The Possibilities of Using CityGML for 3D Representation of Buildings in the Cadastre

Katarzyna GÓŹDŹ, Wojciech PACHELSKI, Poland, Peter VAN OOSTEROM, the Netherlands and Volker COORS, Germany

Key words: 3D Cadastre, CityGML, **C**onceptual Modeling, Integration, LADM

SUMMARY

The main objective of the paper is to elaborate the possibilities of applying CityGML for cadastral purposes, drawing particular attention to the three-dimensional representation of buildings. Technical realization of the issue is executed at the conceptual level by integration the Land Administration Domain Model, officially published as an International Standard ISO 19152, and the CityGML OGC Standard. The proposal of the innovative model is illustrated with the case of Poland. The feasibility study is carried out for the examples of three buildings, located in Warsaw.

The investigations have confirmed that the CityGML provides a flexible conceptual model which can be adapted to land administration domain, particularly for supporting the spatial concepts required for cadastral systems. The studies have revealed difficulties in introducing elements representing non-spatial components of land administration, such as: parties, basic administrative units and rights. For that reason, the proposal of adding the semantic representation for land administration within CityGML has been recommended.

Practical implementation of the CityGML-LADM ADE model demonstrates the benefits of providing relations between spatial objects from legal and physical world. The insight into the third dimension of physical objects helps to understand the location and size of the legal spaces as well as it is relevant in the context of developing the multipurpose cadastral systems.

The Possibilities of Using CityGML for 3D Representation of Buildings in the Cadastre

Katarzyna GÓŹDŹ, Wojciech PACHELSKI, Poland, Peter VAN OOSTEROM, the Netherlands and Volker COORS, Germany

1. INTRODUCTION

According to the FIG Statement on the Cadastre, a cadastre may be established for fiscal purposes (e.g. valuation and equitable taxation), legal purposes (conveyancing), to assist in the management of land and land use (e.g. for planning and other administrative purposes), as well as enables sustainable development and environmental protection. (FIG, 1995) With respect to a prominent role of the cadastre, new challenges have to be taken up to improve its efficiency and effectiveness. Currently, one of the crucial requirements towards cadastral systems is to introduce three-dimensional registration.

The insight into the third dimension can be provided by applying Land Administration Domain Model, officially adopted as an International Standard ISO 19152. The LADM includes an abstract conceptual schema with basic packages related to (1) parties, (2) basic administrative units, rights, responsibilities and restrictions, (3) spatial units (parcels, legal spaces of buildings and utilities). The last package contains the surveying and spatial representation subpackage, with a number of different spatial profiles describing geometrical and topological aspects. (ISO 19152, 2012) The LADM supports the registration of legal items (cadastral parcels, legal spaces of building units, etc.). It constitutes a generic domain model which is expandable in order to meet the specific land administration requirements in a country.

Providing explicit relations between spatial objects from legal and physical world is very beneficial and it can be realized via an SDI approach to connect the different registrations. The physical objects give the reference to understand a location and size of the legal spaces. In some cases legal spaces (parcels) "contain" several physical counterparts (buildings, utilities), which do not constitute separate property units. Information about existence of those objects is then complementary and indicates the possibilities or/and limitations of the property usage and development, as well as is relevant in the context of developing the multipurpose cadastral systems.

There are many formats for the storage and visualization of the spatial data, however they are usually focused only on a description of geometry. In contrast, the CityGML which provides a geographic information model for urban landscapes, not only represents the shape and graphical appearance of the 3D city objects, but also addresses the representation of the semantic and thematic properties, taxonomies and aggregations. (CityGML, 2012) For that reason, the standard has been applied for 3D representation of buildings.
In the context of cadastral requirements, the CityGML does not contain any features describing the legal information about spatial objects. According to El-Mekawy et Östman (2012) the CityGML standard with its current status does not have capabilities to build 3D

cadastral system. With respect to that fact, the proposal of integration of the LADM and CityGML at the conceptual level has been presented in this paper. The innovative model is illustrated in the Polish context and addresses the legal and administrative concepts defined in Polish national regulations. The possibilities of practical usage of the proposed model are verified by appropriate case studies of three buildings from Warsaw.

The paper is organized as follows. In Section 2, the general concept of the spatial package from the Polish 3D-LADM country profile is highlighted. Section 3 gives a brief introduction to the CityGML standard and specifies the ADE development methods. Section 4 elaborates on the integrated LADM-CityGML data model, drawing a particular attention to the buildings. The feasibility study for selected samples is presented in Section 5. Section 6 summarizes the paper and concludes the major findings.

2. THE SPATIAL PACKAGE OF THE POLISH LADM COUNTRY PROFILE

This section discusses the contents of Polish real estate cadastre, with emphasizing a way of registering buildings. Moreover, the general insight into the proposal three-dimensional cadastral data model for Poland based on the LADM is presented. The particular stress is put on the spatial components.

2.1 The cadastral registration of buildings in Poland

In Poland there are three types of real estates, namely land real estate (*pol. nieruchomość gruntowa*), building real estate (*pol. nieruchomość budynkowa*) and apartment real estate (*pol. nieruchomość lokalowa*). The Polish Civil Code defines those three types of real estates as (1) fragments of lands being the object of ownership right, and (2) buildings permanently connected with the ground or (3) parts of such buildings, if they (*buildings or their parts*) are the object of ownership right under pertinent regulations, separated from the land parcels. Moreover, a building may be also an element of a land parcel and then it has the same legal status as land parcels on which the building is located. (Civil Code, 1964)

Following the above-mentioned regulations, two legal registration cases may be distinguished for buildings. A building may be an element of a land parcel or it may constitute a separate building real estate. The vast majority of buildings are integral parts of built-up land parcels, however, separate building real estates occur in particular cases. One example is a building purchased or constructed by a private entity on the lands remaining the property of a governmental entity (State Treasury or a local authority). A private person is then the owner of a building and the perpetual usufructee of a land parcel at the same time. Perpetual usufruct (*pol. użytkowanie wieczyste*) is a right granting long-term use of parcels, which can be established only with respect to lands owned by the State Treasury or local government authorities. Consequently, this legal construct cannot be used for regulating relations between two private entities.

The Polish real estate cadastre includes data about both legal types of buildings. Moreover, a building in the cadastre may be composed of building parts having different number of storeys above or below the ground. The records in the database include also information about objects permanently connected with buildings such as: stairways, porches, verandas or wheelchair ramps.

There is a variety of information about physical features of buildings (e.g. a status, function, year of construction, material of external walls), what results from the fact that the cadastre is a multipurpose register serving many public tasks.

2.2 The contents of the Spatial Package from the 3D-LADM Polish country profile

The Spatial Package of the LADM profile for Poland is modeled in UML (*Unified Modeling Language*) and constitutes a counterpart of Spatial Unit Package included in the ISO 19152. Proposed classes representing spatial objects from Polish land administration are modeled as subclasses of the LADM classes. Additionally, they are distinguished with the prefix "PL_". Since the code lists from the ISO 19152 are non-normative, the Spatial Package makes use of the national code lists with predefined values for attributes (see Figure 1).

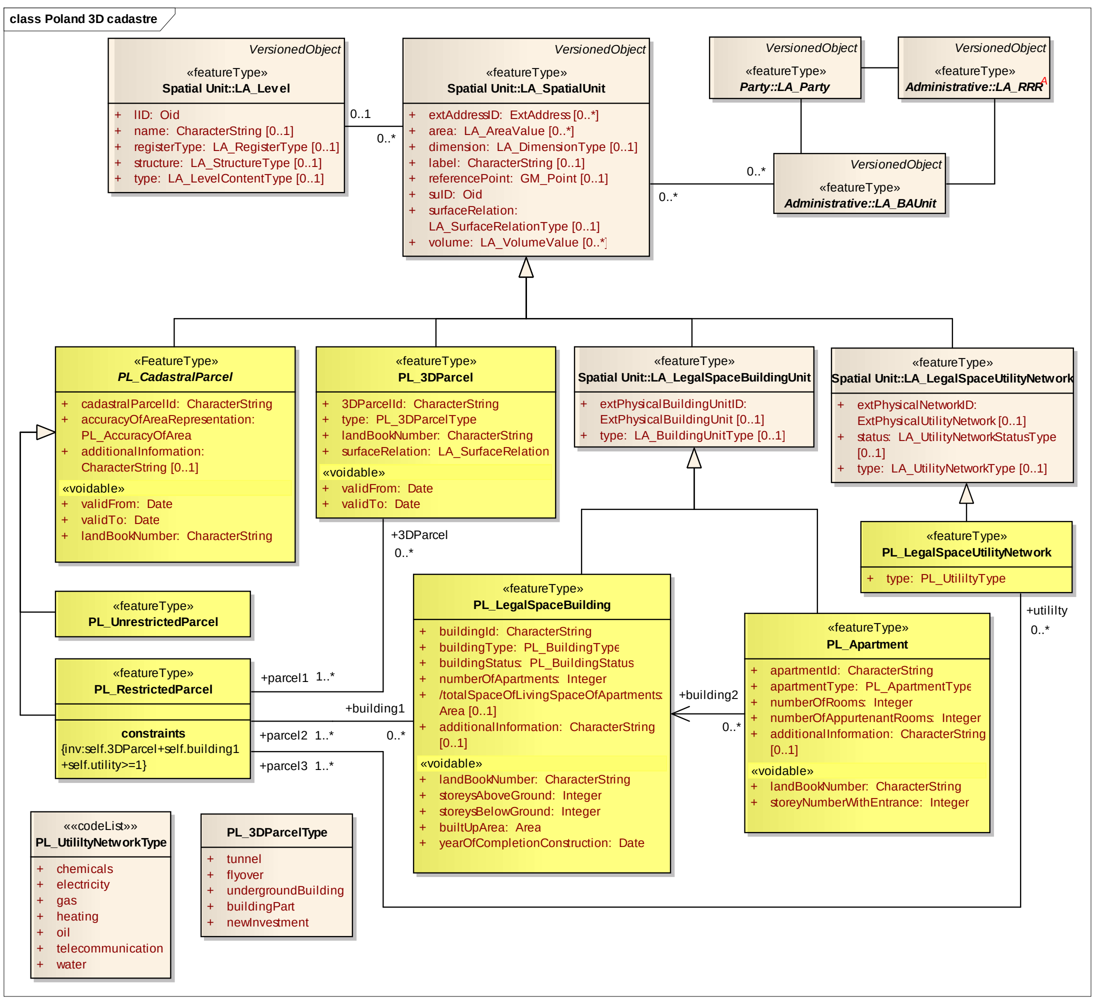

Figure 1. Spatial package of the Polish 3D-LADM country profile (Source: Góźdź and Pachelski (2014))

It should be noted that currently Polish real estate cadastre contains information about three main types of spatial objects, that is parcels, buildings and apartments. Many investigations conducted inter alia by Góźdź (2008), Karabin (2012) and Bydłosz (2013) have revealed that Polish cadastral system meets serious complications with providing information about the legal status of properties in case of 3D complex situations, when different property units are located above each other or constructed in more complex structures, i.e. interlocking one another.

For that reason, the presented Spatial Package is extended to new classes: PL_3DParcel and PL_LegalSpaceUtilityNetwork. Moreover, the class PL_CadastralParcel is an abstract class with two specializations: PL_UnrestrictedParcel and PL_RestrictedParcel. An instance of the class PL_UnrestrictedParcel is a cadastral parcel representing "infinite column" (a column with inaccurate vertical boundaries determined by social and economic purposes of land use), whereas an instance of the class PL_RestrictedParcel is a cadastral parcel representing a column reduced by volume of legal space of: 3D parcel(s), building(s) or utility networks. The proposal of a hybrid cadastre supplemented with the above-mentioned classes has been elaborated in details in the separate paper (Góźdź and Pachelski, 2014).

In Figure 1, some attributes of classes PL_LegalSpaceBuilding and PL_Apartment which can be found in Polish cadastral database are omitted in order to indicate mainly information connected with legal spaces. According to assumptions of the Annex K of ISO 19152, an external class ExtPhysicalBuildingUnit is a representative of buildings as physical objects at the conceptual level.
Spatial representations of cadastral objects are not included in the diagram (Figure 1), although they have been developed as the extension of the Surveying and Representation Subpackage within the LADM country profile for Poland.

3. A GENERAL OVERVIEW OF THE CITYGML

This section gives an insight into general notions of the CityGML, drawing particular attention to summarize the details of the CityGML Building Module. Moreover, previous research on developing CityGML Application Domain Extensions are briefly discussed and some technical principles concerning ADE developments are summarized.

3.1 Introduction to the CityGML

The CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models. It is an application schema for the GML version 3.1.1 (GML3), the extendable international standard for spatial data exchange. The aim of the development of CityGML is to reach a common definition of the basic entities, attributes, and relations of a 3D city model. The standard includes a geometry model and a thematic model.
The CityGML data model consists of a core module and thematic extension modules. The core module comprises the basic concepts and components of the CityGML data model, whereas the extension modules cover specific thematic fields of the virtual 3D city model including: Appearance, Bridge, Building, City Furniture, City Object Group, Generics, Land

Use, Relief, Transportation, Tunnel, Vegetation, Water Body, and Textured Surface (see Figure 2). Moreover, Application Domain Extensions (ADEs) can specify additions to the CityGML data model.

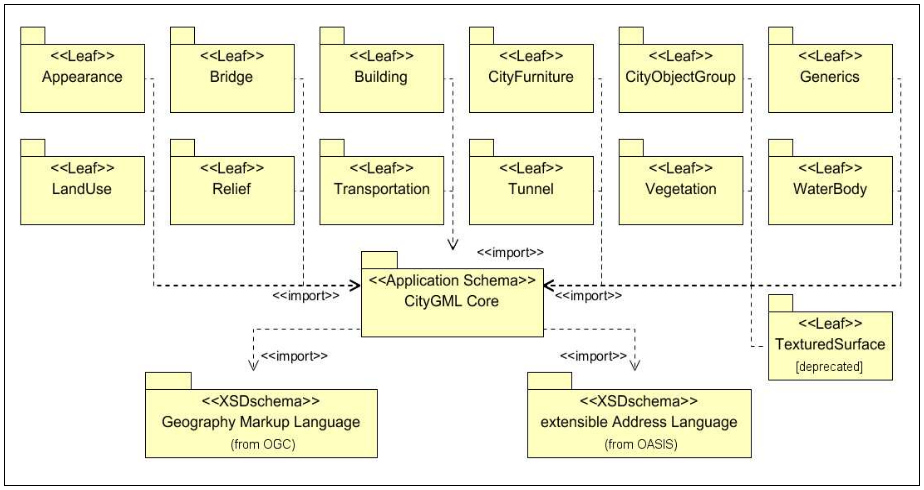

Figure 2. The CityGML modules *(Source: CityGML (2012))*

The CityGML differentiates five consecutive Levels of Detail (LOD), where objects become more detailed with increasing LOD regarding both their geometry and thematic features. (CityGML, 2012).

3.2 The CityGML Building Module

The Building Module is one of the most detailed thematic concepts of CityGML. It allows for the representation of thematic and spatial aspects of buildings and buildings parts in five levels of detail. Buildings may be represented in LOD0 by footprint or roof edge polygons. LOD1 is the well-known blocks model comprising prismatic buildings with flat roof structures. In contrast, a building in LOD2 has differentiated roof structures and thematically differentiated boundary surfaces. LOD3 denotes architectural models with detailed wall and roof structures potentially including doors and windows. LOD4 completes a LOD3 model by adding interior structures for buildings.

The pivotal class of the Building Model is _AbstractBuilding, which is a subclass of the thematic class _Site and transitively of the root class _CityObject. It should be noted that _CityObject may refer to external data sets using the concept of ExternalReference. Such a reference denotes the external information system and the unique identifier of the object in this system. The concept of external references allows for any _CityObject an arbitrary number of links to corresponding objects in external information systems. (CityGML, 2012)
The class _AbstractBuilding is specialized either to Building or to BuildingPart. Both classes inherit the following attributes: the class of the building, the function, the usage, the year of construction, the year of demolition, the roof type, the measured height, and the number and individual heights of the storeys above and below ground. Unfortunately, the class _AbstractBuilding does not provide any legal information which are needed for 3D cadastre aspects.

A building may have zero or more building installation objects such as chimneys, stairs, antennas, or balconies which are represented by the BuildingInstallation class. Moreover, a Building or BuildingPart may consist of rooms (represented by the class Room), with movable parts, such as chairs or tables (as instances of the class BuildingFurniture).

According to the CityGML conformance requirements, if a building is composed of individual structural segments, it should be modeled as a Building element having BuildingPart elements. Then the geometry and non-spatial properties of the main part of the building should be represented within the Building element. Unfortunately, that restriction does not express the most effective way of modeling. Firstly, it means that parts of a building are required to have the same set of attributes as the building itself. This results in unnecessary duplicating information in a Building element and BuildingPart elements. Moreover, the above-mentioned requirement suggests that one building part should be emphasized as the main part of the building, and its geometry should be repeated in the parent building. This makes impossible to create the geometry of a building as a collection of geometries of its segments. Taking the above facts into account, it is recommended to modify the Building Module by introducing different alternatives of modeling Building element and BuildingPart elements.

3.3 Application Domain Extensions (ADE)

Application Domain Extensions (ADE) specify additions to the CityGML data model. Such additions comprise the introduction of new feature types, attributes, geometries, and associations. Also new elements can be added to the existing feature types with the ADE. In general, there are two different approaches to combine city model data and application data:

1) Embed the CityGML objects into a (larger) application framework and establish the connection between application data and CityGML data within the application framework.
2) Incorporate application specific information into the CityGML instance documents.

In this paper, the second option is elaborated.

The ADE is defined in an extra XML schema definition file with its own namespace which must have a unique URI. The advantage of this approach is that the extension is formally specified and extended CityGML instance documents can be validated against the CityGML and the respective ADE schema.

All ADE extensions belong to one of the two following categories:

1) New feature types are defined within the ADE namespace and are based on CityGML abstract or concrete classes. In this way, they automatically inherit all properties (i.e. attributes) and associations from the respective CityGML superclasses.
2) Existing CityGML feature types are extended by application specific properties (attributes) in the ADE namespace. These properties may have simple or complex data types. In this case, an extension of the CityGML feature type is not being realised by the inheritance mechanism of XML schema. Instead, every CityGML feature type provides a "hook" in its XML schema definition, that allows to attach additional properties to it. This "hook" is implemented as a GML property of the form

"_GenericApplicationPropertyOf<Featuretypename>" where <Featuretypename> is equal to the name of the feature type definition in which it is included. The datatype for these kinds of properties is always "xsd:anyType" from the XSD namespace. (CityGML, 2012)

One of the good examples of adapting CityGML to the requirements of a specific application domain is a 3D national standard established in the Netherlands as the CityGML ADE, based on the Dutch information model for large scale topography, called IMGeo. Essential key aspects of developing the CityGML-IMGeo ADE have been explained by van den Brink et al (OGC Best Practice, 2014) as follows.

- Firstly, conceptual mapping is performed to identify matching classes between the IMGeo and CityGML models:
  - the IMGeo class which exactly matches the class in the CityGML is considered as a subclass of the corresponding CityGML class; the stereotype <<ADEElement>> is assigned to that subclass;
  - the IMGeo class which does not exactly match with the CityGML class is remodeled in order to find an equivalent CityGML class and then is specified as a subclass with <<ADEElement>> stereotype assigned;
  - if it is not possible to remodel the concept into a CityGML class, CityGML is extended with a new class, as a subclass of one of the CityGML superior classes. Such a class is modeled as a <<featureType>> subclass with a Dutch class name and is not suppressed from the XML Schema.
- Secondly, the code lists with a <<codeList>> stereotype are provided. CityGML includes code lists with predefined values for the CityGML attributes, however, the CityGML-IMGeo ADE makes use of national classification code lists.
- Finally, the XML Schema (GML application schema) is generated from the ADE defined in UML, using the Java tool ShapeChange.

The elaborated method for the CityGML-IMGeo ADE provides clear rules on modeling an ADE. It has been developed as the most efficient solution after investigating and comparing different modeling alternatives. For that reason the method is applied for preparing CityGML-LADM ADE which will be elaborated on the next Section.

4. THE CONCEPTUAL INTEGRATION OF THE LADM AND CITYGML

This Section presents the proposal of the CityGML-LADM ADE in conjunction with the method discussed in (van den Brink et al, 2014), drawing particular attention to the buildings as cadastral objects. The main purpose is to investigate whether the CityGML data model could be useful in the representation of geometric and descriptive data about buildings for the support of cadastral and administrative tasks.

4.1 Previous investigations

The extensions of CityGML for the land administration domain have been already presented by Dsilva (2009) and Çağdaş (2013).

The research conducted by Dsilva was aimed at developing ADE for cadastral purposes and it was focused on identification of the apartments and the ownership rights attached to them. Since the CityGML Building Module did not include a class for the apartments representation, a new class KadasterApartment with a set of attributes (ownership right, an apartment owner, a floor number, apartment inhabitants, etc.) was proposed.
Çağdaş explored Immovable Property Taxation ADE taking into account requirements of the property taxation system in Turkey. The main objective of his investigations was to introduce classes representing the property units (i.e. CadastralParcel, CondominiumUnit), their components (i.e. JointFacility, Annex), as well as their legal and economic attributes such as ownership type, owner name, part share, tax type, etc., which were indispensable for the process of property taxation.

Both investigations constitute a valuable, scientific contribution into the development of the CityGML for cadastral purposes, however, the way of providing information about people and rights in the form of attributes is objectionable. It should be underlined that land administration systems are based on fundamental relationships between people and spatial objects (e.g. parcels) via rights (see Figure 3). The Triple 'Object - Right - Subject' is the common pattern for LA.

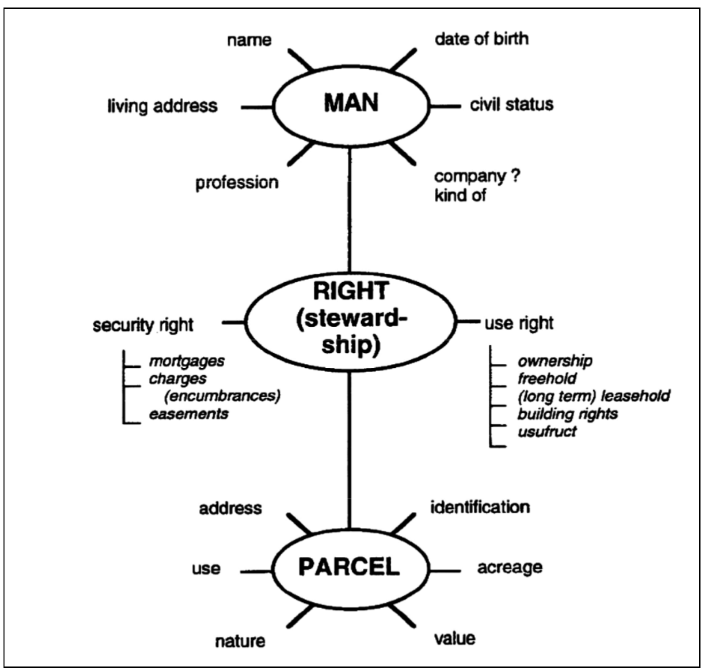

Figure 3. The Triple 'Object-Right-Subject' ***(Source: Henssen (1995))***

With respect to the fact, it is recommended to express information about entities and rights attached to spatial units as separate classes with a set of essential attributes. That solution will also enable to retain the existing "many-to-many" relationships between classes (e.g. a person may be the owner of several spatial units or a spatial unit can be the subject of the ownership of several people).

Neither Dsilva (2009) nor Çağdaş (2013) explore the interrelation between CityGML and International Standard ISO 19152. For that reason, the possibilities of integration the LADM and CityGML, illustrated with the case of Poland, are discussed in this paper. The above-mentioned principles concerning parties and rights are adhered in order to support the efficiency and effectiveness of the land adminstration system.

4.2 ADE of the CityGML for land administration purposes

The presented CityGML-LADM ADE is aimed at indicating links between legal spaces occupied by buildings and their physical counterparts (see Figure 4). The proposal of the model introduces two classes representing buildings: PL_LegalSpaceBuilding with the 'legal space of a building' as an instance, and PL_Building with a 'physical building' as an instance. Since registration of apartments and legal space of utility networks is not within the scope of this paper, classes PL_LegalSpaceUtilityNetwork and PL_Apartment are not shown in the diagram (Figure 4).

Conceptually, a class PL_CadastralParcel with its two specialisations, PL_LegalSpace Building and PL_3DParcel are defined as subclasses of _CityObject, whereas classes PL_Building and PL_BuildingPart are defined as subclasses of their counterparts from the CityGML.

A link between spatial objects from legal and physical world is represented by an association relationship between LA_LegalSpaceBuildingUnit (from LADM) and _AbstractBuilding (from CityGML). It is worth stressing that the legal space of a building shall correspond to at least one physical counterpart. In some cases, a building (PL_Building) is related to zero or more [0..*] cadastral parcels (PL_CadastralParcel). The model provides also for an association between a building (or a building part) and 3D parcel (PL_3DParcel), what is useful when this building (building part) has its own specific RRRs attached. All above-mentioned examples are illustrated with suitable case studies in the next Section.

It should be noticed that LA_SpatialUnit is a subclass of both VersionedObject and _CityGMLObject. To avoid multiple inheritance, the implement relationship is introduced into the diagram. _CityGMLObject provides attributes creationDate and terminationDate for the management and maintenance historical data in the database. Simultaneously, VersionedObject introduces beginLifespanVersion and endLifespanVersion, which serve the same purposes. Fortunately, CityGML temporal attributes are optional, so there is no risk of the data redundancy.

As previously recommended, information about entities and property rights is represented in the diagram by means of separate classes (LA_Party, LA_RRR, LA_BAUnit). It should be explained that LA_Party is the main class of the LADM Party Package, while LA_RRR and LA_BAUnit are representatives of the LADM Administrative Package. In the Polish profile based on ISO 19152, classes from the national land administration system are modeled as subclasses of the LADM classes. Due to the complexity of the LADM country profile for Poland, the presented diagram (Figure 4) includes only LA_Party, LA_RRR and LA_BAUnit. The complete Party Package and Administrative Package of the Polish LADM country profile is elaborated in details in a separate paper (Góźdź and Van Oosterom, 2014).

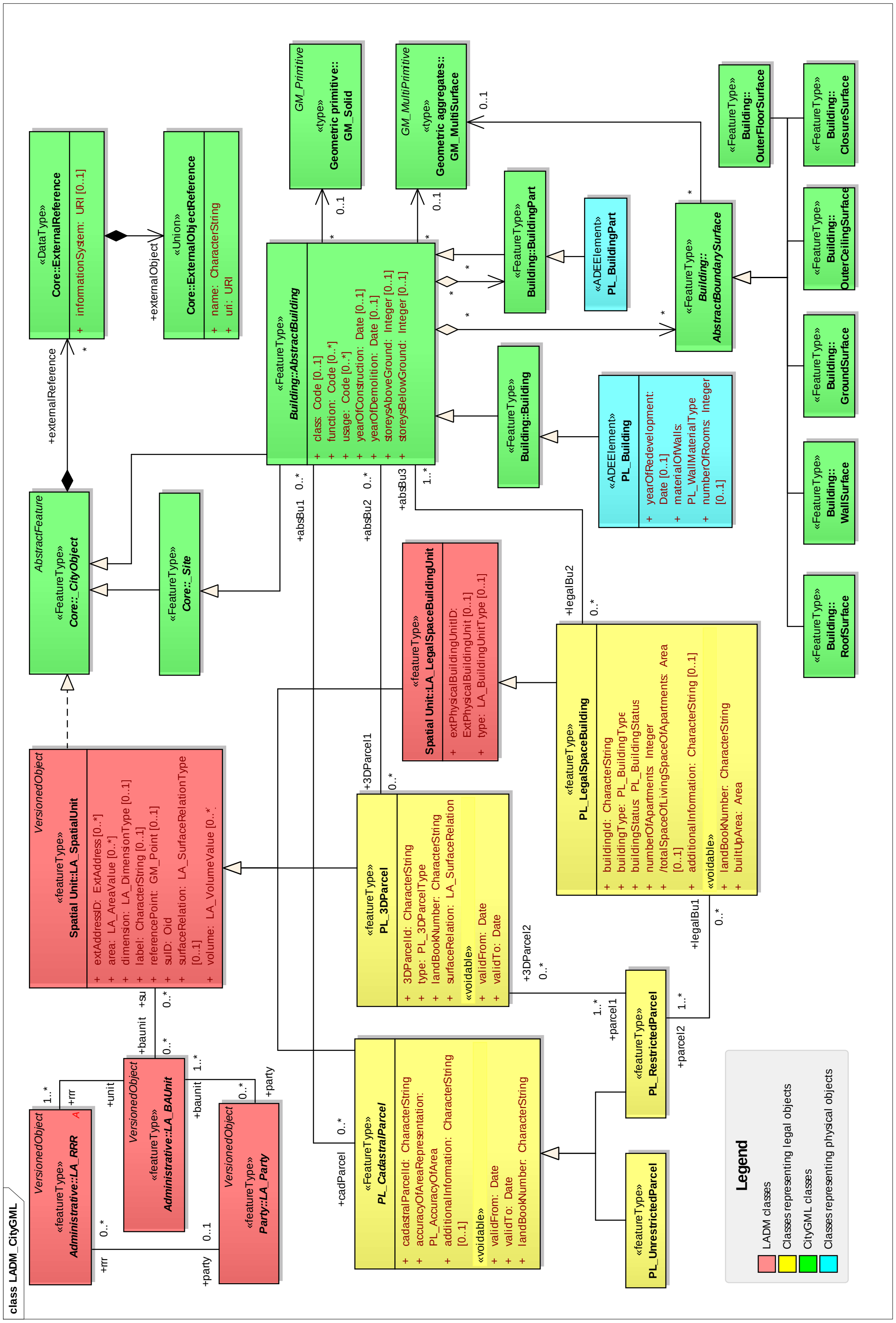

Figure 4. The CityGML-LADM ADE for cadastral purposes (Source: Authors' elaboration)

Unfortunately, it is not possible to indicate classes corresponding to LA_Party, LA_RRR and LA_BAUnit in CityGML. Due to that fact there are many problems during transformation of the model from conceptual to technical level. The results of this investigation entitle to make a statement that introducing the semantic representation for land administration within CityGML will be advisable. That issue is included in the list of work packages that define the scope of next version of CityGML.

5. THE CASE STUDIES

This section presents examples of practical usage of the proposed integrated data model based on the LADM and CityGML. The analysis is illustrated with three case studies:

1) a building situated above another construction,
2) a residential building partially above the public road,
3) a detached house located on the land parcel (with the same owner).

For the final visualization of discussed cases and the preparation of CityGML files, data included in the real estate cadastre and the land and mortgage register as well as LIDAR data have been used. The geometry of objects is presented on LoD1.

5.1 Case study 1: Building situated above another construction

The analyzed object is the Courtyard Mariott Warsaw Hotel, located at the Chopin International Warsaw Airport. The building was erected in 2003 at the top of the building of a multi-storey parking, constructed 11 years earlier. The hotel is located entirely on the roof of the parking (see Figure 5).

The Port-Hotel Company is an owner of the hotel, whereas the Polish Airports' State Enterprise is an owner of the parking. Both entities are perpetual usufructors of a parcel, which belongs to the State Treasure.

A vertical subdivision of space of the parcel between various private owners is not regulated in Polish legal provisions. In order to secure the interests of owners as strongly as it is possible, it has been decided to reveal both buildings as apartments. Following that decision a descriptive part of the cadastre provides detailed information about one building and two separate apartments (hotel and parking). Moreover, every apartment has its own land book entry established. That way of cadastral registration enables the owners to reveal their real rights and gives them the possibility to take out mortgages. Nevertheless, the field situation does not correspond accurately to the cadastral records as in current registration there is no 3D representation.

It is recommended to reveal correctly information about two buildings in the cadastre and give the insight into the third dimension for visualization purpose as well as for determining the range of legal spaces using the CityGML/LADM based approach. However, new technological solutions and changes in legal regulations should go hand in hand.

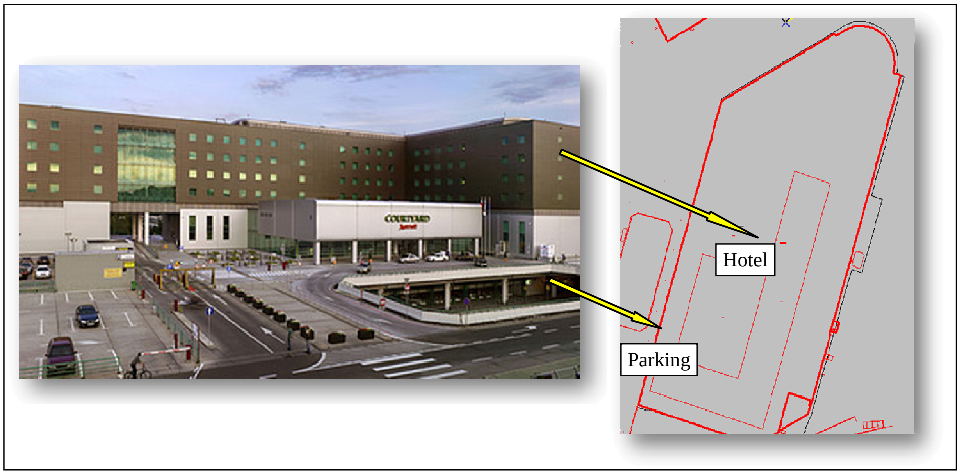

Figure 5. Tested object no. 1: The cadastral map
(Source: The Office of Geodesy and Cadastre for the City of Warsaw) and a photo (Source: Authors)

The structure of relationships between legal spaces and its physical counterparts at the instance level is presented in Figure 6. Sets of attributes are restricted to several values.

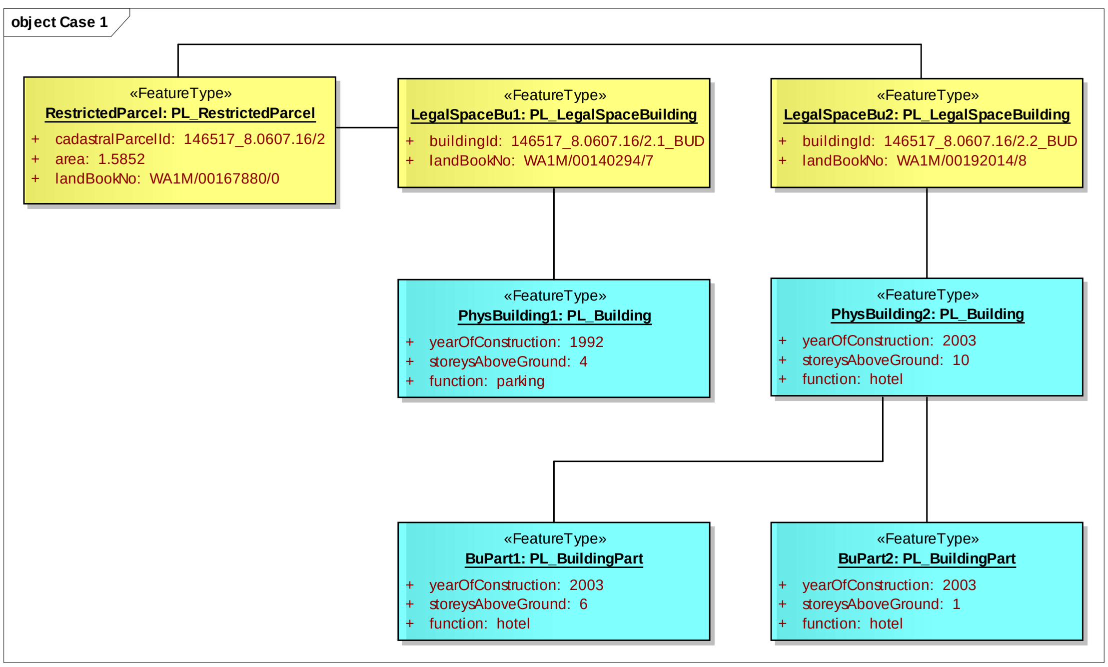

Figure 6. Tested object no. 1: The structure of relationships between objects from legal and physical world at the instance level ***(Source: Authors' elaboration)***

Basing on the cadastral map and the LiDAR data, the three-dimensional representation of the discussed situation in prepared (see Figure 7).

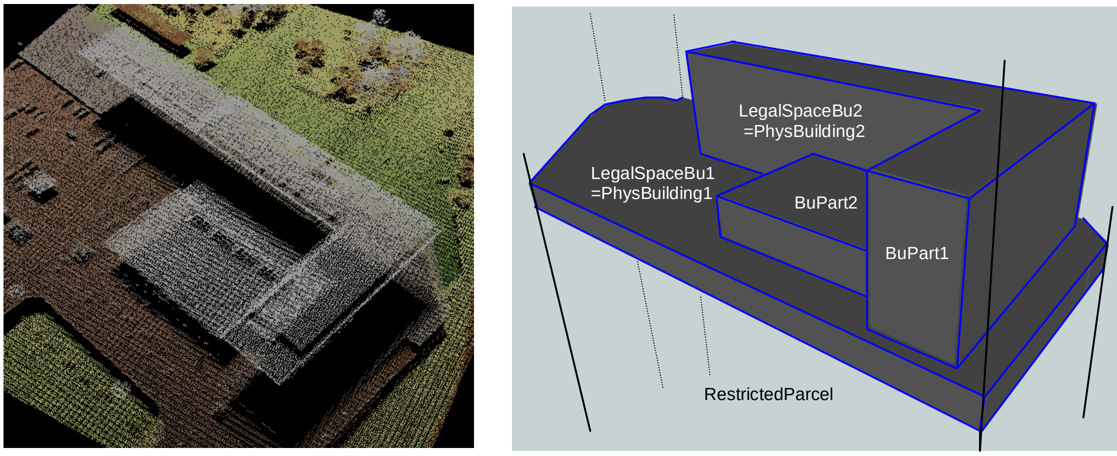

Figure 7. Tested object no. 1 - The point cloud file (Source: The Central Office of Geodetic and Cartographic Documentation) and the proposal of 3D registration in the cadastre (Source: Authors' elaboration)

5.2 Case study 2: Residential building partially above the public road

The second analyzed object presents the residential complex of four buildings with apartment units, located in Ursynów district. One of the buildings partially hangs over the public road (see Figure 8).

Figure 8. Tested object no. 2 - cadastral map (Source: The Office of Geodesy and Cadastre for the City of Warsaw) and photos (Source: Authors)

Records in the descriptive part of the cadastre reveal information about four separate buildings with different identifiers and addresses. Moreover, a cadastral map presents detailed geometrical data, including among others: footprints of building parts distinguished on account of different number of floors and an overhang.

The housing cooperative is the owner of eight parcels on which buildings are situated. Only one parcel with a public road constitutes the property of the City of Warsaw. Unfortunately, information about parts of a building hanging above a public road is not revealed in the land book, established on the real property.

In this case, implementation of the proposed improved data model for the cadastre and, as a consequence, introducing a new cadastral object, namely 3D parcel, will be the first step to regulate such complex 3D situations. Simultaneously, relevant legal regulations defining a new type of real estate shall be put into force. The CityGML-LADM based approach gives the insight into spatial range of 3D parcel and helps to understand the location of property boundaries. The structure of proposed relationships between legal spaces and its physical counterparts at the instance level is presented in Figure 9.

As mentioned above, buildings constitute components of land parcels, and they do not cause any legal problems during cadastral/ legal registration. Only a parcel occupied by public road with a part of the building hanging over it is much more complex. It is recommended to reveal two legal spaces in this case: a restricted parcel and a 3D parcel (see Figure 10).

From the legal point of view only parts of buildings which hang over the road-parcel shall be presented in 3D. However, full three-dimensional visualization of buildings gives the reference for the 3D parcel and supports better understanding a field situation. In order to distinguish physical and legal objects in the Figure 10, different outline colors are used (red color represents physical objects, and blue color - legal spaces).

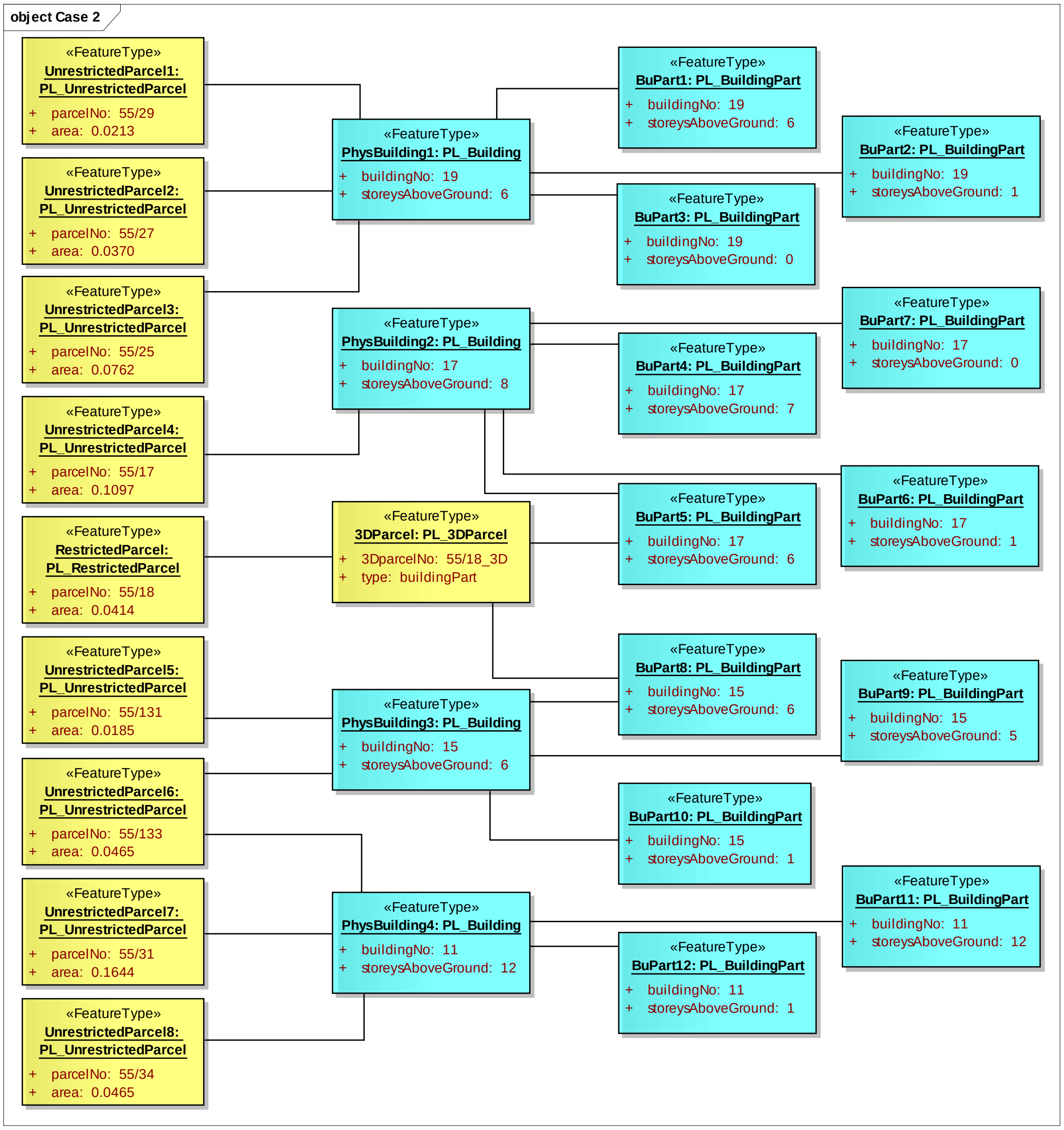

Figure 9. Tested object no. 2: The structure of relationships between objects from legal and physical world at the instance level (Source: Authors' elaboration)

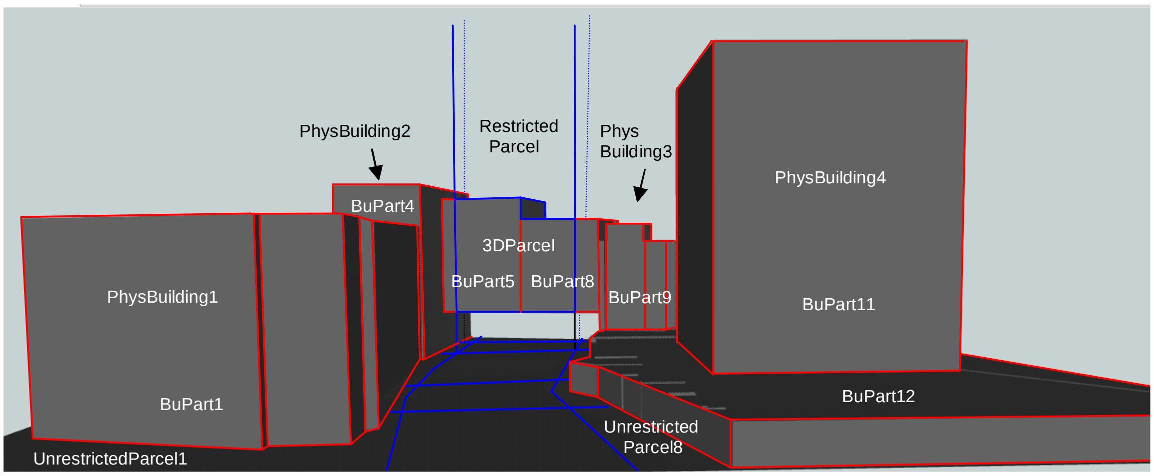

Figure 10. Tested object no. 2 - the proposal of registration of object in the cadastre (Source: Authors' elaboration)

It should be noticed that outlines of building parts which are located above the ground are higher than the surface of the parcel no. 55/18 belonging to the City of Warsaw. Due to that fact the building parts have been 'artificially' subdivided into smaller parts, and coordinates of intersection points have been delimited mathematically (see Figure 11).

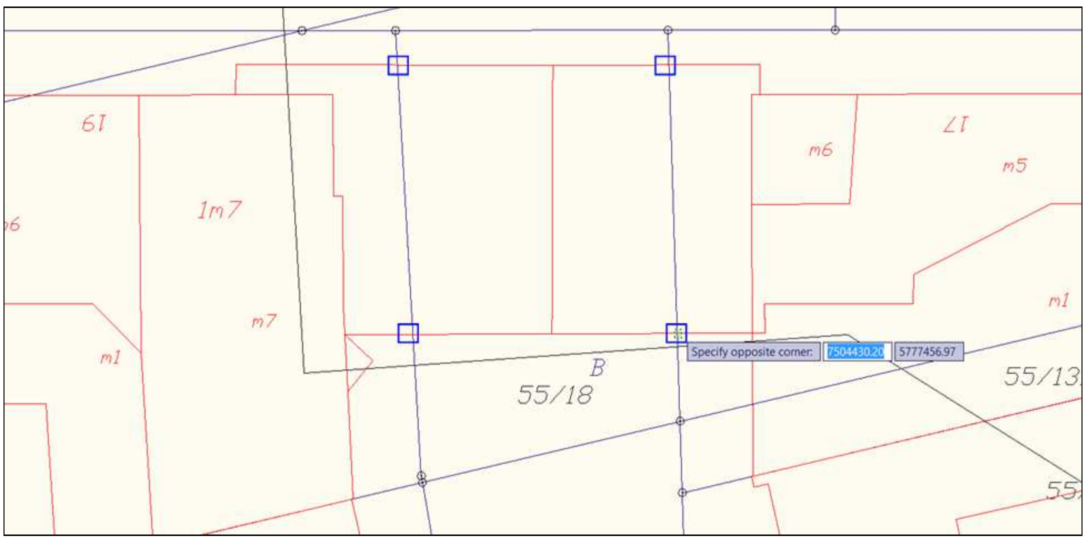

Figure 11. Delimiting intersection points for defining geometry of the 3D parcel (Source: Authors' elaboration)

5.3 Case study 3: A detached house located on the land parcel (with the same owner)

The analyzed object is a detached house, located in Rembertów - the district in Warsaw, situated outside the highly urbanised area of the city (see Figure 12).

Figure 12. Tested object no. 3: The cadastral map (Source: The Office of Geodesy and Cadastre for the City of Warsaw) and a photo (Source: Authors)

Records of the real estate cadastre reveal that a private person is the owner of both a building and two parcels in which the buidling is situated. This means that a legal space is presented by a geometry of the unrestricted parcel, whereas a building is only the element "contained" in the space of a parcel (see Figure 13).

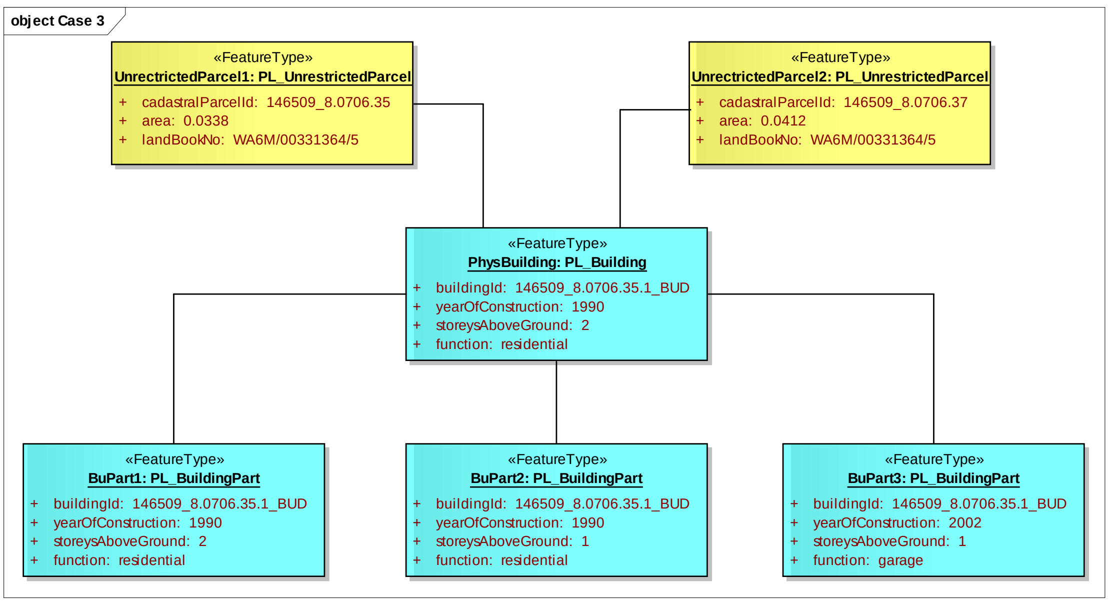

Figure 13. Tested object no. 3: The structure of relationships between objects from legal and physical world at the instance level (Source: Authors' elaboration)

Even if there is no need to give insight into the third dimension of objects from the legal point of view, the 3D representation of buildings can serve other purposes such as: supporting spatial planning, taxation or national statistics. In that case, cadastral parcels are not reduced by any legal object, hence their spatial representation may be two-dimensional.

The proposal of 3D representation of the building is presented in Figure 14.

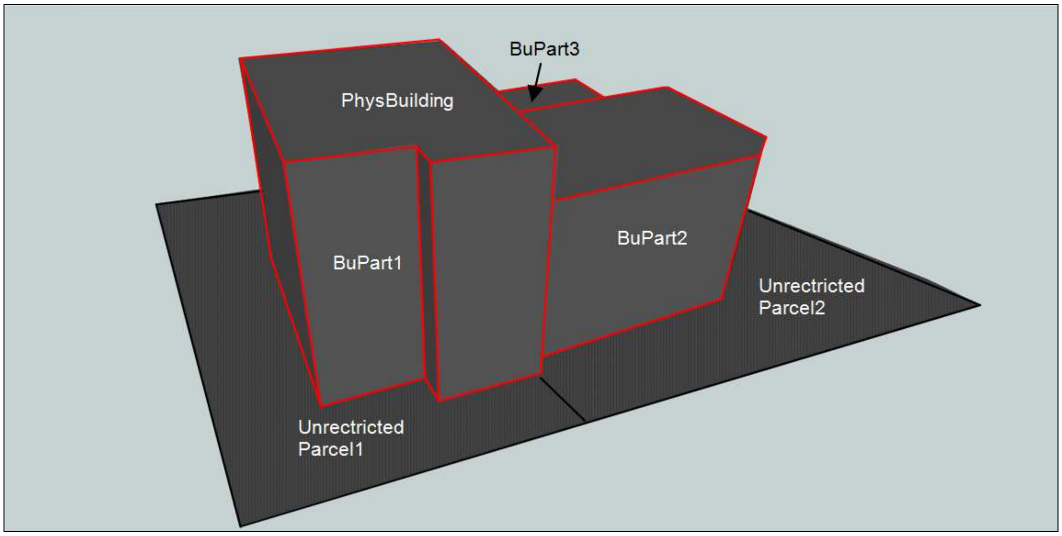

Figure 14: Tested object no. 3: The proposal of 3D registration in the cadastre (Source: Authors' elaboration)

6. CONCLUSIONS

In this paper a proposal of the CityGML-LADM ADE is presented, drawing particular attention to the buildings, both addressing their physical aspects, and their legal counterparts. Technical realization of the issue has been executed at the conceptual level by integration the CityGML OGC Standard and the International Standard ISO 19152.

The studies have confirmed that the CityGML provides a flexible conceptual model which can be adapted to land administration domain, particularly for supporting the spatial concepts required for cadastral systems. On the other hand, the Land Administration Domain Model also constitutes a generic expandable domain model, designed to be connected in SDI-setting to data from other domain models and other standards (e.g. CityGML, INSPIRE Data Specifications).

Practical implementation of the CityGML-LADM ADE model has demonstrated the benefits of providing relations between spatial objects from legal and physical world. The insight into the third dimension of physical objects helps to understand the location and size of the legal spaces as well as it is relevant in the context of developing the multipurpose cadastral systems. In this paper, the geometry of buildings is created on the LOD1, which seems to be sufficient for supporting visualization of the legal spaces. However, for serving other purposes like urban planning or disaster management, the LOD2 is recommended as the most convenient level of detail.

It is worthwhile to notice the interrelation between above-mentioned standards by incorporating the spatial elements of the LADM into the CityGML data model is not problematic. However, some difficulties occur during introducing classes representing other land administration components, such as: parties, basic administrative units and rights. These classes do not have counterparts in the CityGML. For that reason, one of the solutions is to add the semantic representation for land administration within CityGML (see Figure 15).

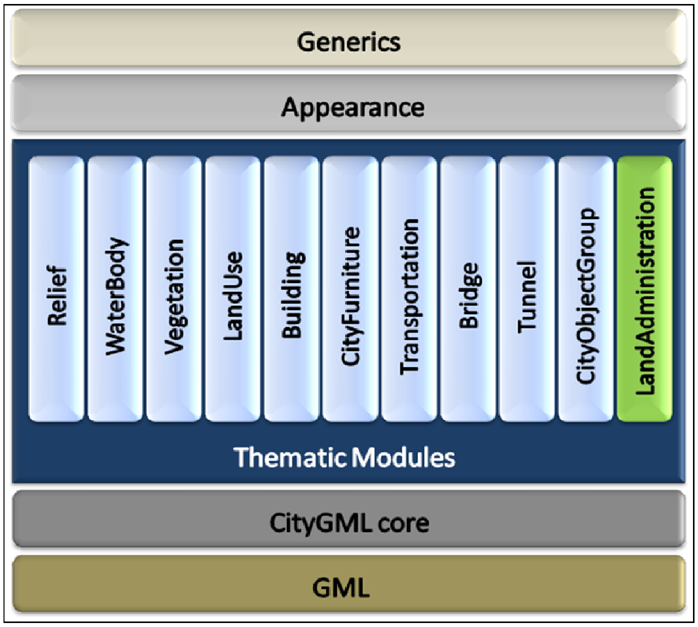

Figure 15. The proposal of introducing the LA module in the CityGML (Source: Authors' elaboration)

Further research will aim at investigating other possible alternatives of combining the LADM and CityGML standards, that is:

- embeding the selected CityGML classes into (broader) LADM framework,
- introducing a link between both domain models (in SDI setting) using references between object instances.

All solutions require elaborating and realizing a technical model suitable for implementation: database schema (SQL DDL) and exchange format (XML/GML).
Adopting the above-mentioned approaches; preparing separate data models and conducting their implementation will help to estimate which solution is easier for applying from technical point of view, less invasive in the context of the current way of functioning the cadastral systems, and more beneficial from the perspective of users' requirements.

ACKNOWLEDGEMENTS

She would also like to thank Prof. Ireneusz Winnicki, Dean of the Faculty of Civil Engineering and Geodesy at the Military University of Technology, for the acceptance and recommendation of her scientific internship at the Stuttgart University of Applied Sciences.
This research is partially supported by a scholarship from the German Academic Exchange Service (DAAD).

REFERENCES

Bydłosz, J. (2012): The Cadastre in Poland - the Current Status and Possibilities of Transformation into 3D One. FIG Working Week 2012, Rome, Italy, 6-10 May 2012.

Çağdaş, V. (2013): An Application Domain Extension to CityGML for immovable property taxation: A Turkish case study. International Journal of Applied Earth Observations and Geoinformation, 21 (1), 545-555.

Dsilva, M.G. (2009): A Feasibility Study on CityGML for Cadastral Purposes. Eindhoven University of Technology. Masters Thesis. Eindhoven, The Netherlands, July 2009.

El-Mekawy, M., Östman, A. (2012): Feasibility of Building Information Models for 3D Cadastre in Unified City Models. International Journal of E-Planning Research (IJEPR), 1 (4), 35-58.

FIG (1995): The FIG Statement on the Cadastre. Technical Report Publication No. 11. Federation International des Geometres, Commission 7, 1995.

Góźdź, K., Pachelski, W. (2014): The LADM as a core for developing three-dimensional cadastral data model for Poland. The 14th International Multidisciplinary Scientific GeoConference SGEM 2014. Albena, Bulgaria, 17-26 June 2014.

Góźdź, K., van Oosterom, P. (2014): Developing the information infrastructure based on the LADM - the case of Poland. Survey Review, submitted for publication.

Góźdź, K. (2008): Analysis of foreign solutions concerning 3D registration in the cadastre and the opportunities of their implementation in Poland. Master Thesis, Warsaw University of Technology, Faculty of Geodesy and Cartography, 2008.

Henssen, J. (1995): Basic principles of the main cadastral systems in the world. The Proceedings of the One Day Seminar held during the Annual Meeting of Commission 7, Cadastre and Rural Land Management, the International Federation of Surveyors (FIG). The Netherlands, Delft, 16 May 1995.

ISO 19152 (2012): International Standard, Geographic Information - Land Administration Domain Model (LADM). Geneva, Switzerland, 118 pages.

Karabin M. (2011): Rules concerned Registration of the Spatial Objects in Poland in the Context of 3D Cadastre's Requirements. 2nd International Workshop on 3D Cadastres, Delft, the Netherlands, 16-18 November 2011.

Open Geospatial Consortium (2014): Modeling an application domain extension of CityGML in UML. OGC Best Practice. 2014.

Open Geospatial Consortium (2012): OGC City Geography Markup Language (CityGML) Encoding Standard. Version 2.0.0, 2012.

Polish Parliament (1964): The Act of April 23, 1964 - The Civil Code. Journal of Laws, 1964 No 16 entry 93 with further amendments.

Van den Brink, L., Stoter, J., Zlatanova, S. (2012): Establishing a national standard for 3D topographic data compliant to CityGML. International Journal of Geographical Information Science, Volume 27, Issue 1, pages 92 - 113.

BIOGRAPHICAL NOTES

Katarzyna Góźdź graduated with a MSc in Geodesy and Cartography from Warsaw University of Technology. From 2008 until 2010 she worked in the Department of Information on Real Properties in the Head Office of Geodesy and Cartography. In 2010 she was moved to the Group of Analysis and Forecasts subordinated to Surveyor General of Poland, where she has worked until now. From 2012 she has been a PhD candidate in the Faculty of Civil Engineering and Geodesy at the Military University of Technology in Warsaw.

Wojciech Pachelski is at present a professor on geodesy and geographic information at the Faculty of Civil Engineering and Geodesy of the Military University of Technology in Warsaw, and an emeritus professor at the University of Warmia and Mazury in Olsztyn and at Warsaw University of Technology. He is a Chairman of the Technical Committee 297 on geographic information of the Polish Committee for Standardization.

Peter van Oosterom obtained an MSc in Technical Computer Science in 1985 from Delft University of Technology, the Netherlands. In 1990 he received a PhD from Leiden University. From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, where he was involved in the renewal of the Cadastral (Geographic) database. Since 2000, he is professor at the Delft University of Technology, and head of the 'GIS Technology' Section, Department OTB, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands. He is the current chair of the FIG Working Group on '3D Cadastres'.

Volker Coors holds a Diploma degree with honours in Computer Sciences and a doctoral degree in Computer Graphics from Technical University of Darmstadt. From 1997 to 2002 he worked as a researcher at Fraunhofer Institute for Computer Graphics, department GIS. Since 2002, he is professor in Geoinformatics and Computer Science at University of Applied Sciences Stuttgart. He is member of the CityGML Standard Working Group (CityGML SWG) at the Open Geospatial Consortium (OGC), chair of the OGC 3D Portrayal Service Standard SWG.

CONTACTS

Katarzyna Góźdź
Military University of Technology in Warsaw
Faculty of Civil Engineering and Geodesy
Gen. Sylvester Kaliski Street, No. 2
00-908 Warsaw
POLAND
Tel.: + 48 22 683-90-76
Fax: + 48 22 683-95-69
E-mail: katarzynagozdz@o2.pl

Wojciech Pachelski
Military University of Technology in Warsaw
Faculty of Civil Engineering and Geodesy
Gen. Sylvester Kaliski Street, No. 2
00-908 Warsaw
POLAND
Tel.: + 48 22 683-90-76
Fax: + 48 22 683-95-69
E-mail: wpachelski@wat.edu.pl

Peter van Oosterom
Delft University of Technology
Faculty of Architecture and the Built Environment
Department OTB
GIS Technology Section
P.O. Box 5030
2600 GA Delft
THE NETHERLANDS
Tel.: +31 15 2786950
E-mail: P.J.M.vanOosterom@tudelft.nl
Website: http://www.gdmc.nl

Volker Coors
Stuttgart University of Applied Science
Faculty of Geomatics, Computer Science and Mathematics
Schellingstrasse 24, 70174 Stuttgart
GERMANY
Tel.: +49 711 8926 2708
Fax: +49 (0)711 8926 2556
E-mail: volker.coors@hft-stuttgart.de
Website http://www.coors-online.de