3D UNDERGROUND LAND ADMINISTRATION BY STANDARDIZED GEOINFORMATION

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ABSTRACT:

The density of the built environment is growing due to the migration from rural areas to urban areas. The challenges that should be addressed are therefore increased in today's built environment. In relation to this, the productive use of underground space is essential to overcome the problems on the surface. Since the built environment has complex and multi-layered buildings more than ever, the delineation and management of the cadastral rights, restrictions, and responsibilities (RRRs) are significantly difficult in two-dimensional (2D). For this reason, creating approaches for the efficient representation of RRRs in three-dimensional (3D) is a hot topic in recent years. Considering the multifaceted structure of the underground, 3D geoinformation regarding the underground is needed for managing the underground space. Regarding this, it is significant to underline that legal and administrative namely land administration considerations are integral parts of the planning of underground space. This paper thus extends the CityJSON core schema in a way that it can be used for 3D delineation of underground cadastral RRRs.

1. INTRODUCTION

There is an increasing movement for living in the urban areas. The estimations show that the majority of the population of the cities will reside in urban areas in the near future. These estimations are obtained from the cities in different regions of the world (OECD/European Commission, 2020). Increased population density in urban areas requires the efficient management of usable areas and spaces in the urban areas to provide issueless living for citizens.

The amount of usable areas on the surface is decreasing expeditiously these days. For this reason, the governments focus on solutions that allow them to benefit from the underground space in the best manner (Durmisevic, 1999). This is because there is a great number of case studies that provide strong evidence that the use of underground space is highly beneficial for dealing with various problems in densely built urban environments (ITA Working Group 20, 2023). Providing hassle-free mobility for citizens is one of the strong needs in urban areas. Disorganization of businesses, increased traffic density, and disruption of utilities and services are also significant challenges that should be addresses for making built environment sustainable.

It is important to note that managing underground space is not an easy task because urban underground space contains many types of structures with distinct functions. Storage (e.g. water, food, oil, and waste), industry (e.g. factory), transportation (e.g. road, railway, and tunnels), utilities (e.g. natural gas, electric cables, and sewerage), public use (e.g. shopping malls and hospitals), and private and personal use (e.g. garages) can be mentioned as main structures and functions within subsurface (Bobylev, 2009). While Figure 1a shows an example of subsurface utilities, Figure 1b illustrates the storeys of a subway.

Noteworthy to mention that the abovementioned solutions regarding subsurface are related to planning, designing, constructing, and managing underground space. What is more, various considerations from different contexts such as geologic, engineering, psychological and physiological, safety, ventilation, economic, and legal and administrative should be paid attention to put into practice these solutions (Goel et al., 2012).

Legal and administrative considerations are subjects of land administration among these considerations. Therefore, Land Administration Systems (LAS) that deal with the overarching management of identification and registration of the cadastral rights, restrictions, and responsibilities (RRRs) are essential for the use of underground space. These systems are generally based on two-dimensional (2D) delineation and registration of cadastral RRRs. However, since 2D registrations might be insufficient for the complete management of cadastral RRRs in densely built urban environments, there is a strong aim to improve LAS such that they cover three-dimensional (3D) representation and registration of property ownership (Guler & Yomralioglu, 2022; Kalogianni et al., 2020). This aim is important for the productive use of underground space to meet the needs of complex urban areas.

3D geoinformation is one of the efficient ways for creating 3D digital models of different types of subsurface objects as well as their associated cadastral RRRs (Guler & Yomralioglu, 2021). Accordingly, specific attention should be given to related data standards to enable interoperability between different applications that use generated 3D models and facilitate the implementation of

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Figure 1. Examples of the underground facilities that legal spaces need to be defined in 3D are (a) underground pipelines, b) storeys of a subway).

underground land administration. This paper thus aims to extend the CityJSON core schema such that it can be used to create 3D representations of cadastral RRRs within underground space. This paper is divided into four sections. After the introduction section, the second section presents the methodology in the present paper by covering the review of approaches that can be used for 3D modelling regarding underground space. Section 3 provides the results that encompass the details of the proposed CityJSON extension. The last section includes a discussion and then concludes the paper.

2. METHODOLODY

Geoinformation is vital for the efficient use of underground space in terms of planning, modelling, constructing, and managing. The standards that facilitate the generating, storing, distributing, and amending the geoinformation are thus related to the management of underground space. Considering the complexity of the underground space, 2D spatial data is insufficient for detailed representations and required analyses. Further, there is a need to analyse the standards regarding 3D modelling of underground space, utilities, and facilities for land administration purposes (Kolbe & Donaubauer, 2021). It is evident that one of the major issues related to underground space is the property ownership. For this reason, the methodology in this paper consists of a review of standards that enable to 3D modelling of underground space.

Geographic Information System (GIS) and Building Information Modelling (BIM) domains are vital for the sustainable development of urban areas since they provide essential data containing rich semantics and geometric information. Such data is used for different analyses that provide a scientific basis for decisions regarding urban areas. While the GIS domain considers covering the whole built environment as a primary aim, the BIM domain focuses on detailed and digital models of buildings and facilities as a first place. However, the integration between GIS and BIM domains is inevitable for the sustainable development of urban areas (Noardo et al., 2020).

The standards play an important role in both GIS and BIM domains to increase productivity regarding the modelling procedures and distribution and sharing of the generated digital data. ISO 19650 standard series provides a basic structure that is beneficial for organizing and digitalizing the information in the Architecture, Engineering, Construction, and Operation (AECO) industry with the help of BIM (ISO, 2018b). A prominent standard to create and manage spatial and semantic information regarding buildings/facilities in a 3D and digital way is Industry Foundation Classes (IFC) (ISO, 2018a). It is an open standard that is managed by BuildingSMART organization (buildingSMART, 2022).

There is another ISO standard namely the Land Administration Domain Model (LADM) that provides a common ontology for land administration purposes. The second edition of this standard is being developed such that it covers all parts of the holistic land administration vision such as valuation and spatial planning (Kara et al., 2024).

Figure 2 shows a part of the IFC structure containing various entities that can be used for 3D delineation of property ownership in the buildings and the built environment. Regarding this, different studies focused on how to benefit from BIM models to represent cadastral RRRs as 3D digital information (Atazadeh et al., 2017).

Most of the studies zoom in on the 3D delineation of property ownership in the buildings. They provide case studies that show the unambiguous modelling of apartment rights/condominium rights within the buildings. For example, Figure 3 shows two examples of condominium units that have main units and annexes that they have the right to use privately.

Even though few studies put forward the opportunity that comes from the use of BIM models to manage cadastral RRRs within urban areas, the implementation of the entities within the IFC schema that can be used for modelling of cadastral RRRs in the context of urban land administration is not at a sufficient level. Recently, Ramlakhan et al. (2023) proposed to extend the IFC schema based on LADM to model the underground legal spaces. A majority of the studies that include underground assets within land administration purposes benefit from LADM standard to develop conceptual models.

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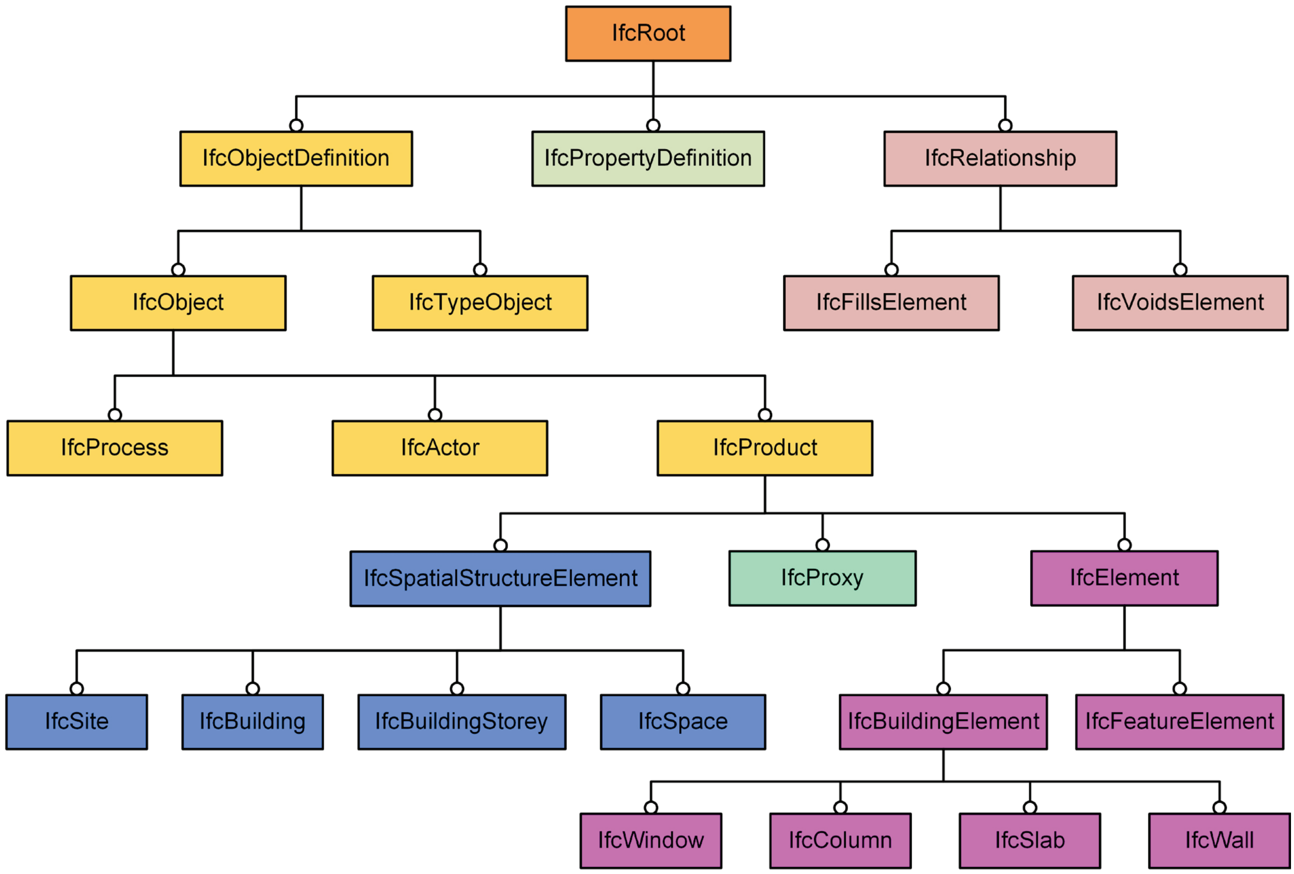

Figure 2. A part of the IFC schema that contains entities related to the representation of property ownership.

Some of them also provide prototypes based on developed conceptual models (Yan et al., 2021).

The use of CityGML for 3D representation and registration of cadastral RRRs that cover underground is another approach. This is because underground legal spaces can cover large areas within the built environment and CityGML aims to enable 3D modelling of the whole built environment along with buildings.

CityGML 3.0 was approved in 2021 as an official Open Geospatial Consortium (OGC) standard (OGC, 2021b). Before, CityGML 2.0 was widely used for creating 3D models of cities. With the latest version, some improvements in the conceptual model of CityGML are provided to enable better integration with other standards that are used for modelling objects within the built environment such as IFC, LandInfra, and LADM (Kutzner et al., 2020). In this regard, new modules such as *Construction* are added to the content of the CityGML standard with its new version. Since the conceptual model of CityGML 2.0 does not cover specific features and relationships for 3D delineation of property ownership, earlier studies investigate the feasibility of the CityGML by developing different Applications Domain Extensions (ADE) for 3D cadastre purposes.

3D representation of legal spaces regarding cadastral RRRs is also investigated with the sharing of the conceptual model of CityGML 3.0 (Sun et al., 2019). This is because CityGML 3.0 provides different types of space modelling such as *occupied space* and *unoccupied space* to enable 3D modelling of logical spaces. However, most of these studies mainly focus on the aboveground cadastral RRRs and they do not provide prototypes regarding the CityGML-based developed conceptual models. Recently, Saeidian et al. (2023b) develop a CityGML ADE for 3D representation of underground cadastral RRRs specifically. They present CityGML-based 3D models of different objects that are occurred underground such as tunnels and pipelines and also 3D representation of cadastral RRRs that can be related to these objects. In another study, Saeidian et al. (2023a) further extend their developed CityGML ADE to be able to model and manage the underground legal boundaries in 3D.

Even though CityGML is widely known data model for 3D modelling of cities, the implementation and usability of the created 3D models based on CityGML might not reach the desired level. One possible reason is that the perception regarding data structure of GML-based data models might not be easy. Further, the implementation potential of the data models is directly proportionate to whether they can be used readily in terms of software development. In this regard, CityJSON is developed as JSON-based encoding of CityGML conceptual model (OGC, 2021a).

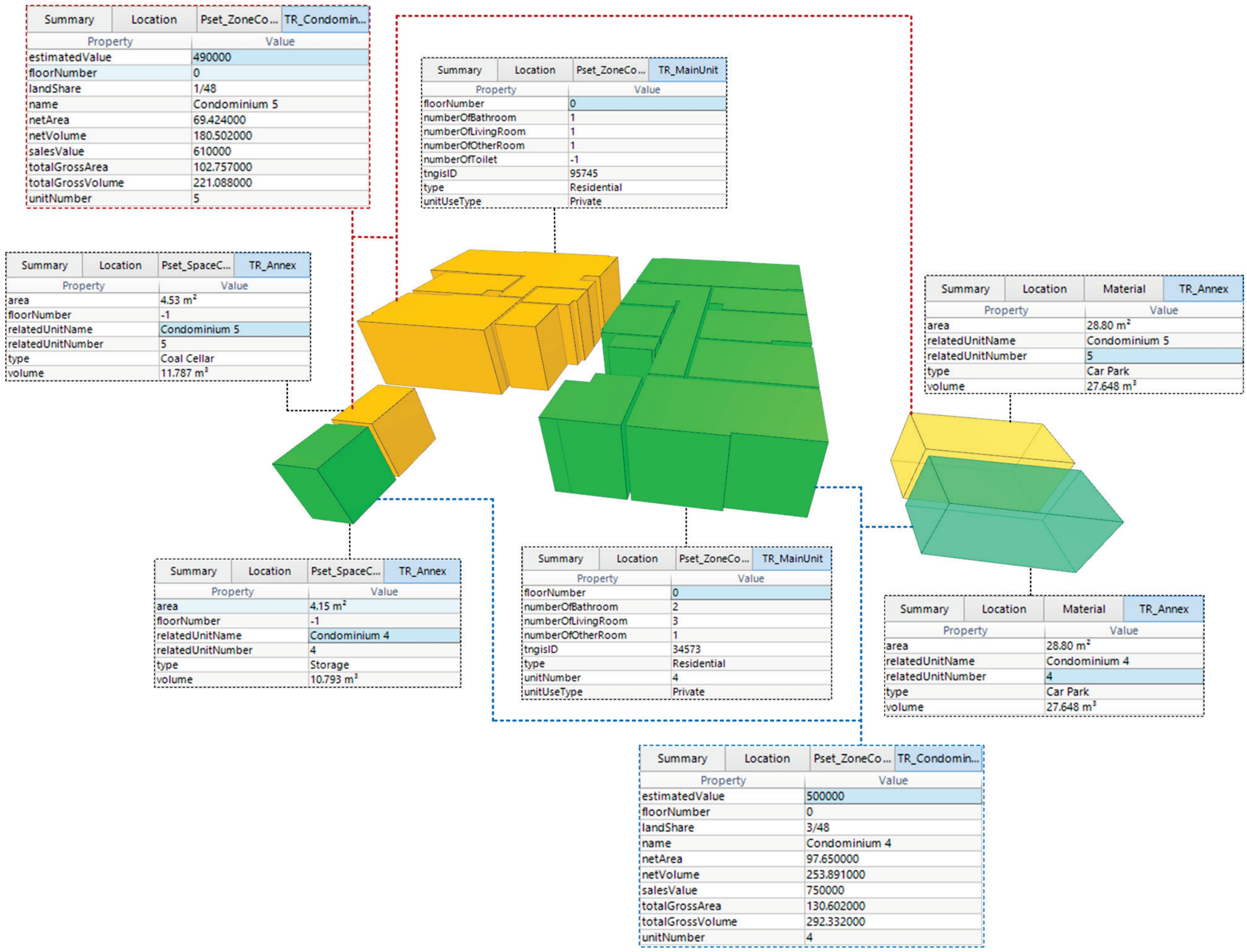

Figure 3. An example of 3D representation of condominium rights using IFC (Guler et al., 2022).

CityJSON is also an OGC community standard and it is conformant to the CityGML 3.0 conceptual model (Figure 4). As can be seen from Figure 5 there are two levels of city objects in CityJSON. In terms of hierarchy within the data model, 2nd-level objects should have parents from 1st-level objects. CityJSON has also an extension mechanism to bring extension opportunities to researchers/developers who deal with specific topics such as energy modelling that should be covered within the CityJSON core model. The important thing regarding extending CityJSON is that the extension files do not need to be provided externally to use the created CityJSON files based on the developed extension. As shown in Figure 6, the JSON file of the extension should include the required classes. Based on the content of the proposed extension and determined requirements, the CityJSON core model can be extended by adding extra root properties, extra attributes to existing city objects, or extra city objects.

Although the number of studies that show the usability of CityJSON is increasing, the investigation of extending CityJSON regarding the 3D cadastre purposes is highly limited. For this reason, the methodology in this paper covers providing the conceptual model for extending the CityJSON core module for 3D cadastre purposes.

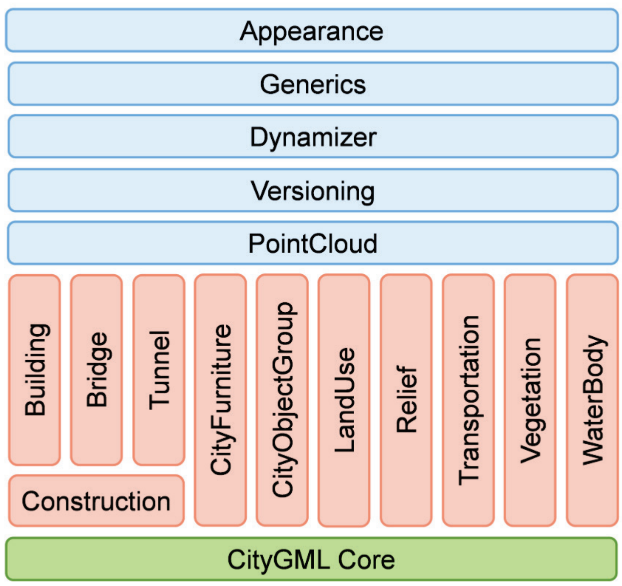

Figure 4. The modules in CityGML 3.0.

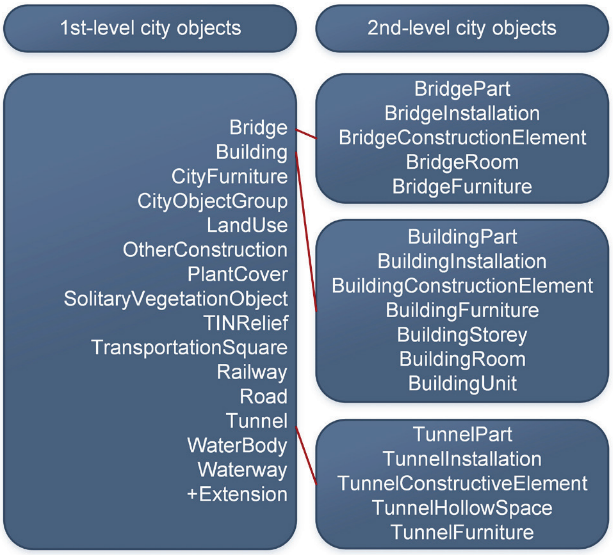

Figure 5. The city objects within the CityJSON standard.

```
{
  "type": "CityJSONExtension",
  "name": "Example",
  "description": "Extension to model the example",
  "uri": "https://someurl.org/example.ext.json",
  "version": "0.5",
  "versionCityJSON": "1.1",
  "extraRootProperties": {},
  "extraAttributes": {},
  "extraCityObjects": {}
}
```

Figure 6. The initial structure of the CityJSON extension file.

3. RESULTS

Figure 8 illustrates the conceptual model that represents the features and relationships within the proposed extension. As can be seen from Figure 8 *+Parcel* feature type is modelled as a subclass of the *_AbstractCityObject* feature type which is one of the feature types in the core schema of CityJSON. This approach is implemented because most of the city objects in the core schema are defined as a subclass of *_AbstractCityObject*. *+Parcel* is the main feature type that represents the main cadastral object within 3D cadastre purposes. As shown in Figure 8, the *+Parcel* feature type contains various attributes to be able to model features of different cadastral parcels. While *parcelName* and *parcelNumber* attributes are used to model basic descriptive information about the parcel instance, *parcelType* can be used to identify whether the parcel instance is a cadastre or zoning parcel. Whether *blockNumber* stores the information regarding the block that covers the parcel instance, different land use types such as residential, industry, and mining regarding the parcel instance are stored by *parcelLandUseType*. Further, *parcelOwner* and *parcelID* can be used to register other descriptive information. Different structure types such as single, part, and multipart can be modelled through the *parcelStructure* attribute. While *journalNumber* can store the journal numbers of old parcel instances, *registrationDate* provides the latest registration data of the parcel. The conceptual model of the extension includes three additional feature types to allow modelling of further cadastral information related to the parcel instances. *+Restriction* is one of the extra city objects that is added to the core model of CityJSON to model different types of cadastral restrictions in 3D. As can be seen from Figure 8, various restriction types such as historical site, mining, and wetland regarding the parcel instances can be stored by *type* attributes of this feature type. Easement is another important ownership type that can occur regarding parcel instances. For this reason, an additional city object namely *+Easement* is included in the proposed CityJSON extension. This city object has an attribute called *easementType* to store different types of easements such as encumbering, appurtenant, and encumberingRoad. Another extra city object namely *+DepthLimitation* is added to the core model to represent depth limitations that can be indicated for underground. The length information is also stored as an attribute as can be seen in Figure 8. The geometry types that extra city objects can have are defined within the proposed CityJSON extension. Considering that different geometry types can be beneficial for the 3D modelling of property ownership and its related information, proposed extra city objects can have *MultiSurface*, *CompositeSurface*, *Solid*, *CompositeSolid*, and *MultiSolid* geometry types. Figure 7 represents the content of the CityJSON extension file related to the *+Easement* feature type. As shown in Figure 7, *+Easement* is modelled as a subclass of *_AbstractCityObject*. The abovementioned attributes and geometry types of *+Easement* can also be seen in the same figure.

```
"+Easement":
{
    "allOf": [
        {
            "$ref": "cityobjects.schema.json#/_AbstractCityObject"
        },
        {
            "properties":
            {
                "type":
                {
                    "enum": [
                        "+Easement"
                    ]
                },
                "attributes":
                {
                    "type": "object",
                    "properties":
                    {

                        "beneficiary":
                        {
                            "type": "string"
                        },
                        "easementtype":
                        {
                            "enum": [
                                "encumbering",
                                "appurtenant",
                                "encumberingRoad"
                            ]
                        }

                    }
                },
                "geometry":
                {
                    "type": "array",
                    "items":
                    {
                        "oneOf": [

                            {
                                "$ref": "geomprimitives.schema.json#/MultiSurface"
                            },
                            {
                                "$ref": "geomprimitives.schema.json#/CompositeSurface"
                            },
                            {
                                "$ref": "geomprimitives.schema.json#/Solid"
                            },
                            {
                                "$ref": "geomprimitives.schema.json#/CompositeSolid"
                            },
                            {
                                "$ref": "geomprimitives.schema.json#/MultiSolid"
                            }
                        ]
                    }
                }
            },
            "required": [

                "type",
                "geometry"
            ]
        }
    ]
}
```

Figure 7. The part of the CityJSON extension file regarding the *+Easement* feature type.

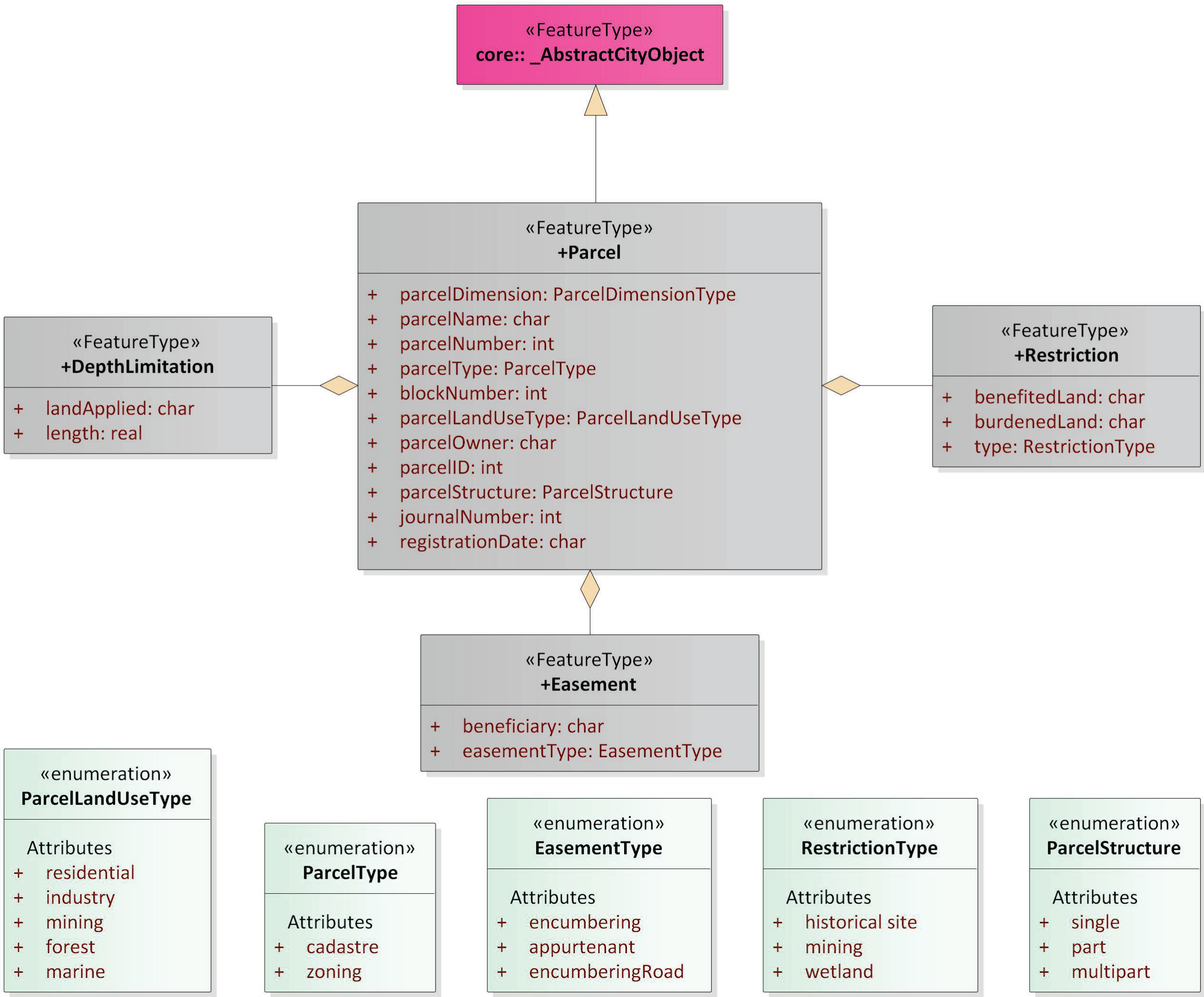

Figure 8. The conceptual model of the proposed CityJSON extension.

4. DISCUSSION & CONCLUSION

This paper provides a CityJSON extension that can be beneficial for the 3D representation of cadastral objects and their associated cadastral RRRs. Even though there are solid studies that focus on the 3D modelling of physical objects and their legal counterparts through creating CityGML ADE, this study presents that CityJSON can be also used for delineating the cadastral RRRs in 3D. This is important because there is a significant opportunity to create a 3D digital representation of cadastral RRRs through CityJSON in an effortless manner. Considering that previous studies underline that the implementation of developed conceptual models does not reach the desired level in terms of efficiency, it can be exploited the extension mechanism of CityJSON to increase the efficiency of the implementation regarding the 3D underground land administration.

It is evident that the importance of productive use of underground space has increased in recent years. For this reason, spatial planning studies aim to cover underground space to improve land use in urban areas. In this regard, there is a need for 3D spatial analyses that can provide a scientific basis for creating spatial plans in different scales (Guler, 2023). Therefore, the integration of 3D spatial planning and 3D underground land administration through the use of generated CityJSON models based on the proposed extensions can contribute to practicing sustainable urban development.

As known, a building permit should be obtained to construct buildings/facilitates underground. Given that the digitalization of building permitting has gained attention to improve the required processes, the importance of the abovementioned integration is significantly augmented because the cadastral RRRs are one of the essential considerations for issuing the building permit regarding underground (Noardo et al., 2022). Further, 3D digital models are started to be requested since 2D delineations might be insufficient to check compliance of designed buildings/facilities with respect to defined rules. For this reason, there is a strong need for the existence of 3D presentations of underground cadastral RRRs.

The implementation of the proposed CityJSON extension can be a topic of future studies. In addition, the 3D modelling of cadastral boundaries based on the CityJSON schema is an important issue that improves the proposed extension in this study.

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