ANALYSIS OF THE SPATIAL-SEMANTIC COHERENCE IN THE GETTY AAT VOCABULARY DATA STRUCTURE - AN EDUCATIONAL EXPERIENCE

V. Bonora[1], A. Meucci[1], L. Fiorini[1-2]

[1] GeCo Lab, Dept. of Civil and Environmental Engineering, University of Florence, Via di S. Marta, 3 - 50139 Firenze, Italy
(valentina.bonora, adele.meucci, lidia.fiorini)@unifi.it
[2] La Sapienza University of Rome, P.le A. Moro, 5, 00185 Rome, Italy

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Abstract

The paper explores the integration of Geomatics and architectural surveying into the educational context of Geomatic for Built Heritage Conservation course within the Master on Architectural Design, in which a multidisciplinary teaching approach is applied, emphasizing the importance of holistic knowledge encompassing historical, geometric, material, and structural aspects for the conservation and restoration of architectural heritage.
A central theme is the role of Geomatics and 3D modelling in historical built heritage documentation, assuming the creation of three-dimensional models as a foundation for integrating various thematic data, enabling interdisciplinary studies, and facilitating knowledge representation and communication.
The paper delves into the challenges and strategies of semantic 3D modelling. It discusses the necessity for a flexible and layered informational model, integrating spatial, geometric, and semantic data. The complexity of semantic annotation is explored, considering the subjectivity and cultural context inherent in identifying and describing architectural elements. The educational approach employed in fostering critical thinking among students, particularly in interpreting cultural heritage issues related to documentation and recording, is presented.
A case study involving Pitti Palace in Florence is considered. An attempt to implement the Getty Vocabulary on Art & Architecture Thesaurus for semantic annotation is described, emphasizing the need for a coherent alignment between the 3D model and controlled vocabulary hierarchy. The study concludes with insights from the student's experience, highlighting the difficulties in aligning spatial and semantic elements within existing controlled vocabularies and suggesting avenues for future developments in refining these vocabularies for enhanced spatial-semantic coherence in 3D modelling applications.

1. INTRODUCTION

The paper aims to illustrate part of the experience carried out with the students of the *Restoration Laboratory*, specifically in the *Geomatic for Built Heritage Conservation* course (Master on Architectural Design at the University of Florence, a.y. 2022-2023). The Master's program is open to students from inside and outside the European Union, and the courses are in English.
The *Restoration Laboratory* provides multidisciplinary integrated teaching in *Restoration*, *Static and Stability of Masonry Structures* and *Geomatic for Built Heritage Conservation,* assuming that preservation, protection, and enhancement of architectural heritage require a complete knowledge of the building, the documentation of its complex morphology, its architectural components and all the events related to it. Therefore, the syllabus intends to provide historical-critical and technical-scientific knowledge at an advanced level to introduce students to built heritage conservation, protection and restoration through a well-rounded approach, where historical research, geometric knowledge, building materials, decay analysis, static analysis, etc. are part of a complete single research process.
In this sense, Geomatics and architectural surveying supporting restoration processes not only focus on technological techniques for digitization and reality-based 3D modelling but can be defined as a primary element for enabling awareness of the artefact and supporting its documentation through a digital representation of it, integrating metric, morphological and even thematic data.
Cultural heritage digitization and 3D modelling processes are based mainly on laser scanning and digital photogrammetry techniques to produce complete, detailed, and photorealistic three-dimensional surveys. The three-dimensional models, thus obtained, can be the basis on which to integrate different thematic data and the starting point for developing shared models consisting of various layers of information, opening the way for interdisciplinary studies, representing and communicating knowledge and a method for generating new knowledge as well (Tucci et al., 2017; Muenster et al., 2016).
Documentation has been recognized as a fundamental requirement for cultural heritage to be known, preserved and promoted. Already in the 1964 *Venice Charter*, the need for the development of a clear, rational and standardized, as well as shared terminology and methodology for technologies of interpretation, representation and documentation of existing heritage was emphasized (The Venice Charter, 1964).
Since then, key points regarding the advancement of technologies and documentation and recording strategies have been summarized in numerous international charters, conventions and principles (Haddad et al., 2021). More recently, the updated ICOMOS *Principles for Recording Cultural Heritage* document recalls the notion of recording as an "*ongoing process of acquiring, storing, and updating information about a cultural heritage place over time, including both tangible and intangible aspects, to create the complete records of the heritage"* (De Vos et al., in press).
Anyway, it remains primary among the goals to be achieved to overcome the lack of uniformity in the structures of the data collected, going to develop, as highlighted in (Quintero et al., 2017), more uniformity in the data management processes related to historical heritage, including standardization in data organization, metadata collection, and three-dimensional presentation. Although the use of Building Information Modeling (BIM) for the management of historic places is

becoming more widespread, the development of standardized procedures is still needed. In addition, the use of controlled vocabularies is essential to ensure valid inventory data and to improve the findability of information through record indexing.

As highlighted in (Zhu, 2023), besides the use of digital technology, it is crucial for new generations to promote critical thinking for the interpretation of cultural heritage through direct education on issues in heritage studies at universities, focusing on the problematics of documentation and recording.

The marked multicultural and multilingual peculiarity of the international curriculum on Architectural Design, with students from different countries (in the a.y. 2022-2023, 27 students from Morocco, France, Germany, Greece, Norway, China, Turkey, Tunisia, Brazil, Kyrgyzstan, Vietnam), makes the occasion of the course an ideal field for experimentation and research in this topic area. Therefore, we seized the opportunity to encourage students to reflect on the complex issue of relating semantics contents to 3D models to enrich them.

Because of the varied origins of the people involved, their first description of the spaces being studied was affected by prior backgrounds and, often, gaps in knowledge of architectural elements specific to the case study. By integrating reality-based 3D modelling and a standardized architectural language, they moved from a subjective perception to a shared interpretation of a structured and objective representation (Fig. 1).

2. BASIC ISSUES OF SEMANTIC 3D MODELING

Two aspects have always steered research in architectural surveying: the ease of in situ measurement to reproduce existing objects with faithfulness and its connotation as a cognitive system (Benedetti et al., 2010). Considering the first aspect, research in Cultural Heritage documentation continuously develops sensors and new strategies for the production of reality-based 3D models from both image-based and range-based techniques (Remondino, 2011; Adamopoulos and Rinaudo, 2021). On the other side, documentation can be considered as an indispensable support for developing progressive knowledge, but from this perspective, there is still a lack of standardization to transform the result of a documentation project into an information system by integrating geometric with semantic information, by setting up a sort of central archive in which all data relating to the architectural asset could be brought together, to be managed as part of an integrated project dossier, as envisaged in (Letellier et al., 2007).

Spaces and places are concepts that technologies make it possible to place and size, but which also retain the possibility of being interpreted according to infinite declinations. Particularly in the context of historic built heritage, meanings and experiences are influenced by the sensitivity of the observer and his or her background, and the temporal dimension must also be considered. In other words, architecture can be considered as a complex system of relationships between aesthetic, technological, historical, and material-related aspects, different ways of using spaces over time, etc.

An attempt at systematisation, being aware that it involves a reduction of terms and thus a simplification of the question, aims to develop an "architectural knowledge system", integrating spatial (geometric and topological) and semantic information, i.e. as a collection of hierarchically organised spatial objects that are identified through a precise architectural vocabulary.

The hierarchical organisation of elements implies a focus on how geometric objects are related to one another topologically and morphologically, i.e. respecting criteria of spatial-semantic coherence, as defined in the 3D city models domain by (Stadler & Kolbe, 2007).

Considering semantics, the link to the geometry (3D semantic annotation) can be keyword-driven or ontology-driven (Attene et al., 2009). The former approach suffers from the subjectivity mentioned above, while the latter allows for a precise and unambiguous conceptualisation within a formalised knowledge system in a certain domain. Uncertainties may remain, however, when it is not easy to unequivocally define an architectural element, for example because the definition of such an element is not only based on geometric and topological aspects, but also includes considerations of a cultural, constructive, material, etc. nature, which contribute to its recognition in linguistic and semantic terms. Both the multicultural background of the students involved and the multidisciplinary approach proposed in the course also influenced this experience: depending on people's background, some elements - formal, plant-related, decorative, etc. - are more familiar than others (and therefore recognised more or less immediately and unambiguously). Moreover, an architectural historian could identify and analyse architectural components with different criteria from those of a structural engineering specialist.

The semantic description of architectural buildings is guided by logic that does not support broad generalizations, making instead the need for approaches optimized with respect to more specific domains (Cera & Campi, 2021).

3. AAT GETTY VOCABULARY AND SPATIAL CLASSIFICATION

For the activities carried out in the Laboratory that we present here, we referred to the Getty Vocabulary on Art & Architecture

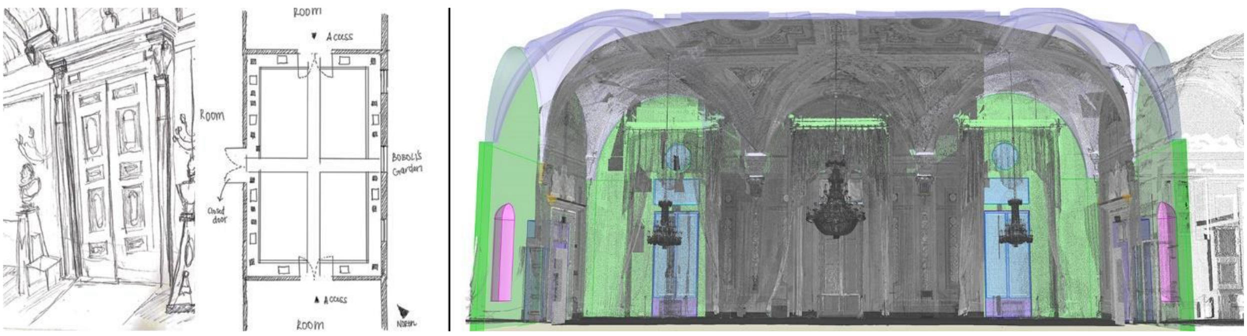

Figure 1. Descriptive sketches developed at the preliminary stage of architectural interpretation and the final 3D model elaborated from the laser scanner data (Students work: Aleksandra Yeliz Durak and Damla Icyer).

Thesaurus (Getty Vocabulary, Art and Architecture Thesaurus, 2017), which, among the controlled vocabularies, is the most recognized and used to fulfil the task of formalizing vocabulary in the domain of Art History and Architecture. It is a controlled domain vocabulary that contains generic terms and other information about concepts, related through hierarchical, equivalence and associative relationships. Obviously, it does not have a geometric component and does not take topological aspects into account in defining the hierarchy since the data structure was not created to represent spatial information. However, given its exhaustiveness and authority in the domain of architectural terminology, several researchers have proposed solutions to associate its semantics with 3D models and spatial data structures. In (Cera, 2018; Grazioso et al., 2018) data from the Getty Vocabularies are related to 3D meshes of buildings to associate abstract concepts with architectural elements through semantic annotation of UV maps. (López et al., 2018), as part of the *INCEPTION Project*, combined HBIM and AAT models, associating the Getty AAT thesauri with the properties of the modeled parametric elements. (Colucci et al., 2021) propose an ontology-based method for generating parametric structured models for historic building heritage, which involves mapping architectural concepts of the domain of castles and fortified architecture among Getty AAT, CityGML and IFC. (Noardo, 2018) in the development of the *CH Application Domain Extension 'CHADE'* of CityGML uses the reference to the URI of the Getty AAT terms as CodeList in the definition of the attributes of some classes such as *BuildingFunction*, *RoomClass*, *RoomFunction* and *RoomUsage*, and in the definition of *BoundarySurface*. Similarly, it is proposed for the extension of the *ResCult* conceptual model (Colucci et al., 2018), where a part of the AAT was taken into account to obtain a shared definition of the architectural parts into which the architectural heritage was segmented, in particular, the two sub-hierarchical classifications (*Building Division - Rooms And Space*) concerning the building spaces and (*Architectural Elements - Structural Elements*) adopted to represent the building elements were selected.

The Getty vocabulary has a very high granularity in defining terms, and even the smallest elements can be classified according to the enumerated hierarchical categories. However, as mentioned, there are no links between terms and their spatial component. Moreover, the extensive hierarchy is designed according to specific representation goals, so that terms are grouped together (e.g. the *rooms and spaces* are *by form*, *by function*, *by location or context*, *by building type*, etc.). Therefore, in most cases, the Getty Vocabulary is used as a reference to define terms related to cultural heritage, but it is not sufficient to fully represent the issue. In fact, in order to achieve a homogeneous representation (i.e., a spatio-semantic alignment between the 3D model segmentation and the controlled vocabulary hierarchy), it should be necessary a criterion by aligning to coherent levels of the AAT hierarchy (Noardo, 2018; Kokla et al., 2019). This can be done for parts of the model but is difficult to use considering the entire model of a (historical) building due to the complex hierarchy of the multitude of descriptive possibilities of the architectural form.

To help students understand the issue, the *Raumbuch* methodology (Petzet and Mader, 1993) was also introduced. It can be considered a proto-spatial information system in that referencing is done according to a topographical logic, thus allowing contextualization of the data and the definition of relationships among them based on spatial aspects. Initially developed in the late 19th century, it consists of the progressive decomposition and coding of the building into progressively simpler portions until each room's spaces and surfaces are identified.

According to the specific project, each element identification string is made by a sequence of codes arbitrarily defined. Thematic or archival data can thus be referenced with a granularity corresponding to the appropriate scales of analysis, case by case. However, although this system is often indicated as focusing on the spatial organization of digital data (Muenster, 2022), the differences from a geometry-based information system are noticeable since in this, it is expected that geometric, topological and semantic properties are registered and managed at the same time (Métral et al., 2009; Anselin, 1989), while maintaining space-semantic coherence criteria.

Recent applications of *Raumbuch* have proposed the digital implementation of the system through the creation of databases, as in the case of the European project *3ENCULT Monument Information System* (Haas et al., 2013), where the principle is extended to energy issues or related to architectural heritage as in (Heine et al., 2006). Instead, the limitations highlighted with respect to geometric and spatial aspects can be overcome by associating the digital inventory with an HBIM (Fiorino et al., 2017; Agus e Fiorino, 2021) or by applying the logic scheme to a real spatial information system (Cinquantaquattro et al., 2013).

4. THE CASE STUDY

The proposed case study is a part of the Pitti Palace in Florence, specifically the rooms on the *piano nobile* where the Grand Dukes of Tuscany apartments were located, now hosting the Museum of the Palatine Gallery and the Royal and Imperial Apartments. The whole monumental complex has recently been the subject of a complete and extremely detailed 3D digitization project, 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.

15 rooms were assigned to the students and used as test areas for the various exercises proposed during the course. Some of these were aimed at the production and processing of geometric data, such as photogrammetric design of vaults, alignment of laser scans, mesh and NURBS modelling, while other exercises focused on heritage information and knowledge engineering in the field of architectural heritage, as similarly proposed in other works such as (Zlodi et al., 2020; Bajena & Kuroczyński, 2023).

Students were first of all asked to describe the rooms discursively, or rather through “natural language”, and then to translate those first attempts to describe the rooms into a “standardized language” through the use of controlled vocabularies.

Students were also asked to consider (and update), at the same time, the structure of the 3D models they were making, based on the point models they had previously developed, to align them conceptually and technically in a coherent way with their descriptions (and vice-versa). In other words, the aim was to maintain space-semantic coherence criteria during the 3D modelling phase between the geometric and non-geometric information, paying attention to establishing connections between the semantic information (derived from the structure of the controlled vocabulary used for the ‘standard description’) and the 3D models defined from laser scanning and photogrammetric data.

The rich representative rooms of the Palatine Gallery present a high degree of descriptive complexity, given both by the rich decorative apparatus present (full of frescoes - mainly by Pietro da Cortona - and stuccoes) and by the abundance of furnishings and fittings (they host the most important and extensive example in Italy of a *quadreria*, i.e. a collection of paintings).

5. RESULTS

The analysis of each room, which began with a 'natural language' description, immediately revealed problems with syntax and the risk of misunderstandings due to incorrect term associations. These factors could compromise the organization of information (e.g. the Italian term 'terrazzo', which can refer both to the architectural structure projecting from the facade, similar to the balcony, but also indicates, internationally, the composition of materials composing the classic floor known as the 'Pavimento alla Veneziana').

The rich terminology of the architectural domain requires, indeed, close attention to the process of internationalization of terminology. The analysis of architectural representation assumes a crucial role in the consistency of the translation process, in which a domain expert and a linguist should cooperate to find the terminological solution best suited to the specificity of the built environment.

For naming architectural elements, students were introduced to the Getty Institute's controlled vocabularies, specifically Art and Architecture Thesaurus (AAT), but also the TGN vocabulary for geographic names or ULAN for artist names. Then, they proceeded with the translation from a natural to a standardized language, supported by controlled vocabulary language. They also annotated the descriptive texts of the rooms with AAT thesaurus identification codes, as similarly proposed in (Cera, 2018).

Adopting a standardized language involves a semantic division of the room itself and the establishment of an appropriate hierarchy by looking at the structure proposed by controlled vocabularies. This is to isolate and define a clear structure that can allow collected documentation to be assigned directly to specific elements, ensuring the readability of stored metadata by humans and machines. Depending on the project's goals and the object's complexity, this division can be very complex or limited to only one level of the hierarchy.

Moreover, the possibilities for subdivision can be multiple - as reflected in the articulated classification structure of the AAT - that is, it would be possible to proceed with a distinction of elements based on material classification or on the structural function of individual elements, and so on. The AAT vocabulary is thus characterized by a large number of lemmas, which allows its fruitful application in the domain of historic architecture; the hierarchical structure according to which they are ordered, however, is not always suitable for describing the relaionships between architectural elements.

To simplify and schematize the work uniformly, students were provided with the first part of the *Raumbuch* code (e.g. PP.11.GP.056), describing building subdivisions into gradually more detailed elements, down to the individual room (i.e., *Pitti Palace*: PP; *first floor*: 11; *Palatine Gallery*: GP; *room number*: 056), as proposed in (Valli, 2012) (Fig.2). This first part of the *Raumbuch* code is taken from the AAT sub-hierarchical classification concerning building spaces (*Building Division*), which includes *Stories, Rooms and Space* and *combinations of rooms.* Then, students continued to decompose the room considering its component surfaces (walls, floor and ceiling), and then they identified the elements on these surfaces (openings, niches, mouldings, etc.). This part of the code is included, for the majority of the specified terms, in the AAT sub-hierarchy inherent to building elements (*Architectural Elements*), which includes the distinction into *openings and openings components*, *surface elements and surface elements components*, *structural elements and structural elements component*, etc. Finally, the last part of the code is assigned according to the element's material, the finishing, the colour, etc.; all these terms are registered in different sub-hierarchies of the AAT vocabulary.

Finally, the 3D model elaborated from the laser scanner data with the Veesus Point Clouds for Rhino plug-in (Veesus Point Clouds for Rhino, Development Team, 2023) was structured with different layers, named according to the adopted AAT vocabulary terms and codes, organizing them hierarchically (by defining layers and sub-layers), corresponding as much as possible to the defined *Raumbuch* codes (Fig.3).

6. CONCLUSIONS

The Lab experience highlighted the usefulness of a standardised vocabulary, such as the Getty's AAT, to define the elements of a historical building in an unambiguous, sharable, machine-readable way. At the same time, students experienced the more challenging process of defining semantic content and relating it to a coherently defined 3D model.

In fact, even if the vocabulary terms are organized according to hierarchical structures, they neglect other types of relationships, such as those inherent to topological aspects, such as adjacency and connectivity between elements. The semantic structure of the AAT, on the other hand, does not envisage this type of classification since the elements that make up a hierarchical ordering of a spatial (or proto-spatial) type, such as the one exemplified above (e.g. the topological relationship between a wall and the opening that is on it), are to be found in different sub-hierarchies and are in any case not connected each other by taxonomic relationships.

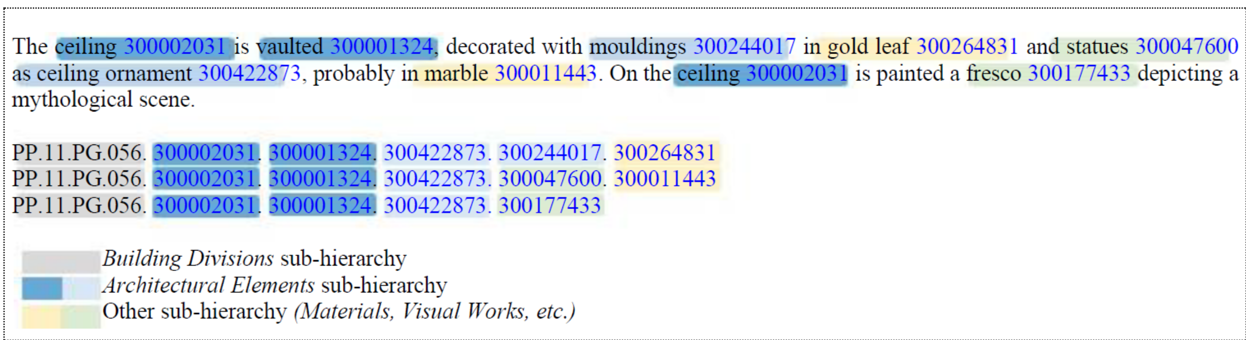

Figure 2. Switching from natural language to standardized language: besides terms used by students to describe their rooms, they annotated the corresponding terms from AAT with identification codes. Following a *Raumbuch* approach, codes propose a progressively more detailed description in which the hierarchical relationships are derived not from the data structure of the AAT but from the spatial relationships between the elements under consideration.

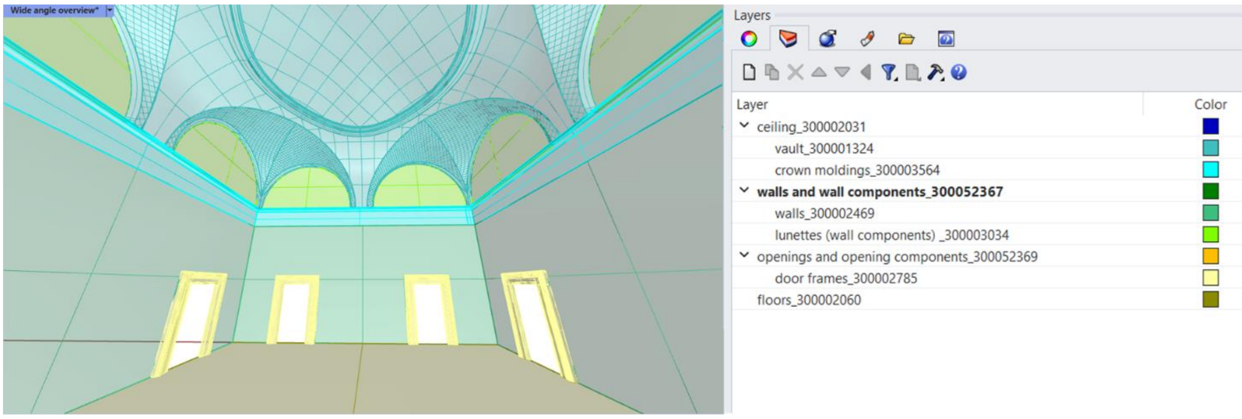

Figure 3. 3D model of *Sala dell'Iliade* based on laser scanner data, elaborated in Rhinoceros through the plug-in Veesus Point Clouds for Rhino: layer structure corresponds to AAT hierarchy (Student work: Torgeir Ketilsønn Kjevik).

Future developments could explore the uses of the vocabulary responding to criteria of spatial-semantic coherence, thus expanding its application in the context of 3D semantic annotation, exploiting the full potential of its complex poly-gerarchical structure.

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