SCIRES it
SCIentific RESearch and Information Technology
Ricerca Scientifica e Tecnologie dell'Informazione
Vol 13, Issue 1 (2023), 101-116
e-ISSN 2239-4303, DOI 10.2423/i22394303v13n1p101

CASPUR-CIBER Publishing, http://www.sciresit.it

3DCityModels to support technical knowledge and management of historic built environments. A semantic CityGML-based model for the ancient core of Carovigno (BR), Italy

Margherita Lasorella, Elena Cantatore**

*Dep. of Civil, Environmental, Land, Building Engineering and Chemistry (DICATECh), Polytechnic University of Bari – Bari, Italy

Abstract

The study presents the characterization of the built environment in historic districts according to the CityGML standard, properly prepared for their management in recovery plans. Knowledge, conservation, and management of such urban areas require a detailed data collection phase and a multi-scale representation technique to describe all the geometric and thematic aspects. To this end, the work identifies the system of simple and complex parameters, namely descriptors and factors, analysing theoretical notions, regulations, and previous scientific studies and experiences, mainly focused on the Italian case. Descriptors and factors are categorized along with the thematic relations with urban and building elements and components, through a well-defined logical-relational scheme and consistently related to the CityGML standard. Finally, the system of descriptors and factors has been applied and validated to the ancient core of Carovigno, in Apulia Region (Italy).

Keywords

Historic district, CityGML, Technical knowledge, Cultural Heritage, 3D semantic model

1. *Introduction*

The recovery and rehabilitation of buildings in historic districts and urban ancient cores are real emergencies. In fact, even if it is not a recent issue, the low levels of conservation of such fabrics represent the main discussion of the vulnerability level in current studies on disaster reduction for such urban areas (Ravankhah, Schmidt, & Will, 2017; Will, 2012). During the time, the complex degree of required activities and the prolonged time necessary to ensure administrative and technical goals heightened the critical levels of decay and the high percentage of disuse, that already affected such buildings. These features are thus combined to their obsolescence caused by long physical persistence in cities. Differently from the Cultural Heritage, as single representative architectures, historic districts have a landscape significance in the urban built environment that reflects multi-level and multi-scale points of relevance; they are featured by combinations of building uses and morphologies which historically serve inhabitants. Moreover, the historical process of development and the persistence over the time offer a complex system of tangible and intangible values to recognize, assess and preserve, both in private (e.g., houses) and public (e.g., squares) dimensions. In that sense, the technical knowledge of such environments represents the key to solve their multi-scale and multi-dimension relevance, considering the scale of building components and aggregates of buildings, as well as focusing on the original form and use of fabric, the transformations carried out and the actual state of use and decay (Della Spina, 2021; Dugato, 2014; Yawer, Bakr, & Fathi, 2023). All of them constitute the complex relations at the basis of the assessment of a historic district, firstly, and the identification of strategies for its recovery, then. Moreover, all the elements involved in the process constitute specific characteristics to be managed and controlled in the equivalent scales and dimensions, highlighting the complexity of the matter. In Italy, as a peculiar laboratory of such traditional environments for extension and operative slowness (Elena Cantatore, 2022), the traditional collection and the management of such characteristics by technicians are ensured by means of thematic datasheets as basic instruments to summarize the peculiarities and create thematic abacus (i.e., building typologies, windows, friezes).

However, this categorization process is still related to the technicians' experience and the peculiarities of single investigated sites. The first experiences of technical knowledge standardization are represented by two major thematic practices: the Chart of Risks for the Cultural Heritage (Fiorani, Acierno, Donatelli, Martello, & Cutarelli, 2022) and the CARTIS form (Zuccaro, Dolce, De Gregorio, Speranza, & Moroni, 2015). Here, the historic built environment is assessed by focusing on the inherent characteristics that affect the global vulnerability of places to such risks. These experiences have demonstrated that the management of data and features requires to be properly organized and distinctively identified and classified in databases that are properly structured (e.g., GIS-based) for the scale of investigated elements (component, building) and the spatial variabilities existing among all of them in the extended districts. This is a clear reflection of the relations among risks and physical vulnerabilities.

Overcoming the traditional tools and strategies, the latest applications in digitalizing the built environment using Digital Models verified high potentialities in collecting and managing characters and features of real cases as systems of well-determined properties (standard codes), organized according to specific relations (ontologies) useful to support i) the objective compiling of structured databases, ii) their unambiguous reading by several users and, specifically, iii) their semantic interoperability (Dembski, Wössner, Letzgus, Ruddat, & Yamu, 2020; Doerr, 2003; Ma, 2021; Marra, Trizio, Fabbrocino, & Savini, 2021; Nespeca, 2019). BIM (or HBIM for the Cultural Heritage) and 3D City Model represent the widest structure of informative rules for the representation, preservation, and maintenance of Cultural heritage and historic buildings. Their applicability in such examples may differ for the extension, according to the associated ontologies: based on the IFC standard, BIM has major relevance in the building scale (Gargaro, Del Giudice, & Ruffino, 2019; Pocobelli, Boehm, Bryan, Still, & Grau-Bové, 2018), while CityGML allows the digitalization of extended part of cities, including specific thematic modules (Gkadolou, Prastacos, & Loupas, 2020; Li et al., 2017). In detail, Digital Models in CityGML standard are represented at thematic/semantic and geometric/topological levels, through specific taxonomies and aggregations. Additionally, the CityGML standard data model is configured to be multiscalar, to the geometric and thematic levels of detail (LOD 0-4), and multidisciplinary thanks to the creation of specific ADEs (Application Domain Extensions) or the model extension in supporting _genericAttribute classes and GenericCityObject or (Kolbe, 2009). Moreover, according to the semantic interoperability among ontologies and associated databases, CityGML is determined as an open structure for BIM models, allowing the management of geometries, semantics and geographical information into the wider digital model. Due to these advantages, major points of discussion in applications of CityGML models for Cultural Heritage and systemic historic urban architectures or urban districts can be summarized as follows:

- Decodification of urban entities (G Agugiaro, 2016; Cecchini, 2019) or historic buildings and components of fabrics (Gkadolou et al., 2020) according to specific ontologies.
- Management of the built environment for the identification of sustainable and/or compatible refurbishment solutions, at the scale of the district, considering historical parts (Bonfanti et al., 2021; Prieto, Luis Izkara, & Béjar, 2017; Suwardhi et al., 2022) and new urban areas (Giorgio Agugiaro, González, & Cavallo, 2020; Mohd Nasir, Azri, & Ujang, 2022; Nasir, Azri, Ujang, & Majid, 2020; Pasquinelli, Agugiaro, Tagliabue, Scaioni, & Guzzetti, 2019).
- Managing urban areas according to specific risks or issues (Egusquiza, Prieto, Izkara, & Béjar, 2018; Kilsedar, Fissore, Pirotti, & Brovelli, 2019).

Near to the wide set of opportunities related to the different scales of application, digital 3D models combined with CityGML ontology demonstrate the chance in managing different levels of knowledge, both at physical and historical levels, which require interdisciplinarity among the technicians involved (i.e., historical evolution) and interoperability during all the phases (i.e., risk management) in the experimented process. Moreover, recent studies have shown the development of functional tools for archiving, using and managing CityGML-based city models including i) 3DCityDB, an open-source suite configured as a geographic database, which allows the visualization, analysis and management of multidisciplinary and multiscale information (Yao et al., 2018) and ii) CityJSON, JSON-based encoding, which provides a compact format easy to view and edit, as well as suitable for programmers for web-based applications developing (Ledoux et al., 2019).

Starting from this framework and combining the potentialities of digital models and the criticalities related to complex systems, such as historic districts, the paper aims at proposing and discussing the application of the CityGML standard for the collection, cataloguing and management of semantic, geometric and geolocated data referred to the historic district of the Carovigno (BR). This is the first application focused on the parameters involved in the recovery process towards the characterization of the testing case.

2. *A well-thought-out process for the conceptualization of digital recovery plans. Parametrization of historic district and interrelation to the CityGML standard*

As introduced in the previous section, the recovery process of historic districts is the result of a multi-disciplinary, multi-scale analysis and assessment, thus requiring several expertise and technical and administrative users. The process requires several operative, conceptual, and instrumental activities allowing the identification of inherent (morpho-typologies, material and constructive techniques, architectural relevance) and extrinsic factors (transformations, social, cultural and economic values), their assessment in terms of performances and normative consistency as well as the knowledge of their relevance in terms of local identity. Moreover, the complexity is mostly related to the correct identification of heterogeneous characters, features and values which interest such heritage, from the component scale to the district one, and the identification of correct relations among them. In fact, for each activity of the process and each collected information, several combinations of tools and sources can be associated: from the *in-situ* investigation with either traditional instruments (i.e., direct measures, photos, printed sheets for the state of maintenance) or smart/digital ones (e.g., Virtual Reality supported by Virtual Tours and spherical images, or based on point cloud models, reducing the time of acquisition *in situ*) (Lasorella, Cantatore, & Fatiguso, 2021), to quantitative (e.g., geometries) and qualitative data (i.e., not in use) derived from the archivist and documental surveys. This reflects the variety and technical relevance of information and its relations in the process (collection, interpretation, assessment). Even if Digital Models and associated databases and ontologies are well prepared for the data codification, the traditional relations among features describing modern cities should be expanded; the traditional relations among "technology" and "performances" require to be outdone considering cultural and historical dimensions of the historic built environment. In fact, the relevance of a proper and structured systematization of data for historic architectures is functional for the identification of intervention and their priority levels into coherent recovery plans. Here, in all the involved scales, the required transformations have to consider the preservation of the inherent values and the opportunities to transform heritage (E. Cantatore & Fatiguso, 2021). In that sense, the creation of Digital Models and the associated database, both at geometric and semantic levels, for the recovery of historic districts requires three key aims, as the main goal of this section: i) find and categorize the regulations and previous experiences to identify geometric and semantic data, coherently identified for terminology and requirements; ii) determine the correct relations and the logical scheme of the identified data; iii) organize data in databases structured according to the CityGML ontology.

Currently, the recovery of such heritage should include specific issues, such as:

- The recognition of environmental, historic and cultural values following national and regional regulations. In this class of data, all material and immaterial elements to be preserved can be associated, from the friezes to construction techniques and building morphologies.
- The identification and qualification of obsolescence of building function, mostly related to static, energetic, and hygienic performances of fabric and components. Here, constructive, technological, and material features of components (walls, windows, roofs, HVAC system, ...), and geometric characters of inner spaces (number of floors, presence of windows, geometry of rooms), constitute the main data to focus on.
- The identification of buildings decays. This is associated to the analysis of physical and technological obsolescence of materials and system technologies that cannot directly affect the function of buildings but may alter the building uses. This is the case of data

describing the state of conservation of non-structural elements of components (decay of plasters or the presence of stone alterations in unplastered walls) and systems (connection to the grid, maintenance of systems).
- The administrative compliance of architectures, such as cadastral information of buildings, the previous intervention of transformations (uses, raisings, demolitions, superfetation), etc.
- The use of "Building Types" as models of architecture, featured by the recurrent combination of morpho-typological, construction, and material characters, as well as extension and height. This is useful for the description of extended heritage featured by various combinations of simple properties, uses and state of conservation to be assessed for criticalities and potentialities and investigated for intervention required.

All these data require to be firstly elaborated, understanding the elements of the built environment to characterize and the properties to enrich the model, and then interrelated within the CityGML database. As briefly introduced before, data to be collected and managed for the recovery plan of historic districts can be classified according to three informative dimensions: the normative frame [N] – prevalently distinguished at national levels-, approved ontologies [O] and scientific ontologies [SO] just proposed and tested in literature, and previous experiences [PE] in setting up recovery plans. Specifically for each category and in the details of the Italian case, Table 1 summarizes the main references about.

In detail, as far as the Italian normative frame [N] is concerned, specific relevance is on the concept of "habitability" for residential spaces, as the prevalent uses of systemic fabrics in historic districts. Habitability of dwellings is determined as a set of minimum requirements which must guarantee safety and security in living residential spaces (statical and hygienic requirements - Ministero della sanità, 1975; Ministero delle Infrastrutture e dei trasporti, 2018). Besides the detail of uses, national regulation considers the qualification of fabrics according to cultural and historic relevance; it is the case of the Italian Code on Cultural Heritage and Landscape (Il Presidente della Repubblica Italiana, 2004). Finally, the last regulations concern urban land uses and management which identify the administrative details of fabrics and the allowed actions (transformations, permissions - Il presidente della Repubblica, 2001).

Considering previous approaches [PE] details, major references are related to the experiences in creating recovery plans. Here, the derived elements are not related to the normative constraints but to the methods applied. Among the major experiences, the recovery plans for the cities of Bologna and Palermo, and of Abruzzo and Sardegna regions that are mainly identified as "recovery manuals".

As the categories of information relates to ontologies [O], the digitalization process of a real

Tab. 1: Summary and codes of Normative [N], Previous experiences [PE], Ontologies [O] and Scientific Ontologies [SO] involved in the qualification of parameters for the recovery process in the Italian case

Code	Name	Reference
NORMATIVE [N]		
N1	Code on Cultural Heritage and Landscape	(Il Presidente della Repubblica Italiana, 2004)
N2	Height and hygienic requirements for residential spaces	(Ministero della sanità, 1975)
N3	Technical Standards for Construction	(Ministero delle Infrastrutture e dei trasporti, 2018)
N4	Urban land uses and management at urban scale	(Il presidente della Repubblica, 2001)
PREVIOUS EXPERIENCES (PE)		
PE1	Manuals for the recovery of urban ancient core	(Adorante et al., 2011; Atzeni & Manias, 2006; Cannarozzo, 2007; P L Cervellati & Miliari, 1977; Pier Luigi Cervellati & Scannavini, 1973)
ONTOLOGIES [O]		
O1	CityGML	(Gröger, Kolbe, Nagel, & Häfele, 2012)
SCIENTIFIC REFERENCES OF ONTOLOGIES [SO]		
SO1	CHADE - Cultural Heritage Application Domain Extension	(Noardo, 2018)
SO2	SEH-SDB - Semantically enriched historical spatial database	(Yaagoubi, Al-Gilani, Baik, Alhomodi, & Miky, 2019)

case study according to specific rules usually generates the setting up of some properties or data which are consistent with the standard but independent to the other necessities. Considering the regulated and approved ones, CityGML and CIDOC CRM (Doerr, 2003) are the most common ontologies applied in the creation of digital and parametric models of large urban areas and/or fabrics or elements featured by cultural relevance. However, for the paper purposes, the attention is on the CityGML standard (Gröger et al., 2012). As inherent requirements for it, some geometric data and geographic properties are introduced in the system of parameters in order to generate the 3D model. In addition, the scientific experiences in studying and extending ontologies have produced a set of scientific ontologies [SO] that are not approved by the related standard but that find their application and test in real case studies. In this case, factors are highlighted due to the similarity in approach or subject matter. Specifically, two main references are detailed: the CHADE (Cultural Heritage Application Domain Extension), as specific ontology CityGML-based for the description of Cultural Heritage (Noardo, 2018) and the SEH-SDB (Semantically enriched historical spatial database) which conceptualize historical, architectural, and cultural information of Cultural Heritage (Yaagoubi et al., 2019).

Following the paper's aim, all the collected classes of data are categorised into three types: i) Descriptors (Ds) that can be directly obtained by means of direct in-situ inspection or documental acquisition (period of construction, buildings permission, uses, state of maintenance of walls, roofs); ii) Primary Factors (PFs), the first level of derived data, that offer a higher and technical level of knowledge about the descriptors as combinations of derived factors (nD); iii) Secondary factors (SFs), the most complex level of derived data, as the combination among primary ones (nPF), primary and descriptors (nPF + nD). Then, all of them are classified for thematic similarities:

- General data include the administrative information of buildings, street assets and district. The cadastral data may be used to identify them (identified as building ID in order to ensure their unambiguous lecture.
- Historical-archival information gathers all the collectable data by means of documental sources and refers to the historical information of elements of the built environment.
- Technical knowledge data refers to the practical information acquired by in-situ inspections and measurements.
- Normative regulation includes notes about the regulatory framework, such as the type of regulations and constraints.
- Architectural emergencies refer to the features and elements with cultural, constructive and historical relevance.
- The conservation level collects details on the state of maintenance of building components (walls, roofs) and systems.
- The derived data collects all the information associated with simple data for the evaluation of the built environment, such as the qualification of performances and interventions and the identification of priority levels of interventions.

Finally, the semantic data are codified and described in order to have an unambiguous reading of information, discussing the level of the data type and the associated CityGML classes. In particular, data are related to semantics already presented in “Building” (B) and “Transportation” (T) classes; when specific ones are not conceptualised in the CityGML standard, they have been implemented by the Generic Attribute class. In this way, the semantic digital model has been extended by applying the characterisation of the existing architectural heritage, underlining the potentialities and the multi-scale approach of data computing. Thus, table 2 shows the details of parameters, introducing codification, name, description, and informative data, following the thematic classification and highlighting the relations with the categories of informative dimensions and the CityGML associated “Class”. Following, Table 3 details the relations among Descriptors and Factors for each Primary and Secondary ones as determined by the scientific and normative review.

Tab. 2: System of data involved in the technical knowledge of historic districts, codified and classified in terms of associated CityGML "Class" (B Building, T Transportation, * when the class is implemented with generic attribute) for their modelling, and related reference ("Ref") according to the categorization in Tab. 1

Section		Code	Name	Description	Ref	Class
1. Gen. Info		ID_C	Cadastral Data	Sheet, parcel and subalterns	-	B*
		ID_U	Urban Data	Urban class in the plan	N4	B*
		ID_T	Toponomastics	Avenue, Street, Square, … house number	O1	B
2. Historical-archival data		B_Cl	Building Class	Building Type (castle, building, church, …)	O1	B
		B_Fct	Building Function	Original use (residential, strategic, etc.)	O1	B
		B_Use	Building Use	Current use (commercial, residential, etc.)	O1	B
		B_CP	Construction period	Construction period of building	N3	B
		B_DP	Demolition Period	Demolition period of building	PE1	B
		B_Ow	Building ownership	Public/Private building	SO1	B*
		B_St	Building State	Current condition (abandoned, partially used, …)	PE1	B*
		B_Tl	Building Title	First and latest building permissions	PE1	B*
		B_PI	Presence of intervention carried out	Alteration of the original fabric	N3	B*
		B_TPI	Type of building intervention carried out	Building renovation, Static recovery, Raising, Conservative restoration, etc.	N3	B*
		B_PPL	Year of intervention carried out	Reference period relating to the execution of previous intervention	N3	B*
		U_Cl	Urban Class	Classification of element (Street, square, …)	O1	T
		U_Fct	Urban Function	Original use type of the urban element	O1	T
		U_Use	Urban Use	Actual use type of the urban element	O1	T
		U_St	Urban State	Current surface decay of urban element	PE1	T*
		U_PI	Previous interventions of urban element	Identification of transformations carried out	PE1	T*
		U_TPI	Type of urban intervention carried out	Urban restructuring urban redevelopment	PE1	T*
		U_PPI	Period/year of urban Intervention carried out	Reference period relating to the execution of past urban interventions	PE1	T*
3. Technical knowledge data	3.1. Geometric	B_nFa	Storeys above ground	Total number of storeys above ground	O1	B
		B_nFb	Storeys below ground	Total number of storeys below ground	O1	B
		B_H	Measured Building Height	Maximum building height above the ground evaluated at the eaves	O1	B
		B_SH	Storey heights above and below ground level	List of storey heights calculated between the floor level and floor extrados height (ground to top)	O1	B
		B_A	Floor area	Commercial area of the building	N2	B*
		B_Pwi	Presence of windows	Presence and relative location of windows	N2	B*
		B_nR	Number of rooms	Total number of rooms in the building	N2	B*
		B_WiA	Window area	Total extension of window in each room	N2	B*
		B_WD	Wall dimension	Thickness of wall	N3	B*
		B_WiAw	Window Area wall	Total extension of windows assessed in the wall	N3	B*
		B_WA	Wall area	Total extension of the wall	N3	B*
		B_Arf	Roof area	Total extension of the roof	N3	B*
		B_RA	Room area with window	Area of room with a window	N2	B*
	3.2. Morpho-types, architect..-constr.	B_Typ	Building Type	Morpho-typology (palace, simplex, …)	PE1	B*
		B_Str	Structural typology	Type of building structure (masonry, vaults, mixed building, etc.)	N3	B*
		B_WT	Wall Type	Description of construction technique of wall and elements + materials of elements (e.g., compound wall with squared stone blocks)	SO2	B*
		B_RT	Roof Type	Description of construction technique for roof and elements + material of elements (e.g., vault in squared tuff blocks)	SO2	B
		B_VCT	Vertical Connection Type	Description of construction technique + material of stairs (e.g., concrete stair, cantilever stone stair)	SO2	B*

	B_WiT	Windows Type	Physical-material features of window elements (e.g., E-low double glass and wooden frame)	SO2	B*
	B_FiT	Type of building finishing layers	Description of materials for wall and roof finishing (e.g., mortar plaster walls; external bituminous finishing of roof)	SO2	B*
	B_MQ	Mortar Qualification	Qualification of mortar in classes (good, medium, bad)	N3	B*
	B_QJ	Quality of vertical and horizontal joints	Presence and quality of joints floor-to-walls, and wall-to-wall in classes (good, low, bad)	N3	B*
	U_PT	Element type of urban paving	Surface finishing and material (e.g., paving in irregular cobblestones)	PE1	T*
3.3. Technolog. Systems	B_TS	Technological system	Presence of any technological system in the building (water; sewage; heating; …)	N2	B*
	B_TST	Technological system type	Type of technological system in the building (water; sewage; heating; …)	N2	B*
	U_PU	Primary urbanisation	Presence of any primary urbanisation	N2	T*
	U_TPU	Primary urbanisation type	Type of primary urbanisation (water, sewerage, electricity, gas, telephone, …)	N2	T*
4. Ref. Legislation	B_ChC	Cultural Heritage Code	Constraints defined by the Cultural Heritage and Landscape Code	SO1	N2
	B_LsR	Landscape restriction	Constraints defined by regional landscape regulation	SO1	B*
	B_MR	Municipal constraints	Constraints defined by municipal policies	SO1	B*
5. Archit. Emerg.	B_EV	Elements of value	Presence of elements with historical and cultural value (portal, epigraph, decorations, friezes, …)	SO1	B*
	B_HR	Historical relevance	Distinctive cultural, historical and identity features	SO1	B*
6. Conserv. Level	B_CSW	Conservative state of wall	Presence of cracking, damp, and decays	SO1	B*
	B_CSR	Conservative state of roof	Presence of cracking, damp, and decays	SO1	B*
	B_CSWi	Conservative state of windows	Presence and/or absence of frames, decay of frame, absence of glass	SO1	B*
7. Derived Data	B_BT	Recurrent Building type	Type of building identified as combination of recurrent characters	PE1	B*
	B_WQ	Wall qualification	Mechanical qualification of wall (good, medium, low)	N3	B*
	B_RQ	Roof qualification	Mechanical qualification of floor (good, medium, low)	N3	B*
	B_CS	Global Conservation state of building	State of conservation of building, considering all the components	PE1	B*
	B_HP	Hygienic parameter	Compliance with the ratio of window area to room surface area, for each residential environment	N2	B*
	B_HSP	Hygienic and sanitary parameters	Compliance with hygiene and sanitary parameters for every residential building	N2	B*
	B_BM	Building mechanical qualification	Mechanical qualification of building	N3	B*
	B_IC	Building Intervention Class	Class of required intervention (ordinary maintenance, static recovery, …)	N4	B*
	B_IPr	Building Intervention Priority Index	Prioritisation of intervention considering value range of Building Intervention Class and building type	PE1	B*
	U_AT	Urban Asset Type	Typical urban element identified as combination of recurrent characters	PE1	T*
	U_CS	Conservative state of urban element	Surface decay and physical lacks in paving	PE1	T*
	U_IC	Urban Intervention Class	Class of required intervention (urban maintenance, regeneration)	PE1	T*
	U_IPr	Urban Intervention Priority Index	Prioritisation of intervention considering the value range of intervention class and type of urban element	PE1	T*

Tab. 3: List of Primary (PF) and Secondary Factors (SF) and codes of combined descriptors and factors

Code	Name	Data Type	Combined Descriptors / Factors
B_BT	Recurrent Building type	PF	B_Typ; Cl; CP; TS; Fct; Use; nFa; PW; WiA; Str; WT; RT; VCT; WiT; TST
B_WQ	Wall qualification	PF	B_WT; WD; CSW; MQ
B_RQ	Roof qualification	PF	B_RT; CSR
B_CS	Global Conservation State of building	PF	B_St; PI; Tpi; PPI; CSW; CSR; CSWi
B_HP	Hygienic parameter	PF	B_WiA; RA; Use
B_HSP	Hygienic and sanitary parameters	SF	B_nR; TS; TTS; HP
B_BM	Building mechanical qualification	SF	B_WQ; RQ; QJ; StQ
B_IC	Building Intervention Class	SF	B_BT; CS; BM; HSP
B_IPr	Building Intervention Priority Index	SF	B_BT; IC; Ow
U_AT	Urban Asset Type	PF	U_Cl; Fct; Use; PT
U_CS	Conservative state of urban element	PF	U_St; PI; TPI; PPI
U_IC	Urban Intervention Class	SF	U_AT; CS
U_IPr	Urban Intervention Priority Index	SF	U_IC

3. *Case study*

Carovigno is a city in the Apulian region, located 8 km far from the Adriatic coast and 28 km from Brindisi (Fig. 1). Its ancient core has Messapic origin, later enlarged and consolidated in the Middle Ages; today, it is surrounded by the ancient defensive walls and four major towers. The relevance of the old core of Carovigno for the study application is related to the intrinsic criticalities in terms of physical and normative obsolescence of buildings, such as the number and size of rooms, the deficiency of services and urbanisation systems, the unchecked alterations of the built-up area, the scarceness of activities for maintenance and and intervention for recovery. These factors have caused extrinsic challenges for local public bodies in managing abandoned buildings and families with a high unemployment rate. On the other hand, such features moved several urban regeneration activities aimed at improving and adapting the existing urbanization services, producing thematic archival and documentary analyses not properly consolidated in a detailed Recovery Plan. This generated a complex system of historic and technical information concerning original characters, uncontrolled and controlled transformations, and the actual state of fabrics, requiring a hard re-organization. The setting up of its Digital Model with the CityGML standard offers the opportunity to undergo the gap. However, coherently to the paper's goals, only the re-organization of knowledge has been

Fig. 1: (Left to right) location of Carovigno (BR) in Italy, perimetration of the historic centre in the city land, Castle of Carovigno as part of ancient walls

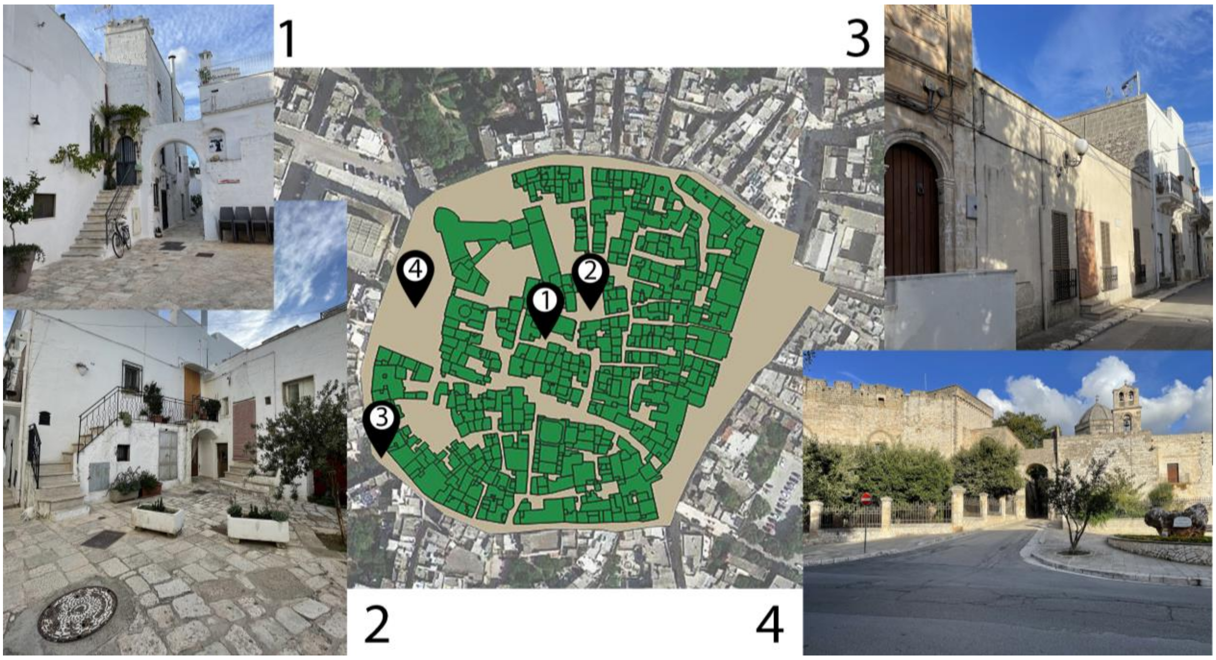

Fig. 2: Details of pavements typologies and transformations within the district asset

presented as preliminary results of a wider study about the case study. Specifically, the discussion is about the proper semantic and geometric representation of descriptors, as determined in Table 2 by the literature and normative review. Moreover, the application highlights the interoperability between GIS-based informative systems, usually open to technicians and public administration, and thus, the higher level of compatibility between not-structured knowledge and ontology-based models.

3.1 Technical qualification of the Ancient Core of Carovigno

The technical cognitive process of the historic centre of Carovigno has focused specifically on the most ancient area. The investigation activities start from the studies carried out by Municipal Authority. Thus, the in-depth analysis allows highlighting all the needed peculiarities for the technical knowledge of the ancient core. In detail:

- The curvilinear asset of routes, properly organized in narrow paths, represents the main character of the old core at a wider scale. This is the major historic and cultural significance resulting from the original defensive needs and the main characteristic orography of the Carovigno territory. This has to be combined with the use of large calcarenitic blocks for paving. However, this original character has been mostly lost during the time in most of the paths, replacing them with asphalt (Fig. 2). The main evidence is located near the Castle of Carovigno and churches, as major architectural emergencies.

Fig. 3: Example of the state of deacay of an external wall of a building, featured by crusts, dampness, and degradation of tuff blocks along the exposed surfaces

- Concerning primary urbanization, the ancient core is equipped with electric, sewage and water systems, while lacks gas supplies in some areas. Here, heating and eating functions increase the electricity needs. However, electric and sewage pipes appear to be inadequate for the final uses and external conditions, generating several discontinuities in functionalities.
- The state of conservation of the place has particular relevance. The functional and normative levels of obsolescence generated the abandonment of dwellings during the time; today, they are also featured by a high level of decay (presence of vegetation and biological colonization and crusts) (Fig. 3). Moreover, the absence of protective layers of tuff and the presence of thrust roofs generated static deficiencies combining cracks, mortar decay and dampness.
- Considering the morpho-typologies of fabrics, prevalently used for residential aims, the old core of Carovigno is featured by four main building types (Fig. 4):
  - (Type 1) "Terraced House", single-cell (a) and double-cell (b) with vertical and horizontal dwelling development. The main difference is referred to the historical process: in single-cell functions of dwellings are vertically distributed by means of a private stair. When two terraced houses are merged in generating double cases, residential uses are horizontally distributed, and stairs connect different private dwellings. Single-cell (a), with a single facing, consist of 1-3 rooms, vertically connected. Only the living area has windows while the

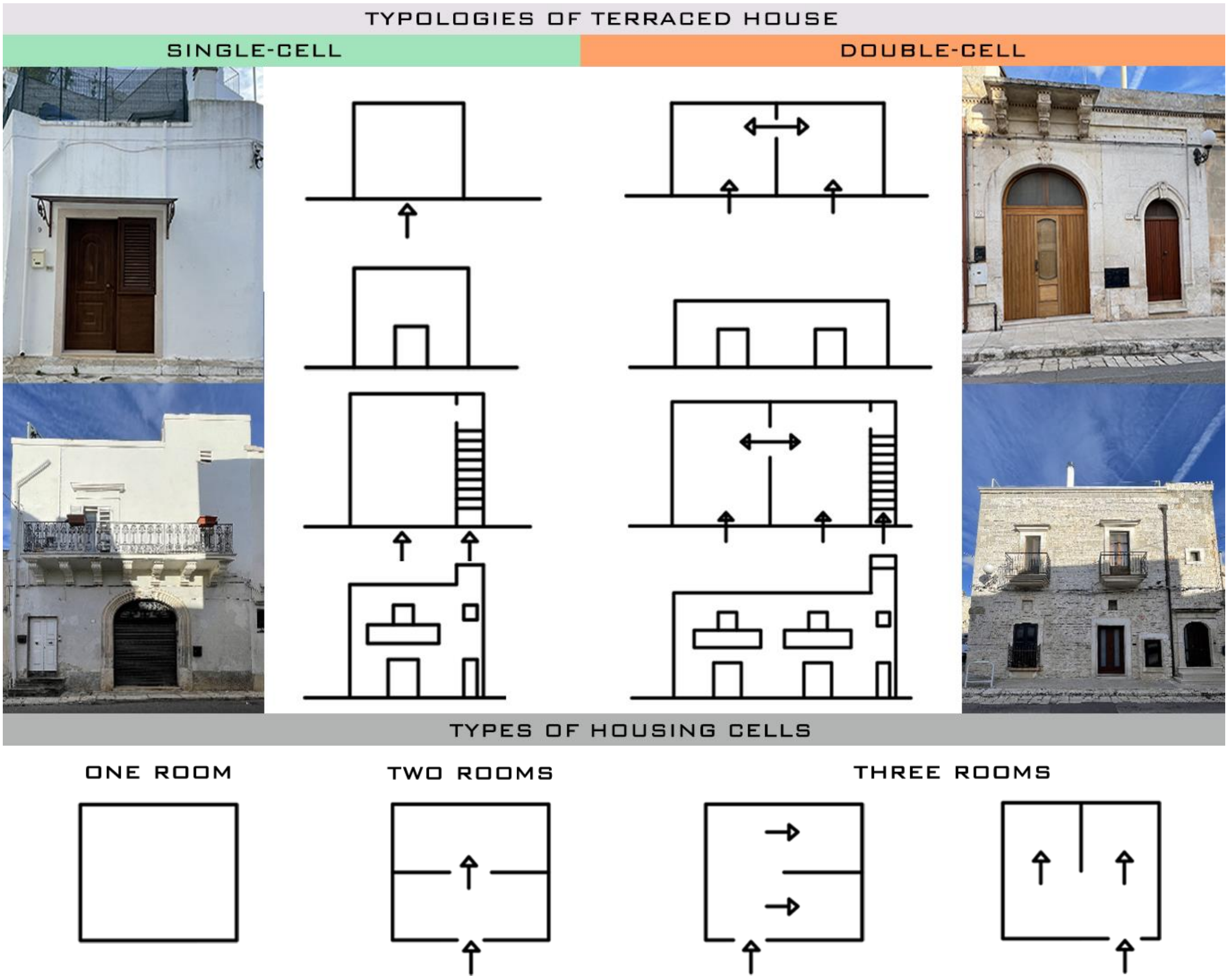

Fig. 4: Details of plan distribution of terraced house, for single and double cells (image created starting from details available in the general land management regulation of Carovigno city)

nocturnal one lacks openings, generating critical ventilation conditions. In the double-cell (b) living room and bedrooms are organized facing the streets, solving the hygienic deficiency. These morpho-types are the most recurrent.

- (Type 2) “In-line house” is a multi-family house characterized by an articulated morphology in plan and a large extension of dwelling on the first floor, with two or more overlooks. The ground floor was usually used for storage. Vertical distribution is guaranteed by a private stair.
- (Type 3) “Palace” is a type featured by similar dimensions and distributive characters of Type 2, but it presents also significant architectural and decorative elements. This morpho-type is the result of recent architectural (the early 1900s).
- (Type 4) “Corner or End Houses” is a building that has no recurring features, but it is a variation of previous ones useful to solve the corner of the district blocks.

• As prevalent constructive and material features, masonry and vault in “Leccese” tuff represent the main technological characters. The presence of small rooms favoured the creation of rigid floors, organized in barrel, cloister and “a stella” vaults. The latest and the use of local materials represent typical values of the place. Masonry may be compounded or in a single layer made by Leccese tuff, prevalently unplastered.

3.2 The 3D Semantical Model setting-up

The semantical 3D model sets up for the case study required two main steps according to the dimensions of data, preliminary processed in the QGIS software. The geometric information about the place and buildings has been derived from the Regional Technical Map, available on the SIT of the Apulia Region. Starting from the regional data, a shape file has been created where each building is represented by vector polygons in the WGS84-UTM 33N reference system. For each vector, cadastral data - already included in the technical map – are related to the buildings as equivalent ID. Geometric level details (ground elevation, buildings and urban elements heights and extension) have been solved by combining data from the Digital Terrain Model (DTM) and Regional Technical Map.

Thus, the geometric data has been implemented with the information collected through archival analysis collected in the municipality of Carovigno. It is the case of historical-archival data, technological systems, legislative constraints and architectural emergencies (see Table 2). Photographic surveys and visual inspections conducted in situ supported the acquisition of buildings and components information (morpho-types, architectural and constructive features, conservative levels – Table 2). Then, as a first step of the digital collection of data, multidisciplinary and heterogeneous information, properly prepared in an alphanumeric format, has been systematized in the GIS database coherently with the descriptors defined in Table 2. This is functional for the subsequent translation of data according to the CityGML standard, through the Safe FME visual programming platform. Here, i) the geometric data are translated in a three-dimensional digital model as a system of entities (buildings and urban elements) using the LOD 1, ii) semantic and geometric data are translated according to the CityGML standard and iii) the logic-mathematical functions for automatic processing of primary and derived factors are implemented. Due to the LOD, both properties of buildings and components are related to the extruded vectors of fabrics, in order to ensure the correct relationship.

According to the parametrization process, each entity is unambiguously identified through the cadastral data for architectural entities and toponymic information for urban elements. This allowed the creation of specific queries and their fruition in the digital model. At the semantic-thematic level, all the collected information was filtered for attribute creation according to the CityGML standard, paying attention to the relations between each datatype entity and specific attributes and among attributes. To that end, the properties of source information have been observed, taking into account the intrinsic nature of the data, vertical relationships among subject classes and horizontal relationships among individual attributes of such specific CityGML class. Thus, the architectural entities populate the “Building” class and urban elements the “Transportation” one. Additional attributes have been translated according to the CityGML

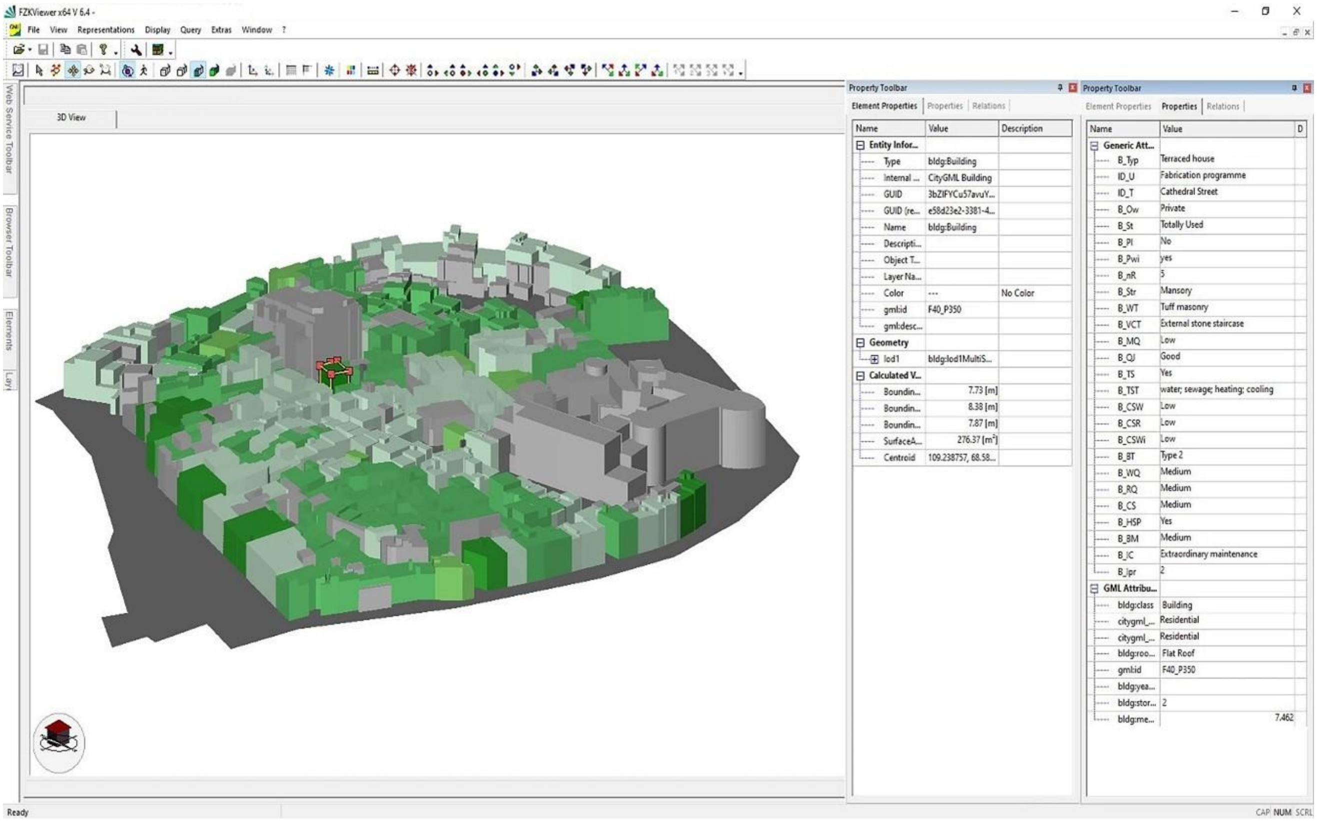

Fig. 5: Visualization in the FZKViewer of architectural entities classified for morpho-typologies. On the right, semantic details about the queried entity

datatype, using the Class "genericAttribute" and "_genericAttribute" attributes, for both thematic models (architectural and urban), as identified in Table 2. Finally, the geometric and thematic-semantic model has been translated into the CityGML standard, as the semantic digital model of the ancient core of Carovigno. All the semantic and geometric information of the model has been imported into the open-source software tool FZKViewer, useful to query the model at the geometric and semantic level, according to specific attributes and/or entities (Figure 5).

4. Conclusions

Historic districts constitute a more complex part of cultural heritage to read, understand and improve, due to their multi-disciplinary and multiscale dimensions of features and properties. Such complexities have to be included and discussed also in the recovery process, merging with all its phases (analysis, assessment, definition of strategies) and the users involved. Near to these, the administrative procedure for their conservation is still not standardised due to i) the criticality of theoretical notions, ii) the architectural complexity of the existing heritage, and iii) the disciplinary disarticulation of technical information.

Today, after a recent but rapid increase of application, Digital Models demonstrate that they can help technical expertise in undergoing the multi-dimensionality of data and assist them in the multi-phases and multi-actors processes. However, even if several ways to create Digital models exist, the use of structured ontologies allows the renovation of traditional procedures ensuring the universality and independence of the technical knowledge for the aim. Among the available ones, the CityGML standard is an open data model developed for storing and sharing parametric three-dimensional city models, supported for the large-scale analysis and all the elements involved in the assessment (buildings, viability, furniture, …).

The present work presents an overview of such complexity, showing the opportunities of CityGML ontologies in broadening its structure towards the creation of digital recovery plans. In fact, the work focuses on the parametrization phase of technical knowledge about systemic architectures in historic districts, mainly for residential uses. At the informative level of detail, this is the fundamental step for understanding the nature of data, for dimensionality (related to building, components, of urban elements) and class of information (feature, boolean data), and the existing relations among them. In a complementary way, the parametrization process offers the opportunity to determine the structured set of classes of details and information required to support the administrative and operative procedure in the conservative process. Specifically for the parametrization details, information is determined starting from the main normative regulations and experiences about residential buildings and preservation processes at the Italian scale, combining them with ontologies requirements related to the digitalization and standardization process. Then, all of them are structured according to a logical-relational scheme in order to ensure i) their relations in terms of simple descriptors (D) or derived ones (primary and secondary factors PF/SF) and ii) their correct scale of representation according to the analysis level (elements, components, building, urban element) useful for a coherent categorization and assessment process based on the CityGML standard.

The set of parameters and the related logical-relational scheme are thus applied and tested to the case study of the ancient core of Carovigno (BR), as representative of the physical and administrative status of historic districts in the southern part of Italy. Here, the created model digitalized the real built environment using a low level of detail (LOD1), due to the computational complexity of representing a large urban district, even if coherent with the paper's goals. Here, the setting up of geometric and semantic information demonstrates the opportunity in supporting all the involved technicians during subsequent activities of i) the elaboration of conservation strategies and ii) the suitable reuse of buildings, the improvement of actual functions or the introduction of new social functions (cultural, managerial, commercial activities).

This first analysis and data pre-processing phases prepare the basis for the setting up of automated multi-scale and multi-dimensional analyses, properly structured to be usable and accessible by all the users in the sector (technicians involved in the setting of the recovery plans and the building transformations), as well as by public bodies.

Considering the well-thought-out process employed for the parametrization process and creation of relations, the work and its aim can be considered as part of studies for the extension of CityGML standards towards more specific classes of information useful for both Cultural heritage and systemic architectures. On the other hand, collaborative activities with computer scientists may support the structurization of a specific domain (ADE), overcoming the generality of generic attributes as complementary means for the extension of CityGML standards.

Coherently with the resilient requirements to have safe and secure cities, the conservation of such fabrics and places is usually combined with specific risk management. The structured process and relation scheme support the chance to merge more levels of discussion details for more articulated management of the transformation required and preservation necessities. However, the management of risks will be discussed according to the specific exposure of fabrics according to the geographical position of cities, distribution into the urban land and national and regional regulation about the matter.

Specific future development of the work may consider the creation of an equivalent complete digital model for the tested real cases using a higher level of their representation, and, according to the opportunities offered by the new version of CityGML standard (v3.0 in progress), the use and management of point clouds for quantitative analysis of such areas.

Acknowledgements

The authors thank the Municipality of Carovigno for allowing access to technical knowledge data.

References

Adorante, M. A., Benevolo, L., Di Zio, L. O., Loi, M., Marconi, P., & Trippetta, L. (2011). *Manuale del recupero della Regione Abruzzo: Nei borghi terremotati il recupero della bellezza in chiave di continuità: l'interpretazione omeomorfica*. Gangemi Editore spa.

Agugiaro, G. (2016). First steps towards an integrated CITYGML-based 3D model of Vienna. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *3*(4), 139–146. https://doi.org/10.5194/isprs-annals-III-4-139-2016

Agugiaro, Giorgio, González, F. G. G., & Cavallo, R. (2020). The city of tomorrow from . . . The data of today. *ISPRS International Journal of Geo-Information*, *9*(9), 554. https://doi.org/10.3390/ijgi9090554

Atzeni, C., & Manias, M. (2006). *Manuale di recupero dei centri storici della Marmilla, del Sarcidano, dell'Arci e del Grighine*. DEI-Tipografia del Genio Civile.

Bonfanti, I., Colucci, E., De Ruvo, V., Del Giudice, M., Fasana, S., Iacono, E., Lingua, A., Matrona, F., Ventura, G., & Zerbinatti, M. (2021). Development of an integrated BIM-GIS management tool for maintenance plan of historical heritage. *Proceedings of the ARQUEOLÓGICA 2.0-9th International Congress & 3rd GEORES-GEOmatics and PREServation*, 1–8. https://doi.org/10.4995/arqueologica9.2021.12131

Cannarozzo, T. (2007). Centri storici come periferie: il caso del centro storico di Palermo, tra eccellenza e marginalità. *Conferenza INU "Territori e Città Del Mezzogiorno:"Quali Periferie*.

Cantatore, E., & Fatiguso, F. (2021). An energy-resilient retrofit methodology to climate change for historic districts. Application in the mediterranean area. *Sustainability (Switzerland)*, *13*(3). https://doi.org/10.3390/su13031422

Cantatore, Elena. (2022). *Resilienza ai cambiamenti climatici dei distretti storici in area mediterranea*. Gangemi Editore spa.

Cecchini, C. (2019). From data to 3D digital archive: A GIS-BIM spatial database for the historical centre of Pavia (Italy). *Journal of Information Technology in Construction*, *24*, 459–471. https://doi.org/10.36680/j.itcon.2019.024

Cervellati, P L, & Miliari, M. (1977). *I centri storici. Saggio bibliografico*. Guaraldi, Rimini-Firenze.

Cervellati, Pier Luigi, & Scannavini, R. (1973). *Bologna: politica e metodologia del restauro nei centri storici*.

Della Spina, L. (2021). Strategic Planning and Decision Making: A Case Study for the Integrated Management of Cultural Heritage Assets in Southern Italy. In *New Metropolitan Perspectives: Knowledge Dynamics and Innovation-driven Policies Towards Urban and Regional Transition Volume 2* (pp. 1116–1130). Springer. https://doi.org/10.1007/978-3-030-48279-4_104

Dembski, F., Wössner, U., Letzgus, M., Ruddat, M., & Yamu, C. (2020). Urban Digital Twins for Smart Cities and Citizens: The Case Study of Herrenberg, Germany. *Sustainability*, *12*(6), 2307. https://doi.org/10.3390/su12062307

Doerr, M. (2003). The CIDOC Conceptual Reference Module an Ontological Approach to Semantic Interoperability of Metadata. *AI Magazine*, *24*(3), 75–92.

Dugato, M. (2014). Strumenti giuridici per la valorizzazione dei beni culturali immateriali. *Aedon*, (1), 0.

Egusquiza, A., Prieto, I., Izkara, J. L., & Béjar, R. (2018). Multi-scale urban data models for early-stage suitability assessment of energy conservation measures in historic urban areas. *Energy and Buildings*, *164*, 87–98. https://doi.org/10.1016/j.enbuild.2017.12.061

Fiorani, D., Acierno, M., Donatelli, A., Martello, A., & Cutarelli, S. (2022). *Centri storici, digitalizzazione e* *restauro: Applicazioni e prime normative della Carta del Rischio* (Vol. 109). Roma: Sapienza Università Editrice. https://doi.org/10.13133/9788893772082

Gargaro, S., Del Giudice, M., & Ruffino, P. A. (2019). Towards a multi-functional HBIM model. *SCIRES-IT - SCIentific RESearch and Information Technology*, *8*(2), 49–58. https://doi.org/10.2423/i22394303v8n2p49

Gkadolou, E., Prastacos, P., & Loupas, T. (2020). Documentation of cultural heritage monuments with CityGML: an application for ancient theatres. *AGILE: GIScience Series*, *1*, 1–16. https://doi.org/10.5194/agile-giss-1-4-2020

Gröger, G., Kolbe, T. H., Nagel, C., & Häfele, K.-H. (2012). *OGC city geography markup language (CityGML) encoding standard*. Retrieved from https://portal.ogc.org/files/?artifact_id=28802

Il presidente della Repubblica. *Decreto del Presidente della Repubblica 6 Giugno 2001 n. 380 "Testo unico delle disposizioni legislative e regolamentari in materia edilizia. (Testo A)."* , (2001). Italy.

Il Presidente della Repubblica Italiana. *Decreto Legislativo 22 gennaio 2004, n. 42 "Codice dei beni culturali e del paesaggio", ai sensi dell'articolo 10 della legge 6 luglio 2002, n. 137.* , (2004). Italy.

Kilsedar, C. E., Fissore, F., Pirotti, F., & Brovelli, M. A. (2019). Extraction and visualization of 3D building models in urban areas for flood simulation. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*(2/W11), 669–673. https://doi.org/10.5194/isprs-Archives-XLII-2-W11-669-2019

Kolbe, T. H. (2009). Representing and Exchanging 3D City Models with CityGML. In *3D geo-information sciences* (pp. 15–31). Springer. https://doi.org/10.1007/978-3-540-87395-2_2

Lasorella, M., Cantatore, E., & Fatiguso, F. (2021). Smart approaches to enhance technical knowledge of in/low-accessible heritage. *SCIRES-IT - SCIentific RESearch and Information Technology*, *11*(2), 97–112. http://dx.doi.org/10.2423/i22394303v11n2p97

Ledoux, H., Arroyo Ohori, K., Kumar, K., Dukai, B., Labetski, A., & Vitalis, S. (2019). CityJSON: A compact and easy-to-use encoding of the CityGML data model. *Open Geospatial Data, Software and Standards*, *4*(1), 1–12.

Li, L., Tang, L., Zhu, H., Zhang, H., Yang, F., & Qin, W. (2017). Semantic 3D modeling based on CityGML for ancient Chinese-style architectural roofs of digital heritage. *ISPRS International Journal of Geo-Information*, *6*(5). https://doi.org/10.3390/ijgi6050132

Ma, Y.-P. (2021). Extending 3D-GIS District Models and BIM-Based Building Models into Computer Gaming Environment for Better Workflow of Cultural Heritage Conservation. *Applied Sciences*, *11*(5), 2101. https://doi.org/10.3390/app11052101

Marra, A., Trizio, I., Fabbrocino, G., & Savini, F. (2021). Digital models for e-conservation: the HBrIM of a bridge along the Aterno river. *SCIRES-IT - SCIentific RESearch and Information Technology*, *11*(2), 83–96. https://doi.org/http://dx.doi.org/10.2423/i22394303v11n2p83

Ministero della Sanità (1975). *Modificazioni alle istruzioni ministeriali 20 giugno 1986, relativamente all'altezza minima ed ai requisiti igienico-sanitari principali dei locali di abitazioni*. Decreto Ministeriale 5 luglio 1975 (G.U. n. 190 del 18.07.1975). Italy.

Ministero delle Infrastrutture e dei Trasporti (2018). *Aggiornamento delle "Norme tecniche per le costruzioni"*. Decreto 17 gennaio 2018 (G.U. Serie Generale n.42 del 20-02-2018 - Suppl. Ordinario n. 8) Italy.

Mohd Nasir, A. A., Azri, S., & Ujang, U. (2022). Managing 3D asset management using CITYGML concept.

Journal of Information System and Technology Management, *7*(25), 139–147. https://doi.org/10.35631/jistm.725011

Nasir, A. A. I. M., Azri, S., Ujang, U., & Majid, Z. (2020). Conceptual model of 3D asset management based on myspata to support smart city application in Malaysia. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *44*(4/W3), 313–322. https://doi.org/10.5194/isprs-archives-XLIV-4-W3-2020-313-2020

Nespeca, R. (2019). Towards a 3D digital model for management and fruition of Ducal Palace at Urbino. An integrated survey with mobile mapping. *SCIRES-IT - SCIentific RESearch and Information Technology*, *8*(2), 1–14. https://doi.org/http://dx.doi.org/10.2423/i22394303v8n2p1

Noardo, F. (2018). Architectural heritage semantic 3D documentation in multi-scale standard maps. *Journal of Cultural Heritage*, *32*, 156–165. https://doi.org/10.1016/j.culher.2018.02.009

Pasquinelli, A., Agugiaro, G., Tagliabue, L. C., Scaioni, M., & Guzzetti, F. (2019). Exploiting the potential of integrated public building data: Energy performance assessment of the building stock in a case study in Northern Italy. *ISPRS International Journal of Geo-Information*, *8*(1), 27. https://doi.org/10.3390/ijgi8010027

Pocobelli, D. P., Boehm, J., Bryan, P., Still, J., & Grau-Bové, J. (2018). BIM for heritage science: a review. *Heritage Science*, *6*(1), 30. https://doi.org/10.1186/s40494-018-0191-4

Prieto, I., Luis Izkara, J., & Béjar, R. (2017). A continuous deployment-based approach for the collaborative creation, maintenance, testing and deployment of cityGML models. *International Journal of Geographical Information Science*, *32*(2), 282–301. https://doi.org/10.1080/13658816.2017.1393543

Ravankhah, M., Schmidt, M., & Will, T. (2017). Multi-hazard disaster risk identification for World Cultural Heritage sites in seismic zones. *Journal of Cultural Heritage Management and Sustainable Development*, *7*(3), 272–289. https://doi.org/10.1108/JCHMSD-09-2015-0032

Suwardhi, D., Trisyanti, S. W., Virtriana, R., Syamsu, A. A., Jannati, S., & Halim, R. S. (2022). Heritage Smart City Mapping, Planning and Land Administration (Hestya). *ISPRS International Journal of Geo-Information*, *11*(2), 107. https://doi.org/10.3390/ijgi11020107

Will, T. (2012). Risk preparedness and the limits of prevention: safety vs. authenticity in the conservation of urban waterfronts. *Paper Delivered at the ICOMOS Scientific Symposium*.

Yaagoubi, R., Al-Gilani, A., Baik, A., Alhomodi, E., & Miky, Y. (2019). SEH-SDB: a semantically enriched historical spatial database for documentation and preservation of monumental heritage based on CityGML. *Applied Geomatics*, *11*(1), 53–68. https://doi.org/10.1007/s12518-018-0238-y

Yao, Z., Nagel, C., Kunde, F., Hudra, G., Willkomm, P., Donaubauer, A., … Kolbe, T. H. (2018). 3DCityDB-a 3D geodatabase solution for the management, analysis, and visualization of semantic 3D city models based on CityGML. *Open Geospatial Data, Software and Standards*, *3*(1), 1–26.

Yawer, A. S., Bakr, A. F., & Fathi, A. A. (2023). Sustainable urban development of historical cities: Historical Mosul City, Iraq. *Alexandria Engineering Journal*, *67*, 257–270. https://doi.org/10.1016/j.aej.2022.12.042

Zuccaro, G., Dolce, M., De Gregorio, D., Speranza, E., & Moroni, C. (2015). La scheda CARTIS per la caratterizzazione tipologico-strutturale dei comparti urbani costituiti da edifici ordinari. Valutazione dell'esposizione in analisi di rischio sismico. *Proceedings of the GNGTS*.