KNOWLEDGE REPRESENTATION OF BUILT HERITAGE MAPPING AN AD HOC DATA MODEL IN OGC STANDARDS: THE CASE STUDY OF PITTI PALACE IN FLORENCE, ITALY

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ABSTRACT:

The description of a historic building can be made by considering many different aspects: stylistic, technological, formal, function-related, etc. In Architecture, as in any artistic form, intangible elements also play an essential role and are closely related to individual interpretation; therefore, achieving an objective description is challenging, and several efforts have been undertaken over time to reach the goal.
Nested hierarchical or complex multi-dimensional relationship structures can be defined to represent various interrelationships between a huge variety of elements and their properties. Categorisation, standards definitions and adoptions, data modelling, etc., should come after the data collection phase to adequately support the sharing of disparate datasets and thus facilitate communication between experts in different domains and improve knowledge dissemination.
The paper considers different approaches in the built heritage representation, then presents the ad *hoc data* model initially adopted in the Pitti Palace documentation project, where a comprehensive and highly detailed 3D digitisation project was recently carried out, and finally proposes to map it into widely adopted standard, such are CityGML and IndoorGML.

1. INTRODUCTION

The description of a historic building can be made by considering many different aspects: stylistic, technological, formal, function-related, etc. In Architecture, as in any artistic form, intangible elements also play an essential role and are closely related to individual interpretation; therefore, achieving an objective description is challenging, and several efforts have been undertaken over time to reach the goal.
Nested hierarchical or complex multi-dimensional relationship structures can be defined to represent various interrelationships between a huge variety of elements and their properties. Categorisation, standards definitions and adoptions, data modelling, etc., must follow the data collection phase to adequately support the sharing of disparate datasets and thus facilitate communication between experts in different domains and improve knowledge dissemination. Transposing studies into digital environments makes it possible to explore new connections between well-established approaches to cataloguing and representations of space, developing synergies and paving the way for the development of digital twins (Grieves and Vickers, 2017), declining the concept of twining not only in terms of visualisation but also in terms of the current or historical functioning of the architecture under consideration. This contribution aims to explore ways to structure data and information that connect the physical and digital twins.
The operational actualization and application of theoretical investigations in this field relies on the accessibility, sharing, and sustainability of data, and thus on embracement of what are called FAIR principles. The following sections consider available standards for historical buildings representation and propose how to overcome some of their limits considering the case study of Pitti Palace in Florence, Italy, where a comprehensive and highly detailed 3D digitisation project was recently carried out.

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2. FROM A PROTO-SPATIAL INVENTORIES AND CATALOGUES TO SPATIAL DATA MODELS

According to the physical characteristics of spaces or logical aspects, different modes of representation of a building can be generated by different subdivision methods (Liu et al., 2013; Meijers et al., 2005). Focusing on physical aspects, a building can be interpreted and therefore described by decomposition, e.g. in building parts, levels, rooms, walls etc.; in the built heritage field, more articulated structures should also be considered, as are intermediate floors, semi-internal or semi-external spaces.
Subdivisions can also take into account logical or functional aspects. In the case of contemporary buildings, reference standards can be profitably applied (IFC, CityGML Building module, IndoorGML, etc.), while historical buildings also suggest (or require) consideration of aspects such as historical designations, past uses and functions, and adaptations and transformations underwent by spaces.

2.1 Raumbuch

The *Raumbuch* (Petzet and Mader, 1993) is a tool for compiling descriptions of the architectural heritage. It allows the referencing of data from various documentary sources with respect to rooms, even when these are not characterised by historical, specific or consolidated use names, also considering that the identification of a room through a toponym should be referred to the chronological dating of the toponym itself (Valli, 2012). The *Raumbuch* can be considered a proto-spatial information system insofar as the referencing takes place according to a topographical logic but not a strictly geometric one: therefore, it makes it possible to contextualise the data considered and to define relations between them also based on spatial aspects. It is especially effective for supporting the study of large architectural structures with complex historical layering, analysing the building with a systematic approach and requiring limited resources. It originated at the end of the 19th century and consists of the progressive disaggregation and

coding of the building into increasingly simple portions until all the spaces and surfaces of each space are identified. The identifying strings corresponding to each element considered are established by the succession of identifying codes arbitrarily defined according to the specificities of the project. Thematic or archive data can thus be referenced with a granularity corresponding to the scales of analysis appropriate from time to time.
The coding system thus makes it possible to describe the building in a capillary manner and the constitution of a structure for the collection of the various knowledge contributions useful for fully representing the building, their archiving and eventual implementation (Del Curto, 2007).
Although this system is often referred to as focusing on the spatial organisation of digital data (Muenster, 2022), the differences to a geometrically based information system are plain to see: in the latter geometric, topological and thematic properties are expected to be recorded and managed at the same time and therefore an accurate metric reference (2D or 3D) is needed (Métral et al., 2009; Anselin, 1989). (Stadler and Kolbe, 2007) also propose to consider the degree of similarity of both the semantic and spatial subdivisions (spatial-semantic coherence).
Recent applications of the *Raumbuch* have primarily proposed the digital implementation of the system through the creation of databases (Heine et al., 2006). The limitations highlighted with respect to geometric and spatial aspects can instead be overcome by associating the digital inventory with an HBIM (Fiorino et al., 2017; Agus and Fiorino, 2021) or by applying the logical scheme to a real spatial information system (Cinquantaquattro et al., 2013). However, the *Raumbuch* offers interesting possibilities for the management of the information gathered during a survey campaign, when graphic and geometric support is not yet available: the intended adoption of open series of codes makes it possible to add information as the work deepens progressively and the massive amount of information acquired during the study of a historical building gradually begins to stratify itself within a system of logical references, in which the collected data ensemble reaches a greater significance than a simple sequence or accumulation (Del Curto and Grimoldi, 2010).

2.2 Spatial data models

The standard data models developed for documenting the urban environment and built heritage (IFC, CityGML, IndoorGML, etc.) already present structures combining semantics, geometry and topology. These play a fundamental role in the knowledge and conservation of cultural heritage, as they allow the creation of structured and interoperable information since the rules adopted to structure data, both thematic and spatial, are known and explicit. Moreover, these standards are potentially extensible, as they provide normalised mechanisms to extend the representation of what we want to describe through applications domain extensions (ADE). (Colucci et al., 2020; Noardo, 2018).

2.2.1 From territorial to urban to architectural scale: Focusing on geographic domain ontologies, the INSPIRE standard must be considered (INSPIRE, 2014). The primary objective of the European directive INSPIRE (Infrastructure for spatial information in Europe) (INSPIRE 2007) was to ensure the coherent and homogeneous representation of cross-border data in order to support common environmental policies in Europe.
Moving to the urban level of detail, CityGML, published by the Open Geospatial Consortium (OGC), and recently updated (Kolbe et al., 2021), is probably the most widely used international standard data model for the representation of multiscale 3D information about cities.
Both INSPIRE and CityGML are compliant with the ISO/TC211 standard on the management of geographic and spatial information, and both involve the use of GML (Geographic Mark-up Language). The INSPIRE data model (INSPIRE DM) is based on the CityGML data specification for the *Building* theme (INSPIRE BU) (INSPIRE, 2014) and, although not completely compatible with each other due to the application of some modifications and simplifications, the two still aim to represent a common data frame, regardless of any specific application for which they may be used.
The extension of the INSPIRE data model with the *Protected Sites* class has been proposed (Fernández-Freire et al., 2013; Chiabrando et al., 2018) to take into account historic sites and buildings. For CityGML, on the other hand (Noardo, 2018) and (Gkadolou et al. 2020) developed ADEs to consider specific aspects related to building heritage management.
In the field of cultural heritage, the need for multiscale approaches is particularly relevant, as is the case with “composite sites” or diffuse heritage (Bonfanti et al., 2021), where the studies require seamless focusing up and down from the geographical scale to the site scale, to the artefact scale. The connection, integration and extension of available spatial ontologies would allow the recognition of historical monuments, the identification of parts of buildings and cities, the extraction of different information, and so on.

2.2.2 From the building to the room scale: Moving up to the architectural scale, data models commonly used to describe buildings were developed in Building Information Modelling (BIM) and Geographic Information Systems (GIS) in the early 2000s. The Industry Foundation Classes (IFC) from Building SMART International (Building SMART International, 2013) for BIM and the *Building* LoD 4 module of CityGML for GIS are the most popular on both sides, combining geometry, semantics and topology (Corongiu, 2021). Furthermore, the OGC introduced IndoorGML (Lee et al., 2020), explicitly dedicated to indoor 3D navigation and introducing the “cellular space” concept. One of the main differences between IndoorGML from other approaches is that it does not focus on building components such as roofs, walls, etc.: it focuses on the spaces themselves, on voids rather than on solids. Here again, IndoorGML can be considered complementary to existing models rather than independent, based on the assumption that their integration can give a synergetic effect. Experiences of mapping between these data models can be found in the literature, such as in (Kim et al., 2021) and (Claridades et al., 2022) which establish correspondences between some of the classes defining spatial elements in the *Building* module of CityGML LoD 4 and in IFC. Considering the interior spaces of the building, the *CellSpace* class defined in IndoorGML can be related to the *Room* class of CityGML or to an *IfcSpace* in IFC.

Figure 1. Pitti Palace, 3D model.

3. PALAZZO PITTI IN FLORENCE: A RESEARCH ROUTE PROPOSAL

Pitti Palace has been the subject of an extensive 3D survey campaign carried out by the Geco Lab of the University of Florence (directed by Prof. Grazia Tucci) as part of an agreement with the Uffizi Galleries (headed by Dr Eike Schmidt), the institution responsible for the maintenance and management of the Palace, as well as the museums housed there. It is an articulated documentation project focused primarily on (but not limited to) 3D digitisation, which took place with a laser scanner and photogrammetric survey of all interior and exterior spaces (Figure 1). On this occasion, non-geometrical aspects were also documented, although relevant according to their spatiality, such as those related to materials, state of preservation, etc. The research project focuses, therefore, on structuring spatial and non-spatial features to effectively produce, maintain, update and enhance the Palace's digital twin to become a powerful tool for analysing and managing the original building, documenting maintenance and conservation works, changes in the use of spaces, and more.

3.1 Previous experiences of spaces categorisation in Pitti Palace

The documentary sources pertaining to Palazzo Pitti are numerous but fragmented, not readily available, and above all, unstructured. For example, multiple identification codes have been attributed to the rooms over time, as various cataloguing and inventory projects have been undertaken in different ways and for various purposes. Most of them, moreover, have been limited, from time to time, to specific areas of the complex, attributing a code only to rooms in certain quarters or to those pertaining to a single museum institution. However, some studies tried to examine the Palace in its entirety, such as (Forlani Conti et al., 1979) titled indeed "The Thousand Rooms of the King" (*Le mille stanze del Re*) or, more distant in time, the eighteenth-century *cabrei* specifying the name and code numbering of each room. Moreover, only the recent survey campaign has given an account of all the rooms in the Palace, documenting more than 1,500 rooms of various types, as described below.

3.2 Preliminary considerations on Pitti Palace data structure

The long history of the palace and the succession of different uses led to continuous transformations, which were necessarily followed by as many changes in the designations of the building bodies, apartments and rooms. This is an example of possible spatial decomposition of the building, which is quite effective when considered for its original residential functions. Viewing their contemporary uses instead, the rooms could be aggregated with respect to offices, museums or other institutions currently active in the building. In both cases, however, it is not always possible to define unambiguous relationships between all the rooms and the corresponding macro-areas (or however one wishes to express their clusterings). The need to unambiguously identify the spaces, define the relationships between them and make it possible to link the data gradually collected to them became evident since the very beginning of the 3D digitisation project. The survey campaign of such a large and articulated complex cannot be considered as the summation of a series of data as they are produced. Still, it is an articulated activity process that can also occur in parallel, in different parts of the building, by different teams. Moreover, the intention to go beyond the one-off production of 3D documentation of the building is still emphasised, with the goal of supporting a true digital twin and thus documenting the twinning process itself to enable the qualification of the results obtained and their integration and updating over time.

Faced with the extent of the building and the heterogeneity of the actors involved in the management and current use of the complex, the possibility of uniquely identifying a room by referring only to toponyms, now considered in everyday use, was deemed ineffective. In fact, some of them refer, from time to time, to their more remote (Queen's Bedroom – *Camera della Regina*) or more recent uses (Superintendence Archive – *Archivio della Soprintendenza*) or the decorations or objects contained therein (Room of Saturn – *Sala di Saturno*).

At the same time, the pressing need for a quick start-up of field survey operations made it necessary to postpone the design of a more complex data structure to a later phase of studies. Moreover, the operating rapidity allowed by technologies such as laser scanning and digital photogrammetry entails recording huge amounts of data in a very short time, which nevertheless imposed the need to define criteria for organizing and storing the spatial and non-spatial data as they were captured.

The data model initially adopted to store the 3D survey information for the Pitti Palace is independent of existing standards, as it is closely related to the survey and documentation processes. Firstly, the level of detail considered as suitable was defined to allow punctual references to all recorded data, ensuring the usability and effectiveness of the system. The "room," in its broadest meaning, was considered the minimum spatial unit adopted to structure the information during the 3D survey. The coding adopted also takes into account the storey of the building at which each room is located, although this cannot really be considered an unambiguous regrouping of rooms due to the variations in elevation between one building body and another, the presence of double-height rooms, the extrados spaces of the vaults, and in general the articulated conformation of the building. Spatial and functional re-groupings of the rooms were conceived as described in the following section.

For each room, openings were also considered, which were classified according to the articulated variety present in the Pitti Palace: through openings, plugged, coated (by tapestries), faux, etc. Finally, a system of classification of windows and doors, which in some cases may be numerous (e.g., interior shutters, double-glazed sashes, shutters), was prepared for each opening.

The goal of the work (still in progress) is a timely assessment of the mapping possibilities between the data model defined *ad hoc* for this case study versus existing standards to potentially enable the connection of the collected documentation with a more extensive data network, making sure that the data can be easily shared and usable in broader contexts.

3.3 Logical and functional classifications of the spaces in the Pitti Palace

Interior space can be subdivided according to different approaches, either by identifying structural components (e.g., walls or doors) or according to human perception (e.g., an exhibition area) (Liu et al., 2019). It is possible to refer to physical or logical/functional characteristics of spaces, depending on which different ways of representing a building can be generated through various subdivision methods (Liu et al., 2013; Meijers et al., 2005). This twofold nature in space characterization (thus leading to different classification schemes) not being unique affects interoperability between data models. In fact, how one chooses to divide a building into smaller parts can affect the complexity of data transformation between models and standards (Eriksson et al., 2018).

Revisions to CityGML version 3.0 introduced a new concept of space (Kutzner et al., 2020) that considers this dual concept, defining the distinction between physical and logical spaces, also called abstract spaces. Physical objects completely or partially delimit physical spaces; this is the case with the classes *Building* or *Room* as spaces delimited by walls, floors etc. On the contrary, logical spaces are not necessarily bounded by physical objects but are defined based on thematic constraints. Depending on the application, logical spaces may be delimited by nonphysical/virtual boundaries and represented as aggregations of physical spaces. Examples are the *Storey* or *BuildingUnit* classes - subclasses of *AbstractBuildingSubdivision* - that represent logical spaces as they aggregate specific rooms into floors and apartments. Rooms are the physical spaces that are bounded by wall surfaces, while the aggregation as a whole is bounded by a virtual boundary. In the literature, it is possible to find many references inherent to the concept of logical space; this turns out to be fundamental, for example, for cadastral purposes, notably to support the representation of non-spatial concepts and components, as required by the Land Administration Domain Model (LADM) standard, such as parcels, administrative units, to express ownership and use rights, etc. (Saeidian et al., 2022; Eriksson et al., 2018; Alattas et al., 2018; Alattas et al., 2017; Zlatanova et al., 2016). Similarly, in the domain of the representation of the historic built heritage, logical spaces are indispensable for the organization of all those non-tangible aspects that define spaces, such as the description of elements that are not referable to the single room but concern homogeneous sectors in their entirety. In the case of the Pitti Palace, therefore, examples of logical spaces are:

- apartments and quarters, such as the *Quartiere d’Inverno*, on the second noble floor;
- areas affected, in the past, by renovations and, sometimes, changes in function, such as the *Quartiere del Principe di Napoli* (on the mezzanine between the second and third noble floors, in spaces previously used as service rooms);
- aggregations of courtly and service rooms with a common destination (e.g., museum – Pitti Palace now houses five museums).
- some of the stairwells, which, in addition to ramps and landings, sometimes include small under-stair rooms and spaces above vaults (e.g., the Ammannati stairway).

4. ATTEMPT TO APPLY CITYGML AND INDOORGML TO THE REPRESENTATION OF PITTI PALACE SPACES

In the following, we take the CityGML 3.0 data model, particularly with regard to its thematic extension module Building (Kolbe et al., 2021) and the IndoorGML data model (Lee et al., 2020), as a reference and analyze their applicability to the spaces of Pitti Palace, considering the physical and logical aspects of the spaces and how these affected data collection during the survey campaign (Table 1). The subdivision of spaces - and thus their interpretation - in some cases was not possible *a priori* but required considerations and evaluations possible only when faced with the digital model resulting from the survey. Thus, the chicken-and-egg problem in identifying priorities, both conceptual and operational, between "knowing" and "surveying" is confirmed to be topical, albeit renewed in terms.

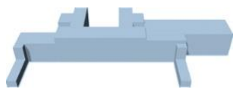
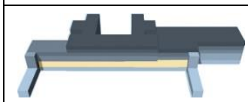
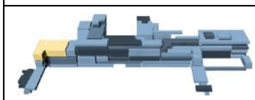
Pitti	CityGML
	*Building*
 *Meridiana, South Wing, North Wing, Central Part, Rondos*	*BuildingPart*
 *S1, 00, 00R, 01, 11, 11M, 12, 22, 23, 33, 33T*	*Storey*
 *by Denomination, by Function, by Preservation Authority*	*BuildingUnit*
	*Room*

Table 1. Comparison between the spatial feature classes of the Building module LoD 4 of CityGML and the spatial elements of the Pitti Palace.

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4.1 CityGML

***BuildingPart* class:** A *BuildingPart* is a physical or functional subdivision of a building. It would be considered a building, if it were not part of a collection of other *BuildingParts*. As physical subdivision it refers to spaces that are fully or partially bounded by physical objects. Therefore, to subdivide Pitti Palace according to physical aspects, it is possible to identify as *BuildingPart* the set of various rooms grouped to form a separate building organism: the central body, the two wings, the *Palazzina della Meridiana*, the two Rondos, etc. Among the logical aspects that can be taken into account in this case study are those related to the building's construction phases. However, the inevitable uncertainty arising from the need to interpret heterogeneous and not immediately referable historiographical sources must be kept in mind. In this sense, the original fifteenth-century core of the Palace, contained in the outline of the larger central body, can belong to the *BuildingPart* class.

***Storey* class:** In architecture, a traditional subdivision of built volumes is based on floors. In the Pitti Palace, the presence of intermediate levels and especially the complex spatial articulation of rooms with different heights, often the result of successive building transformations, do not allow easy identification of homogeneous levels. In this case, homogeneous levels are intended to be those that group rooms with floors at similar heights and allow them to be walked through with continuity, eventually passing a few steps. Moreover, this criterion has always been adopted for drawing 2D plans of buildings. One of the Pitti Palace digitization project's priority objectives was the drawing of plans and sections. The graphic restitution in coherent plans, as defined above, of all the rooms of the Palace was completed in 11 drawings (in addition to one for the roofs). The attribution to a specific level of the main rooms on the noble floor and many of those on the mezzanines was not problematic. Still, for many other rooms (particularly double volumes, mezzanines, understairs, etc.), it was impossible to identify the level at which the representation was most appropriate until the entire 3D model surveyed by laser scanner had been available. In this case, the viewpoint can virtually exit the building and simultaneously assess the elevation position of noncontiguous spaces. Moreover, the conceptual model of CityGML 3.0 in the definition of the *Storey* class specifies that a floor is generally a horizontal section of a building but also that they are not always defined according to the structure of the building itself and, if needed, defined according to logical considerations. The case of the Pitti Palace highlights how in complex buildings, consisting of parts built in different periods and that have undergone numerous changes over time, it is not easy (if not impossible) to define *a priori* the structure of the levels, which in the Palace were in fact determined according to logical considerations, possible only as a result of the three-dimensional survey.

BuildingUnit* class*: The CityGML 3.0 specification defines *BuildingUnit* as a logical subdivision of a *Building* based on some homogeneous property such as function, ownership, management, or accessibility. The complex functional stratifications that have occurred over time in Pitti Palace make it difficult to unambiguously identify the *BuildingUnit* class, with similar considerations to those presented for the *Storey* class - although in that case, the complexity of the building was considered from a spatial point of view and now it is considered from a logical point of view.
As far as the *BuildingUnit* class is concerned, the first evidence found in Palazzo Pitti is that it is not possible to identify a correspondence between zone designations (*BuildingUnit by Denomination*), zones that can be classified according to a specific function (*BuildingUnit by Function*), and zones pertaining to one of the different museums (*BuildingUnit by PreservationAuthority*). For example, the zone that is identifiable under the authority of the Palatine Gallery includes within it zones with other functions (exhibition, administrative, etc.); at the same time, the opposite is also possible, i.e., that a zone classified according to its functional characteristic is managed by a different museum (e.g., a storage facility shared between various museums). The intent to adopt *BuildingUnit by Denomination* also clashes with the fact that the building blocks, quarters, and apartments have been named differently over time.

4.2 CityGML - *Room* class and IndoorGML – *CellSpace* class

Defining an appropriate data structure appeared essential from the beginning of the Pitti Palace 3D digitisation project: the needs at that time were, in fact, to plan the control network, to define the areas to be surveyed day by day, also in function of the access possibilities to be agreed upon with the management, to organise the storage of the raw data and to prepare that of all the subsequent processing steps. The relationships between spaces inevitably had to be considered in an approximate way - precisely because their knowledge would be built up progressively during the 3D survey itself. At the same time, however, it was necessary to consider data typical of the digitisation project and their relationships, such as topographic-target vertices, scans-targets, subprojects of 3D scans, photogrammetric flight-target, etc. It is important to emphasise that during the field acquisition phase, the recorded spatial data are accompanied by numerous attributes, as the validity of the entire process also relies on appropriate metadata.
Given the limitations highlighted in the previous paragraphs by the CityGML classes and the need to proceed quickly with the field measurement campaigns, a "minimum spatial unit" was identified to simplify the spatial aspects of the *ad hoc* data structure used. In the specific case of Pitti Palace survey, spatial and thematic data were then referred to three different spatial types: *Room*, *VerticalPenetration* and *OpenSpace*.
All three can be considered as corresponding to Indoor Subspaces (and more in detail to *Static Partitions*) (Zlatanova et al., 2014) and the concept of cellular space used in the IndoorGML standard. Their mapping in CityGML could instead lead to the *Room* class, but their re-aggregation into a single class obviously involves a generalisation process and, thus, simplification. It seemed therefore more appropriate to individuate mapping criteria to IndoorGML, where first-level semantics distinguishes *NavigableSpace* (rooms, corridors, doors) and *NonNavigableSpace* (walls, obstacles). *NavigableSpaces* are those used to define the navigation network and are further specialised into *GeneralSpace* (e.g. ordinary rooms), *ConnectionSpace* (e.g. openings) and *TransitionSpace* (e.g. corridors). *GeneralSpaces* are the spaces in which people stay, and *TransitionSpaces* are those people use to move from one *GeneralSpace* to another.
For the vast majority, cells classified as *Rooms* can be mapped with the *GeneralSpace* class, except for corridors and vestibules, which will have to be considered as belonging to the *TransitionSpace* class, such as *HorizontalTransition* (Table 2). Some situations, such as the rooms of the Royal Apartments, are currently for museum use but historically with different functions (kitchens, bathrooms, bedrooms, etc.) - as is the case with the King's Bath (*Bagno del Re*) (Table 2, img. 2) - can be well described through the use of function and usage attributes, already normalised in the IndoorGML model, or through the

Pitti	**IndoorGML**
 **1.** Sala della Stufa  **2.** Bagno del Re  **3.** Galleria del Poccetti  **4.** Corridor	
<Room> *<MuseumGallery>* *<StorageRoom>* *<GuardStation>* *<…>* **(1;2;3)** →	*<NavigableSpace>* *<GeneralSpace>* *<MuseumSpace>* *<StorageSpace>* *<FacilityServiceSpace>* *<…>*
<Corridor> **(4)** → *<Vestibule>*	*<NavigableSpace>* *<TransferSpace>* *<TransitionSpace>* *<HorizontalTransition>*

Table 2. Correspondence between *Room* class defined for Palazzo Pitti and IndoorGML: *MuseumGallery, StorageSpace, GuardStation, etc.* as *GeneralSpace* (*MuseumSpace, StorageSpace, FacilityServiceSpace, etc.*) and *Corridor* and *Vestibule* as *TransitionSpace* (*HorizontalTransition*).

Pitti	**IndoorGML**
 **1.** Scalone del Poccianti  **2.** Stairway  **3.** Cavity	
<VerticalPenetration>	
<Stairway> **(1;2)** → *<ElevatorShaft>*	*<NavigableSpace>* *<TransferSpace>* *<TransitionSpace>* *<VertcalTransition>*
<Cavity> **(3)** →	*<NonNavigableSpace>*

Table 3. Correspondence between the *VerticalPenetration* class defined for Palazzo Pitti and IndoorGML: *Stairway* and *Elevator Shaft* as *TransitionSpace* (*VerticalTransition*) and *Cavity* as *NonNavigableSpace*.

definition of new “DataTypes” for the management of more complex attributes. However, some distinctive situations present ambiguities that require further investigation. It is the case with the classification of some courtly rooms originally intended for passage (*Cell*, *NavigableSpace*, *TransferSpace*, *TransitionSpace*, *Horizontal* or *VerticalTransition*) but used as museum galleries (*Cell*, *NavigableSpace*, *GeneralSpace*, *MuseumSpace*), such as the *Andito degli Angiolini* and the *Galleria del Poccetti* (Table 2, img. 3). Similar considerations can be made for monumental staircases (Table 3, img. 1).
Volumes intersecting multiple building levels and having a building or system distribution function, such as *Stairway*, *ElevatorShaft*, *Cavity*, *HVACshafts*, have been classified as *VerticalPenetration*. To align with the structure of IndoorGML, the *Stairway* and *ElevatorShafts* will have to be classified as *VerticalTransition* (thus under the *Cell*, *NavigableSpace*, *TransferSpace*, *TransitionSpace*, *VerticalTransition* hierarchy); as for the *Cavities*, i.e., generally intercluded spaces, in the IndoorGML model, which focuses on navigation, they would be classified simply as *NonNavigableSpace*s (Table 3).
OpenSpace has been used to classify spaces that are not fully enclosed but nevertheless spatially defined, such as courtyards, balconies or loggias. In future developments, it will be possible to specify further the cells classified as *OpenSpace*, aligning with the spatial definition structure proposed by (Yan et al., 2019), which includes a distinction between semi-interior spaces (*sI-space*), such as loggias, and semi-exterior spaces (*sO-space*), such as courtyards.

5. CONCLUSIONS AND PERSPECTIVES

Standards for documentation play a fundamental role in the knowledge, preservation and valorization of cultural heritage, as they allow for creating structured, interoperable and understandable information for experts in different domains, given that the rules used for cataloguing are known and explicit. A detailed evaluation of the mapping possibilities between the data model specifically defined for the case study of Pitti Palace to existing standards will allow the collected documentation to enter a wider data network, making the collected data easily shareable and usable in a global context. A summary description of the data model defined *ad hoc* in the early stages of the Pitti Palace 3D digitization project is presented, along with preliminary considerations to enable its mapping to widespread standards such as CityGML and IndoorGML. The intent to move toward standards that facilitate sharing and support data reuse steered the decision to first translate the data structure used for Palazzo Pitti using controlled vocabularies (The Art & Architecture Thesaurus – AAT) (Getty Vocabulary, 2017) and classification system (OmniClass) (CSI, 2014).
Reference to available standards in defining a data structure for the representation, organization, and querying of spatial data and related attributes requires further investigation, most notably concerning:
- Defining a "proto-spatial" data structure at the time when the survey is not yet available, but it is necessary to store and manage the data collected in the field also with respect to spatial aspects;

- Management of the temporal dimension, both with respect to the past (e.g., for the management of different designations given to parts of a building or its transformations) and to the future (predisposition to updates of spatial and functional aspects);
- Possibility to thoroughly transpose IndoorGML to contexts related to the historic built heritage, defining possible integration to the standard.

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