codes and scripts needed to replicate and adapt this workflow are openly available on GitHub (https://github.com/Tars4815/OSMind-WIKICH). This ensures that the methodology is reproducible and ready to evolve alongside future advancements in OSM's indoor mapping standards or new developments in digital heritage technologies. Future developments will involve exploring the integration of dynamic OSM data extraction directly within the web application to ensure that the virtual experience remains aligned with the latest updates in the online geospatial database.

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