Development of an Extension for CityGML 3.0 for Fire Prevention Projects

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ABSTRACT

To elaborate on a technical fire and disaster prevention project, information about the building and its surroundings is key to determining which safety measures should be used. The use of 3D models that integrate GIS and BIM has been a promising tool for this type of analysis, which requires information from different sources in the same environment. This study presents the construction of a conceptual model for an extension of CityGML (Application Domain Extension - ADE) with the necessary information to elaborate a technical fire and disaster prevention project, following the standards of the Fire Department of the state of Paraná, Brazil. In addition to information from IFC models, information obtained from mapping carried out by the UFPRCampusMap (UCM) project at the Federal University of Paraná was also added. To build the ADE, IFC and UCM conceptual model formats were studied, as well as their geometric and semantic correspondence with CityGML. New classes were created, classes for specific attributes, and subclasses derived from existing classes. For a total of 86 attributes, 21 have full correspondence, 27 partially correspond, and 38 have no correspondence. The correspondence of real-world objects to IFC was much greater than that of CityGML, since the latter had more generic classes regarding the interior of the building. Using this model, it will be possible to implement this extension in 3D models, as a suggestion for future studies.

Keywords-CityGML; application domain extension; IFC; fire prevention

I. INTRODUCTION

CityGML is a standard based on Geography Markup Language (GML), created for a common definition of entities, attributes, and basic relationships of a 3D city model, which favors sustainable and economical maintenance of the modeling, allowing reusing the same data in different fields of application [1]. Version 3.0 published in 2021, had the latest structure adopted by the format [2]. This consists of a core module, which comprises the basic concepts and components of a virtual city, and several extension modules, referring to specific thematic fields such as buildings, bridges, and vegetation, which meet specific needs [3]. Once it aims at simplicity, it is possible to consider CityGML limited and not suitable for many use cases and situations. For this reason, it is often extended through a mechanism called Application Domain Extension (ADE) [4]. An ADE incorporates specific application data into the CityGML conceptual model in a systematic and well-structured way, preserving the core concepts [1]. ADEs can be built by introducing new classes or resources, adding new attributes to existing classes or resources, or extending attribute code lists [4]. Like the CityGML conceptual model, an ADE must be defined in UML language, according to the ISO 19109:2015 specifications, which guide the rules for application models. The rules of ISO 19103:2015, which standardizes the use of UML for geographic information [1] must also be followed. The ADE classes must be derived from the original classes that define concepts such as space and can have an unlimited number of features and associations, in addition to those inherited from existing classes. To ensure semantic interoperability, the predefined attribute types of CityGML or the standardized models of the ISO 19100 series of international standards should also be used when appropriate. If a predefined type is not available, ADEs can define their own data types or import others from external conceptual models [1].

This study focuses on using data from BIM models and indoor and surrounding mapping to enrich the CityGML model, in a specific extension for fire prevention. 3D models that combine GIS with BIM are promising tools in applications that involve spatial data. The integration of information from CityGML and IFC, an open BIM format that has richer semantics regarding the inside of buildings, has been studied for several applications, such as emergency routes, event security, campus evacuation, LEED certification of buildings, energy simulation, urban planning, multimodal routes, microclimate analysis, and legal property boundaries [4-8]. In this research, the conceptual model for a CityGML extension was developed, with the information needed to draw up a technical fire and disaster prevention project (PTPID - projeto técnico de prevenção a incêndio e desastre). In Brazil, PTPID aims to demonstrate the security measures to be adopted in the building and must be submitted to the fire department for approval. It is developed based on standards and codes published in each state. The Fire and Panic Safety Code of the Paraná Fire Department [9] presents safety measures that should be adopted in buildings, according to the type of occupancy, height, and fire load. For its elaboration, information about building elements, such as doors and staircases, and surrounding information, such as the distance to the nearest building or access for fire engines, is necessary. It is common for designers to search for this type of information from different sources, which is why an application that can gather it together in a single model would be useful.

II. MATERIALS AND METHODS

Figure 1 shows the steps followed to develop the ADE. The first step is the definition of classes, based on the safety measures required for the building. Once the classes are determined, geometric compatibility is carried out based on the level of information needed and semantic compatibility, with the alignment of classes and attributes.

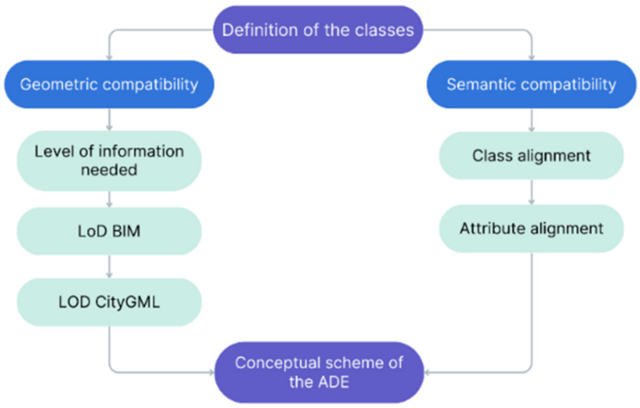

Fig. 1. Method to develop the ADE.

To elaborate on the ADE structure, the conceptual models of the IFC's CityGML and the vector geospatial data obtained by the UFPR CampusMap Project (www.campusmap.ufpr.br) mapping were analyzed. The project makes data available for the entire university community and has helped several sectors in infrastructure management and planning, as well as the planning of contracts. The data is structured using a conceptual model based on the ET-EDGV (Technical Specification for Structuring Vector Geospatial Data). The ET-EDGV is the Brazilian standard that defines the structure of all object classes, attributes, and the spatial and topological relationships that are dealt with when acquiring geospatial data [10]. UCM mapping was used to obtain data on internal elements that did not have a specific class in the IFC model, such as fire extinguishers (according to the conceptual diagram in Figure 2), and the buildings' surroundings, which could be used as a basis to create the 3D CityGML model (according to the conceptual diagram in Figure 3).

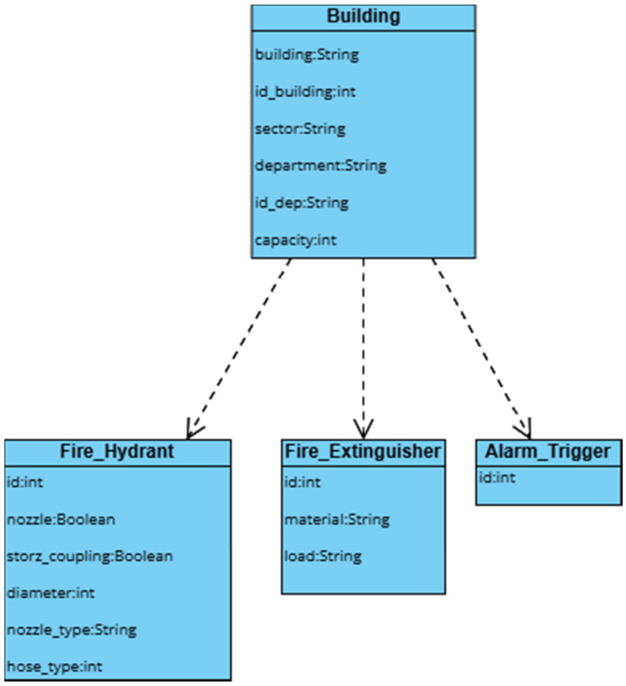

Fig. 2. UCM conceptual model for internal fire prevention elements.

A. Class Definition

The safety measures required by the Fire and Panic Safety Code of the Paraná Fire Department are: vehicle access, separation between buildings, fire resistance of building materials, compartmentalization, control of finishing materials, emergency exits, emergency elevator, smoke control, fire risk management, fire brigade, emergency lighting, extinguishers, automatic fire detection, structural safety, fire hydrants and hose reels, sprinklers, and emergency plan [9]. For each safety measure, there are information requirements that are necessary for the elaboration of the project, related to building elements. These elements were identified as objects and, based on these, the classes that represent them in CityGML, IFC, and UCM conceptual models were defined (Table I). The correspondence between the CityGML, IFC, and UCM data models was carried out geometrically and semantically, as described below.

B. Geometric Compatibility

To make IFC and CityGML geometrically compatible, the BIM Forum's Level of Development (LoD) concepts were used for IFC and CityGML's Level of Detail (LOD). A LoD of 350 was used for IFC objects, as their quantity, size, shape, location, orientation, and interface as adjacent or dependent model elements must be measurable [12]. The IFC LoD was then matched with the CityGML LOD. For the doors, for example, LOD involves an internal and external LOD3. Version 3.0 from CityGML differentiates between the LODs from inside and outside the building. External openings were added to LOD3, and the same logic was followed for the internal part.

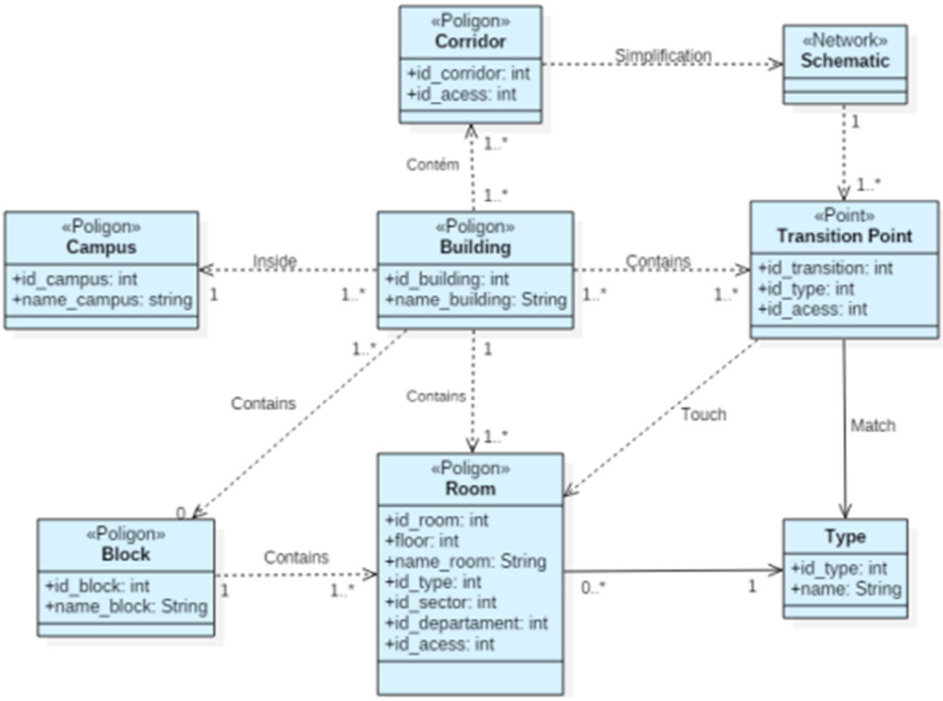

Fig. 3. UCM conceptual model for external elements [11].

TABLE I. OBJECTS AND CLASSES

Objects	CityGML	IFC	UCM
Window	Window	IfcWindow	-
Room	BuildingRoom	IfcSpace	Room
Building	AbstractBuilding	IfcBuilding	Building
Opening	AbstractFillingElement	IfcOpeningElement	-
Water Tank	BuildingConstructiveElement	IfcTank	-
Stair	BuildingInstallation	IfcStair	-
Corridor	BuildingPart	IfcSpace	Corridor
Door	Door	IfcDoor	-
Handrail	-	IfcRailing	-
Gate	Door	IfcDoor	-
Floor	FloorSurface	IfcCovering	-
Wall	InteriorWallSurface	IfcWall	-
Ceiling	CeilingSurface	IfcCovering	-
Roof	RoofSurface	IfcCovering	-
Road	Road	-	Street_Stretch
Slab	BuildingConstructiveElement	IfcSlab	-
Beam	BuildingConstructiveElement	IfcBeam	-
Facade	WallSurface	IfcWall	-
Elevator	BuildingInstallation	IfcTransportElement	-
Floor	BuildingUnit	IfcBuildingStorey	-
Air inlet/outlet	-	IfcFlowTerminal/ IfcDuctSegment	-
Emergency lamp	-	IfcLightFixture	-
Emergency sign	-	IfcSign	-
Extinguisher	-	-	Extinguisher
Alarm trigger	-	IfcAlarm	Alarm_trigger
Alarm indicator	-	IfcAlarm	-
Smoke detector	-	-	-
Hydrant	-	IfcFireSupressionTerminal	Hydrant
Fire pipes	-	IfcPipeSegment	-
Fire pump	-	IfcPump	-
Pressure relief valve	-	IfcValve	-
Sprinkler valve	-	IfcValve	-

For the UCM classes, geometric compatibilization was carried out as proposed in [13], based on the provisions of Brazilian standard ET - ADGV (Technical Specification for the Acquisition of Vector Geospatial Data) and the CityGML 2.0 documentation, which was used here as an analogy, since the LOD specification is more complete in this version. For the classes *Building* and *Street_Stretch*, the scales and their relationship with the CityGML LODs were analyzed. The purpose of this relationship is to define, for each class, which LOD at each scale and whether they would exist in the representation [13]. The classes *Building* and *Street_Stretch* are shown in Table II. The *Room* and *Corridor* classes do not exist in ET-ADGV but were included in the IFC analysis. Table II shows the scales envisaged for class acquisition, with the value referring to the thousands of scale denominators. For example, it is possible to represent *Street_Stretch* from scale 1:1,000 to scale 1:100,000. *A*, *L*, and *P* represent possible options of graphic primitives for object acquisition, according to its dimensions. In the case of an area representation (*A*), for *Street_Stretch*, for example, this must be bigger than 12.5 mm². In the case of a line representation (*L*), the length must be greater than 10 mm. Representation by point (*P*) is not possible for this class [10].

TABLE II. ACQUISITION OF OBJECTS ACCORDING TO THE SCALE

Class	Scales	A	L	P
		s >= (mm²)	*D* >= (mm)	
Street_Stretch	1-100	12,5	10	-
Building	1-100	1	-	X

Table III shows the minimum elements that can be represented in CityGML. It was adapted from [13], excluding LOD 4, since in version 2.0 this was used for representations of interiors and building elements. The minimum dimensions for the *A* and *L* representations, in Table II, were calculated for each scale. They were also compared to the minimum considered for CityGML 2.0, to verify their representation in this model.

TABLE III. REPRESENTABLE ELEMENTS IN CITYGML

	Area (m²)	Line (m)
LOD 1	36	6
LOD 2	16	4
LOD 3	4	2

C. Semantic Compatibility

After defining the classes, it was determined which information requirements for each object were relevant to the development of the project. These were considered to be attributes of the classes in the ADE conceptual model and were divided into three categories:

- Those that correspond to CityGML attributes and classes. For example: the height of the rooms, in IFC, is stored in the *Height* attribute of the *Qto_BuildingBaseQuantities*, property set, a class associated with *IfcSpace* [14]. In CityGML, this attribute is stored in the class *BuildingRoom*, specifically in the attribute *RoomHeight*.
- Those with a partial correspondence: there is a class corresponding to that object or property in CityGML but not the attribute, or there is the attribute but there is not the specific class for that object. For example: the operation and direction of doors whose class exists but not the attribute or data referring to materials or localization of elements that do not appear in CityGML, such as emergency lamps.
- Those that do not have any correspondence.

Then, the attributes that should be included in the ADE were identified. The attributes that have total correspondence do not need to be included. Figure 4 shows how the classes were created.

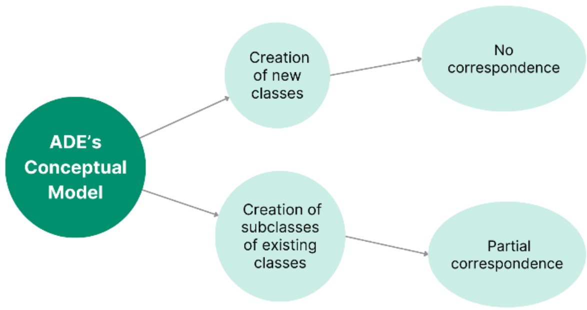

Fig. 4. ADE class creation process.

Initially, it was checked which real-world objects did not have a representation in CityGML. These were: railing, air inlet/outlet, emergency lamp, emergency sign, fire extinguisher, alarm trigger and alarm indicator, smoke detector, hydrant, fire pipe, fire pump, pressure relief, and sprinkler valves.

A new class, referring to a real-world object with geometry must be directly or indirectly derived from *Core::AbstractSpace* or *Core::AbstractSpaceBoundary*. Thus, the spatial properties predefined from CityGML and the associated LOD concept are inherited and made available to the class [1]. Based on this guidance, the *AbstractFireElement* class was created and the following classes were derived from it: *Air_duct*, *Railing*, *Air_terminal*, *Emergency_lamp*, *Emergency_sign*, *Fire_extinguisher*, *Alarm* (triggers and indicators will be defined in the attributes), *Smoke_detector*, *Hydrant*, *Pipe_segment*, *Pump*, and *Valve* (the difference between pressure relief and sprinkler will be defined in the attributes).

The attributes of classes with partial correspondence were added to the existing classes through the attribute *adeOfFeatureTypeName*, with the feature being the name of the class in which the attribute is defined. Subclasses of abstract data corresponding to the following classes were created: *AbstractAppearance* from the Core module, *BuildingRoom*, *AbstractBuilding*, *BuildingInstallation*, and *BuildingUnit* from the *Building* module, *Door*, from the *Construction* module, and *Road* from the *Transportation* module.

Additional application-specific attributes and associations were modeled as properties of the ADE subclass. Geometric attributes, such as localization and width or height, for example, can be measured directly in the model and, therefore, were not included in the ADE.

III. RESULTS AND DISCUSSION

32 real-world objects were identified (Table I). Of the 32 listed objects, 19 had classes in the CityGML that represented them. The IFC classes, in turn, encompassed 29 of the 32 elements. The UCM classes comprised only seven elements. This result was expected since many of the objects are edification elements and IFC is the richest format in information about the interior of the building.

A. Geometric Compatibilization

Table IV presents the minimum LODs of the CityGML model for each object, considering the BIM LoD set at 350, for all, due to the need for reliable measurements of the elements. When windows need to be represented, for example, the minimum external LOD of CityGML is 3, as the openings are needed. No details are needed internally, so a LOD of 0 could be accepted. If the rooms have a fundamental representation in the CityGML model, the external LOD can be 1, as there is no need for detailing. Internally, there must be divisions, therefore, a LOD 3 is the minimum recommended.

TABLE I. LEVEL OF DETAIL

Object	**External LOD CityGML**	**Internal LOD CityGML**
Window	3	0
Room, Slab, Beam, Corridor, Ceiling, Elevator, Floor, Fire Extinguisher, Air inlets/outlets, Emergency lamp, Alarm trigger, Alarm indicator, Smoke detector, Hydrant, Fire pipes, Fire pump, Pressure relief valve, Sprinkler valve	1	3
Building	2	0
Opening	3	3
Water Tank	2	3
Stair	3	3
Door	3	3
Gate	3	-
Wall	3	3
Roof	3	0
Road	-	-
Facade	1	0

Regarding the UCM classes, *Street_Stretch* and *Building* were derived from ET-ADGV. Tables V and VI show which are the minimum representation dimensions of area and length for each scale. It is also presented which CityGML LODs can be represented for each scale and whether it occurs through line, area, both, or neither. For scale 1:1,000, for example, the minimum dimension to be mapped for an object of the *Street_Stretch* class would be an area of 12.5m² and a length of 10 m. An object with these dimensions would be represented in CityGML only in LOD3. However, buildings begin to be mapped in CityGML from a scale of 1:10,000 in LOD3.

The classes *Room* and *Corridor* do not belong to ET-ADGV, but since they are classes that belong to IFC and that had their analysis accomplished in this section, they were not addressed again. The classes *Fire_Extinguisher*, *Hydrant*, and *Alarm_trigger* are not derived from ET-ADGV and do not have any corresponding classes in CityGML.

TABLE II. MINIMUM DIMENSIONS FOR AREA AND WIDTH REPRESENTATION

Street_Stretch					
Scales	1000	10000	25000	50000	100000
Minimum area (m²)	12,5	125	312,5	625	1250
Minimum dimension (m)	10	100	250	500	1000
LOD1	no	yes	yes	yes	yes
LOD2	no	yes	yes	yes	yes
LOD3	yes	yes	yes	yes	yes

TABLE III. MINIMUM DIMENSIONS FOR AREA AND WIDTH REPRESENTATION

Building					
Scales	1000	10000	25000	50000	100000
Minimum area (m²)	1	10	25	50	100
Minimum dimension (m)	-	-	-	-	-
LOD1	no	no	no	yes	yes
LOD2	no	no	yes	yes	yes
LOD3	no	yes	yes	yes	yes

B. Semantic Compatibilization

For a total of 86 attributes analyzed, referring to the classes in Table I, 21 had total correspondence, 27 partially corresponded and 38 did not have any correspondence. These are:

- Total correspondence: location of windows, height and area of rooms, height, location, address, type and occupancy of buildings, location and volume of the water tank, height and width of stairs, width of corridor, direction of opening and operation of doors, and width and height of the gate.
- Partial correspondence: room population, material and ceiling height of stairs, length of landings, length of the enclosed staircase antechamber, ceiling height of the enclosed staircase antechamber, door material, presence of a fire door and panic bar, floor, walls, lining, roofing, slabs, beams, façade, and elevator materials, width, load capacity, and free height of the road, and floor population.
- No correspondence: distance to the fire station, height of railing, distance from floor to duct in enclosed stairs, duct section area, proportion of duct dimensions, vertical distance between duct inlet and outlet, horizontal distance in plan from the air outlet to the entrance door of the antechamber, horizontal distance in plan from the air inlet to the entrance door of enclosed staircase, location, level of lighting and type of emergency lamps, location and type of emergency signage, height of alarm indicators, location of smoke detectors, location of and type of fire extinguishers, location and height of alarm triggers, location, dimensions, height, material and type of hydrants, diameter and length of the hydrant hose, quantity of hydrant valves, minimum hydrant flow and pressure, distance of hydrants to doors and stairs, location, diameter, material, condition (apparent

or hidden), and color of fire pipping, pump flow and power, and location of pressure relief registers and sprinklers.

The fire prevention project involves several edification items that have generic classes in CityGML and more detailed classes in IFC. Therefore, a reduced number of total correspondences was expected. However, this does not necessarily generate more classes in ADE, as many attributes can be related to the same class, such as *Hydrant*, for example.

The conceptual model was divided into two parts, A and B, and is represented in Figures 5 and 6. In part A, there are the existing classes that had attributes added. These are: *AbstractAppearance*_PTPID, *BuildingRoom_PTPID*, *AbstractBuilding_PTPID, Door_PTPID, Road_PTPID* , and *BuildingUnit_PTPID*. In part B, the class *AbstractFireElement* was created, from which 12 classes were derived: handrail, air duct, air terminal, emergency lamp, emergency sign board, fire extinguisher, alarm, smoke detector, hydrant, fire pipe, fire pump, and valve. The classes are classified in colors: blue classes are CityGML pre-existing classes, yellow classes are classes created by the ADE mechanism from the blue classes, and orange classes are the new classes.

The attributes related to stairs are geometric and can be measured in the elements, therefore, it was decided to maintain the class *BuildingInstallation* without the need to add attributes to it. In total, one superclass (*AbstractFireElement*) and 12 new classes derived from it were created. In addition, eight property classes were created for specific attributes. Six subclasses were also created, derived from existing classes. For a total of 86 attributes, 21 have full correspondence, 27 partially correspond, and 38 have no correspondence. The fire prevention project involves several building items that have generic classes in CityGML and more detailed classes in IFC. Therefore, a reduced number of full correspondences was expected. However, this does not necessarily generate more classes in ADE, because many attributes can be related to the same class, such as *Hydrant* for example.

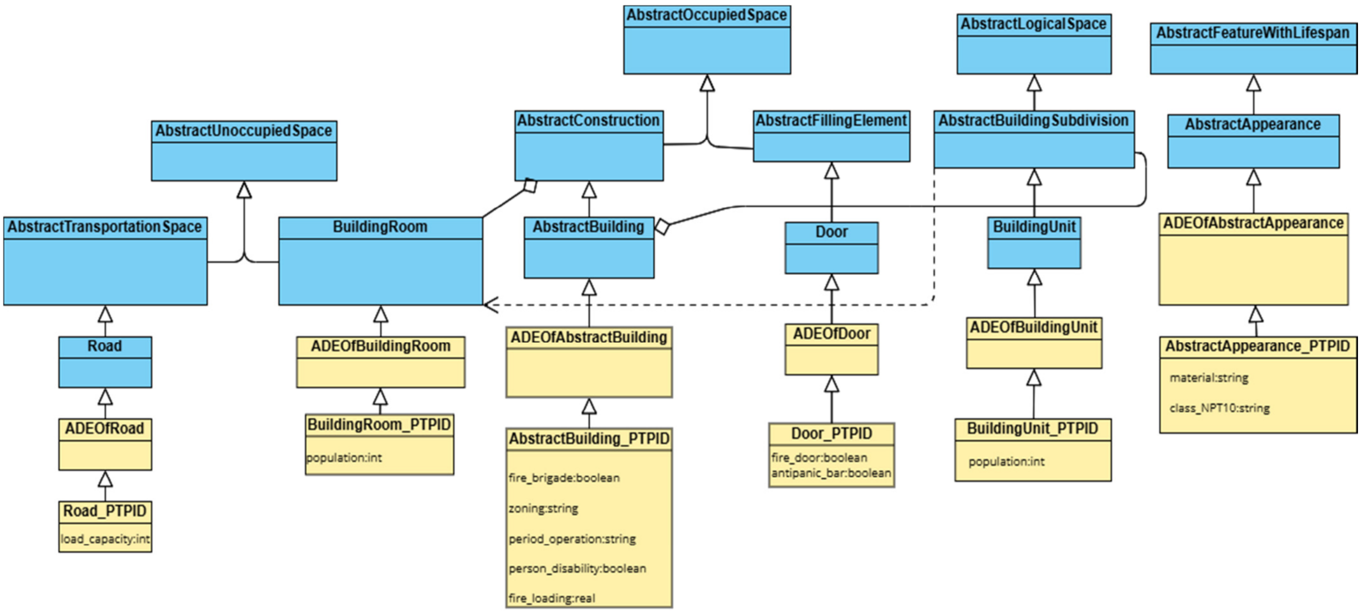

Fig. 5. Part A of the conceptual model.

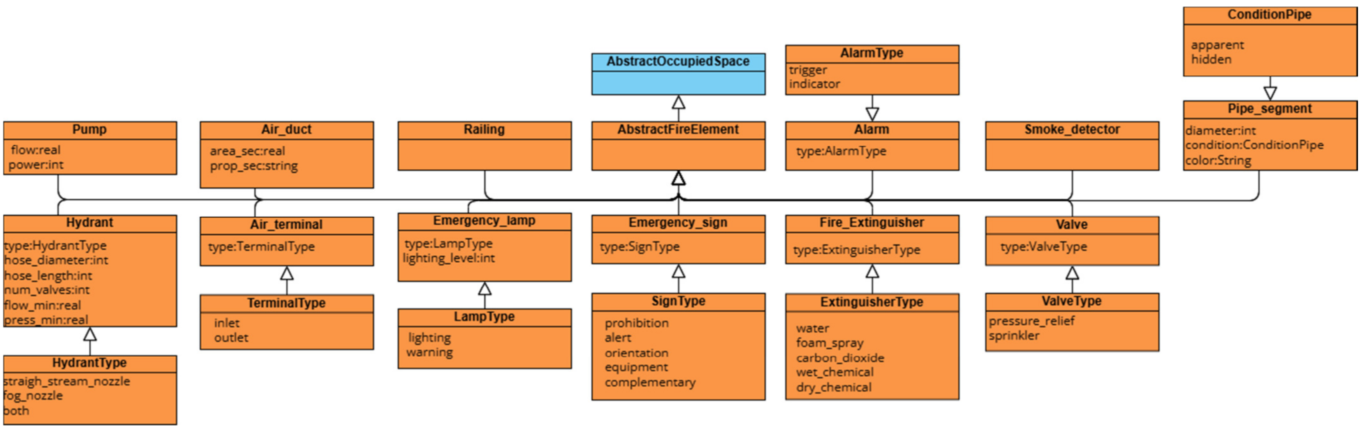

Fig. 6. Part B of the conceptual model.

IV. CONCLUSION

The correspondence of real-world objects (referring to buildings and surroundings) with IFC was much greater than that of CityGML, which can be explained since the last had more generic classes regarding the interior of the building. Therefore, activities that involve internal elements of the building can be better represented in CityGML with the addition of information from IFC. Although UCM had fewer correspondence classes with CityGML, its contribution was important to fill some gaps, such as fire extinguishers that do not have a specific class in IFC, in addition to serving as a basis for creating the CityGML model. The choice to use CityGML as a basis for the data conceptual model was the right one, once the addition of attributes to this format occurs logically and efficiently. The model can be extended to a wide range of activities by users, and with version 3.0 some changes made adding new attributes even simpler. There are some classes, such as fire extinguishers, that also do not exist in the IFC. However, the ADE mechanism makes it easier to create a class for this element in CityGML than in IFC, since in the latter, new classes must be created by the official standard.

This study demonstrates the benefits of using modeling technologies such as BIM and 3D city models. Currently, the use of BIM has been targeted by several sectors: companies, governments, experts, and training providers [15]. The integration of BIM with 3D city models, as shown in this work, is an area of study with great potential for application. This research focused on elaborating the conceptual model. Coding and implementation will be performed in later steps. The proposed data model, when implemented, will allow access to object attributes along with its visualization, which will speed up the process. Furthermore, measurements that need to be verified on-site can be obtained by users when accessing the model.

Despite the benefits of the proposed model, several points should be emphasized when dealing with limitations in obtaining IFC data, mainly as reported in [4]. In practice, IFC datasets are not always semantically rich. Therefore, there may be a lack of information on incorrect classification that hinders its use. This study also presents some other limitations, such as the use of CityGML, which is still not supported by several software packages.

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