Extension of the CityGML Schema for a New Model of Accessible Urban Environment

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Abstract

The study explores the extension of the CityGML schema to improve accessibility analysis in urban environments. Given the increasing focus on making cities more inclusive, particularly historical centres, managing urban accessibility requires a multidisciplinary approach integrating cartographic and architectural data. The methodology involves data collection by geomatic sensors to realize 3D urban models using CityGML, incorporating semantic, geometric, and topological information to assess accessibility barriers. Through the Application Domain Extension mechanism, a new "UrbanAccessibility" class is introduced, enabling detailed mapping of urban obstacles and facilitating the design of inclusive pathways. The process involves with data management by means mobile mapping system, followed by 3D modeling and semantic structuring in a GIS geodatabase. The resulting model allows for real-time analysis, supporting accessibility plans such as the PEBA (Barrier-Free Environmental Planning) and PAU (Plan for Urban Accessibility Plan). The integration of accessibility attributes by CityGML enhances decision-making tools for urban planners and policymakers, promoting sustainable and inclusive urban development. Furthermore, the approach not only ensures continuous monitoring and updating of accessibility data but also advances urban planning towards a more equitable and barrier-free environment.

1. Introduction

In recent decades, there has been a renewed focus on urban environments, particularly historical centres, highlighting their dual role within the urban context: as a socio-cultural value to be protected and enhanced, and as existing urban realities to be planned and made more accessible (ICOMOS 2011, UNESCO 2011). This dichotomy introduces a complex issue that forces local authorities to manage these urban realities as articulated systems. It is, therefore, a multidisciplinary approach that concerns both the territory and the urban environment in its various physical and functional components. This requires the implementation of multi-scale tools and the definition of accessible and shared digital databases for information management. Moreover, the amount of heterogeneous information to be managed is constantly growing, making the issue of data semantics crucial, alongside the 3D modeling of built environments, in order to implement an information system suitable for the appropriate scale (Colucci et al., 2021; Gorgoglione et al., 2023).

New computer applications related to GIS, particularly CityGML (OGC)[1], make it possible to manage geometric, topological, and semantic information so that it can be shared and correctly interpreted. CityGML can offer a structured and standardized approach to support various urban management plans, including the so-called accessibility plans for urban environments, such as the PEBA (Barrier-Free Environmental Planning, Italian Law No. 41/1986) and the PAU (Urban Accessibility Plan, Italian Law No. 104/1992).

Urban plans, which have become mandatory, aim to overcome architectural and sensory barriers with provisions related to the accessibility of urban spaces, particularly concerning the identification of obstacles and the creation of accessible and inclusive pathways. The management of urban plans can be facilitated through an extension of the semantic domains (ADE - Application Domain Extension, Biljecki et al., 2018, Zarei and Nik-Bakht, 2024) of CityGML, allowing the integration of accessibility-related features and attributes into the 3D digital urban model.

[1] https://www.ogc.org/it/publications/standard/citygml/

2. State-of-the-Art

2.1 CityGML 3.0 and ADE

CityGML standard defines the open Conceptual Model (CM) for storing and exchanging virtual 3D city and landscape models, covering key urban elements such as buildings, transportation, vegetation, and terrain. The schema specifies how real-world objects are classified and decomposed, representing their semantics, 3D geometry, topology, appearances, and temporal changes. Objects can have multiple spatial representations (indoor and outdoor) across four Levels of Detail (LOD 0-3)[2]. The CityGML 3.0 CM is formally defined via UML class diagrams. It serves as the foundation for encoding standards that map its concepts to exchange formats or databases.

Beyond 3D visualization, CityGML supports applications in decision-making, urban planning, Smart Cities, facility management, indoor/outdoor navigation, BIM integration, autonomous driving, and simulations (Kolbe, 2009). Many applications already utilize CityGML, with some requiring it (Wysocki et al., 2024).

CityGML CM allows easy enrichment of 3D objects with thematic data, such as traffic density for streets or energy demand for buildings. Even building parts (e.g., roofs or walls) can include details on solar irradiation and insulation. Various domain-specific extensions have been developed for CityGML CM (Biljecki et al. 2018).

CityGML serves as a universal information model, defining object types and attributes for various applications. However, real-world 3D city models often require additional attributes or object types not explicitly covered by CityGML.

An ADE is a structured extension of the CityGML CM tailored for a specific application or field. It is represented as a UML conceptual model, where domain data is linked to extra classes, attributes, and relationships. ADEs can utilize elements from the CityGML CM to create application-specific subclasses, add extra properties, link application data to existing CityGML content, or define value ranges for attributes.

[2] https://docs.ogc.org/is/20-010/20-010.html

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An ADE must be defined following the guidelines for creating application schemas in UML outlined in ISO 19109:2015, as well as the rules and constraints for using UML to model geographic information specified in ISO 19103:2024.

The ADE mechanism in CityGML is widely used to support various applications by enriching the standard data model with specialized attributes and features referred to urban environment (Biljecki et al. 2018). Among the most mature and widely implemented ADEs is the Energy ADE (Agugiaro et al., 2018), developed by European institutions to enhance urban energy modeling. Another well-established extension is the Noise ADE (Kumar et al., 2017), included in CityGML 2.0, which supports noise pollution modeling by segmenting roads based on noise requirements. Other notable ADEs include the UtilityNetwork ADE, which models utility networks such as water and electricity with detailed operational parameters (Hijazi et al., 2017). Additionally, the Hydro ADE aids in dynamic 3D flood modelling (Shen et al., 2020), while the Air Quality ADE integrates air pollution data into city models (Arco et al, 2016).

Overall, these ADEs significantly extend CityGML's capabilities, making it adaptable to specialized domains such as urban planning, energy efficiency, noise mapping, and environmental monitoring.

In the literature, there is only one case of ADE applied to urban accessibility, specifically in the definition of accessible pathways within the urban environment. ADE-AP aims to improve pedestrian mobility in smart cities, especially for individuals with mobility impairments. It provides accessible pathways based on widely agreed-upon standards, ensuring that developers can create personalized applications for safe and comfortable navigation. The study demonstrates the extension's benefits by comparing typical route options with accessible pathways preferred by people with disabilities, such as wheelchair users (Wheeler et al., 2020).

2.2 Accessibility Plans for Urban Environment: Italian Study Case

Italian Law No. 41 of February 28, 1986, in Article 32, paragraph 21, introduces the obligation to draft PEBA (Barrier-Free Environmental Planning) aimed at overcoming architectural barriers in public buildings and their surrounding areas. Italian Law No. 104 of February 5, 1992, in Article 24, paragraph 9, introduces PAU (Urban Accessibility Plan), extending the accessibility requirement to all urban and extra-urban spaces (roads, squares, parks, gardens, urban furniture, parking areas, public transport, etc.).

PEBA and PAU are two integrated tools aimed at the same goal: the identification, preliminary design, and planning of interventions to achieve accessibility in buildings (particularly through PEBA) and in urban and extra-urban spaces (particularly through PAU).

The goal of PEBA (Barrier-Free Environmental Planning) is, therefore, to ensure that people with disabilities achieve the highest level of mobility in the inhabited environment and accessibility to buildings, based on planning criteria, prevention, and good design.

PEBA must therefore clearly and unambiguously indicate: 1. the critical issue to be eliminated and its location; 2. the type of solution that the executive project must include; 3. the cost required to resolve each issue. The PEBA provides the guiding tool for: the planning of interventions to remove architectural barriers based on the priorities previously defined and considering the available financial resources; the definition of intervention priorities.

Considering the variety of space types, such as the difference between outdoor spaces in an urban context and indoor spaces within a building, it becomes evident that different types of spaces may require distinct approaches and objectives in the process of defining and drafting the PEBA. This necessitates the introduction of specific parameters during the analysis and survey phases, the development of proposed solutions, and the integration with various planning tools. The main areas of action of the PEBA include the urban environment, which encompasses built-up areas, pathways, transportation; the building environment; and the cultural heritage sector, which involves places of cultural and historical interest.

PEBA is an interdisciplinary tool that integrates various areas of expertise and is closely related to both aspects of territorial planning and public works, as well as the management of municipal assets.

The preparation of a PEBA is developed in four distinct phases:

- Preliminary analysis of the current situation, the territorial context, and the needs through consultation with citizens and stakeholders;
- Definition of the design solutions and planning of the interventions;
- Estimation of costs;
- Planning of the interventions.

After its approval, PEBA typically has a ten-year validity and can be updated and integrated based on the implementation of the planned interventions.

Currently, PEBA has become mandatory across the entire Italian national territory. Several best practices have already been adopted, as demonstrated by case studies from Trento[3], and other Italian city, and nearly half of the Italian regions have drafted general guidelines. These elements form a fundamental basis for the implementation of plans aimed at eliminating architectural and sensory barriers. There are no minimum standards to be met for the removal of these barriers, as such parameters (e.g., presence of obstacles, stairs, slopes, types of access, etc.) vary on a case-by-case basis due to the diversity of urban environments. These aspects are determined following a detailed preliminary analysis and on-site survey.

Many of these plans utilize GIS tools in the analysis and definition phases of PEBA, but they often remain limited to 2D representation (LOD0) and face issues with data interoperability. For this reason, the CityGML-based approach proposed in this contribution could provide a detailed and interoperable model for the 3D representation of cities, enabling a more in-depth analysis of urban accessibility.

CityGML allows the modeling of buildings, roads, sidewalks, staircases, ramps, and other urban elements with progressive levels of detail (LOD), thus facilitating the identification of obstacles and architectural barriers such as steps, elevation changes, narrow passages, or street furniture. Thanks to the integration of spatial data and semantic information, it is possible to identify and report critical accessibility issues with greater precision. Moreover, as an open standard, CityGML is compatible with various GIS and BIM software, promoting data exchange among public authorities, designers, and urban planners.

3. Methodology

This work proposes an attempt to implement CityGML for managing a plan to eliminate architectural and sensory barriers. The described methodology (Figure 1) focuses on the initial phases of PEBA definition, including preliminary analysis, field survey and inspection activities, and the subsequent

[3]https://gis.comune.trento.it/it/map/cartografia-generale/qdjango/30/

management of collected data based on CityGML. The CityGML 3.0 ontological model and 3D semantic modeling are utilized, followed by the development of an ADE dedicated to Urban Accessibility. This ADE enables the integration of new features and properties for representing accessibility-related elements within the urban space.

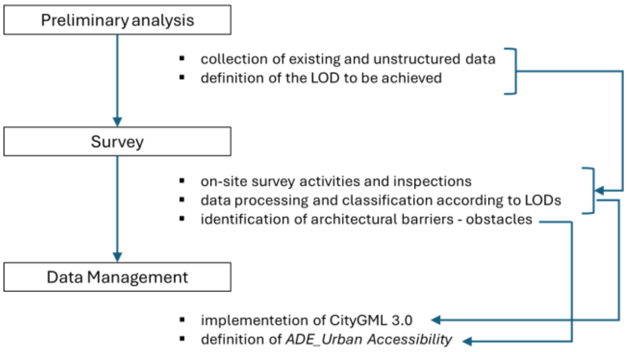


Figure 1. Methodology workflow

3.1 Preliminary Analysis

The preliminary analysis phase is based on a fact-finding survey and the collection of existing and unstructured data useful for urban accessibility planning. The technical analysis of the territorial context involves mapping collection and the use of sensors for data collection and applications for data processing managed in GIS, as well as the analysis of public spaces, identifying buildings, public facilities, services, and mobility systems that are crucial for assessing connectivity and usability conditions.
The collected data will be more functional for PEBA if the cartographic bases are digitized and include information such as cadastral boundaries, addresses, street numbers, the presence of sidewalks, and any other details that can precisely identify critical points or areas. Regarding buildings, since these also require specific surveys, having access to updated floor plans becomes essential.
Since the aim is to implement PEBA based on CityGML, it is also important at this stage to determine the necessary and sufficient LOD to be achieved in the next phase of representing urban elements.

3.2 On-site Survey and Data Processing

The survey activity consists of on-field work and inspections carried out in direct contact with the urban environment under examination. Data collection forms are prepared to identify existing critical issues, and on-site inspections are carried out for metric measurements that can clearly and accurately provide the necessary information for any specific LOD.
The metric survey can be performed using sensors such as mobile mapping, which provide data on the terrain and infrastructure and generate volumetric representations of the urban built environment (Di Stefano et al., 2019). Depending on the type of sensor used for 3D surveying, a certain level of accuracy (LOA) can be achieved, capable of satisfying the predefined requirements for urban reality representation.
The data processing phase of the survey involves an initial management of the point cloud, allowing for the classification of urban context elements in order to extract 3D features for subsequent modeling. An approach is described in Di Stefano et al. (2023), where a semi-automatic classification methodology leverages AI algorithms to define various urban reality feature objects (Figure 2), following the semantic schema of CityGML and its representation across different LODs.

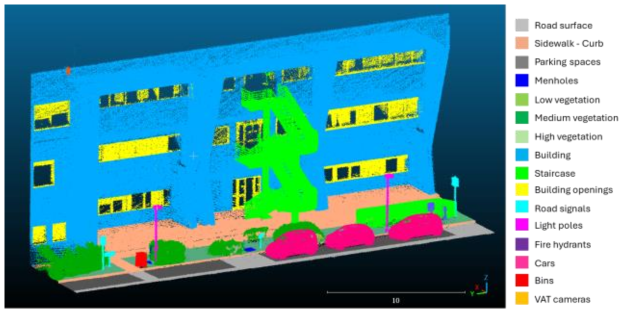


Figure 2. Point cloud classification of urban environment with semi-automatic approach (© Di Stefano et al., 2023)

3.3 Data Management

3.3.1 CityGML 3.0 These data are then structured through the definition of an ontological model dedicated to the urban context, based on the CityGML 3.0 schema, which includes terrain, buildings, and other elements of the built environment. This ontological model distinguishes features corresponding to different classes and subclasses, connected by arrows representing relationships of belonging or composition, as shown in the UML diagram in Figure 3.
At the core of the schema, the *CityModel* contains various *CityObjects*, which are further classified into different feature categories such as *Buildings*, *CityFurniture*, and *Transportation* and *Relief*. Each class is linked to a single object representing the geometrical feature related to the LOD assigned to each class, which ranges from LOD0 to LOD3 depending on the entity describing the urban context.
In the CityGML schema, each feature object is characterized by a set of properties that define its spatial, functional, and semantic attributes. Below is a description of the key properties associated with each feature object:

- *lod*: defines the level of detail at which a feature is represented, ranging from LOD0 to LOD3;
- *class*: specifies the classification of the object according to predefined categories (e.g., residential, commercial, transportation);
- *function*: describes the function or purpose of the feature, supporting multiple entries (e.g., a building used for both residential and commercial purposes);
- *usage*: Defines the actual usage of the object, which may differ from its intended function.

In addition to the previously mentioned properties, additional attributes are introduced to enhance this analysis of the urban environment, in accordance with the guidelines provided by the CityGML 3.0 standard.

3.3.2 ADE_Urban Accessibility. Once the CityGML 3.0 schema is defined the next step consist of implementation of an extension of the CityGML domain incorporating features relevant to the identification and classification of architectural and mobility barriers. This process leverages the ADE mechanism, introducing properties or objects linked to ADE_UrbanAccessibility within the ontological model. For *Building* and *Trasportation* objects specific accessibility attributes such as length, height, width, slope, surface type, and surface condition, are added ensuring detailed accessibility assessments. Properties like localization and type of obstacle are associated to *CityFurniture* objects (Figure 3).

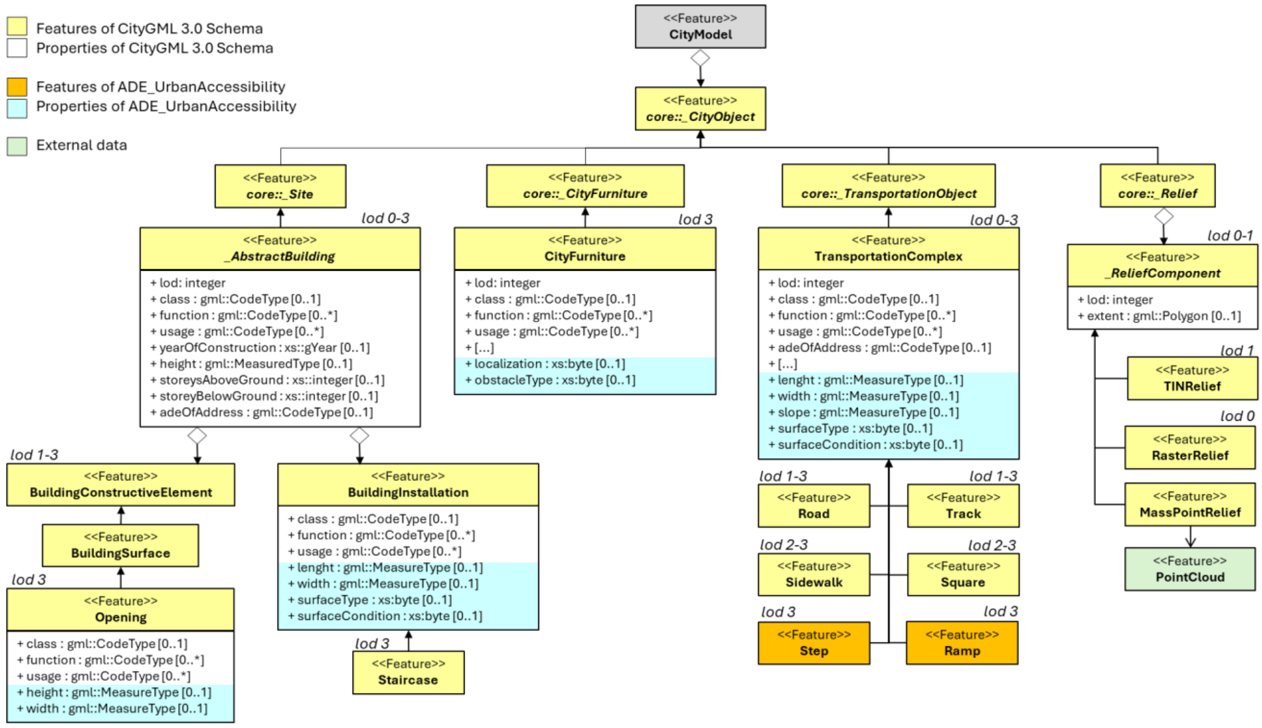


Figure 3. CityGML 3.0 schema with ADE_Urban Accessibility

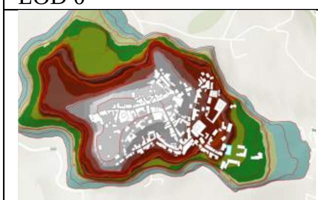
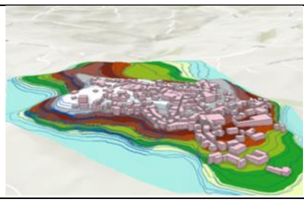
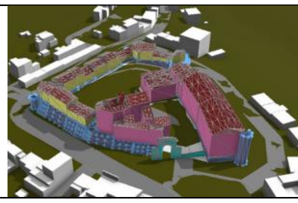
LOD 0	LOD 1	LOD 2	LOD 3
			
2D plan: - Building footprints - Road lines object - Raster terrain	Basic 3D: - Building simplified volumes with height - Road surface geometry in the actual shape - TIN terrain	Standard 3D: - Building volumes with roof shapes - Road surface geometry divided thematically into traffic areas (sidewalk) - TIN terrain	Detailed 3D: - Approximate vertical development of the building structure with roof shapes and openings - Road surface geometry divided thematically into traffic areas (sidewalk) - City furniture simplified representation; steps, ramps - TIN terrain (textured)

Table 1. LOD definition according to CityGML. Images produced by © the authors, 2025

4. Results

In applying the previously described methodology, two urban areas represented by small villages were selected as case studies. Following the initial site assessment and field survey phases, the urban environment was modeled based on the CityGML schema and different LODs (Atila et al., 2013; Biljecki,et al., 2016, Di Stefano et al., 2024). Table 1 provides a summary of the LODs:

- LOD0 corresponds to a two-dimensional (2D) planimetric representation with building footprints and road lines over terrain in raster format.
- LOD1 represents a basic 3D model, where buildings are simplified into simple blocks, and road surfaces are depicted as flat elements resting on the terrain's TIN (Triangulated Irregular Network).
- LOD2 introduces a standard 3D representation, including roof structures for buildings and the thematic classification of traffic areas.
- LOD3 provides an even higher level of detail, where buildings are enriched with openings (windows and doors), while the thematic classification of traffic areas is expanded to include sidewalks. Additionally, urban furniture elements such as traffic signs, street furniture, and urban service components are incorporated. At this level, staircases and ramps are also represented. A realistic visualization is achieved by applying textured surfaces to the terrain's TIN model.

Thanks to the point cloud obtained from the geomatic survey, it is possible to model each component of the urban environment with high accuracy.

The process begins with the terrain, where the point cloud data allows for the creation of a Digital Terrain Model (DTM) in raster format and the generation of a TIN to represent the topographic surface.

For buildings, the georeferenced point cloud is particularly useful for extracting height values, both from ground level (using the DTM) and from the roof level (derived from the Digital Surface Model, DSM). This enables a precise definition of building volumes in accordance with different Levels of Detail (LOD).

In addition, the point cloud can be classified to identify and extract other urban elements to be modeled, such as roads, sidewalks, ramps, staircases, and street furniture. By following the LOD levels, it is possible to progressively refine the representation of the urban environment, ensuring a structured and semantically enriched model, as illustrated in Figure 2.

The 3D modeling of the built urban environment is carried out by GIS environment, in fact a geodatabase stores geometric, semantic, and topological information associated with each component of the 3D urban model. The geodatabase is structured in accordance with the CityGML ontological schema, ensuring consistency and interoperability. Each urban feature within the model is defined through a set of properties that are systematically organized in attribute tables. In this structure, each row corresponds to a specific physical element of the 3D model, while each column represents a distinct attribute associated with that element. These attributes capture essential details such as geometry, function, usage, height, and other relevant properties, following the specifications outlined in the CityGML ontological schema.

It is possible to manage the 3D CityModel by visually representing certain attributes within the 3D environment, such as the functional classification of buildings. This allows for an immediate and intuitive identification of different categories, making it easier to distinguish between residential, commercial, and public buildings. Similarly, this approach can be applied to squares, roads, and green areas, enabling a clear visualization of their spatial distribution and relationships within the urban environment (Figure 4).

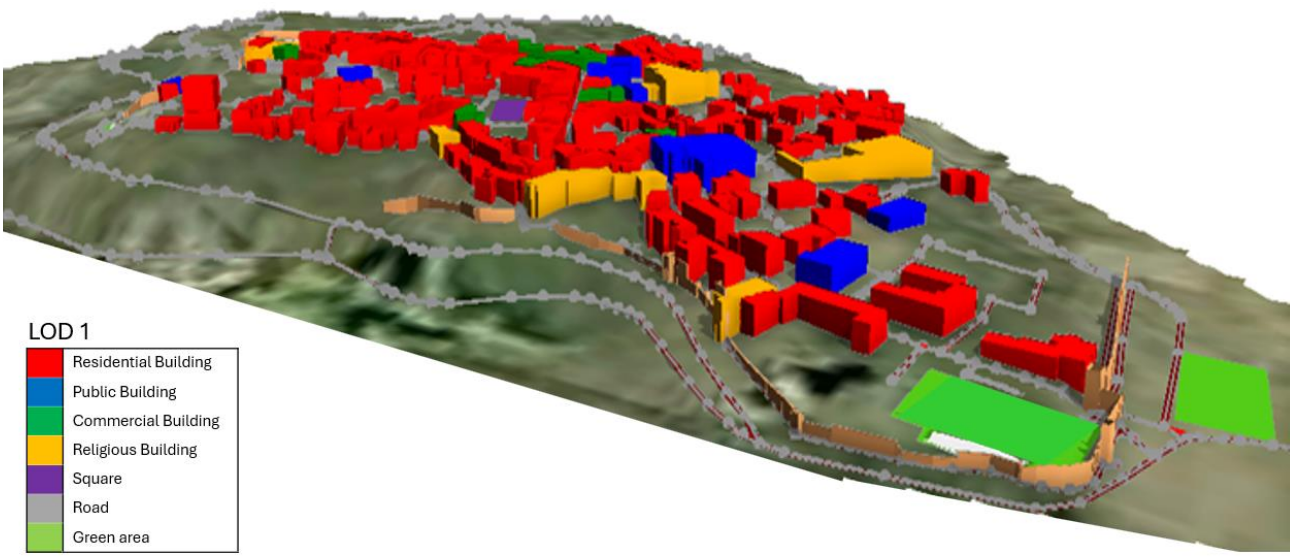
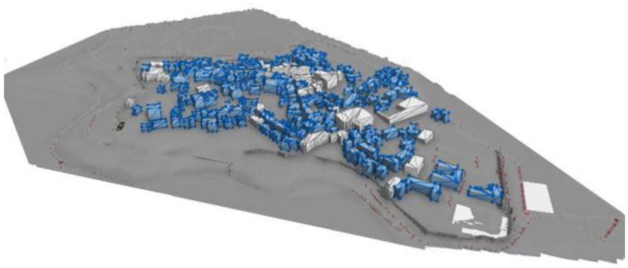


Figure 4. Functional classification of the 3D CityModel (© the authors, 2025)

3D CityModel serves as a powerful information tool that can be queried to facilitate advanced data management and spatial analysis within a GIS environment, such as ESRI CityEngine. By leveraging a structured query system, users can extract specific information related to various urban features, enabling a more detailed understanding of the built environment and accessibility conditions. Using Python programming language, you can formulate and execute queries on the model. Through custom scripts, it is possible to retrieve, filter, and analyse data based on predefined parameters, such as building functions (Figure 5), road system, height variations, terrain morphology, and accessibility elements. Python allows for automated validation of the information contained in the 3D CityModel, ensuring that attributes and properties adhere to the expected structure and semantic rules.

Moreover, Python-based queries enable the identification of specific spatial features, such as barrier-free paths, ramps, staircases, and street furniture, which are essential for assessing urban accessibility. By integrating Python with CityGML data structures, it becomes possible to refine the model's usability, enhance data interoperability, and generate thematic visualizations based on query results.



```
ce = CE()

objects = ce.getObjectsFrom(ce.scene)
selection = ()

for item in objects:
      attribute = ce.getAttribute(item, "Function")
      if =="Residential"
            selection.append(item)

ce.setSelection(selection)
```

Figure 5. Response to a query by Phyton code to identify residential buildings.

Figure 6. 3D CityModel (LOD3) and the pop-up window showing a reported obstacle and its properties according to ADE_UrbanAccessibility

In addition to formulating queries to identify objects within the 3D CityModel, users can interact directly with the urban model of the city. For instance, by clicking on an element, a pop-up window appears, displaying detailed information about the selected feature.

Thanks to the ADE Urban Accessibility, additional properties have been integrated into CityGML to describe obstacles and architectural or sensory barriers present in the urban environment. Figure 6 illustrates an example of a pop-up related to an obstacle that has been selected within the 3D CityModel. Each obstacle is identified by a unique code and a short name specifying its type. The pop-up then presents a list of properties, including location details, geometric measurements, description, surface type, and surface condition.

This tool proves to be highly effective in quickly visualizing and assessing obstacles that have been mapped and identified throughout different parts of the CityModel, facilitating urban accessibility analysis and planning.

5. Discussions

Urban environments often lack adequate documentation that provides the richness and level of detail necessary to manage complex management and planning interventions. The required information is sometimes already available but dispersed among various heterogeneous sources (such as maps, geoportals, technical and descriptive documents, etc.), managed by various administrative offices. The planning processes, such as PEBA, require different information as a reference base and can be optimally facilitated by digitalization and effective data representation, which includes semantic, spatial, and temporal aspects. This has led to identifying advantages and issues related to information management of urban environment. In this scenario, dedicated ontologies, like CityGML, can be useful tools for collecting, structuring, and integrating this multi-scale and multi-level information from multiple sources.

ADEs are useful tools in enhancing the capabilities of CityGML for specialized urban planning and management tasks. These extensions allow CityGML to be tailored to specific domains, such as urban accessibility planning, by incorporating additional attributes, relationships, and object types that are not included in the core CityGML model. For instance, an ADE_UrbanAccessibility extends CityGML to include detailed information about sidewalk conditions, geometrical measures of staircase, presence of city furniture elements as obstacles and other accessibility features.

An important consideration when extending CityGML with an ADE_UrbanAccessibility is ensuring that the newly added objects and properties are represented at an appropriate LOD. The chosen LOD must be sufficient to accurately identify and characterize architectural barriers and obstacles that compromise the usability of the urban environment. For instance, while a lower LOD might be adequate for representing general building outlines, a higher LOD would be necessary to capture detailed features such as entrance steps, narrow doorways, or uneven surfaces. By carefully aligning the ADE with suitable LODs, we can ensure that the CityGML model provides the granularity of information required for effective accessibility analysis and planning.

CityGML models, enriched by ADE, serve as dynamic digital representations of urban environments, offering a powerful tool for tracking and enhancing urban accessibility. These models can be regularly updated to reflect real-world changes, such as the removal of architectural barriers, the implementation of new accessible structures, and the creation of barrier-free pathways. This adaptability allows for:

- Continuous monitoring: city planners and accessibility experts can use these models to assess the current state of urban accessibility and identify areas needing improvement.
- Progress tracking: by comparing models over time, stakeholders can visualize and quantify the progress made in making cities more inclusive and accessible.
- Informed decision-making: up-to-date CityGML models provide valuable data for prioritizing accessibility projects and allocating resources effectively.
- Simulation and planning: these models enable virtual testing of proposed accessibility improvements before physical implementation, potentially saving time and resources.
- Public engagement: interactive 3D visualizations based on CityGML data can be used to educate the public about

accessibility initiatives and gather feedback from diverse users.

- Integration with smart city technologies: CityGML models can be linked with IoT devices and real-time data streams to provide dynamic accessibility information, such as temporary obstructions.

6. Conclusions

The implementation of CityGML 3.0 with the proposed ADE_UrbanAccessibility extension offers a comprehensive and dynamic approach to urban accessibility planning and management. This method integrates various data sources and provides a structured, semantically rich 3D representation of urban environments. By leveraging different LODs and incorporating accessibility-specific attributes, the model enables accurate identification and characterization of architectural barriers and obstacles.

The CityGML-based approach addresses several key challenges in urban accessibility planning:

1. It consolidates heterogeneous data from multiple sources into a unified, interoperable format.
2. It allows for continuous monitoring and updating of accessibility features.
3. It supports informed decision-making by providing detailed, queryable information.
4. It facilitates simulation and virtual testing of proposed accessibility improvements.

Furthermore, this approach aligns well with existing accessibility plans like PEBA and PAU, offering a more sophisticated tool for their implementation. The integration of GIS technologies, 3D modeling, and semantic structuring within the CityGML offers extraordinary opportunities to address social challenges in the urban context, especially in improving accessibility and promoting the inclusion of people with disabilities. The extension of the CityGML 3.0 model through the ADE mechanism represents a key innovation for enriching the data model with new classes and specific attributes, enabling the detailed description of the characteristics necessary to map and analyze critical aspects of urban accessibility.

As future perspectives for this research activity, several promising avenues can be explored to enhance the comprehensiveness and utility of urban accessibility planning:

- Integration of IndoorGML: the incorporation of IndoorGML presents an opportunity to extend accessible planning to building interiors. This integration would allow for a seamless representation of accessibility features from outdoor urban spaces to indoor environments. By establishing links between building interiors and the urban context, as demonstrated in the research work by Malinverni et al. (2022), a more holistic approach to accessibility planning can be achieved.
- Urban Digital Twin simulations: the 3D models developed using CityGML offer powerful capabilities for simulating accessible pathways within an Urban Digital Twin framework, as highlighted by Kasprzyk et al. (2024). These simulations can be tailored to different categories of users, accounting for various mobility needs and challenges.
- Enhanced data integration: future research could focus on improving the integration of real-time data sources with the CityGML model. This could include information from IoT devices, crowd-sourced accessibility reports, and public transport systems, providing a dynamic representation of urban accessibility that accounts for temporary obstacles or changes in the urban environment.
- AI and LLM applications: exploring the use of AI algorithms could enhance the predictive capabilities of the accessibility model and the use of LLM could improve CityGML through automation, data enrichment, and simplification of interaction with 3D urban models.

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Appendix

Extract of XML format version of UML diagram in Figure 7.

```xml
<?xml version="1.0" encoding="UTF-8"?>
<CityGML_ADEUrbanAccessibility
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

xsi:noNamespaceSchemaLocation="CityGML_ADEUrbanAccessibility.xsd">
    <CityModel>
        </core:_CityObject>

        <core:_TransportationObject>
            <TransportationComplex>
                <Sidewalk>
                    <length>50.0</length>
                    <width>2.0</width>
                    <slope>5.0</slope>
                    <surfaceType>1</surfaceType>

    <surfaceCondition>1</surfaceCondition>
                </Sidewalk>
                <Road>
                    <length>100.0</length>
                    <width>6.0</width>
                    <surfaceType>2</surfaceType>

    <surfaceCondition>2</surfaceCondition>
                </Road>
                <Square/>
                <Track/>
                <Step/>
                <Ramp>
                    <length>10.0</length>
                    <width>1.5</width>
                    <slope>8.0</slope>
                    <surfaceType>1</surfaceType>

    <surfaceCondition>1</surfaceCondition>
                </Ramp>
            </TransportationComplex>
        </core:_TransportationObject>
    </CityModel>
</CityGML_ADEUrbanAccessibility>
```

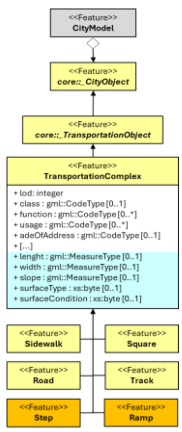

Figure 7. Extract of the UML diagram of CityGML 3.0 with ADE_UrbanAccessibility (see Figure 3)