Deliverable
D4.1 CIM Structure definition and Existing components

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List of abbreviations

Abbreviation	Explanation
SOA	State of the art
LoD	Level of detail
CIM	City information modelling
UML	Unified modelling language
ADE	Application domain extension
CI/CD	Continuous integration and deployment
OSM	Open Street Map
OA	Older adult
CS	Civil servant
LIDAR	Light detection and ranging
DSM	Digital surface model
DTM	Digital terrain model
SQL	Structured query language
WFS	Web feature service
XML	Extensible markup language
GIS	Geographic information system
CSS	Cascading style sheets
HTML	Hypertext markup language
WMS	Web map service
API	Application programming interface
XSD	XML schema definition
GDI	Geospatial data infrastructure

1 Executive summary

The deliverable 4.1 – CIM Structure definition and Existing components describes the URBANAGE City information model (CIM) as the main information model for Digital Twin. This document defines the technologies and the processes for generating the CIM, that will be used for storing the city 3D model and the city semantic data. In the document user requirements from WP2 and use cases from WP6 has been analysed and processed into CIM requirements. The CIM is designed to support human interactions with the digital twin, specifically two types of human interactions have been identified. One for citizens and in specific older adults, to which digital twin must be accessible and easy to use, showing for instance information about unsafe places of the city such as obstacles or insufficient lighting zones, and creating safe routes avoiding this problem. The other main user will be the civil servants, for which the digital twin is going to be a working tool, that will be used for viewing real time data and for launching different types of simulations, helping them make decisions in a digital environment before actually carrying them out.

The technologies that will be used for generating the urban data model are identified in this deliverable. The task 4.1 will impact directly task 4.2, generating the modelling and mapping.

In Section 3 a connection has been done with WP2 and WP6, and the section explains how CIM requirements have been obtained and how these requirements will be implemented in future tasks. User requirements from D2.3 have been analysed and the ones that have an impact on the CIM have been chosen and converted to CIM requirements. Also, D6.1 use cases have been analysed and converted to CIM requirements; the identified CIM requirements are common to the pilot cities and will be used in Task 4.2 for generating the model. Section 4 is directly connected with WP5, specifically with task 5.1. First an overview of the architecture is presented and then it is explained how the CIM relates with the URBANAGE Architecture. Finally, the four components of Digital Twin are explained in detail.

In section 5 different geospatial technologies are analysed and evaluated on how each technology can help the CIM. CityGML is the chosen technology for generating the CIM, but it needs to be extended for use case requirements so some of the ADE extensions are evaluated. For visualization purposes there is a need of streaming format, that's why 3DTiles will be used for this. Some of the technologies are still on a development phase which means that even if they are studied, they may not be a real option of implementation in URBANAGE.

Section 6 is the main section of the deliverable; it includes a study of the work that the pilot sites have done before URBANAGE in urban planning and how URBANAGE CIM is designed for providing solution to all use cases requirements.

For development purposes of the URBANAGE Platform, the project established a CI/CD (Continuous Integration and Deployment) process, that includes among the tools to be used, a code repository (i.e., GitLab). The code repository collects the prototypes of the main components (e.g., baseline tools, libraries, datasets, etc.) constituting the City Information Model and their future developments. The deliverable "D5.2 Initial Platform Prototype" provides details about the CI/CD process and the code repository.

2 Introduction

This document explores the URBANAGE CIM from different points of view. In the third section an analysis of the CIM requirements will be made, facing it from the user requirement perspective and the use cases perspective, as a result the CIM requirements will be generated. In the fourth section the relation between Digital Twin and the CIM with URBANAGE architecture will be analysed. A generic overview of the architecture will be made and will be explained in more detail in task 5.1. Then the different parts from CIM and Digital Twin are explained in detail. In the section 5 an overview from the SOA of different geospatial technologies is made, checking how this technology can fit the CIM. Some of the technologies analysed are in a development phase, this means that even if they provide solutions to part of the CIM requirements, they may be discarded because they do not have a sufficient state of maturity. CityGML will be analysed, but also CityGML extension like urban ADE or utility network ADE, finally a complementary technology for visualization is analysed, in this case 3DTiles. The work done in this deliverable will directly feed into the rest of the tasks of WP4. Finally, the main section of the document is presented, in which the work before URBANAGE of the three pilots is identified. Taking this into account the CIM will be defined for giving solution to all the pilots requirements.

3 URBANAGE CIM requirements

3.1 Analysis of URBANAGE use cases

The identification and analysis of the use cases of interest for URBANAGE was carried out through participatory sessions in the 3 pilot sites of the project (Santander, Helsinki and Flanders). The complete analysis of the use cases is detailed in D6.1. The accessibility and liveability of the city goes beyond physical barriers.

3.1.1 Santander

In the case of Santander, the groups involved in the participatory sessions with the Santander City Council were:

- Senior citizens
- Neighbourhood associations
- Associations identified as particularly relevant in the senior citizen's segment
- Civil servants with responsibility for or knowledge of services to citizens

During the participatory sessions, relevant aspects were identified on needs, challenges, and opportunities to improve the day-to-day life of senior citizens in the city. Among them, the following can be highlighted:

- Having a catalogue of information with public toilets, benches or shaded areas or protection from rain.
- Knowing the type of pavement and its condition as an important aspect for the safety of senior citizens.
- Have a safer mobility from dangers like bicycles and especially electric scooters.

As a result of the sessions two relevant use cases for Santander were defined:

- **Age-friendly -route planner**: This case focuses on the design of a solution, developed as a citizen service app, to identify safe routes from and for the citizens able to send notification about incidents in the urban space and to simulate different incidents, to assess the impact on citizens
  One of the aspects of interest of the Digital Twin for this case is the possibility to include in the digital model the exact location of some urban furniture, defined and needed from older people e.g., benches, public toilets or fountains or urban buildings of special relevance for older people such as civic centres. The digital model should also include the possibility to identify benches within shaded areas, sheltered from the rain or that are in itineraries where the pavement is suitable for the mobility of older people or even in safe routes regarding the transit of bicycles or electric scooters.

- **Simulation tool for long-term urban planning**: In this case, the aim is to help the people who are responsible for making decisions about the development of the city to elaborate the urban planning, taking into account relevant aspects such as the complicated orography of the city and the aging of the population.

The focus of the Digital Twin should be on identifying and analysing the consequences of urban planning alternatives in a digital environment, before implementing the measures in the real urban environment. The elaboration of the urban planning focused on the senior citizen will be supported by the concept of age friendliness index elaborated in URBANAGE. The Digital Twin can be an ideal complement to the "Santander Smart City Platform" that is currently being developed in the city.

Taking this into account, for the case of Santander some relevant requirements for the CIM data model are:

- Include furniture location (public toilets, benches, fountains etc.)
- Include shadows, shaded areas, or shadow simulation
- Include pavement type (important for mobility)
- Include bike lanes or electric scooter traffic zones
- Enable the representation of information at different scales (city, district, area, building or city element)
- Enable the representation of urban planning alternatives
- Enable the representation of geospatial distribution of age friendliness index

The generation of the CIM model will require a set of data sources, among which the following can be highlighted:

- Building footprints and geometric representation of main urban elements of the city (streets, green areas, sidewalk, urban furniture etc.)
- Elevation maps including Digital Terrain Model and Digital Surface Model will be used to calculate the altitude of the points in the city and the height of buildings and urban structures.
- Representative characteristics of buildings and urban elements (e.g., use, year of construction, type of pavement)
- Street map of the city.
- Location about the urban furniture

Other data sources that can be useful for the CIM

- Transit Map
- Calendar of maintenance works
- Lighting and occupancy of streets

Some preliminary data sources are available in the current version of the Santander's Open Data platform.

3.1.2 Flanders

In the case of Flanders, the groups involved in the participatory sessions were:

- The care and health department

- Several Flemish towns and cities
- The older people community

As a result of the sessions two relevant use cases were defined for Flanders:

- **Green comfort**: The aim is to offer information and services for citizens to increase the green comfort of the body and minds of the older people. It also offers the possibility to collect feedback from the citizens and to participate in the decision for the improvement of the comfort.
  The most relevant aspects to be considered in the Digital Twin with regard to green comfort are the identification of shaded areas, green infrastructures (such as trees or parks), blue infrastructures (such as fountains, swimming pools or rivers) and furniture for rest and relaxation (such as benches, tables, toilets and lighting). In addition, it is important that these infrastructures and elements are accessible. For the evaluation and comparison of green comfort in different areas of the city, the concept of green comfort index value will be developed in URBANAGE.

- **City services planning for older people**: The objective is to predict how the demographic distribution of older people and mobility of impaired people is expected to evolve in the future. This case will help policy makers to plan new services for the older people by offering options for their optimal location.
  Of relevance in this case is the location of services for older people, such as care centres, supermarkets, or pharmacies. The distribution of the population, considering their age and mobility, is also particularly relevant.

Although the debate on the data needed for the case of Flanders is still open, in the first reflection the following are considered relevant for the CIM data model:

- Include information on age, gender, and address of the person
- Include furniture for rest and relaxation (public toilets, benches, or fountains)
- Including shadows, shaded areas, or shadow simulation
- Include blue infrastructures (fountains, pools, or rivers)
- Include green infrastructures (trees and gardens)
- Enable the representation of services for the older people (care centres, pharmacies, or supermarkets)
- Enable the representation of the geospatial distribution of the green comfort index value

For the representation of the information identified for the CIM model, a set of available data sources will be used as a reference, among which the following can be highlighted:

- Layers with geometric and semantic information of buildings (existing 3D models, OSM, terrain data)
- Points of Interest and street furniture available in OSM layers
- Green infrastructure available in local datasets with delimitation of green areas and information on tree species
- Blue infrastructure with detailed maps of water elements

- Transport, accessibility and urban mobility layers

3.1.3 Helsinki

In Helsinki, the Vuosaari neighbourhood in eastern part of the city was selected as a pilot area for two reasons. Firstly, the area consists of a high proportion of older residents and, secondly, there has lately been significant amounts of urban redevelopment which have had an impact on accessibility. In the case of Helsinki, the groups involved in the participatory sessions were:

- Older adults
- Urban Environment Division (urban planners)
- Culture and Leisure Division (civil servants)
- Social Services and Health Care Division (civil servants)
- Elderly Citizens Council
- Helsinki City Construction Services

As a result of the sessions three use cases relevant for Helsinki were defined:

1. **Feedback on accessibility issues**: The objective is to collect data related to accessibility issues for older adults. This use case includes the development of IoT devices that will be used to collect user generated data and facilitate citizen participation.
   The most relevant aspects to be considered in the Digital Twin with respect to this case are the lighting of public spaces, the location of rest elements (benches), the existence of signage and its correct location, maintenance of pavements, pedestrian areas and access points to public services and transport, in this case it is especially relevant in winter when the pavement is snowy and can become dangerous.

2. **Point of Interest:** This is to generate a dataset of places and spaces that the senior citizens find interesting and particularly pleasant. In this case the aim is to explore what factors contribute making public spaces and places pleasant for older citizens. This data will help to improve urban planning in medium to long term.
   Of particular relevance in this case is the location of services for the older people.

3. **Travel-time matrix**: Update and iterate the existing Travel-time matrix and add attribute data regarding the accessibility of older citizens. This matrix will contribute to developing Age Friendliness Index and assist urban planning by providing data to evaluate accessibility of services.

For the representation of the information identified for the CIM model, a set of available data sources will be used as a reference, among which the following are worth mentioning:

- Geometric and semantic building information layers (city map services, semantic city information model & HQ reality mesh model)

- Traffic and transport layers (public transport stops, street network, walkways/walking paths, bicycle lanes, traffic and warning lights)
- Points of interest and street furniture (interesting places, events and activities, public benches, public toilets, health care centres)

In Helsinki use cases, CIM should be able to receive points with coordinates, attribute data and possibly user generated photos which are linked to previously mentioned requirements. This data will be collected with IoT-Device designed by Forum Virium Helsinki. In Helsinki, the majority of open data is available in Helsinki Region Infoshare (https://hri.fi/en_gb/).

3.1.4 Summary of requirements from Use Cases

The following table summarizes the main requirements for the URBANAGE CIM collected from the three pilot sites.

Table 1: Summary of URBANAGE use cases requirements

CIM Requirement	Pilots
CIM must include city furniture elements (such as, public toilets, benches, fountains…)	Santander, Flanders, Helsinki
CIM should be able to visualize shadows, shaded area or shadow simulations	Santander, Flanders, Helsinki
CIM must include the representation and attributes of the blue infrastructure of the city (fountains, pools or rivers)	Flanders
CIM must include the representation and attributes of the green infrastructure of the city (trees and gardens)	Flanders
CIM must include information about the pavement type and maintenance	Santander, Helsinki
CIM must include pedestrian paths, bike paths and zones with regular traffic of electric scooter	Santander, Helsinki
CIM should enable the representation of information at different scales (city, district, building)	Santander, Flanders
CIM should enable the representation of urban planning scenarios	Santander
CIM should enable the representation of geospatial distribution of indices characterising areas of the city (age friendliness index and green comfort index)	Santander, Flanders, Helsinki
CIM should enable the connection between the citizen and their address	Flanders
CIM should enable the location of services for the older people (care centres, pharmacies or supermarkets)	Flanders, Helsinki
CIM should be able to receive points with coordinates, attribute data and possibly user generated photos	Helsinki

3.2 Analysis of URBANAGE user requirements

This section collects the main user requirements identified in WP2. The following table lists the user requirements from the 3 pilot sites of URBANAGE project and the associated data requirement for the CIM.

Table 2: URBANAGE user requirements

Pilot	User	User Requirement	CIM Data Requirement
Helsinki	Civil Servant	To easily access to updated and accessible data	Accessibility of data about urban elements or points of interest
		Work with data at different scales (Masterplan, neighbourhood level, city level etc.).	Define different elements at different scales with relevant information
		To know what are the places that are more attractive for older people	Geospatial representation and attributes for attractive places
		To have data that can support me on understanding the specific needs and interests of older people	Geospatial representation of older people services
	Older Adult	Walk on safe and obstacle free pavements	Material used to build the infrastructure
		To have sufficient lighting so that I feel safe and secure	Location of streetlights and their lighting capacity Roads and sidewalks map
		To preserve and care of the nature of the local environment	Location of parks, gardens flower beds
		To have enough benches for resting	Location of benches Roads and sidewalks map
		To have temporary pedestrian routes to be safe	Historical data of maintenance intervention (location, type of intervention etc.) Schedule interventions (location, type on intervention etc.)
Santander	Civil Servant	To ensure that the procedures and information are friendly and accessible to the older people	Geospatial representation of procedures and information for user friendly interaction
		To have up to date information of city facilities for older people for promptly fixing any issue	Geolocation of city facilities for older people
		To have a common data treatment system in all the different services of the municipality	Interoperability and open standards
	Older Adult	To have safe, well maintained and well-designed public spaces	Location of public spaces (toilets, benches, fountains, sidewalks, trees, parking lots for people with reduced

			mobility) Scheduled sidewalks maintenance interventions Sidewalks maps
		To have more mechanical escalators (optional)	Location of mechanical escalators
		To have wider bicycle lanes (optional)	Location of bike paths
		To be free of electric scooters, skaters, and bicycles (optional)	Location of bike paths Location of zones with regular traffic of skaters and electric scooter
Flanders	Civil Servant	To help me understand what are the needs of older adults in their urban environment	Geospatial representation of older adult services and points of interest
		To help me understand and predict the demand for care services	Location of care services
		To know whether essential services are accessible and reachable	Location of essential services (such as health care, shops, ...)
		To use data at different scales (city level, borough level, ...)	Define different elements at different scales with relevant information
		Intuitive front-end that helps me communicate insights and information efficiently to my target group	Geospatial 3D model for user friendly interaction
	Older Adult	To have high-quality sidewalks	Location of sidewalks, obstructions, steps, stairs or ramps.
		To have accessible and available health care services	Location of care services (hospital, shops, pharmacy, physiotherapist, service centre)
		Visual information to be available on both digital and physical maps	Virtual representation of the city (3D city model)
		To sit in a clean & well-maintained bench	Location of benches Scheduled maintenance interventions on benches
		Benches to be located on walking routes, parks, but also shopping streets (rest stops)	Location of benches, parks Walking routes Shopping streets
		To know where dangerous crossroads and other traffic situations	Maps of roads and sidewalks Location of crossroads Map of bike lanes Public transport network
		To access public transport (optional)	Location of bus stops

	To have public drinking fountains	Location of public drinking fountains

3.3 CIM requirements

Table 3: CIM requirements

REQ_ID	Requirement	Actor	Priority
Urban infrastructures and services			
REQ_1	CIM must include city furniture elements, at least: • public toilets • benches • fountains • mechanical escalators • bus stops	OA, CS	High
REQ_2	CIM must include the representation and attributes of the blue infrastructure of the city, at least: • fountains • pools • rivers	OA, CS	High
REQ_3	CIM must include the representation and attributes of the green infrastructure of the city, at least: • trees • parks • gardens	OA, CS	High
REQ_4	CIM should enable the location of city facilities and services for the older people, at least: • care centres • pharmacies • supermarkets • hospitals • physiotherapists • shops	OA, CS	High
REQ_5	CIM should enable the location of services and places which are especially attractive for the older people, at least: • civic centres	OA, CS	High
Relevant data for accessibility			
REQ_6	CIM must include historical data of maintenance intervention, as well as schedule interventions (location, type on intervention etc.)	CS	High
REQ_7	CIM must include information about the pavement type, material and maintenance status	OA, CS	High

REQ_8	CIM must include accessibility data about urban elements or points of interest.	OA, CS	High
REQ_9	CIM must include the location of sidewalks, obstructions, steps, stairs or ramps.	OA, CS	High
Technical infrastructure networks			
REQ_10	CIM must include the location of streetlights and lighting capacity.	CS	Low
REQ_11	CIM must include the representation of transportation network, including: – roads – sidewalks - pedestrian paths - bike paths - zones with regular traffic of electric scooter - parking lots for people with reduced mobility - walking routes - crossroads - traffic lights	CS	High
Representation of future scenarios			
REQ_12	CIM should enable the representation of urban planning scenarios	OA, CS	High
Features for visualization purposes			
REQ_13	CIM should allow to visualize shadows, shaded area or shadow simulations	CS	High
REQ_14	CIM should enable the representation of information at different scales (city, district, building)	CS	High
REQ_15	CIM should enable the representation of geospatial distribution of indices characterising areas of the city (age friendliness index and green comfort index)	CS	High
Interoperability and connexion with external application and data			
REQ_16	CIM should enable the connection between the citizen and their address (connection with external applications and data)	CS	High
REQ_17	CIM must be based on standards in order to facilitate interoperability	CS	High
REQ_18	CIM should be able to receive points with coordinates, attribute data and possibly use generated photos	CS	High
REQ_19	CIM must include geospatial representation of procedures and information for user friendly interaction	OA	Low
General Requirements			

REQ_20	CIM must include geographic, 2D and 3D as well as semantic information (attributes/ properties/ values)	CS, OA	High

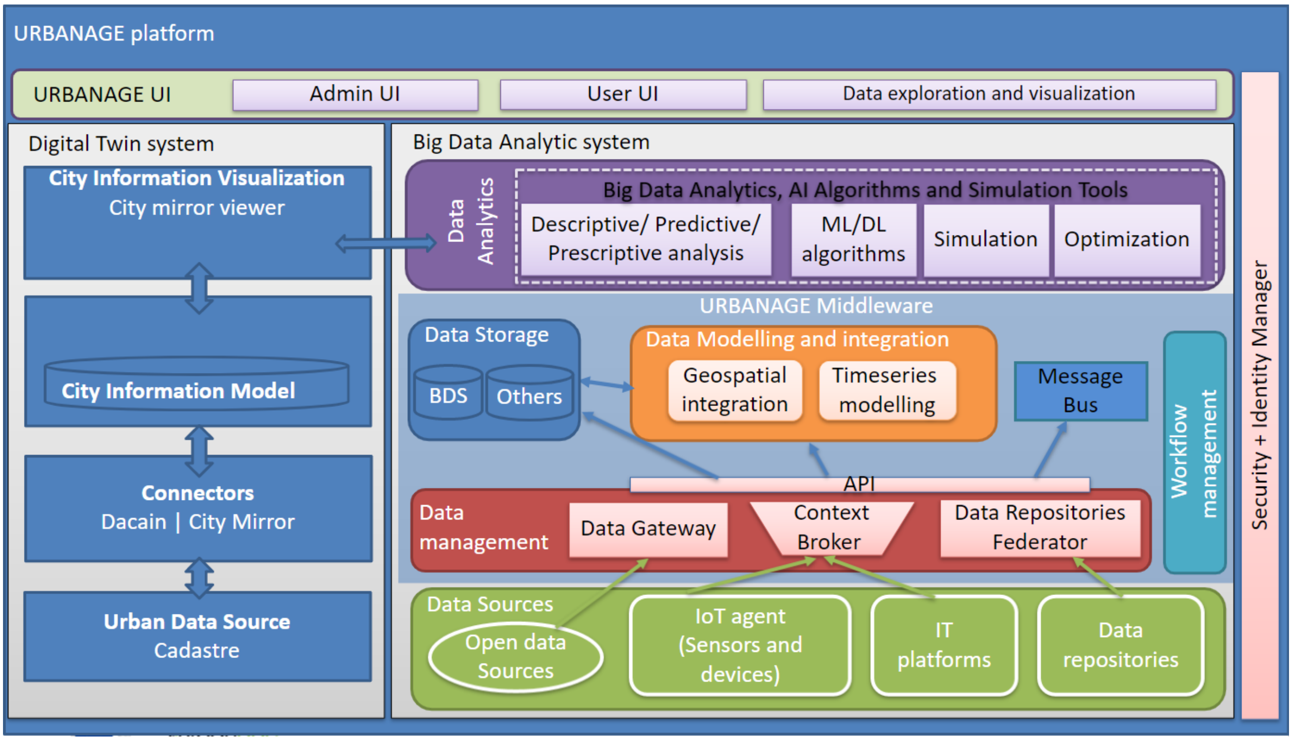
4 CIM in the context of URBANAGE architecture

In this section, CIM architecture will be described in more detail. This deliverable has been conducted at the same time as the architecture in D5.1. In this deliverable we focus on the part of the CIM and the Digital Twin. CIM and Digital Twin are both part of the URBANAGE architecture, they can be shown in the left part in [Figure 1]. The CIM is the data model of the city, it contains not only the 3DModel but also the semantic data of the city, the data stored in the CIM will be visualized in the Digital Twin using a web viewer.

4.1 CIM in the Digitial Twin Architecture

In this chapter Digital Twin components will be described in more detail, starting from data sources, following with the data connectors, then the City Urban Model and finally the web viewer, see [Figure 1].

Figure 1: Architecture by component



4.1.1 Urban Data Source

Although, as this is logical in each pilot sites, the data will be obtained from different places, in this project we are going to focus on Santander pilot sites since its model will be the one that serves as a replicable example. In the case of Santander, the primary data is gathered from National cadastre-in Spain there are four different cadastres, in this case we need the National 49 From cadastre we get the footprint of the buildings and some basic data such as the year of construction or the number of dwellings. However, cadastre data alone is not enough for generating urban 3D model, and therefore LIDAR data is needed for calculating buildings' height and roof shape. Buildings' height is calculated using DSM (Digital Surface Model) and DTM (Digital Terrain Model) and then can be added to the model. Any other building model data or semantic data should be added at this point.

4.1.2 Data Connectors

Once all the data sources are identified, gathering gather and processing the data is needed. In Santander site, we start from the National cadastre. The information is downloaded in shape file extension (.shp). DACAIN, a QGIS plugin developed by Tecnalia, is used for this purpose. This plugin connects with any of the Spanish cadastres and downloads the data, once the data is downloaded DACAIN also homogenises the data for storing in a Data base. If this process is carried out for a cadastre outside of Spain, DACAIN will need to be updated adding compatibility with that cadastre or implement a similar data gathering and processing process.

With cadastre data homogenized we can start the next data connector. CityMirror is an FME process that reads the output of DACAIN and generates city model in CityGML. This process can be expanded with additional data and can be exported to 3D Tiles file.

4.1.3 City Information Model

In this section the CIM is approached from an architectural point of view. The structure of the CIM is described in the section 6.2 of this document.

City information model needs to be stored in a data base which can serve the data and enable geospatial services. For this reason, the CIM database needs to be different from the rest of the project databases, traditional SQL databases are not optimized for these tasks. The final decision for storing the CIM is to use a 3DCityDB [6].

3DCityDB is an open-source geodatabase for storing CityGML models. 3DCityDB implements CityGML schema and thematic modules from CityGML are included, allowing multi-scale urban object and semantically rich information differentiating five level of detail, is used all over the world with more than 14 years of productive and commercial use. Over 3DCityDB a Web Feature Service (WFS) will be deployed for geospatial petitions. The database will be installed over a PostgreSQL with PostGIS plugin installed.

4.1.4 City Information Visualization

This section explains how to visualize the previously generated city model. The visualization is not locked to a single software, any visualization software that is compatible with CityGML[7] or any of the formats to which it can be exported will work, but in our case, we choose Cesium for being interoperable and open source.

Within the context of the URBANAGE project, a web viewer will be made for each pilot. This viewer will be different between them, but at least base the functionality will be the same.

Helsinki already has a Digital Twin which is a system of systems, explained in more detail in section 6.1.2 of this document, the web viewer can be used and updated for project requirements. Also, Flanders has a Digital Twin viewer called "Duet", is explained in more detail in section 6.1.3, similar to Helsinki this viewer will be upgraded and used for URBANAGE project. In the case of Santander, the city has some GIS services but not a Digital Twin or web 3d viewer, in this case it will be made from scratch with Tecnalia City Mirror Viewer.

Taking this into account, some generic aspects of the viewer will be described. In all cases viewer will be a web application, made with HTML, JavaScript and CSS. Pilot sites are going to use libraries for creating world-class 3D globes, generally CesiumJS. For visualization the CityGML will be converted to 3DTiles which is native for streaming data and allowing faster and better city visualization. CityGML will be used for giving geospatial services to the Digital Twin through Web Feature Services (WFS).

4.2 Connecting CIM with URBANAGE platform

This section describes how the CIM is related with the rest of the URBANAGE platform, for the sake of clarity, when we mention CIM, we are referring to the 3DCityDatabase that contains the city model but we also refer to the web application that we use for viewing the digital twin. Keeping this in mind, we are going to differentiate two types of processes, those that modify the CIM and those that are done on the fly and don't modify the database.

The first case of processes will be launched in the long run, such as solar potential simulation. In this case, the model will use rest service from context broker for obtaining the data of the project and will make the simulation, finally adding the simulated map to the CIM, in this case through a WMS. In case of urban planning simulations or modifications in real world city the CIM will be directly modified in the database. If any of the data generated by URBANAGE platform needs to be added to the city model, this will be gathered through the rest APIs and will be added to the model as CityGML "generic attributes".

On the other hand, there is information that needs to be shown in the digital twin but doesn't modify the CIM. As an example, when we are showing real time information like sensors data, this data will be gathered and processed and will be stored into an Elastic or Influx DB or similar. But this doesn't imply a change on the CIM, it will be charged via web application.

Finally, the URBANAGE platform business layer will be connected with digital twin via rest services.

5 Existing geospatial standards for definition of URBANAGE CIM

5.1 CityGML

CityGML [7] is an open data model based on Extensible Markup Language (XML) format for storage and exchange of virtual models of 3D city defined by the Open Geospatial Consortium (OGC)[8]. The aim of the development of CityGML was to reach a common definition and understanding of the basic entities, attributes, and relations within a 3D city model. This is especially important since it allows the reuse of the same data in different fields of application. The extension of the 3D model with semantic information is the main feature of the CityGML data model. CityGML extends the geometric information with additional information on the use and function of objects through an ontology defined in this data model. The aim of this approach is to ensure the integrity and validity of the city model to be useful for administrative use. CityGML is based on Geography Markup Language (GML).

Each component in CityGML is a CityObject. Subclasses of CityObject represent different thematic modules of the city model. CityGML defines modules for the terrain, buildings, bridges, tunnels, coverage by land use objects, water bodies, vegetation, generic city objects, city furniture objects, city object groups and transportation.

Each thematic module includes features. Features represent real-world entities such as buildings, walls, windows, rooms, railway, road, square, etc. Spatial properties of CityGML features are represented by geometry models. The geometry model in CityGML is based on the standard GML3. Generally, most of the features have the attributes class (classification), function (aimed functionality) and usage (current usage). Specific attributes are also defined for each feature and additional attributes can be included for each of them. The CityObjectGroup module provides a grouping concept for CityGML. Arbitrary city objects may be aggregated in groups according to user-defined criteria to represent and transfer these aggregations as part of the city model.

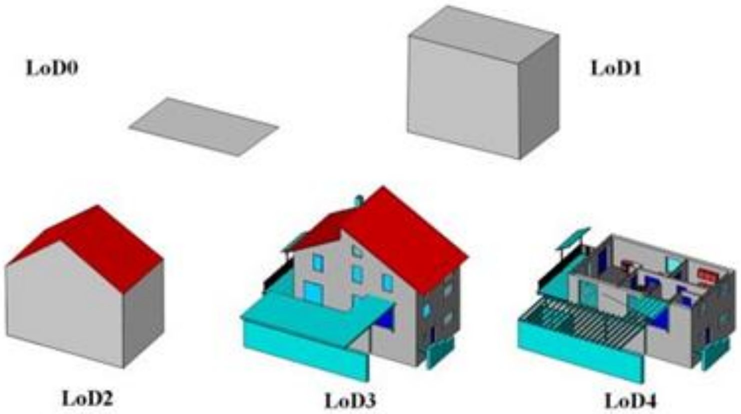
The main characteristics of CityGML Data Model are:

Modularity: CityGML data model is broken down into a core module and thematic extension modules. The main module covers the basic concepts and components of the CityGML data model and, therefore, must be executed by any system. Based on the core module, each extension covers a specific topic within the virtual 3D city model. The CityGML data model includes the geometry and thematic information of the different city elements such as digital terrain model, buildings, vegetation, water bodies, transportation facilities and urban furniture. Other objects, which are not explicitly modelled, can be represented using the concept of generic objects and attributes. Extensions can be made in the CityGML data model using the ADE.

Multi-scale Modelling: CityGML supports different LoD. The LoD are necessary to adjust the level of detail of the information to the requirements of each application. Moreover, LoD facilitates visualization and analysis of data. CityGML represents the same object with different LoD simultaneously. This allows analysing and displaying the same object with different degrees of resolution (see figure below). LoDs defined in CityGML are:

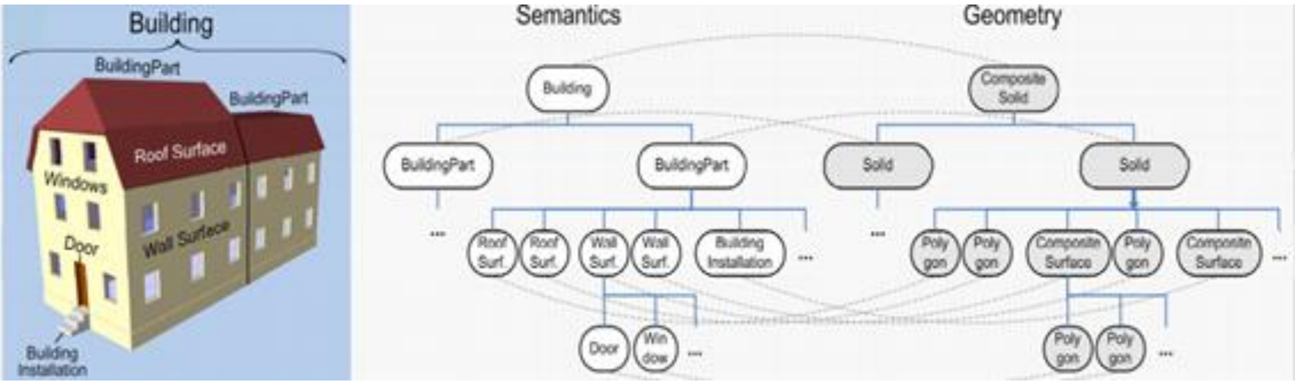
- LoD0: The digital terrain model in two and a half dimensions. A map or aerial image can be represented by this level.
- LoD1: The block model including buildings represented as simple blocks with flat roofs.
- LoD2: Differentiates between the surfaces of façades and roof, as well as the type of the roof. Vegetation objects can also be represented.
- LoD3: Details architectural models with walls, roofs, openings (windows and doors). High resolution textures can be applied to these structures. In addition, detailed vegetation and transportation objects can be represented at this level.
- LoD4: Completes LoD3 adding interior structures. For example, buildings are composed of rooms, doors, stairs and furniture.

Figure 2: LoDs in CityGML



Coherence between semantics and geometry: CityGML represents the graphical appearance of city models and also semantic and thematic properties, taxonomies and aggregations. One of the most important design principles of CityGML is the coherent modelling of the semantic and geometrical properties. At the semantic level, real-world entities are represented by features such as buildings, walls, windows or rooms. The description also includes the attributes, relationships and hierarchies of aggregation between features. Thus, part of the relations between features can be obtained from the semantic level without geometry. However, in spatial dimension, geometric objects are assigned to the features representing their spatial location and extension. The model consists of two hierarchies: semantics and geometric objects which are linked by relationships. [Figure 3] shows the coherence between semantics and geometry in CityGML.

Figure 3: Coherence between semantics and geometry in citygml [2]



Extensibility: CityGML has been designed as a universal model of topographic information that defines the most general types of objects and attributes that are included in the applications at urban scale. However, in real applications of the model, objects or attributes that are not explicitly defined in CityGML can be necessary. This is covered by the extension of CityGML. CityGML provides two different ways for the extensibility of the model:

- Generic objects and attributes: This concept allow the extension of CityGML applications without modifying the schema. Any object can be extended by additional attributes, whose names, data types and values can be provided by an application without any change to the CityGML schema. Similarly, the features that are not represented in the CityGML predefined themes can be modeled using generic objects defined in CityGML.
- Application Domain Extension: The ADE extensions specify the additions to the CityGML data model required for a specific domain. Such additions include the introduction of new features to existing classes of CityGML. For example, the number of inhabitants of a building or the definition of new object types. The difference between ADEs and generic objects and attributes is that an ADE has to be defined in a new file that defines the XML schema with its own namespace. This file has to import explicitly the XML schema definition of the extended CityGML modules. The advantage of this approach is that the extension is formally specified. Extended documents can be validated against the schema of CityGML and ADE.

5.1.1 CityGML 3.0

While the URBANAGE project is being carried out, the CityGML 3.0 standard has been approved. CityGML 3.0 will be considered when developing the CIM and the differences with CityGML 2.0 will be compared.

CityGML 2.0 has been widely adopted. It is used to create, maintain, and publish city models all around the world. In general, CityGML keeps the key concepts of the previous version and makes the implementation of CityGML more versatile[7]. Although version 2.0 is the most used version today, version 3.0 includes improvements that we list below.

Functionalities added to CityGML 3.0:

1) Data encodings other than GML
2) Updated LoD concept supporting a greater variety of indoor representations, covering simple floorplans as well as detailed 3D room details
3) Easier integration with Building Information Models (BIM)
4) The integration of dynamic sensor feeds
5) Quicker implementation through a developer-friendly modular specification
6) Faster extension by making user-specific additions to published UML model

The application that will be used to generate the models is FME Server 2021, which at the time of writing this deliverable does not support CityGML 3.0. For this reason, although CityGML 3.0 is taken into consideration for the realization of URBANAGE, CityGML 2.0 is going to be chosen for the moment.

5.2 3D Tiles

3D Tiles is a format designed for streaming and rendering massive 3D geospatial content [9]. 3D Tiles supports different types of contents, such as photogrammetry, 3D Buildings, BIM/CAD, instanced features, and point clouds. The format is especially useful for big city models, because it allows to load model tile by tile, and these tiles don't need to be homogeneous and the model can be in different LoD.

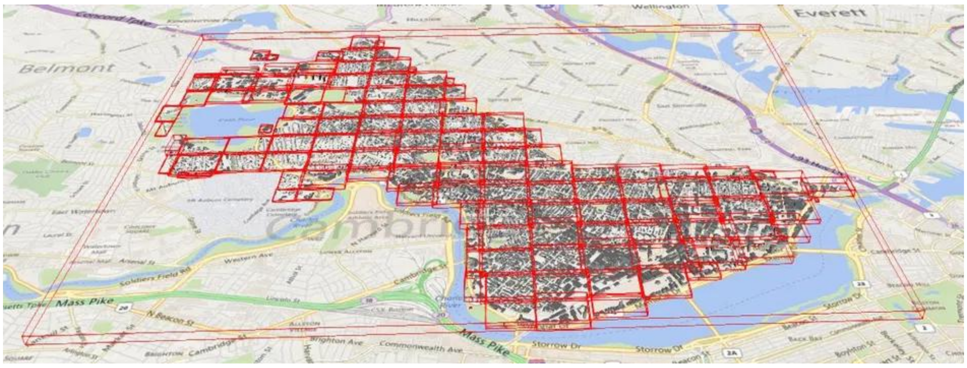
Now we are going to see the main characteristics of 3D Tiles in more detail [Link4]:

1) <u>Open:</u> 3D Tiles is an open specification with an open-source implementation. In URBANAGE project 3D Tiles will be visualized with Cesium but can be used with other 3D engines.
2) <u>Optimized for streaming and rendering:</u> This is the most important characteristic for Digital Twins. 3D Tiles is optimized for streaming, as only the content that is required is served. In other words, if a model is not visible, it is not rendered. This is made possible with Hierarchical Level of Detail (HLOD). 3D Tiles is optimized for rendering; it was designed by a team that has used WebGL and OpenGL, focusing always on rendering and reducing the number of draw calls.
3) <u>Designed for 3D:</u> It may sound redundant, but some of the 3D models are designed over 2D or 2.5D perspective. Most of the traditional models work with polygon that are extruded, in case of 3D Tiles the are natively generated meshes and materials in 3D.
4) <u>Interactive:</u> Individual building interaction is supported; it doesn't matter if the building is stored as batch. A visible example can be colouring the building on mouse over.
5) <u>Styleable:</u> One of the most useful characteristics for Digital Twins. 3D Tiles allow styling all the elements and styles are applied quickly, e.g., it takes less than a second for 30.000+ buildings. These styles will allow to colour/remove/apply transparency to every single element in the tile by any of the parameters and if a parameter come from external Data Source it can be added to the model.
6) <u>Adaptable:</u> Adaptability is another key characteristic for city models. As cities are not divided in similar number of buildings per area, i.e., generally the historic areas have more concentrated

number of buildings, meanwhile the outskirts are more dispersed, there is a need to define heterogeneous tiles, with different size and different LoD.

7) Flexible: This characteristic focuses on what is known as refinement in rendering. Refinement is the process made when we zoom in/zoom out in the map. Traditional engines need to load all parent tiles before they can start loading child tiles, however, in 3D Tiles child tiles are loaded as additive refinement at the same time with parent tiles.
8) Heterogeneous: 3D Tiles support heterogeneous datasets enabling different formats, this mean that can be added two different 3D Tiles with different format, for example a 3D Model mesh and a cloud point and it's also enabled for different type of elements in same 3D Tile.
9) Precise: Auto explicative characteristic and needed, 3D Tiles uses requires of precision, they are used even for rocket science, that's for what they have full precision in the data and representation.
10) Temporal: 3D Tiles are designed for time-dynamic visualization, that's why supports temporal data.

Figure 4: 3D Tile example for city model [Link4]



5.2.1 3D Tiles Next

Although the improvements implemented by 3D Tiles Next are many and with a direct impact on the City Digital Twin, it is a recently introduced technology. This is why its applicability is constantly analysed and taken into account, but for the moment it will not be implemented in the URBANAGE project. Furthermore, FME Server 2021, which is the software chosen to generate the URBANAGE models, does not yet support 3D Tiles Next.

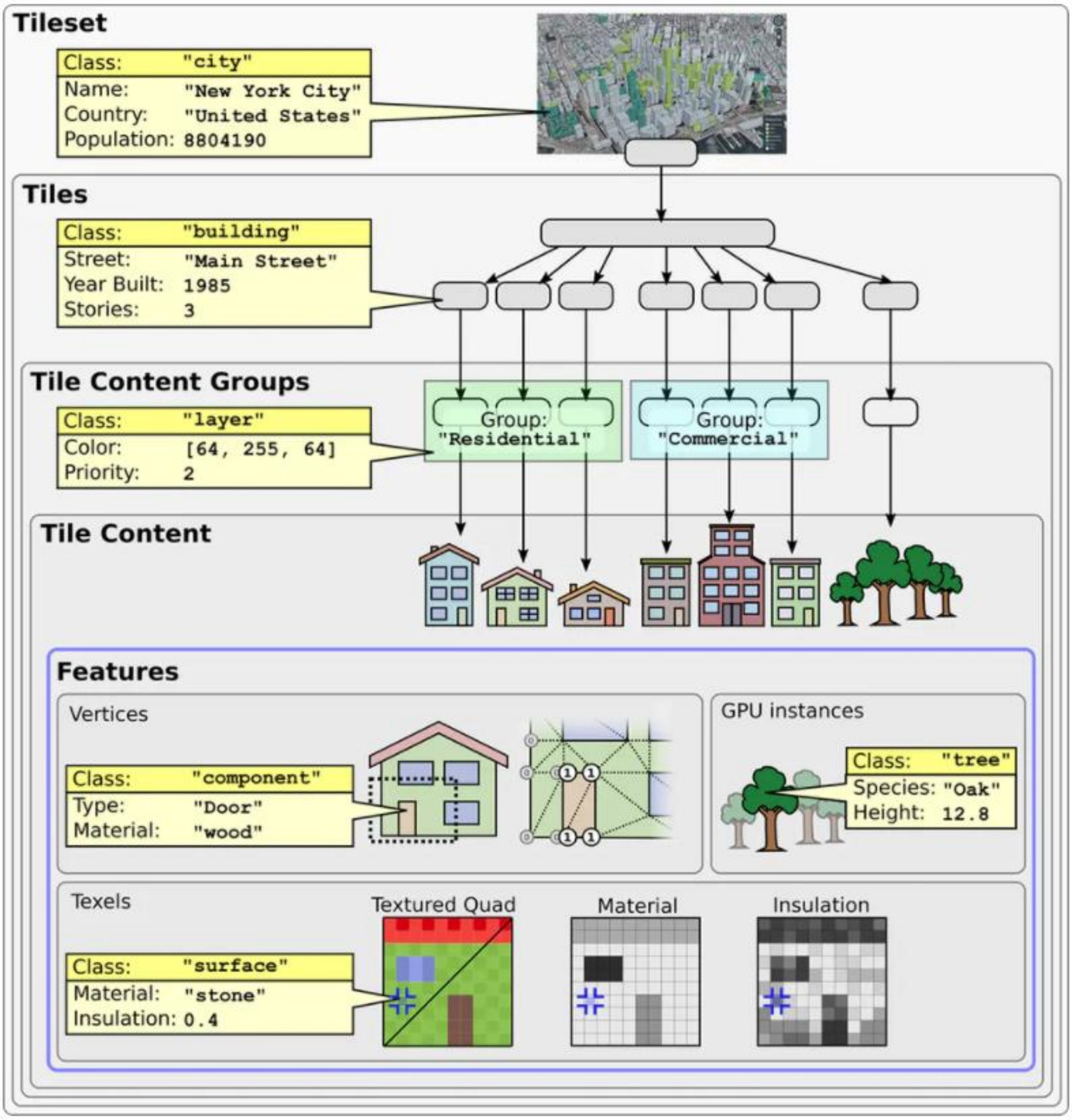
During the elaboration of this deliverable, 3D Tiles Next has been introduced. 3D Tiles Next implements some extensions, focused on the developer community. The principal improvements are[10]:

1. Streaming Semantic Metadata Efficiently: One of the biggest challenges of the Digital Twin is to store semantic data homogeneously and easily accessible. Nowadays a lot of sensors, compute and photogrammetry capture data to add to the model, 3D Tiles Next tries to give a solution to this with

three improvements: allowing more encoding such as JSON, more granularity options and semantic meaning added to metadata.

2. Metadata Type System: 3D Tiles 1.0 uses JSON for metadata, 3D Tiles Next is more strongly typed, allowing classes, vectors, and matrices.
3. Metadata at Varying Granularities: 3D Tiles Next allow to store metadata at varying granularities, this can be per tileset, per tile, per feature, per GPU, per vertex and per texel.

Figure 5: Example metadata at various granularities. [15][11]



For example, as Figure 6 shows, granularity allows the model to be coloured or rendered depending of the data stored, e.g., a window can be translucent, or a roof can be red.

4. Semantic Specifications for Metadata: With 3D Tiles Next new dictionary domain extensions can be created, which means that any data can be structured and stored in the model. This is especially useful for simulations where all data is important.
5. Run Massive Simulations and Analytics via Spatial Indexes: 3D Tiles Next is designed for working with spatial data, enabling faster spatial queries and analysis. This is interesting for cities' Digital Twins. The problem of 3D Tiles 1.0 is that it was created for working as 2D map loading tiles using global quadtrees, meanwhile 3D Tiles Next allows more flexibility to create spatial data structures with different tiling pipelines.
6. S2 Subdivision: 3D Tiles Next includes the S2 Subdivision, which is a cube-based global subdivision where each tile at the same level has equal area and there is minimal distortion [Figure 6].

Figure 6: The S2 Hilbert curve on the WGS84 ellipsoid. [15]

The S2 Hilbert curve on the WGS84 ellipsoid.

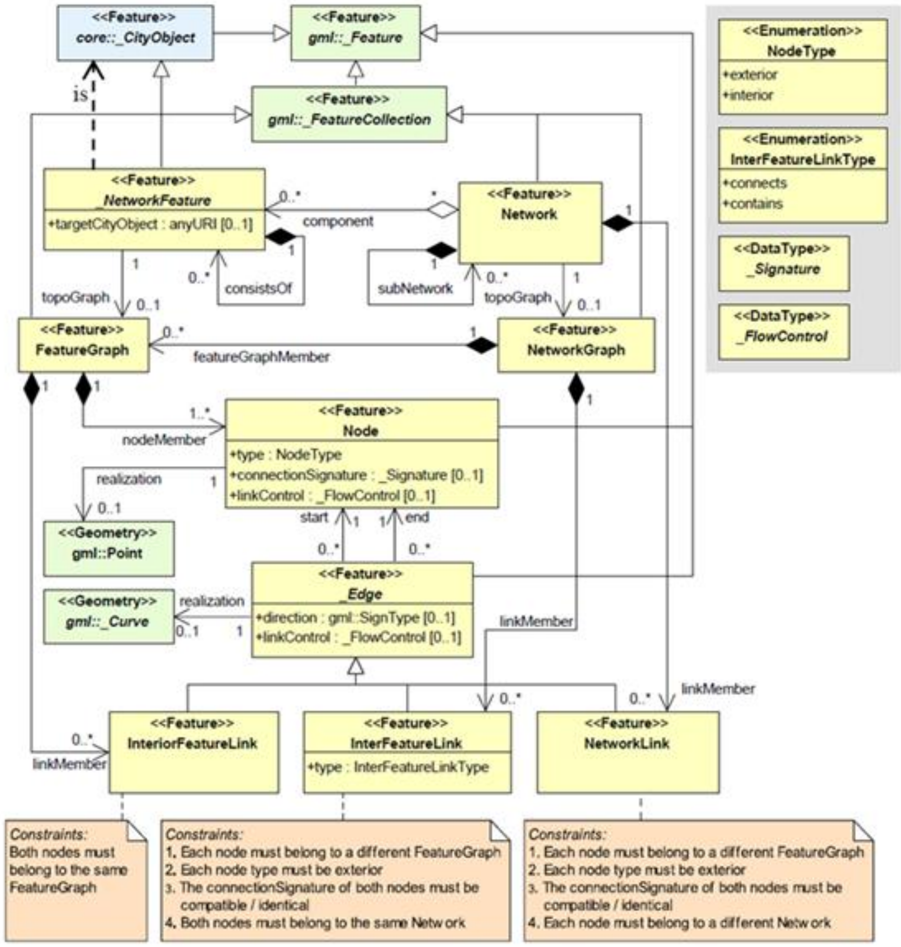
7. Layering with Multiple Contents: Very useful for City Digital Twins. It is very common to render more than one layer at the same time, such us highways, points of interest, buildings etc. 3D Tiles Next supports layers more efficiently, defining a layer metadata for each layer.
8. Integrating with the glTF Ecosystem: In 3D Tiles 1.0 the files were created in b3dm or i3dm files, which internally includes a glTF file encoded. Now glTF files are directly referenced, this way any of the work done for glTF files can be integrated.

5.3 Utility network ADE

For defining the model of the utility infrastructures at urban scale we need a model that contains not only geometry but also semantics, representing both the topology and the topography of the networks and that allow defining the relationships between the different elements of the network. The main alternatives are represented by extensions of general data models (i.e., INSPIRE, IFC, ESRI and CityGML). This section briefly details the main characteristics of the Utility Network ADE extension of CityGML, since this is the standard chosen for the representation of the URBANAGE CIM.

The CityGML Utility Network ADE is an extension of the CityGML model for the representation of supply and waste collection networks in 3D city models [Figure 8]. The model defines network components divided into three categories: transport and distribution elements (pipes, canals and cables), functional elements for network operation and maintenance (manhole and station), and safety-relevant protection elements (cable protection package and ductwork).

Figure 7: CityGML Utility Network ADE



The data model represents the utility networks in 3D, including both the topography and the topology of the network, including the functional properties of the elements and the interdependencies of the elements and the different networks. The model allows the representation of hierarchies within the networks and of the network elements themselves. The representation as an extension of the CityGML model facilitates the integration of different public service networks with the elements of the 3D city model for joint visualisation and combined analysis. The current version of the model does not allow representation at different levels of detail (LoD) and the 3D modelling options are limited to specific types of 3D elements (Multisurfaces, Solids and graphical structures).

One of the main differences between the CityGML ADE Utility Network and the other utility network representation data models is that the CityGML ADE allows to represent different types of networks and to relate these networks to the rest of the elements of the urban space. This relationship allows the analysis of network systems at all spatial scales (e.g., city, district and building) and at different levels of detail. In addition, it allows analysis according to the different roles of the elements in the network.

Currently, there are different software packages that support the CityGML model and its extensions (ADE). These software packages range from model generation to visualisation, through data storage and data analytics. An updated list can be found on the official CityGML wiki [13]. While the core CityGML modules are mostly supported in existing software packages, ADEs are only partially supported and only some of the packages are up to date. Of particular interest of URBANAGE project is the CityGML geodatabase solution 3DCityDB which recent version (3DCityDB v4.0) supports the integration of extensions. In addition, there are independent developments that have focused on the 3DCityDB extension for UtilityNetwork ADE[16]. The most developed commercial software package for dataset extraction, transformation and loading (ETL) processes works natively with CityGML and its extensions as long as the XSD schema is provided. FME facilitates the transformation of data represented in CityGML to a large number of geospatial representation formats. It also allows the visualisation of datasets and their attributes through the FME Data Inspector.

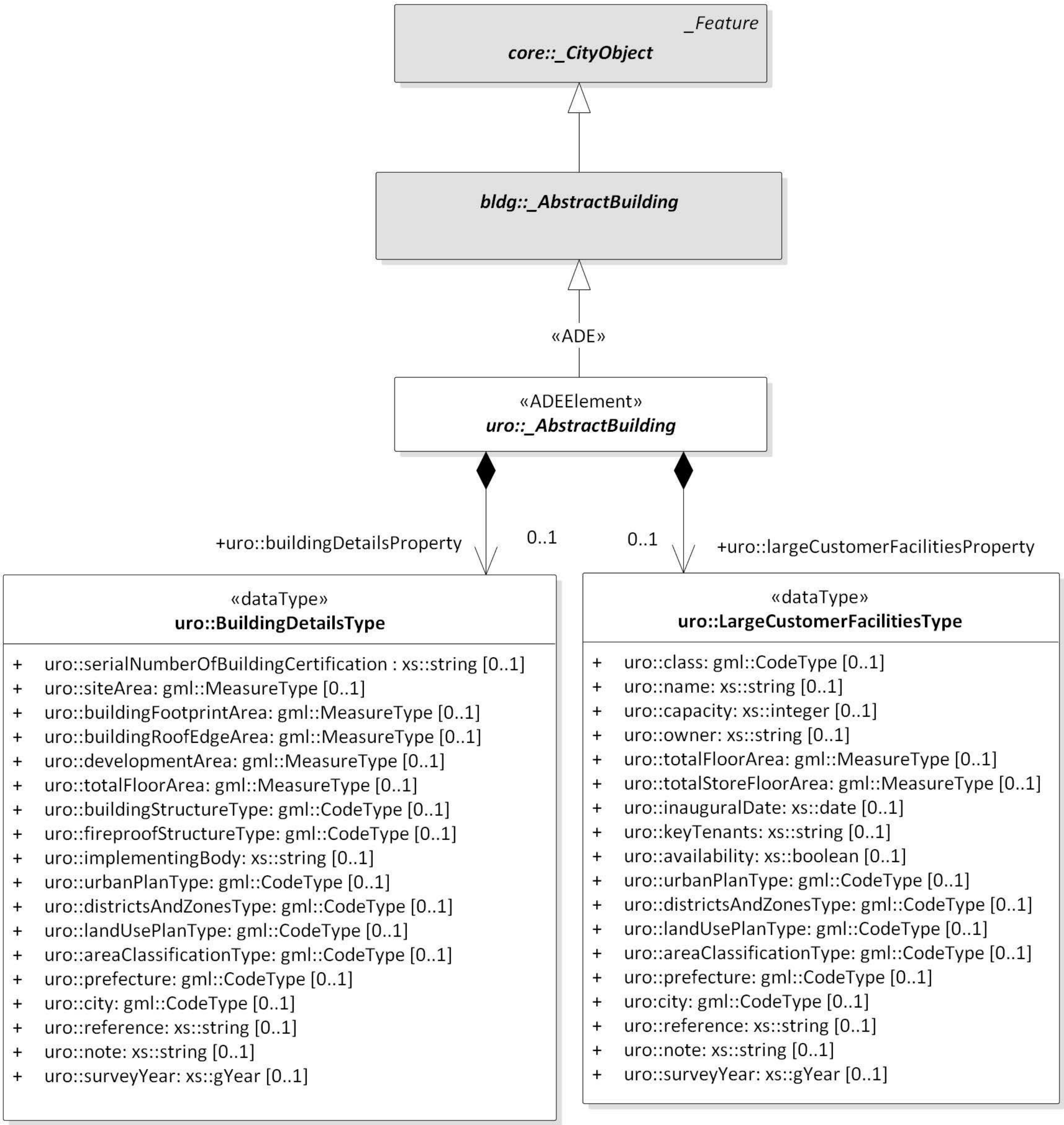
5.4 Urban planning ADE

Although at the moment Urban Planning ADE is not an official CityGML ADE, it will be taken into consideration since it is under internal revision and has a direct impact on Digital Twin. Urban planning ADE introduces two new LoD, the LoD-1 (minus one) for nationwide city models and LOD-2 (minus two) for worldwide city model, the principal use of this two new LOD are Statistic, Estimation and Time series.

This ADE contains three different modules:

- Urban Object Module: This module defines additional data for buildings, roads, and other city objects, and extends the existing modules such as *building, land use, transportation* and *cityObjectGroup*. Figure 9 shows a part of the extensions proposed for building, specifically the extensions proposed for *BuildingDetailsType* and *LargeCustomerFacilitiesType*.

Figure 8: UML diagram of extended properties of AbstractBuilding.



Some other classes are extended as well. For example, Transportation network is an important element of the city and it is identified in CityGML core, but needs to be extended, especially *TransportationComplex* and *Road*. The transportation network is identified as part of the user requirements in URBANAGE project.

- Urban Function Module: In urban planning, plans and regulations are very important, e.g., for disaster management, preservation areas and urban development. This module allows the definition of virtual areas with a specific function, giving a meaning to that zone. The module focuses on the new feature *UrbanFunction* that extends from core feature *CityObject*. Depending on the type of UrbanFunction some subclasses are defined for extending it.

- Statistical Grid Module: The Statistical Grid Module focuses on enabling time-series analysis and regional comparison. For this purpose, the map to be analysed is divided into a grid, which size may vary depending on the area and LoD which user prefers. To create this grid, the core *CityObject* class is extended again with the feature *StatisticalGrid* and Subclasses.

6 CIM Structure in URBANAGE

6.1 Current situation of the CIM in URBANAGE pilot sites

In this section the background of the three URBANAGE pilot sites will be described. In the case of Helsinki and Flanders, cities already have an urban data model and a web viewer. In these two pilot sites, Digital Twins will be improved during the URBANAGE project. The city of Santander has a GIS system, but doesn't have an urban data model or similar. In this case a Digital Twin will be developed from scratch during the URBANAGE project.

6.1.1 Santander

Since 2010, Santander has tackled a set of activities towards the Smart City paradigm. In parallel with research activities and development of pilots and experiments, several initiatives have been carried out with a further implementation in the city. Although the city doesn't possess a digital twin, and its implementation is one of the main objectives of this project, there are some existing elements that will be used as a starting point. These are explained in more detail below:

[1]. Municipal Geographic Information System (GIS)

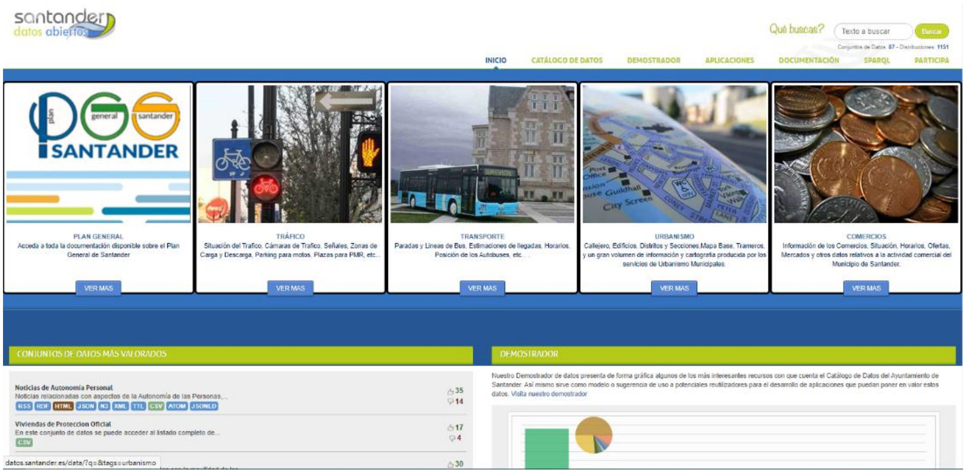
The city council has a municipal GIS based on ESRI technology [Figure 10]. It is used internally by municipality services, and there is also a public portal for the use of citizens. The municipal GIS has many use cases and it works for example as an address finder. The portal is located at https://aytosantander.maps.arcgis.com/.

Figure 9: Municipal GIS of SANTANDER.

[2]. Open Data Portal

Following the current standards of public information openness and advanced services development, Santander has setup its Open Data Portal (https://datos.santander.es). Currently it has 87 data catalogues but municipality is continuously enhancing the amount and quality of data published with the only restriction of applicable laws and norms regarding personal data. Since its establishment, it has federated with the national open data portal (https://datos.gob.es/) and provides the data in formats that are current interoperability standards. Also, through an API, it promotes creation of new services by citizens, companies and entrepreneurs.

Figure 10: SANTANDER Open Data Portal.



[3]. Smart City Platform

The Smart City Platform is a data repository that is a single point of centralisation for all municipal data. This is where the information collected on the operation of the different municipal services arrives and is the source of information for the rest of the services and, in general, for all those responsible for them at all levels. This approach is intended to break down the traditional silo approach and to provide summarised, up-to-date and efficient information for decision-makers. The project is currently under development and in an advanced state, so it will be an important asset for URBANAGE project.

[4]. Smart Citizen project

Santander Smart Citizen was one of the 14 projects selected in the 2nd Call for Smart Cities of the Digital Agenda for Spain and was tendered by the General Directorate of Red.es (Spanish Government entity focused on the execution and deployment of plans for the digitalisation of the whole country) in 2018. With the main objective of placing the citizens at the centre of all municipal action, it provides them with tools that allow the city to listen, know and meet their needs in the simplest and most effective way.

The project is made up of different components [Figure 12], including e.g., a city application and a citizen card with an electronic wallet. These and other components are aimed at gathering data on the behaviour and needs of citizens while establishing an agile and personalised two-way communication channel with the citizens and the municipality.

Figure 11: SANTANDER SmartCitizen components.

6.1.2 Helsinki

Figure 12: Background of City Information Model of HELSINKI.

The Helsinki Digital Twin is a “system of systems” [Figure 12], consisting of the current spatial data infrastructure of the city, various registries, sensor data APIs, etc. The 3D city information model is a central spatial data product for the city digital twin, as it allows the semantic and geometric representation of many of the components in the city environment and also forms a potential platform for visualization and analysis.

Currently, the city of Helsinki maintains two distinct 3D city models: a city information model and a city mesh model (for further details: https://www.hel.fi/helsinki/en/administration/information/general/3d/3d). The city information model is produced following the CityGML standard, representing the terrain surface and buildings. For buildings, models are provided with two LoD levels. The city mesh model is produced from oblique aerial photography with photogrammetric methods and provides a visually realistic representation of the city. Both models cover the entire administrative area of Helsinki.

The maintenance of the city information model is tied to the maintenance of the buildings’ registry and the city base map. New buildings are added to the CityGML model in conjunction with their update to these registries. The facade textures are updated via airborne oblique imaging campaigns performed in a few years interval. The same campaigns form the basis for re-computation of the city mesh. Otherwise, the city mesh is not updated between these surveying campaigns.

Both the city information model and the mesh are available as open data via Helsinki Region Infoshare portal (e.g. https://hri.fi/data/en_GB/dataset/helsingin-3d-kaupunkimalli). For application development, they are also available as pre-tiled, multi-LoD data in 3D Tiles format, compatible with CesiumJS platform. Open online viewers are available for both models, based on CesiumJS (https://www.hel.fi/helsinki/en/administration/information/general/3d/view/view-the-models).

Extending the 3D city information model to cover new aspects and themes of the city environment is a topical development task for the development of the Helsinki Digital Twin. Forming new spatial data assets depicting various phenomena in a standardized, machine-readable format is a pre-requisite to this. The potential topics pertaining to the URBANAGE project include the gathering of feedback, its accumulation and analysis to support urban planning and production of spatial data describing the accessibility of the urban environment.

6.1.3 Flanders

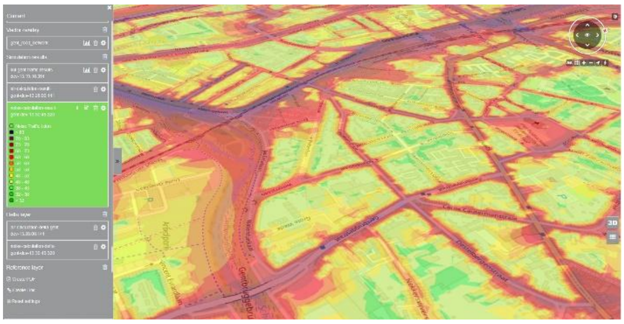
In the past 20 years, the Flanders region invested in several data platforms on a central level and on a department level. A GDI infrastructure has been set up on the central level leading to a 2D Geo-data portal called geopunt, a central open data catalogue and a GDI platform. Next to these geo-information-oriented initiatives, a data exchange platform has been built to provide data about persons and companies. This MAGDA platform and the data platforms are the backbones of many e-government and smart city applications in the Flanders region and local communities.

The Flanders region integrated in 2016 all the above services and platforms together with the first-line helpdesk in one organisation (Agentschap Informatie Vlaanderen). In ~~2019~~ 2021 the ICT-unit of the Flemish government was integrated and the name changed to Digital Flanders (DV).

Digital Urban Twins are one of the more recent domains where DV is active. An Urban Digital Twin builds further on a number of essential initiatives from the past, e.g., the 2D and 3D LoD1 highly detailed reference map of Flanders (GRB), georeferenced address database, building database and advanced simulation models (e.g., traffic, air quality and noise models) [Figures below].

Together with the research institute IMEC, ATC and 12 other partners, Flanders is building and testing a scalable, open Urban Digital Twin infrastructure in the H2020 DUET project to study the feasibility of Digital Twins on a regional, city and neighbourhood level.

Air quality impact simulation after a road closure



Noise dispersion map caused by traffic

Based on the feasibility and the demand from potential customers, Flanders will work on a smart city and data-strategy including the Flemish departments (e.g., transport and mobility, urban planning, environment), the 13 major cities and by extension, the urbanized areas where a great majority of the Flemish population lives.

6.2 Design of the URBANAGE CIM

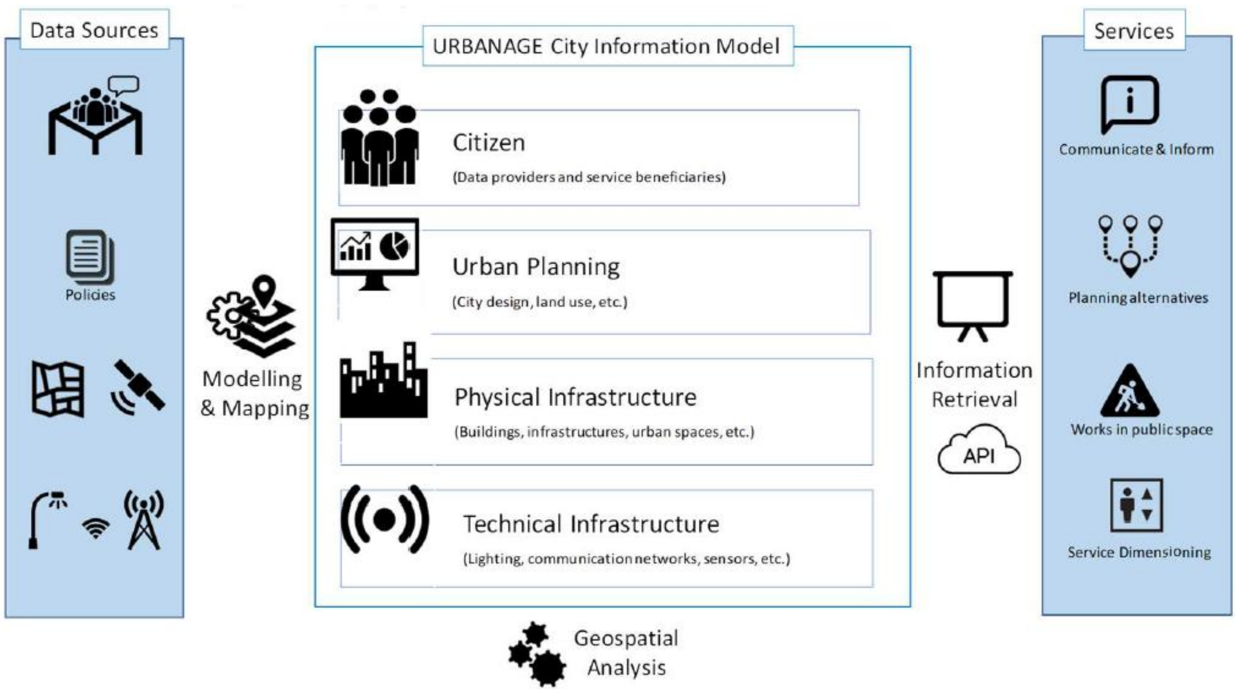
In this section the design of the CIM is documented. First, we describe the approach followed to represent the relevant information about URBANAGE. And then, the design of the CIM that extends CityGML, is described.

For development purposes of the URBANAGE Platform, the project established a CI/CD (Continuous Integration and Deployment) process that includes among the tools to be used, a code repository (i.e., GitLab). The code repository collects the prototypes of the main components (e.g., baseline tools, libraries, datasets, etc.) constituting the City Information Model and their future developments. The deliverable "D5.2 Initial Platform Prototype" provides details about the CI/CD process and the code repository.

6.2.1 URBANAGE relevant information

The modelling of the city elements will be achieved through the City Information Model (CIM). For the URBANAGE project, four different layers have been identified: Citizen, Urban Planning, Physical Infrastructure and Technical Infrastructure [Figure 14].

Figure 13: URBANAGE City Layers.



Each layer focuses on one aspect of the city. Although they have different scope, the CIM must support all four layers. They are described in more detail below:

- Citizen: The first of the layers of the CIM, citizen is part of it and user at the same time. As such, it is a living layer, its elements do not have a geographically fixed location and they are not controllable from the digital twin. But they are active generators of information and consumers of it. Therefore, the CIM not only has to support the city's own data, but also must be designed in such a way that the data is interoperable with external applications. Looking at it with a specific case, one of the identified requirements of the CIM is that citizens in an external application will have an address. The CIM must be interoperable with that address, capable of later locating that address in the digital twin. Finally, it must be taken into account that the CIM must dispose of the data in a friendly manner, storing the data in a structured way, understandable by users and being able to serve it through a user-friendly web application.
- Urban Planning: The second urban planning layer tries to respond from a technical and political point of view. Designing and developing the city and defining its land uses. In this aspect, the CIM has to address a problem that is not easily approachable from the data structure, in urban planning it is

contemplated that a land has a history of the data or a version control, even if function of a land changes in time. We are going to see this idea in more detail, suppose that we have several buildings that are going to be demolished to build a park, at the data level the entrances of the buildings cannot disappear even though they no longer exist physically because we would lose the historical data, and the area of the new park does not have to be exactly that of the buildings, so it is not easily relatable either. This problem is something that was not contemplated in the core of CityGML 2.0 and that in CityGML 3.0 a property called versioning has been proposed to solve part of the problem, this as its name indicates helps us to save different versions or historical data of city objects, but it does not contemplate that these can change their function and with it their properties. Moving on in this What-If dilemma, what if a building is converted to vegetation (a park) or to a waterbody. In the definition of CityGML it contemplates different relationships and properties for each of these classes, but at the same time we cannot lose the data history. That is why to solve this problem, we will study the possibility of having an xml file or database table so that it picks up those changes (this is explained in more detail in section below). Another challenge addressed by this CIM is to be able to contain the georeferenced data in such a way that afterwards they can be consulted from the viewer or another API. Urban planning ADE also delves into this aspect and proposes statistical grid to be able to represent the data, this can give us answers to the use cases of having an age-friendliness or green comfort grid.

- Physical Infrastructure: The third layer is the one that refers to the physical infrastructure of the city. The first things that come to mind when we think of a city are physical elements, but they share a property that differentiates them from the technical ones, they are not controllable. In this layer are the buildings, infrastructures etc. We generate the models using the cadaster, satellite, and Lidar data. This layer will also identify e.g., the works that are carried out on public roads and that will serve to feed the route calculator.
- Technical Infrastructure: The fourth and last layer identified, unlike the physical infrastructure layer, in the technical infrastructure we have controllable elements, which can be physical (large or not) but they will always have a control element, e.g., the streetlights or the communications network or sensors. In some cases, we can see the elements, such as the streetlights, and in other cases, they may go underground such as telecommunications networks, but all are controllable or interact with the city Digital Twin.

6.2.2 CityGML on URBANAGE CIM

URBANAGE City Information Model encompasses the four layers of a city definition: citizens, urban planning, physical and technical infrastructure that are well explained in the previous section of this deliverable. This model based on dividing the city scope in different layers for the different domains, has to include all the information and parameters needed to cover the entire schema and should meet the different requirements identified for URBANAGE.

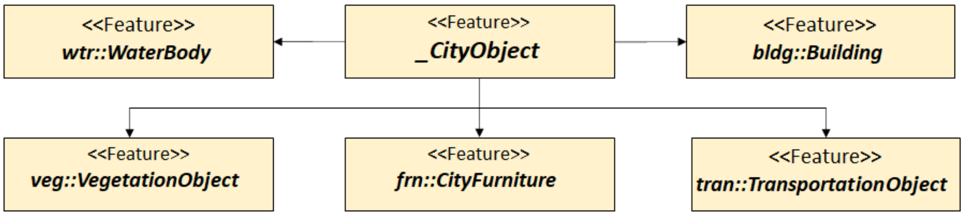
The entities of the CIM are going to be modelled using CityGML. The core module of the CityGML covers the main components of a city data model. Thus, there are different thematic modules that work separately, and its function is to extend the core to represent the different domains of the CityGML Data Model. Like this, the main class of the CityGML core module is *_CityObject*, inheriting from this class there are defined different thematic fields supporting the model of the city that can be freely combined: terrain, buildings, bridges, tunnels, land use, water bodies, vegetation, city furniture, transportation and generics.

To cover the requirements of the URBANAGE model, it should include the entities to enable the representation of urban infrastructures and services, technical infrastructure networks, relevant data for accessibility, and representation of future scenarios. Based on that, an approach for the representation of the different features of interest for URBANAGE has been done identifying the combination of the different thematic fields and creating a CityGML URBANAGE Profile.

The CityGML URBANAGE profile will be using the following classes corresponding to the CityGML Standard Specification: Urban infrastructures and services like fountains, benches, public toilets, bus stops or mechanical escalators will be represented as *CityFurniture* elements. Green infrastructure in the city such as trees, parks and gardens will be included as *Vegetation* objects. Blue infrastructure like fountains, pools and rivers are part of the *Waterbodies*, and the city facilities and services interesting for older people for instance care centres, pharmacies, supermarkets, hospitals, physiotherapists, shops and civic centres are part of the *Building* thematic module. Finally, to represent the elements of the transportation network including roads, sidewalks, pedestrian paths, crossroads the *Transportation* class will be used.

Next figure [Figure 14] represents the CityGML URBANAGE profile, including the main classes of the different thematic modules identified to be used for representing the URBANAGE CIM:

Figure 14: CityGML Features.



In addition to this, one of the URBANAGE CIM requirements defined in previous sections is to enable the representation of information at different scales. In this case, the information could be represented from city scale to building scale. CityGML is a multiscale data model, so it is possible to represent the data in different resolutions to fulfil the requirements.

According to the classes -or thematic fields- identified before, the definition of the most suitable scale to represent the information could be done. Actually, all classes can be represented at a city scale, but there are some elements that could be a bit overwhelming when using city scale, because of the likely big amount of them, those could be trees, benches, traffic lights, bus stops, fountains, shops... In those cases, a district scale will be used, and just keep the city scale representation for big extension elements, or the most meaningful ones to understand the city context in the URBANAGE like: rivers, green areas, hospitals, civic centres, roads or bike paths. Building scale is appropriate to represent the city facilities in detail, and any city furniture o element they have associated.

Figure [Figure 15] summarizes the most adequate scale for the representation of the CIM.

Figure 15: URBANAGE CIM scale

City	District	Building
River	Tree	Hospital
Green Area	Bench	Care Centre
Park	Traffic light	Civic Centre
Garden	Bus Stop	Pharmacy
Pool	Fountain	Mechanical Escalator
Hospital	Public Toilet	Shop
Care Centre	Shops	Supermarket
Civic Centre	Supermarket	Parking Lot for reduced mobility
Pharmacy	Phisiotherapist	
Mechanical Escalator	Sidewalk	
Road	Parking Lot for reduced mobility	
Bike Path	Crossroad	
Pedestrian Path		

6.2.3 CityGML extensions

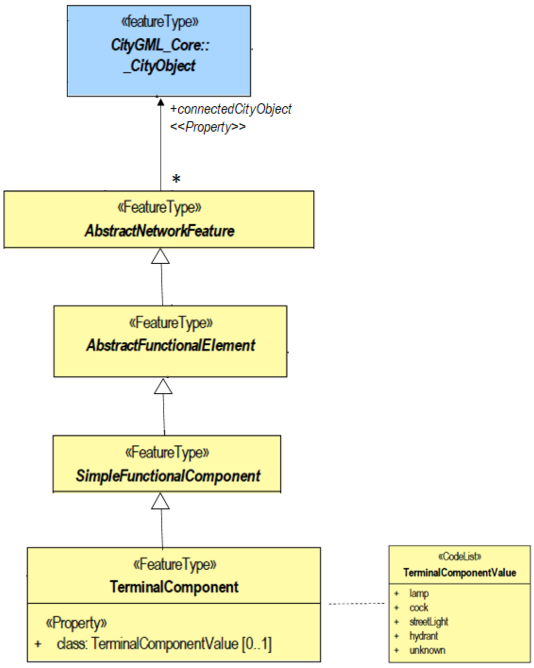
CityGML standard covers the main features for the representation of a city, so it is designed to be universal and applicable in different contexts. Some of those contexts may require some additional information to be modelled that it is not present in the CityGML core model. [17] To overcome this situation, the CityGML ADEs (Application Domain Extension) mechanism has been designed. The CityGML ADE purpose is to extend the CityGML model with additional domains, to widen the scope of the model and enable the representation of the information related with a very specific context. The ADE is implemented by adding additional schemas to the CityGML base. As mentioned in the state of the art, the two relevant ADEs that can be of interest in URBANAGE are Utility Network ADE and Urban Planning ADE, although the last one is not an official one yet, it should be taken in consideration looking to the future.

The requirements for the CIM include some elements and information to cover that can be modelled using with those ADE.

- **Utility Network ADE:**

Extends the CityGML to enable the representation of different utility networks such as electricity, freshwater, wastewater, gas or telecommunication networks [18]. Although the Utility Network ADE is defined to represent in detail the utilities domain in a city, and that is not the scope of the URBANAGE project, it includes the definition of elements that are part of the requirements. Using the ADE definition for those elements, will extend their properties and provide a more detailed characterization of them. Particularly, the Terminal Component could be of interest for defining the lightning of the city or the public toilets.

Figure 16: CityGML utility network UML



The figure [Figure 16] shows the UML the schema to represent Terminal components in the Utility Network ADE. The ADE relates to the CityGML base via the property *connectedCityObject*. This link allows to relate the utilities with the city context. In this case, to model some of the *CityFurnitures*, there is a *TerminalComponent* class that is an extension of *SimpleFunctionalComponents*. Using that class, it would be possible to include those specific elements.

6.2.4 Representation of Urban Planning Scenarios

To allow the representation of the urban planning scenarios is one of the requirements of the URBANAGE project. The creation of urban planning scenarios will tell us the alternatives for the city evolution, how the city could evolve over time and the best approach to address this growth towards a sustainable and inclusive future. The creation of urban planning scenarios implies the creation of different alternatives from the current city planning including all the modifications that are going to be done and the result of each one of these changes. The approach to cover this, can be addressed from these three alternatives: 1. Including the Urban Planning ADE, 2. Versioning as the new concept included in CityGML 3.0, 3. What-If solution.

1. **Urban Planning ADE**

Although at this moment it is still a proposal, we find the inclusion of this reference very appropriate for the project's context. Urban Planning ADE focuses its scope in urban planning and sustainable city growth and development, allowing a better understanding of the city evolution and facilitating the city management by extending the properties of the main city objects present in CityGML. Urban Planning ADE is composed of the three modules defined for the Urban Planning ADE data model, Urban Object, Urban Function and Statistical Grid.

The **urban object Module** is intended to extend the attributes or properties of the thematic modules for buildings, land use, transportation and cityobject. Figure [Figure 17], represents the UML schema for the building element in the ADE. It divides the building type in two different classes, one for the simple Buildings, and the second one for LargeCustomerFacilties. URBANAGE project will represent edifications of different nature, purposes, size etc. This division facilitates the differentiation of the edifications when doing city planning and also, although the classes have more attributes, here there are represented the main attributes of these classes that can be more interesting, or meaningful for planning purposes. The representation of transportation network is also key in Urban Planning, in URBANAGE it is envisaged to represent elements like roads, pedestrian paths, bike paths, traffic zones, etc. Figure [Figure 18**]** shows the UML classes and attributes of the ADE that can be of interest in this project:

Figure 17: Urban planning ADE AbstractBuilding

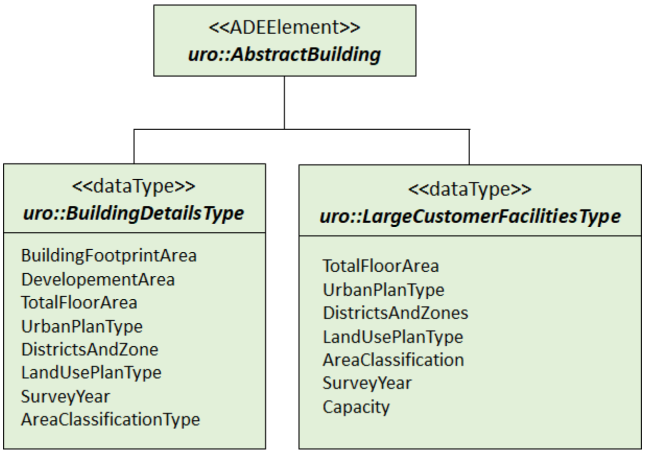
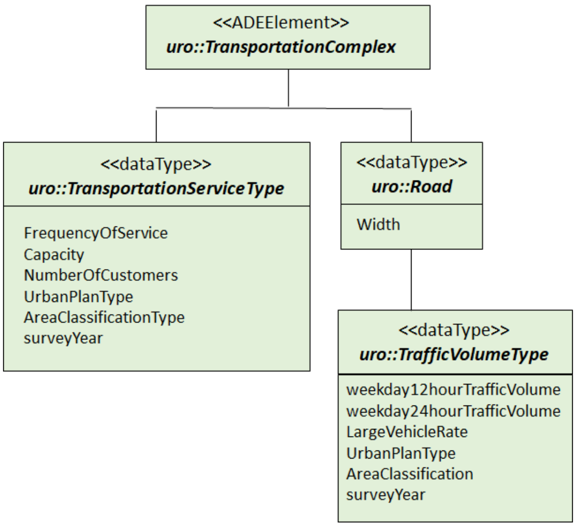
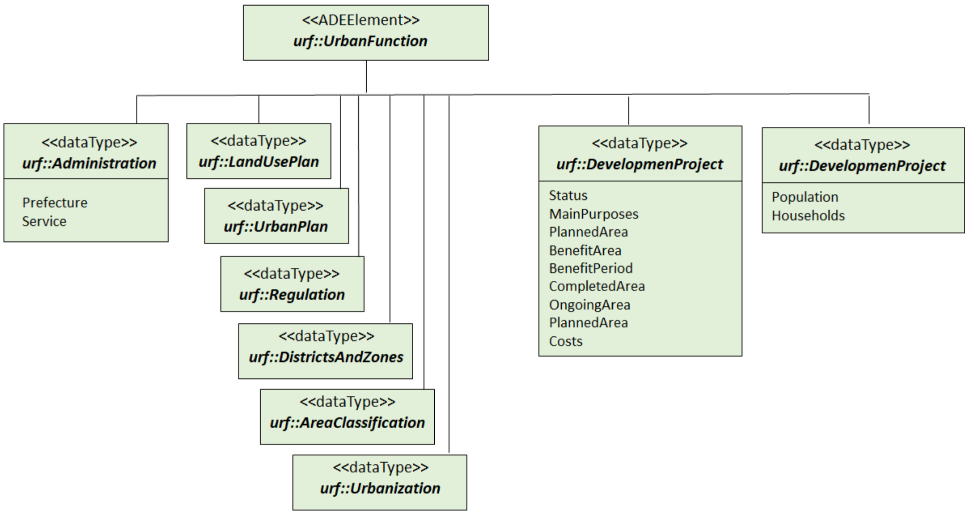


Figure 18: Urban planning ADE TransportationComplex



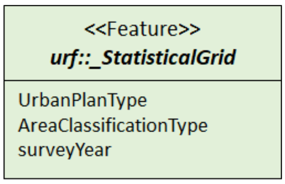
The function of **Urban Function Module** contains administrative information and regulations, that although cannot be seen in the real world are necessary to define and plan urban areas. Next figure shows the main classes of this module that can be necessary to store the information of this nature.

Figure 19: Urban planning ADE UrbanFunction



Urban Grid Module based on defining grid cells over the city with KPI indicators. This module is designed to enable time series comparison in cities and see how the city has evolved over time to understand the current situation and plan better the city for the future:

Figure 20: Urban planning ADE StatisticalGrid



2. What-If

What-If is a proposed alternative to model the changes of the city by creating new XML files for each variant in the model. The result of the implementation of this alternative is to have one CityGML model, and separated variants of it (one for each scenario) without modifying the base model. These separated variants would contain only the changes applied to the model. The modifications that can be done are:

- City Object changes the type: For instance, if a building is demolished and converted into a park, this change should be stored. The main city object that could be changed to another city object are buildings, vegetations, water bodies and transportations.
  It should be possible to change the object type from any of the object to another one by creating a new *change* tag with attributes to keep track of the element changed: *fromElement*, *toElement*.
  Also, the identification of the original city object type is needed in *fromId*:

```
<change fromElement="Building" fromId="1234" toElement="Vegetation" />
```

- Creation/Deletion of City Objects that are defined as punctual with coordinates x, y z like benches, lightning, fountains etc. In order to do that, *addPOI* element has to be added to the variant. With attributes name, function and lat/long to define the position.

  ```
  <addPOI name="Bus Stop - Av. Los Castros, 12," lat="43.468757" long="-3.843338" function="1110" />
  ```

  To delete one POI, element *remove* with just the id should be specified:

  ```
  <removePOI id="12345" />
  ```

- Modification of City Object information, like changing the building function, for instance from industrial to civic centre. In this case a generic element is created *parameter.* In the attribute ‘element’ the object type has to be set and in the ‘id’ the identified of the same. Then in ‘name’ the attribute that has to be changed is indicated and in ‘value’ the desired value.

  ```
  <parameter element="Building" id="54321" name="function" value="1000" />
  ```

7 Conclusion

The definition of the CIM realized in this document will permit to create an urban model that takes into consideration the requirements identified in WP2 and all three pilot sites coming from WP6. As a result of the analysis, CityGML is selected for developing the CIM. It will be extended with some of the technologies presented on this document, for example 3DTiles will be used for visualization purposes as CityGML is not optimal for web visualization. This work will be used in task 4.2 for developing the city model.

In this document also the background of the pilots is described, identifying the work done before to URBANAGE project and analysing how URBANAGE can improve the pilot GIS, in the case of Helsinki and Flanders the already have an urban model, which will be extended during URBANAGE project for giving response to the new requirements. In the case of Santander, they have a GIS system but doesn't have an urban model, this means that a Digital Twin will be developed from scratch.

In any case the requirements of the three pilot sites are aligned, and in section 3.1.4 the summary of these requirements is explained, creating the same CIM requirements for three pilots.

Finally, the relation of CIM with the rest of the architecture is defined, based on a components architecture, making easier to collaborate between partners and making the system more interoperable.

The CIM Structure defined in this document will permit to develop the City Information Model taking into account the requirements of three pilot sites, it is important to emphasize the importance of defining the CIM well because it is the base for Digital Twin and need to give answer to the use cases of each city .

8 References

Literature review

[1]. Kolbe, T. H. (2009). *Representing and Exchanging 3D City Models with CityGML*. Proceedings of the 3rd International Workshop on 3D Geo-Information, Lecture Notes in Geoinformation & Cartography, pp. 20. Seoul, Korea, Springer Verlag.

[2]. Kolbe, T. H., Groger, G., Nagel, C. & Hafele, K.-H. (2012). *OGC City Geography Markup Language (CityGML) Encoding Standard*. Open Geospatial Consortium. Category: OpenGIS Implementation Specification, GC Document: OGC 12-019.

[3]. den Duijn, X., Agugiaro, G. & Zlatanova, S., 2018: Modelling Below- and Above-Ground Utility Network Features with the CityGML Utility Network ADE: Experiences from Rotterdam. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Science, IV-4/W7, 43-50: https://doi.org/10.5194/isprs-annals-IV-4-W7-43-2018

[4]. Nobuhiro Ishimaru, Chikako Kurokawa, Yuichi Tanaka, Tomohisa Oishi, Kentaro Akahoshi, Tatjana Kutzner, Thomas H. Kolbe (2020). CityGML Urban Planning ADE for i-Urban Revitalization. Category: OGC® Discussion Paper. OGC Document: 20-000r1.

[5]. https://www.sedecatastro.gob.es/

[6]. https://www.3dcitydb.org/3dcitydb/

[7]. http://www.citygml.org/

[8]. https://www.ogc.org/

[9]. https://www.ogc.org/standards/3DTiles

[10]. https://cesium.com/blog/2015/08/10/introducing-3d-tiles/

[11]. https://www.ogc.org/standards/requests/219

[12]. https://link.springer.com/article/10.1007/s41064-020-00095-z

[13]. https://www.citygmlwiki.org/index.php?title=Citygml_Wiki

[14]. https://github.com/gioagu/3dcitydb_utility_network_ade

[15]. https://cesium.com/blog/2021/11/10/introducing-3d-tiles-next/

[16]. https://www.citygmlwiki.org/images/2/2a/NetworkCore_-_UtilityNetworkADE.pdf

[17]. https://opengeospatialdata.springeropen.com/articles/10.1186/s40965-018-0055-6

[18]. https://github.com/TatjanaKutzner/CityGML-UtilityNetwork-ADE

[19]. https://portal.ogc.org/files/?artifact_id=92113