Resilient Improvement of Historic Districts via Digital Tools. The Virtualization of Energy Retrofit Actions Using Simplified CityGML-Based Plans

Elena Cantatore(✉), Margherita Lasorella, and Fabio Fatiguso

Department of Civil, Environmental, Building Engineering and Chemistry (DICATECh), Polytechnic University of Bari, 70126 Bari, Italy
{elena.cantatore,margherita.lasorella,fabio.fatiguso}@poliba.it

Abstract. The management of the built environment directly exposed to the effect of climate change and the assessment of buildings for their participation in such environmental processes are part of the main challenges in scientific, technical and administrative fields. On the other hand, the increasing endorsement of IT expertise and tools in traditional processes offers the opportunity to manage specific knowledge and relations using Digital Models. As unusual parts, historic centers represent unconventional districts of cities in treating mitigation and adaptation strategies, because of their overordered system of preservation normative framework and inherent formal and technical variabilities. Historic centers, as well as Cultural Heritage, require specific plans of actions for their resilient improvement to climate change. In that sense, the paper discusses and tests a simplified Digital Model based on the CityGML standard for the creation of a virtual recovery plan of historic districts, starting from previous results in supporting their management in an energy-resilient perspective. The Model has been conceived as a structured system of technical and scientific knowledge, re-organized according to the IT structure of CityGML to support public administration in managing adaptive and mitigative actions and practitioners in choosing compatible technical solutions.

Keywords: Digital model · Historic district · Energy-resilient and virtual plan

1 Introduction

Climate change and its unpredictability are, until now, a paramount challenge for technicians, scientists and administrators, above all in relating quantitative certainties on the effects, from natural eco-systems to anthropic systems as the cities. On the other hand, recent effects confirm the necessity to move towards strong and coherent actions that support mitigation on the climate change process and adaptability to the exposed systems. In cities, the built environment and the building sector represent the most challenging targets due to the dealings with urban users and energy relevance. In Europe, the building sector affects more than 40% of energy sources but just 1% of building stock

O. Gervasi et al. (Eds.): ICCSA 2021, LNCS 12956, pp. 155–172, 2021.
https://doi.org/10.1007/978-3-030-87010-2_11

is involved in renovation processes, delaying mitigation and adaptation goals expected in 2030 for this sector. This is widely recognized by the European Commission that announced the European Green Deal [1] to support the European transition towards climate-neutrality. As extensively highlighted in the document, climate neutrality can be supported by long-term combined strategies of mitigation and adaptation actions, increasing the resilience of cities.

The concept of resilient cities is linked to the necessity to analyse and manage cities prone to all the risk related to natural and anthropic hazards, also involved in climate-changing. However, the concepts of preparedness and readiness are fully implied in the resilient perspective, both for urban users and stakeholders. Thus, the management of wide territories requires the use of smart tools and systems. In fact, if the implementation of energy systems with ICTs can enhance the fast management of efficient supplies and control specific issues for urban or built environments, the digitalization of cities, in all their components, supports their knowledge by major public administrators of cities and wider territories. The concept of "Smart Cities" recently evolves towards the Urban "Digital Twin" (DT) as a digitalized version where different actors of the built environment study and manage urban challenges. Moreover, due to their nature, the use of digitalized cities and their parts allows sharing information, strategies, solutions and results among technicians and local administrations, overcoming the administrative borders of the single city landscape as required by the European Green Deal [1].

In the complex system of the urban built stock, historic buildings and landscape Heritage are part of an intricate and semi-paradoxical process of management. Such buildings require a depth transformation aimed at solving energy deficiencies, however, the necessity to preserve their social, cultural and environmental values limits the interventions. In the European frame, the management of Cultural and Landscape heritage is entrusted to the national authorities which provide their research and listing and define the national legislative frame of conservation and preservation, according to previous "Charters" [2]. However, near to the listed buildings, directly recognized as "Cultural Heritage", buildings in historic districts represent part of Landscape Heritage and usually still require primary recovery on the district, i.e., methane supplies, and building levels, e.g., static recovery [3]. Here, the normative frame is related to the regional landscape plans. Due to the nature of normative constraints, these buildings are not directly listed as single buildings but by means of regulations aimed at preserving them as a *unicum* of the district. Due to that, previous scientific experience in managing historic districts highlighted the use of "building types", as recurrent combinations of morpho-typological, constructive and material features [4], to overgo the singularities of traditional artefacts and to recognize the recurrent aesthetic and cultural values to preserve. Besides, this approach is in line with traditional planning instruments ("Recover plans for ancient core") for the management of such districts. Here, the process of recovery combines the relevance of values widely present in the ancient core to the system of suitable and allowed actions, in compliance with the overordered Authorities for their preservation. Moreover, such traditional buildings include some inherent features linked to the *genius loci* experiences; here, the resolution of residential needs and geo-morphological adaptation to local environmental features are part of inherent values to preserve as cultural and historical traces of human abilities to adapt to external stresses.

In the light of resilient management of such Heritage prone to the climate change process, the assessment of these buildings requires a coherent analysis of the described cultural and aesthetic values declined to the current challenges and constraints. These buildings are part of the existent stock that participates in the increasing CO_2 emissions and suffers the exposure of the consequent effects. However, specific strategies for their resilient improvement are still incomplete due to the inherent complexity derived by the preservation actions required, as well as in extending strategies and solutions overcoming the traditional process of refurbishment for single cases of listed buildings.

All the described issues involving the historic districts that are already solved by the authors in previous work [5], combining previous experiences of managing buildings in such part of cities. Here, a structured set of actions and solutions are identified for a representative case study as the result of the combined assessment of inherent adaptation capacities and energy deficiencies identified in a multi-scale approach.

The present work aims to complete the previous one by discussing and testing a structured database for sharing data and results based on its Digital Model. In detail, the work uses the CityGML database as a smart tool to generate a digitalized 3D district, organizing the resulted actions and solutions according to the "building type" scheme of analysis and creating a georeferenced database of buildings. These goals are planned in order to propose a system of technical actions that will support all the stakeholders involved in the management of such parts of cities; among them are included i) the increasing IT relevance in managing digitalized models, ii) technical and scientific knowledge for the management of district behaviour according to the discussed methodology, iii) public administrator in managing priority of interventions and compatible actions to suggest to iv) technical practitioners involved in designing final solutions.

2 CityGML Applications to the Cultural Heritage and Historic Urban Districts

Digital Twin is not a recent concept. However, the first applications were found in manufacturing and industrial sectors where the concept of "Industry 4.0" easily involved the creation of the Digitalized Model (DM) to control and assess processes and products [6]. Cities are the latest application for DM that follows the increasing trend in associating smart technologies aimed at monitor environmental or managing processes to the digitalized models, ensuring automatic dialogue among urban actors and digitalized city, as well as between digitalized and real city [7]. Moreover, DMs require to be structured in order to include and share all the virtualized parts or elements in the same platform as well as to have common tools for their interactions [8]. Today, all the created DMs are conceived aiming at the creation of Digital Twins applied to cities, districts or single buildings, encompassing several of their abilities [9]: i) import and observe sensing data in the real world and define the specific process of monitoring actions (related to the goals, i.e., pollution); ii) integrate and share data and knowledge according to structured and georeferenced data (i.e. geometric information and building properties and performances); finally, iii) simulate, predict and optimize urban behaviours in compliance with single domain (e.g. energy) or combined ones. If BIM architecture is the widest tool in treating buildings according to the DT concept, the CityGML architecture represents the most complete tool used by academia for the digitalization of cities or their part, correlating semantic and geographical data.

CityGML is an open data model based on an XML format adopted by the Open Geospatial Consortium (OGC). The main purposes of such IT architecture refer to the modelling, storage and exchange of virtual and semantic 3D city models and all the information related [10]. Finally, its structure is in line with the Geography Markup Language version 3.1.1 (GML3), the extendible international standard for spatial data exchange issued by the Open Geospatial Consortium (OGC) and the ISO TC211.

All the DMs represented in CityGML requires the association of real properties to specific feature classes in the models, as pre-organized in a proper structure. In detail, these are referred to i) geometric and topological information that includes spatial properties of single city objects and ii) thematic and semantic information aimed at improving the city objects and their properties considering the relations among them. The system of relations and classes of properties, as well as classes of city objects, are already determined in the CityGML standards that are applicable all-around the issues [11]. However, CityGML is an "extensible" architecture thanks to its implementable system of properties [12]. It is an enclosed property of the database which allows improving several classes of parameters with the "Generic" module according to which for any City object a set of wider properties can be related. On the other hand, when specific classes of properties and relations were already structured and validated by the OCG, CityGML can be improved by means of Application Domain Extensions (ADEs). Furthermore, the detail of the representation of city objects is another paramount issue in the CityGML standard. To very detailed geometric data correspond more detailed semantic features to associate specific classes of properties to single parts of city objects. In detail, five Levels of Detail (LODs) are determined referring to the LOD 0 up to LOD 4, moving from Regional to Interior model ("walkable" architecture) models [12].

Main characteristics and field of applications were discussed in [13] recognizing i) simulations on the noise spread and its mapping in cities, ii) energy assessment of buildings based on sensing tools and energy (cadastral) certificates, iii) urban and landscape planning, iv) various application in managing cadastral 3D data and v) disasters on the large scale and vi) vehicular and pedestrian traffic modelling and simulations [13].

As far as the goal of this work is concerned, in this section, a brief state of the art of CityGML applications to the historic district is discussed, in order to highlight common point of application and novelty. In detail, a selected number of previous works is chosen in the SCOPUS database, applying the filter "CityGML; AND Cultural Heritage; OR historic AND districts; AND application" to research papers (excluding reviews). The searching phase shown firstly 18 results, reduced to 17 for the availability of documents. Table 1 reports details of the analysed applications.

As far as the review is concerned, recurrent points of discussion are highlighted.

Table 1. Applications of CityGML structure on Cultural Heritage and Historic Districts. Reference reports the year of publication, the scale of application (S-BS for Sub-part of Building; SB Building scale; DS District Scale; CS City scale) and LoD for the cases (1 to 4), the aim of application and the type of extensibility (ADE, Generic enrichment G, any detail)

Ref.	Year	Application Scale - LOD	Aim of application – (type of extensibility)
[14]	2020	DS - LOD1; BS - LOD3	Analysis of historical evolution of the pilot historic district; insertion of a high-resolution 3D construction (any detail)
[15]	2020	BS - LOD3	Correlation between HBIM and CityGML ontologies to implement a 3D model in CityGML-based one (any detail)
[16]	2019	BS - LOD3	Reference for LOD, any CityGML integration (any detail)
[17]	2019	BS - LOD3	Correlation between HBIM and CityGML ontologies to implement a 3D model in CityGML-based one (G)
[18]	2019	BS - LOD4	Correlation between HBIM and CityGML ontologies to implement a 3D model in CityGML-based one (New ADE)
[19]	2018	BS - LOD4	Creation of 3D high-level-of-detail data harmonized with CityGML existing structure (new ADE)
[20]	2018	DS - LOD2	Assessment of parameters involved in Energy Conservation Measures for listed and common buildings in the historic district for the creation of an automatic generation of classes of priority for energy retrofitting (New ADE)
[21]	2018	DS - LOD1-2	Platform creation for the creation of a district CityGML-based model enriched with detailed point clouds of buildings (G)
[22]	2017	S-BS, LOD3	Semantic enrichment of LOD3 for ancient Chinese-style architectural roof styles (new ADE)
[23]	2017	SB - LOD3	Geometric data enrichment for texturized facade elements (G)
[24]	2016	DS - LOD1	Assessment of reduced parameters involved in planning management for energy retrofit priority for buildings in historic districts for the creation of a web-based platform (G)

(*continued*)

Table 1. (*continued*)

Ref.	Year	Application Scale - LOD	Aim of application – (type of extensibility)
[25]	2015	DS - LOD2	Geometry semantics analysis for landscape heritage visual protection (any detail)
[26]	2013	SB - LOD3	Coordination of 3D model semantics and CH class (New ADE)
[27]	2013	Any	Web application based on CityGML ontologies (any detail)
[28]	2010	Any	Creation of CityGML-based APP applied to CH aiming at the import and visualize detailed 3D models (New ADE)
[29]	2010	Any	Creation of CityGML-based APP applied to CH aiming at the import and visualize detailed 3D models (New ADE)
[30]	2010	Any	Enrichment of semantics for archaeological sites combining CityGML and CIDOC-CRM (G)

CityGML applied to CH and historic districts is part of a recent issue of analysis that covers the last 12 years in the scientific world. Near to that, applications moved from the large scale of 3D models on the district scale to the single building one. Here, the use of the large scale for models is not an overcome issue for scientists and technicians but the attention is moved towards the HBIM and BIM model implementation in CityGML-based ones as the result of the increasing trend in using high-resolution models for the management of listed buildings.

All the analysed works focus on the necessity to balance the proper LOD to the semantic issues of the model. Obviously, to the high level of representation corresponds more information details that involve both geometric and technical data. When high-resolution models have been discussed for CityGML implementation the system of ontologies required to be enriched according to the relative modelled structure (as building) or parts (i.e., walls, roofs). Nevertheless, for all the cases, basic ontologies for CityGML are implemented according to the nature of the real environment, as well as to the real aim of the representation. Thus, if for BS cases the main goal is the identification of a structured system of properties and processes aimed at importing high-resolution model (HBIM/BIM-based) and maintaining the native ontologies by means of the semantic implementation of CityGML ontologies, for large scale of representation (DS) CityGML ontologies requires to be reorganized and structured according to the main aim of the representation and goals. Here, the main classes of ontologies are referred to medium scale of details for historic buildings, including both geometric and semantic data for their conservation. In that sense, all the works highlighted the necessity to determine and use a homogeneous system of ontologies for CH, as a proper ADE, or when it cannot be possible, structure a coherent system of features classes.

3 The Energy-Resilient Management for Historic Districts by Means of CityGML-Based Models

3.1 Background on the Methodological Frame in Managing the Built Stock in Historic Districts

As discussed in Sect. 1.1, the present work is related to a previous one presented by the authors, where a structured methodology for the management of energy-resilient retrofit actions for buildings in historic districts that combine their inherent adaptability and transformability capacities [5]. These are based on a multi-scale approach based on the theories of "resilient thinking" according to which every system exposed to external stress can be assessed focusing on its aptitude to transform and adapt itself. Borrowing it for the urban systems of historic districts, the transformation ability (or transformability level) consists in the building attitude to be modified without altering its historical and architectural features as inherent results of technological construction features (and relative preservation level) and state of disrepair, analysed for each sub-component of the envelope. Furthermore, the adaptability of such buildings includes classes of positive effects in energy consumption derived by boundary conditions (e.g. shading effects for the compact arrangement of blocks) and technical solutions at building scale (e.g. massive walls, stack effect) that are associated to inherent bioclimatic features in the traditional built environment. These classes of transformability and adaptability are useful in assessing the built stock according to combination classes of such capabilities, identified as MUERIs (Minimum Units of Energy-Resilient Intervention). Finally, for all of them, a system of solutions is provided as guidelines for technical practitioners including materials and technics compatible with the existing solutions. MUERIs are identified for each "building type" as recurrent combinations of technical, material features and main morpho-typologies of buildings. Combining administrative features for such buildings and major experimental results, recurrent geometric features and specific semantic data should be collected and organized. Specifically, for the geometric details, the footprint and the height of buildings are required to define the virtual geometry of 3D buildings. On the other hand, semantic information can be structured according to six main classes: i) administrative data; ii) directly derived from onsite measures, or iii) indirectly from normative preservation framework (city or regional); iv) external measures; v) final data for the management of energy transformation. Specifically, Table 2 reports the details of required features, classified according to the described classes and specified according to the inherent meaning (description).

3.2 Technical Approach for the Web-Service Development

The creation of a CityGML as a web-service instrument can be based on interoperable tools. Notably, among the other, four tools are identified for the creation of the free web server based on CityGML architecture.

Safe FME (Feature Manipulation Engine) is a Spatial ETL (Extract Transform Load) software used for the conversation of main data in proper format files, including spatial and semantic information. It is based on a graphical interface that allows a simplified

Table 2. Classification of collected features in GIS, highlighting classes of data and description

Data classes	Feature	Description
Geometric data		
	Height [He]	Height of building
	Building footprint [BF]	Geometric data inherent in the .shp file
	Number of Floors [F]	Number of floors
Semantic data		
Administrative data	Cadastral data [CD]	Administrative information of buildings
	Construction Period [CP]	Referred to the historic development of district
	Construction class [CC]	Class of construction artefacts (church, castle)
	Property [PP]	Type of properties (public or private)
	Use of Building [UB]	Main Uses for buildings (residential, touristic)
Normative framework	Preservation codes [PC]	System of compatible actions for each type of dispersant surface
	Preservation restriction [PR]	Listed buildings according to the national or regional framework
Onsite survey	State of maintenance [SM]	Referred to each dispersant surface
	Morpho-typology [MT]	Recurrent building types (tower, palace houses, etc.)
External measures	Classes of dispersant surfaces [CS]	For each dispersant surface, materials and technologies involved in the construction
Data for the management of energy transformations	Transformation levels [TL]	For each relevant sub-system, the level of transformability
	Adaptability levels [AL]	For each relevant sub-system of the envelope, the level of adaptability
	System of actions [SA]	For each relevant sub-system of the envelope, the system of technical solutions
	MUERI code [MUERI]	Identified for each Building type, a technical sheet of compatible resilient solutions

conversion of data based on specific categories of functions [31]. FME also supports the validation of the CityGML schema, thus, to check semantics and their relations.

Near to that, the online "Val3dity" tool is chosen to validate 3D primitives according to the international standard ISO 19107 [32].

3D City Database (3DCityDB) is an open-source software based on and structured according to the CityGML structure. The database architecture supports ORACLE Spatial and PostgreSQL/PostGIS relations and it is based on the CityGML v.2.0 for LODs up to 4. The 3DCity database is equipped with the 3DCityDB Import/Exporter tool, useful for the creation of semantic relations between the starting database and the CityGML standards, including geometric and semantic features. Moreover, the software allows to import CityGML data and export KML/COLLADA/gITF data, to integrate and manage data through external spreadsheets and ADE structures [33].

Finally, the 3DCityDB Web-Map-Client is a free viewer based on a simple web-browser (APACHE structure), structured as an extension of Virtual Globe CesiumJS WebGL. The Web-Map-Client aims at the visualization of the virtualized city models and properties in the webpage, importing them following the CityGML standards. The easily use help users in interacting with the DMs showing the structured details. It is fully compatible with KML/gITF files exported from the 3DCityDB Import/Exporter tool. The upload of model databases can be available for two classes of users: end-users that can just upload and visualize the data and overarched-users able to manage the contents of databases. It is possible thanks to the management of thematic features through external sheets (i.e. Spreadsheet Google API or PostgreSQL REST API) [34], restricting accesses to a limited number of users.

3.3 Method for a Simplified CityGML-Based Plan for Historic Districts

Due to the methodological background and the aim of the work, the DM could support public administrators, in managing acceptable transformations, and practitioners, in choosing relevant and compatible solutions. Thus, the model cannot automatically qualify the required solutions, but it is proposed as a digitalized version of the traditional energy plans for historic districts as the results of external analyses made by technical and IT expertise. The creation of the interactive web service is based on the tools described in previous sub-section. However, it requires a structured system of actions for the digitalization of real cases and the organization of semantic data, considering specialistic capacities and functional activities. In detail, the model is structured according to the CityGML structure of data based on LOD1 ("block model") and the information required for the aim. Method, tools and data are summarized in Fig. 1.

Phase 1 consists in the processing and translation data stage. All the collected data in GIS (.shp file), concerning geometric and sematic features (see Table 1), are translated according to the CityGML standard (.gml file). The process follows the specific workflow ETL in FME in order to create the system of (vertical) relations between single city objects to attributes, as well as (horizontal) relations among them. In detail, aims and tools are described as follows:

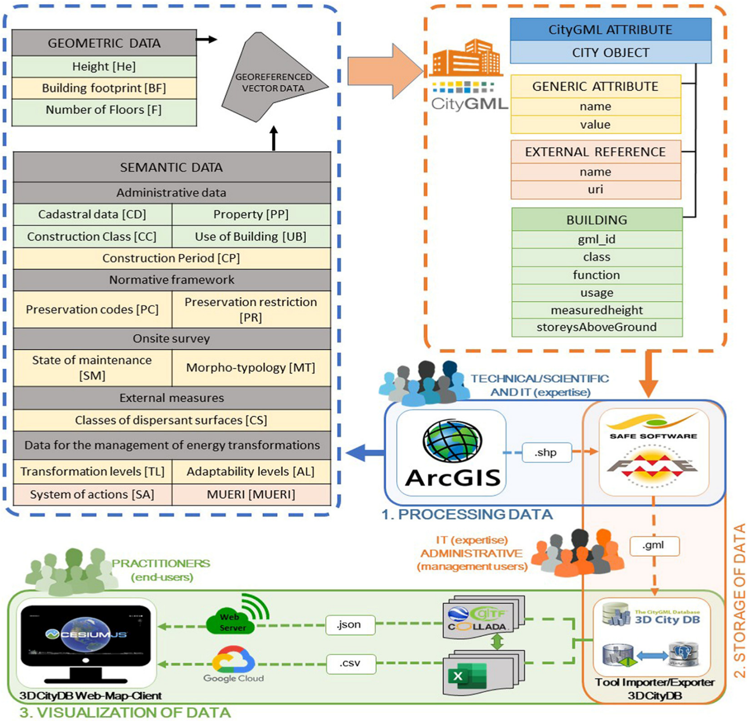

Fig. 1. Process and tools involved in the creation of the simplified CityGML model

– geometric information is processed extruding the footprint using the height of buildings derived by DSM, for the full representation in LOD1 (transformer: Extruder);
– Codification of buildings according to the Cadastral information; all the extruded buildings are associated to a specific alphanumeric ID that includes the cadastral data (transformer: UUIDGenerator and String Concatenator), aiming at supporting final activities of searching and visualization of objects and data;
– Generation of CityGML attributes, where all the .shp features are translated in the CityGML standard (script: AttributeCreator);
– Identification of relations between geometric building and attributes, aiming at the enrichment of extruded buildings with sematic information (CityGML LOD Name: Lod1MultiSurface; FeatureRole: cityObjectMember);
– Creation of CityGML model and concordance with thematic classes; here, all the data are related to the features of "building" classes, when already structured with the CityGML standard, or to the "_genericAttribute" and "ExternalReferences" as a conclusive semantic enrichment. Specifically, an ExternalReference defines a hyperlink from a _CityObject to a corresponding object in another information system. Each of them includes the name of the external information system, represented by a URI, and the reference of the external object, given either by a string or by a URI.

In this phase the validation of the model is included, by means of the CityGML writer option included in the FME Workbench, as well as the geometric validation of features using the Val3dity tool. In this stage are included the scientific and technical expertise resulting from the analysis of the districts as i) the critical management of semantic data derived resulting from external calculations, ii) the critical reading of buildings properties (onsite surveys, external measures) and iii) the normative framework for the preservation of the site. Other geo-topological information (construction classes and cadastral ID), as well as the functional ones (property, use), include technical information organized to solve the administrative level of knowledge. At the same time, guidelines for practitioners are created using specific sheets, including all the descriptions.

Phase 2 aims at the storage of a queryable and editable database with conditional accesses. Here, the structure of features is imported in the 3DCityBD using the relational database based in PostgreSQL/PostGIS that can be readable by means of a specific graphical interface. The process requires a medium-high level of IT support (expertise) due to the programming procedure. In fact, in this phase the database is also prepared for the management of data between final users (administrative and technical). In that sense, .csv files can be created from the database to be shared with different levels of accessibility in the Google Cloud Platform by means of Google sheets API.

Phase 3 consists in the visualization of data in the front-end webpage. Particularly, the model is queryable for cadastral information of buildings and all the related semantic data are shown in the specific pop-windows. The importing process for the visualization by the authorized users requires both.json file and data, organized in sheets in the previous phase. The use of Google sheets allows the visualization of thematic data, while only administrative ones are authorized to modify and manage the contents.

4 Application to the Case Study

According to the work aim, this section presents the experimental proposal of the web-service. Due to the big amount of data required for the creation of the database, the application is traced for the case study presented and validated for the management of the built stock in the historic district in previous work. Particularly, it is the case of the ancient core of Molfetta, a city located in the south of Italy in the Apulia region.

This urban district has a medieval foundation featured by a regular structure in building arrangement, organized in long blocks. These are organized shaping narrow streets canyons and creating consequent compactness of the district. The historical and slow process of recovery plans created local variations in such inherent enclosed structure, generating local exceptions to the main feature (i.e., squares and garden).

In addition to special buildings as churches, the building stock is featured by two main typologies, tower and palace houses, mainly used for residential aims that differ from the orientation of living spaces. As common geometric features, all the buildings are classified for the number of floors and heights for them, to create the simplified building models. For both the typologies, the built stock is analysed summarizing technologies and materials involved in dispersant surfaces, organizing them for recurrent typologies (e.g. wooden, concrete roofs or vaults) and consequent thermal and optical properties directly involved in the energy assessment. For each of them, an alphanumeric

Table 3. Relation of collected attributes and CityGML semantics for the case study

Class of feature	Title of attribute	Data type	Name of attribute	Class of city object
Height [He]	Height	gml::LenghtType	measuredHeight	Building
Building footprint [BF]	Floor extension	xs::string gml::MeasureType	name value	genericAttribute
Number of Floors [F]	Floors	xs::nonNegativeInteger	storeysAboveGround	Building
Cadastral data [CD]	Sheet_Parcel	xs::string	gml_id	Building
Construction Period [CP]	Constr_period	xs::string	name value	genericAttribute
Construction class [CC]	Constr_class	gml::CodeType	class	Building
Property [PP]	Property	gml::CodeType	usage	Building
Use of Building [UB]	Building_use	gml::CodeType	function	Building
State of maintenance [SM]	SM_wall SM_roof	xs::string	name value	genericAttribute
Morpho-typology [MT]	Building_Type	xs::string	name value	genericAttribute
Classes of dispersant surfaces [CS]	Wall_Type_code Roof_Type_code	xs::string	name value	genericAttribute
Preservation codes [PC]	Pres_Code_wall Pres_Code_roof Pres_Code_window Pres_Code_groundfloor Pres_Code_Basement	xs::string	name value	genericAttribute

(*continued*)

Table 3. *(continued)*

Class of feature	Title of attribute	Data type	Name of attribute	Class of city object
Preservation restriction [PR]	Listed_building	xs::string	name value	genericAttribute
Transform. levels [TL]	Transf_Wall Transf_Roof	xs::string	name value	genericAttribute
Adaptability levels [AL]	Adapt_wall Adapt_roof	xs::string	name value	genericAttribute
System of actions [SA]	Action_Code_Wall_therm Action_code_Roof_therm Action_code_Roof_opt Action_code_Roof_inert	xs::string	name value	genericAttribute
Description of actions	Action_link	xs::string xs:anyURI	name uri	ExternalReference
MUERI [Mx]	MUERI	xs::string xs:anyURI	name uri	ExternalReference

code is associated to simplify the codification in the database. Moreover, linking them to the district recovery plan (developed by urban administration) and strategies for the preservation of landscape protection (identified at regional scale), the equivalent system of preservation alphanumeric codes is generated. This process is based on the qualification of multiple combinations of techniques, materials and building typologies and supported the creation of a simplified database in the GIS model. The external analysis focused on inherent energy deficiencies for dispersant surfaces. Major relevance is associated to roofs and walls, considering the combination of thermal, optical and inertial deficiencies and only thermal one, respectively. Moreover, due to the compactness of the district, walls are also analysed for the assessment of inherent qualities derived by compact cities. In detail, vertical components are assessed to evaluate bioclimatic consequences of the high shading between buildings, take into account i) the variation of air temperatures along the narrow street canyons and large squares and ii) the energy effects derived by direct solar radiations on vertical surfaces. Finally, "transformation levels" and "adaptability levels" are associated to walls and roofs. All the described information was implemented in the GIS model by means of a .shp file and it constitutes the main system of features to transform in the CityGML attribute. In particular, Table 3 summarizes .shp attributes and the transformed ones in the CityGML standard, according to the method. The 3D model has been created using geometric information derived from the DSM of Molfetta (LIDAR based, resolution of grid 2×2) obtained by the Italian Geoportale [35], featured by a planar and height accuracy of 0.3 m and 0.15 m. Finally, the created model has been geometrically and semantically validated according to the method.

Following phases 2 and 3, the 3DCityDB web-map client has been designed in order to visualize contents and manage accesses (Fig. 2). The use of cadastral data as ID of buildings helps technicians in searching for the specific building in the web-map, highlighting the searched building in the virtual model (Fig. 2). Specifically, the ID name is identified by combining Cadastral Sheet and Parcel according to the Italian structure.

As far as the visualization of information is concerned, at the right of Fig. 2, the pop-windows shows all the catalogued and structured data for the selected building. Special attention is given to the "Action_link" and "MUERI" attributes. For them, the database is structured using a website link (.http) that allows users to show the specific sheet of detailed actions in separated webpages (Fig. 3). Here, the complete sheet of MUERI information and detail of compatible actions are described as technical details to support the final solutions of practitioners. In detail, in Fig. 3 technical sheets of MUERI 1 and detailed information of actions are reported (Fig. 3a and Fig. 3b, respectively).

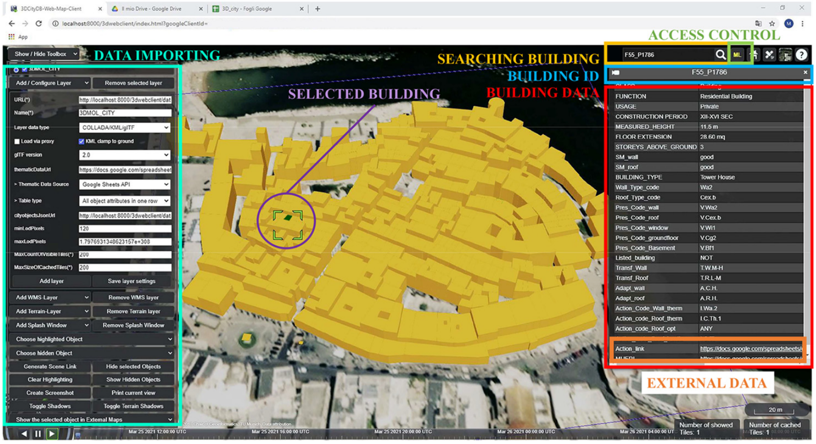

Fig. 2. Web-page structure and details of information and data

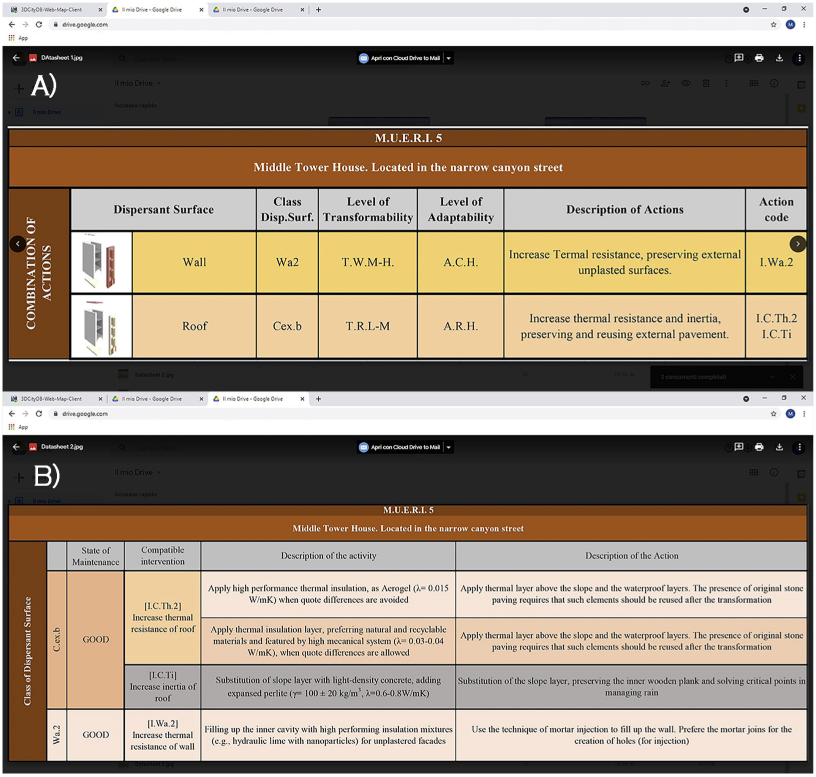

Fig. 3. External sheets generated for the MUERI 5 about Tower Houses (A) and detailed actions for the practitioners (B)

5 Conclusions

The increasing use of virtual models to manage cities moved the IT experiences in creating tools and system to support multiple aims. Today, BIM and CityGML-based are the most used tools for the representation and management of buildings and city/districts with their parts, respectively. However, the virtualization process requires coherent and severe structure to correlate the data visualization to the correlated information. When these tools are applied to the management of urban infrastructures, relations between data and users involved became complex, both for the amount of data and relations as well as for the expertise. It is exasperated when the infrastructure is the Cultural Heritage in all its macro-classes. Here, the knowledge of such buildings has to consider several technicians and an over-ordered normative framework, requiring that collected data should be translated in a universal language to be shared with all the users.

This work is part of the structured application of digitalized knowledge for Architecture, Engineering, Construction and Operations (AECO), aiming at supporting the management of data for historic districts with specific application to the energy-resilient plans by means of CityGML potentialities. Moreover, the work is presented as a coherent *continuum* with previous theoretical results discussed by the authors, where the creation of a digitalized recovery plan for building in historic districts support the share knowledge between users and stakeholders involved in the process. According to the increasing trend in modelling and sharing data for CH, CityGML represents an efficient tool in managing high-resolution models derived by BIM, as a spreading request for the public buildings. However, the CityGML does not present a parallel tool to achieve the experimental results but a system to collect all the data, coherently with the traditional systems of "recovery plans" for historic districts. In detail, starting from the structure of objects and semantic data, the work presents how knowledge can be structured in order to be harmonized with the CityGML architecture towards a web-service for the goal. The main attention is set to the end-users of this plan, public administrators and private technicians, allowing the management and the visualization of design choices, respectively, following a set of over-ordered compatible solutions. Moreover, the application offers the opportunity to test the shared knowledge for future scenario application, as well as to join it freely and available anywhere and any time.

Despite the enclosure of CityGML structures for attributes, the process highlighted a convenient and compatible system of data organization, bypassing the necessity to create an ADE. However, it represents a future scenario for the work. In this attempt, the proposal will be tested with final users of the platform, also creating a proper manual of instruction as well as a specific sheet to help the data reading, as fundamental elements for the translation of technical and IT knowledge in real actions of practitioners.

Acknowledgements. This research is funded under the project "AIM1871082-1" of the AIM (Attraction and International Mobility) Program, financed by the Italian Ministry of Education, University and Research (MUR).

References

1. Commission European Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The European Green Deal. COM/2019/640 final (2019)
2. De Naeyer, A., Arroyo, S.P., Blanco, J.R.: Krakow charter 2000: principles for conservation and restoration of built heritage (2000)
3. Cantatore, E., Fatiguso, F.: Riabitare il patrimonio edilizio dei centri storici come strategia di retrofit energetico – un caso studio. In: D'Andria, P.F.E. (ed.) Small towns… from problem to resource Sustainable strategies for the valorization of building, landscape and cultural heritage in inland areas, pp. 1193–1201. FrancoAngeli, Milano (2019)
4. Cyx, W., Renders, N., Van Holm, M., Verbeke, S.: IEE TABULA-typology approach for building stock energy assessment. Mol, Belgium (2011)
5. Cantatore, E., Fatiguso, F.: An energy-resilient retrofit methodology to climate change for historic districts. Application in the mediterranean area. Sustainability **13**(3), 1422 (2021)
6. Tao, F., Zhang, H., Liu, A., Nee, A.Y.C.: Digital twin in industry: state-of-the-art. IEEE Trans. Ind. Informatics **15**, 2405–2415 (2018)
7. Fuller, A., Fan, Z., Day, C., Barlow, C.: Digital twin: enabling technologies, challenges and open research. IEEE Access **8**, 108952–108971 (2020)
8. Jones, D., Snider, C., Nassehi, A., Yon, J., Hicks, B.: Characterising the digital twin: a systematic literature review. CIRP J. Manuf. Sci. Technol. **29**, 36–52 (2020)
9. Boje, C., Guerriero, A., Kubicki, S., Rezgui, Y.: Towards a semantic construction digital twin: directions for future research. Autom. Constr. **114**, 103179 (2020)
10. Gröger, G., Kolbe, T.H., Nagel, C., Häfele, K.-H.: OGC city geography markup language (CityGML) encoding standard (2012)
11. Stadler, A., Kolbe, T.H.: Spatio-semantic coherence in the integration of 3D city models. In: Proceedings of the Proceedings of the 5th International ISPRS Symposium on Spatial Data Quality ISSDQ 2007 in Enschede, The Netherlands, 13–15 June 2007 (2007)
12. Kolbe, T.H.: Representing and exchanging 3D city models with CityGML. In: Lee, J., Zlatanova, S. (eds.) 3D geo-information sciences, pp. 15–31. Springer, Heidelberg (2009). https://doi.org/10.1007/978-3-540-87395-2_2
13. Gröger, G., Plümer, L.: CityGML–interoperable semantic 3D city models. ISPRS J. Photogramm. Remote Sens. **71**, 12–33 (2012)
14. Pepe, M., Costantino, D., Alfio, V.S., Angelini, M.G., Garofalo, A.R.: A CityGML multiscale approach for the conservation and management of cultural heritage: the case study of the old town of taranto (Italy). ISPRS Int. J. Geo-Information **9**, 449 (2020)
15. Colucci, E., De Ruvo, V., Lingua, A., Matrone, F., Rizzo, G.: HBIM-GIS integration: from IFC to cityGML standard for damaged cultural heritage in a multiscale 3D GIS. Appl. Sci. **10**, 1356 (2020)
16. Hejmanowska, B., et al.: The comparison of the web GIS applications relevant for 4D models sharing. In: Proceedings of the IOP Conference Series: Earth and Environmental Science, vol. 362, p. 12158. IOP Publishing (2019)
17. Matrone, F., Colucci, E., De Ruvo, V., Lingua, A., Spanò, A.: HBIM in a semantic 3D GIS database. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **42**(2), W11 (2019)
18. Yaagoubi, R., Al-Gilani, A., Baik, A., Alhomodi, E., Miky, Y.: SEH-SDB: a semantically enriched historical spatial database for documentation and preservation of monumental heritage based on CityGML. Appl. Geomat. **11**(1), 53–68 (2018). https://doi.org/10.1007/s12518-018-0238-y
19. Noardo, F.: Architectural heritage semantic 3D documentation in multi-scale standard maps. J. Cult. Herit. **32**, 156–165 (2018)

20. Egusquiza, A., Prieto, I., Izkara, J.L., Béjar, R.: Multi-scale urban data models for early-stage suitability assessment of energy conservation measures in historic urban areas. Energy Build. **164**, 87–98 (2018)
21. Prieto, I., Izkara, J.L., Mediavilla, A., Arambarri, J., Arroyo, A.: Collaborative platform based on standard services for the semi-automated generation of the 3D city model on the cloud. In: Proceedings of the eWork and eBusiness in Architecture, Engineering and Construction: Proceedings of the 12th European Conference on Product and Process Modelling (ECPPM 2018), Copenhagen, Denmark, 12–14 September 2018, p. 169. CRC Press (2018)
22. Li, L., Tang, L., Zhu, H., Zhang, H., Yang, F., Qin, W.: Semantic 3D modeling based on CityGML for ancient Chinese-style architectural roofs of digital heritage. ISPRS Int. J. Geo-Information **6**, 132 (2017)
23. Slade, J., Jones, C.B., Rosin, P.L.: Automatic semantic and geometric enrichment of CityGML building models using HOG-based template matching. In: Abdul-Rahman, A. (ed.) Advances in 3D Geoinformation. LNGC, pp. 357–372. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-25691-7_20
24. Egusquiza, A., Prieto, I., Izkara, J.L.: Web-based tool for prioritization of areas for energy efficiency interventions in historic districts. In: Proceedings of the Euro-American Congress REHABEND 2016, May 24–27, 2016. Burgos, Spain (2016)
25. Rubinowicz, P., Czynska, K.: Study of city landscape heritage using LiDAR data and 3D-city models. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **40**, 1395 (2015)
26. Costamagna, E., Spanò, A.: CityGML for architectural heritage. In: Rahman, A.A., Boguslawski, P., Gold, C., Said, M.N. (eds.) Developments in multidimensional spatial data models, pp. 219–237. Springer Berlin Heidelberg, Berlin, Heidelberg (2013). https://doi.org/10.1007/978-3-642-36379-5_14
27. San Jose, J.I., et al.: An open source software platform for visualizing and teaching conservation tasks in architectural heritage environments. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. **5**, W2 (2013)
28. Finat, J., Delgado, F.J., Martinez, R., Hurtado, A.: GIRAPIM A 3D information system for suveying cultural heritag environments. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. (2010)
29. Delgado, F., Martínez, R., Hurtado, A., Finat, J.: Extending functionalities of management systems to CityGML. eWork Ebus. Archit. Eng. Constr. 409–415 (2010)
30. Felicetti, A., Lorenzini, M., Niccolucci, F.: Semantic enrichment of geographic data and 3D models for the management of archaeological features. In: Proceedings of the Proceedings of the 11th International conference on Virtual Reality, Archaeology and Cultural Heritage, pp. 115–122 (2010)
31. Safe Software FME. www.safe.com/fme
32. Ledoux, H.: val3dity: validation of 3D GIS primitives according to the international standards. Open Geospatial Data Softw. Stand. **3**(1), 1–12 (2018). https://doi.org/10.1186/s40965-018-0043-x
33. Yao, Z., et al.: 3DCityDB-a 3D geodatabase solution for the management, analysis, and visualization of semantic 3D city models based on CityGML. Open Geospatial Data Softw. Stand. **3**, 1–26 (2018)
34. Chaturvedi, K., Yao, Z., Kolbe, T.H.: Web-based Exploration of and interaction with large and deeply structured semantic 3D city models using HTML5 and WebGL. In: Proceedings of the Bridging Scales-Skalenübergreifende Nah-und Fernerkundungsmethoden, 35. Wissenschaftlich-Technische Jahrestagung der DGPF (2015)
35. Italian Minister for Ecological Transition Geoportale Nazionale. http://www.pcn.minambiente.it/mattm/servizio-wms/. Accessed 30 May 2021