3D Cadastre in the Case of Engineering Objects, such as Bridges and Road Viaducts

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- Anh Vu Vo – University College Dublin, Ireland

Preface

These proceedings reflect on the content of FIG's (International Federation of Surveyors) 7th International Workshop on 3D Cadastres, 11-13 October 2021. The workshop was planned to be organized in New York City (USA), for the first time outside the Eurasia region. This as an attempt to attract more participants form the Americas. The covid-19 pandemic caused a change in plans: instead of having the event in New York, it was a virtual event. There are pro's and con's to virtual events, and we will not list them here, but we do hope that we can soon have real gatherings again, or at least hybrid events, partly onsite and partly online.

The 3D Cadastres Workshop is one of the activities of the 3D Cadastres Working Group, which belongs to FIG Commission 3 'Spatial Information Management' and Commission 7 'Cadastre and Land Management'. For the 4th time, the 3D Cadastres Workshop will be combined with the 3D GeoInfo Conference (after Dubai 2014, Athens 2016, Delft 2018). The 1st Workshop was organized in Delft, the Netherlands, 28-30 November 2001. The 2nd Workshop was held one decade later, November 2011, again in Delft. The 3rd Workshop was organized in Shenzhen, China (25-26 October 2012). The 4th Workshop, 9-11 November 2014, was organized in Dubai, United Arab Emirates. The 5th Workshop, 18-20 October 2016 was organized in Athens, Greece. To conclude this historic overview, the 6th Workshop, 2-4 October 2018, was again organized in Delft, together with: 3D GeoInfo Conference, Smart Data and Smart Cities Conference, and ISPRS Commission IV Spatial Information Sciences Symposium. The 7th Workshop is organised by New York University, Universiti Teknologi Malaysia, and TU Delft.

Based on the call for contributions, authors have submitted their extended abstracts. Each abstract was typically reviewed by five or more Programme Committee members. This resulted in 24 finally accepted full papers included in these proceedings. In addition two fantastic keynote speakers were invited. The result is a very full programme as the workshop is organized as a single track. The on-line proceedings (papers and presentations) are available on the FIG 3D Cadastres website: http://www.gdmc.nl/3DCadastres/workshop2021/programme/.

The 3D GeoInfo partner organizers are acknowledged for their enthusiastic collaboration during the preparation: Debra Laefer (New York University, USA) and Anh Vu Vo (University College Dublin, Ireland). Finally, we would like to thank all authors for their submissions, and the Programme Committee members for their diligent work in assessing the quality of the contributions. We are looking forward to the 7th 3D Cadastres Workshop and stimulating interactions within the online setting of Remo!

Delft/Johor, October 2021,

Eftychia Kalogiani, Alias Abdul Rahman, and Peter van Oosterom, the Editors.

Keynote presentation

The Australia / New Zealand 3D Cadastral Survey Data Model and Exchange Project

Anselm HAANEN, New Zealand

SUMMARY

The '3D Cadastral Survey Data Model and Exchange' (3D CSDM) project aims to enable, as far as possible, a standard way of transferring cadastral survey datasets in all nine Australian states and territories and New Zealand. It aims to create a solution that will be supported by the survey software suppliers operating in the Australian and New Zealand market. It is intended to enable surveyors to progressively transition from lodging paper or PDF files to fully digital data. The project has two primary objectives:

- To develop a harmonised data model that covers all cadastral survey data components required by the nine New Zealand and Australian cadastral agencies. This includes both 2D and 3D elements.
- To identify, in liaison with survey software suppliers, options for encoding and exchanging the data in the model.

BIOGRAPHICAL NOTES

Anselm Haanen has been the Surveyor-General at Land Information New Zealand since 2018. He was previously the Deputy Surveyor-General. He holds a Master of Surveying degree from the University of Otago and has worked in various technical capacities since joining the department in 1978. He was heavily involved in the development of Landonline, New Zealand's automated survey and title system, and helped develop New Zealand's Cadastre 2034 strategy. He is the Sponsor of the 3D Cadastral Survey Data Model and Exchange project on behalf of the Australia New Zealand Intergovernmental Committee on Surveying and Mapping.

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Keynote presentation

Utilising current and new Galileo Services for 3D Surveys Status of Galileo

Peter BUIST, The Netherlands

SUMMARY

Status of Galileo

Galileo has made significant progress in recent years: twenty-six Galileo satellites are in-orbit, a significant part of the supporting ground station infrastructure has been deployed, the *European Agency for the Space Programme* (EUSPA) has assumed the role of the Galileo Service Provider, various new Galileo services are being tested, and the 2^{nd} generation of the system is already under definition.

To support Galileo's service phase, a service facility called the *Galileo Reference Centre* (GRC) was established. The centre plays an important role in the Galileo service provision as it permits EUSPA to independently monitor the performance of the services delivered to users, and serves as the door through which *European Union* (EU) *Member States* (MS) can contribute to these tasks.

New Galileo Services

Galileo has recently started testing *Open Service Navigation Message Authentication* (OS-NMA) and *High Accuracy Service* (HAS) in the signal-in-space. Galileo's OS-NMA is an authentication protocol that allows GNSS receivers to verify the authenticity of part of the Galileo information, making sure that the navigation message they receive are indeed from Galileo and have not been modified in any way.

Galileo's HAS will provide free of charge high accuracy PPP corrections in an open format for multi-constellation and frequencies through the Galileo signal (E6-B) and Internet. It will offer real-time improved user positioning performances with accuracy less than two decimetres at two service levels: one global and the other one over Europe.

Other services are also under way. These include, for example, the *Emergency Warning Service* (EWS), where the Galileo's messaging function is used to transmit, in case of an emergency, an alert to user devices. The alert will contain specific instructions to follow, which depend on the area the user is located in.

Galileo for Surveying

With Galileo's progress, new opportunities occur also for the surveying application: Galileo-only RTK with cm-level accuracy has been possible for some time (Galileo-only Cadastral boundary reconstruction of the GRC premises has been performed for the first time in July 2019) and the availability of the Galileo supported RTK solutions, benefitting from the high accuracy of its observables, will increase when more satellites become available. PPP solutions benefit, as well, in terms of convergence time, accuracy and robustness.

The authentication features of Galileo's OS-NMA may prove to fill a gap in surveying; currently no generally accepted technology exists able to authenticate the position of the surveyor. With HAS, Galileo will pioneer free high-accuracy positioning service aimed at applications including 3D surveys that require higher performance than that offered by OS.

BIOGRAPHICAL NOTES

Peter Buist is at the EUSPA, responsible for the GRC. He worked in the aerospace industry, the academia and governmental organisations in Europe and Japan, specializing in GNSS. He holds both Masters and PhD degrees from the Delft University of Technology. At the GRC, he is managing the inhouse developments, contributions from contractors and EU Member States and Norway/ Switzerland (currently 24 organisations form 14 different countries).

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Converting BIM Data to CityGML for 3D Cadastre Purposes

Hanis RASHIDAN, Alias ABDUL RAHMAN and Mohammed J. SANI, Malaysia

Key words: BIM, CityGML, Strata XML, 3D Cadastre

SUMMARY

Currently, stratified property rights are registered and managed using two-dimensional subdivision plans. These plans do not accurately depict property spaces in complex structures such as high-rise buildings, tunnels and utilities, underground infrastructures, etc. 3D rich data like building information modelling (BIM) could be utilized as a source of 3D data for 3D urban data management especially 3D Cadastre. However, not all available data are useful and straight forward when it comes to 3D Cadastre due to the existing strata regulations. This paper describes how the BIM data could be transformed, modelled, and utilized for 3D Cadastre. Here, the conversion involves BIM data and Strata XML to CityGML format. This paper also demonstrates the procedure of the conversion of a building data. Several issues and challenges are highlighted at the recommendation section of this paper.

Converting BIM Data to CityGML for 3D Cadastre Purposes

Hanis RASHIDAN, Alias ABDUL RAHMAN and Mohammed J. SANI, Malaysia

1. INTRODUCTION

Currently, stratified property rights are registered and managed using two-dimensional (2D) subdivision plans. These plans do not accurately depict property spaces in complex situations (high-rise buildings, tunnels and utilities, underground infrastructures, etc.). Additionally, the spatial complexity of three-dimensional (3D) property spaces associated with irregular physical structures within buildings may not be adequately represented by their projection into horizontal and vertical planes. Therefore, the cadastre should be extended to 3D space to accurately represent stratified properties and rights above or below a particular parcel (Gulliver et al., 2017).

The advancements in 3D Geographic Information Systems (GIS) and Building Information Modeling (BIM) propose novel methods for modelling urban space in 3D geometrically and semantically. Both systems propose appropriate methods capable of representing the geometry and semantics of 3D objects. 3D GIS can be used to capture the geometry and topological relationships of three-dimensional cadastral objects. Additionally, it enables the structuring of semantic data about these cadastral objects in a relational 3D spatial database. By contrast, BIM is a process that is object-oriented and describes buildings in terms of their geometric and semantic properties. As a result, it enables the creation and management of spatial models of the physical and functional characteristics of building spaces and their surroundings (Isikdag and Zlatanova, 2009).

3D cadastre enables the representation and management of legal information concerning RRRs (Rights, Restrictions, and Responsibilities) and their physical models in 3D. Numerous scholars have explored the use of BIM and 3D GIS in the development of cadastral approaches. Extensions to the IFC (Industry Foundation Class) standard to represent cadastral concepts were therefore proposed in the context of BIM (Atazadeh et al., 2016), while 3D GIS-based approaches have adopted the CityGML standard to provide an environment for 3D spatial analysis (Ying et al., 2012). The integration of BIM and 3D GIS is largely based on the exchange of data between the two systems. Among the proposed approaches, the transformation between IFC and CityGML is adopted as a solution for semantic mapping between the two schemas. The conversion of BIM data to 3D GIS has shown a growing interest in several applications such as urban planning, 3D cadastre (Ohori et al., 2018).

Based on the current situation of BIM to 3D cadastre, there outmost need to consider the use of Strata XML which is currently implemented by the Malaysian mapping authority. Due to limitation on the Strata XML for 3D physical geometry storage, thus, there is a need to adopt CityGML for the 3D data storage. The authority uses Strata XML to store strata objects information such as *Building, Parcel Unit, Accessory Unit, Land Parcel, Common Property Unit, Limited Common Property Unit, etc.* for the management and registration. The Strata XML is currently a custom format for defining properties and attributes related to strata unit (title) and was developed based on XML syntax. Unfortunately, it is not able to be visualized in 3D views (the physical 3D strata objects) due to the lack of geometry information stored in the Strata XML. Therefore, this study aims to take advantage of the 3D data from the BIM model to support the legal ownership boundaries, cadastral attributes, and 3D visualization of the Strata XML objects. The remainder of the paper is structured as follows: Section 2 describes the related works on BIM and 3D cadastre, whereas Section 3 on the methodology, and finally, Section 4 highlights discussion and conclusion.

2. THE RELATED WORKS ON BIM AND 3D CADASTRE

BIM is an acronym for building information model and building information modelling. The later involves the creation, administration, derivation, and sharing of information across many specialists in the fields of architecture, engineering, and construction (AEC) industry, making communication and cooperation easier (Eastman et al. 2011). Where it's resulted to 3D model comprises of the following: semantic information, functional elements, geometry also, created mutual relationship between structural components like the architectural and structural components within the structures (Atazadeh et al., 2018). BIM has tremendously solved the issue surrounding 2D and 3D, therefore suggested numerous resourceful benefits in the AEC industry (Arayici and Tah 2008), that leads researchers developed interest in this domain in order to find a solution related to interoperability and information integration (Isikdag et al., 2013). The problem of interoperability within the industry was solve by introducing an open data model that serves as a link for interoperability and information sharing among numerous BIM software packages and thus "industry foundation classes" IFC developed by buildingSMART in 1994 (buildingSMART). As aforementioned, it is an open BIM standard that uses a common information model to manage physical building components and increase interoperability across various BIM applications.

The application of BIM world based on IFC standard in 3D cadastre has been explored in various countries across the world as shown in Table 1.

Table1: Summary of related work on BIM (IFC) in 3D cadastre based on country.

Country	Author(s)	Deliverables
Australia	Rajabifard et al., 2019; Atazadeh et al. 2019; Atazadeh et al. 2021; Atazadeh et al. 2018	Developed an approach enriching BIM with cadastral information, where the IFC standard is broadened with various data requirements in urban cadastre such as boundaries, attributes, administrative plan information, legal ownership space etc. Extending IFC data by harnessing LADM data elements to support the integration of legal and physical view. Create a relationship between BIM and LADM environment which would subsequently provide a better understanding of legal spaces

Country	Author(s)	Deliverables
Netherlands	Storter et al., 2017; Oldfield et al., 2016.	BIM is considered as a primary source of 3D digital data 3D cadastre. Enactment of BIM for 3D cadastre based on a new workflow to facilitate cadastral registration using 3D PDF.
China	Ying et al., 2019	The study focused on the developed easement modelling approach (EMA) by utilising BIM environment. It's determined that IFC standard is an effective data model for easement specialization. BIM environment enhances the representation of 3D cadastral objects. Developed and analysed a conceptual model based on IFC standard. Finally, it was presented that the integration of legal and spatial information in BIM was named as a successful approach for handling and functioning buildings as well as planning and developing a compressed city in China.
Sweden	Andree et al., 2018; El-Makawy et al., 2014; Sun et al., 2019	A smart built environment was created to serve as a strategic program to identify potential methods for effective utilization of BIM data during the building development process including planning, building permit, property formation and management. The following were taken into consideration, legal problem, financial aspect, and technical matters. More recently research has proposed a generic framework for 3D cadastre by integrating IFC and CityGML data the integrated model was later link to LADM data in order to provide a comprehensive legal and spatial view of indoor and outdoor ownership spaces in a complex built environment.

Based on the literature, it has been spelled out that IFC as a BIM standard provides data for 3D cadastre such as a comprehensive legal and spatial data of ownership spaces in complex structures. The integration of IFC and LADM environment create a mutual relationship that would provide a better understanding of legal spaces in future. It is noted that in many countries current registration and modelling of buildings is not sufficient to give unambiguous and faithful spatial representation in the cadastre. Therefore, the mentioned situation motivates this particular work in Malaysian 3D cadastre scenario.

2.1 IFC XML

In this paper we used IFC an open data model for our conversion to 3D cadastre. The default IFC file format is based on the international standard organisation (ISO) a standard for the exchange of product data (STEP) physical format (SPF) standard. IFC SPF is the most widely used format of IFC, it is a text format defined by ISO 10303-21 (STEP file), where each line typically consists of a simple file extension “ifc”. It has the advantage of compact size set readable text. The file can also be opened with Notepad in Windows, or any other text editor. However, this can only be done in order to see the text data that make up the file, the 3D design cannot be visualized in any of these programs. In contrast, ifcXML files are XML-based, is a substitute to the plain text. The IFC format, utilises XML formatting so that the building model data can be exchanged and parsed more easily also, use XML viewer and editor in order to understand the text in those types of files. Converting IFC file to ifcXML and others like OBJ etc. IfcOpenShell can be used to save IFC file to several other file formats.

2.2 CityGML

Gózdz et al. (2014) presented an investigation confirmed that CityGML offers a flexible conceptual model which can be tailored to land administration domain, specifically for supporting the spatial concepts needed for cadastral systems. The CityGML is an XML-based open data standard for storing and exchanging virtual 3D city models. It's an application schema for GML 3.1.1 (GML3), an open international standard enabling geographic data sharing. The goal of CityGML development is to arrive at a standard description of a 3D city model's core entities, characteristics, and relationships. A geometric model and a theme model are included in the standard.

A core module and theme extension modules make up the CityGML data model. The expansion modules address particular theme aspects of the virtual 3D city model, such as Appearance, Bridge, Building, City Furniture, City Object Group, Generics, LandUse, Relief, Transportation, Tunnel, Vegetation, Water Body, and Textured Surface. Moreover, Application Domain Extensions (ADEs) can contribute to the CityGML data model. The CityGML distinguishes five successive Levels of Detail (LOD), with each LOD increasing object detail in terms of both geometry and thematic elements (CityGML, 2012).

3. THE METHODOLOGY

The methodology involves three phases which are BIM data filtering, 3D objects extraction and conversion, and integration with Strata XML. Figure 1 illustrates the overall of data integration from IFC model and Strata XML into 3D Strata Units. The use of geometric data from IFC model is to build a 3D cadastre in the context of buildings (by conversion into CityGML format).

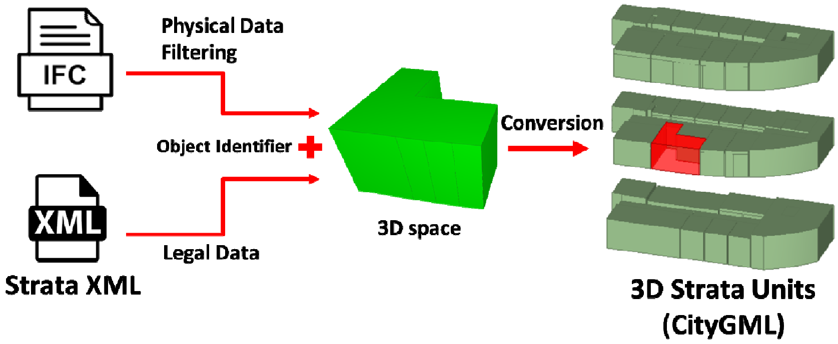

Figure 1: The overall of data integration from IFC model and Strata XML into 3D Strata Unit.

3.1 BIM data filtering

BIM data filtering phase was carried by identifying the important elements (e.g., *IfcSpace* and *IfcZone*) in the IFC model. The IfcSpace refers to an entity that is used to represent volumetric functional spaces within a building. Figure 2 shows the use of IFC model dataset that contains rich IFC structural entities such as *IfcWindow*, *IfcSpace*, *IfcDoor*, *IfcRailling*, *IfcSite*, *IfcWall*, *IfcSlab*, etc.

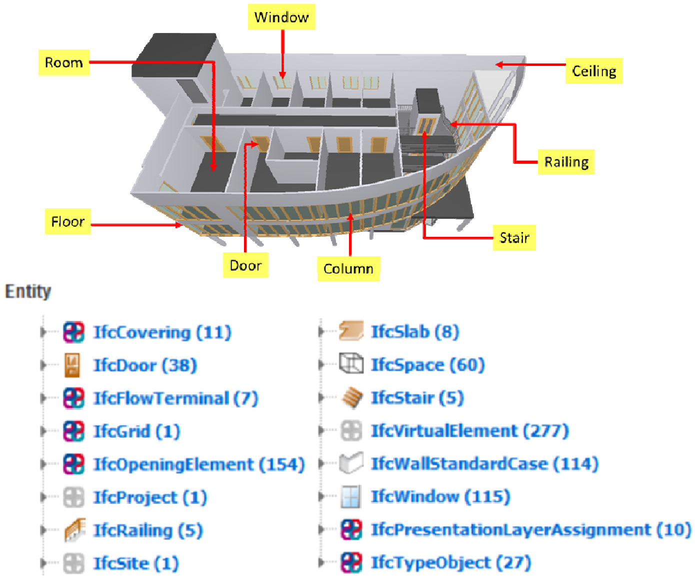

Figure 2: The IFC model for 3D cadastral purpose.

The physical BIM data which is *IfcSpace* filtered to create 3D cadastral objects based on the legal data contain in the Strata XML. The space data from the BIM can be used to provide legal boundaries in 3D which is limited in the current 2D strata and subdivision plans.

3.2 3D objects extraction and conversion

The 3D physical object extraction phase involves the extraction of geometries and semantic data from the IFC model. The *IfcSpace* and *IfcZone* entities are filtered to match with the strata objects in the Strata XML file. Figure 3 shows the filtered IFC physical data (geometries) that have been identified belong to a strata unit.

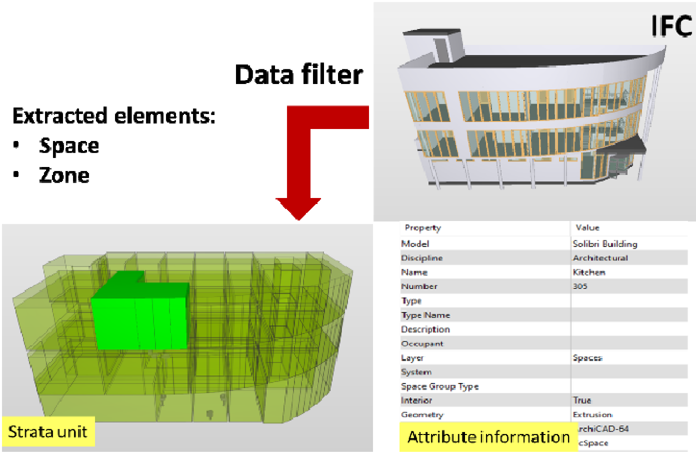

Figure 3: The extraction of 3D space from the IFC model.

The process of physical data extraction, mapping, and conversion are conducted using the data integration platform called FME (Feature Manipulation Engine). Figure 4 shows a part of the data processing workflow in FME, which is translating the IFC elements into CityGML data format. The role of CityGML is for the 3D physical data storage due the limitation of Strata XML. Legal data from the Strata XML (e.g., *Building, Parcel Unit, Accessory Unit, Land Parcel*, *Common Property Unit*, *Limited Common Property Unit, etc.*) are transferred to CityGML and stored as attributes information under the Building and Space layers.

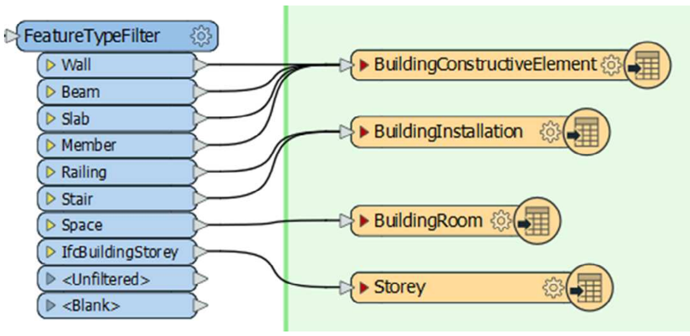

Figure 4: Data extraction and conversion from IFC to CityGML through FME.

3.3 Coordinate transformation

The converted 3D model in CityGML is georeferenced based on the coordinate system used in the Strata XML. IFC files are 3D models in a planar surface, therefore do not contain geographic information. The files are often placed using the LCS (local coordinate system), mostly used in the computer 3D design tools, in this case the origin of the file is at (0,0,0). Geographic coordinate system (GCS) is to define the location of object on the earth, considering the 3D spherical surface. The transformation of the LCS building model to a GCS model in the host CityGML, is significant to choose the right coordinate systems, so also the process for the translation of the coordinates. At this point the absolute projected coordinates system was selected (EPSG:4920) for the georeferencing purposes.

In order to extract the geometric information of a building elements, two categories of information are significant, and was considered, these include: the placement of the element (*IfcLocalPlacement*) and its representation (*IfcProductDefinitionShape*). The placement defines the location of an element, and the representation defines the shape of that element. Next, the local coordinates of the objects' vertices were computed using the following equation (1).

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = Ax \begin{bmatrix} Wx \\ Wy \\ Wz \end{bmatrix} + \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad \text{………… (1)}$$

where:

(*Wx,Wy,Wz*): represents the direction Vector of sweeping
A: represents the sweeping distance.
(*x',y',z'*): represents the LCS.
(*x,y,z*) : represents the GCS.

Finally, is the computation and the transformation of the LCS to GCS using a transformation matrix equation as presented by (Wu & Hsieh, 2007) in the equation (2), CityGML object model is generated.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\varphi x & sin\varphi x \\ 0 & -sin\varphi x & cos\varphi x \end{bmatrix} \begin{bmatrix} cos\varphi y & 0 & -sin\varphi y \\ 0 & 1 & 0 \\ sin\varphi y & 0 & cos\varphi y \end{bmatrix} \begin{bmatrix} cos\varphi z & sin\varphi z & 0 \\ -sin\varphi z & cos\varphi z & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} \quad \text{-- (2)}$$

where:

(x,y,z): represents the GCS.
(x',y',z'): represents the LCS.
(Δx,Δy,Δz): represents translation (change) from LCS to GCS from the origin.
(φx,φy,φz): respectively represents the angle of rotation with respect to (x-axis, y- axis and z-axis)

3.4 Integration with Strata XML

The integration phase involves the process of identifying and linking the extracted 3D physical objects with the legal data from the strata objects (Strata XML). There are two types of identifiers used related to cadastre management in Malaysia called Unique Parcel Identifier (UPI) and Unique Feature Identifier (UFI). UPI is crucial in matters related to land and strata since it is used to describe each land parcel individually. Code for each UPI is determined by the authority with 16 characters according to State, District, Town / City, Sections and Lot No. Meanwhile, UFI is a code that consists of 26 characters with additional 10 characters of UPI used to describe 3D cadastre in Malaysia. It was introduced to represent multi-level buildings such as Apartments and commercial buildings. Figure 5 illustrates the process of linking the 3D geometry with the strata objects through the utilization of UFI as the key object identifier.

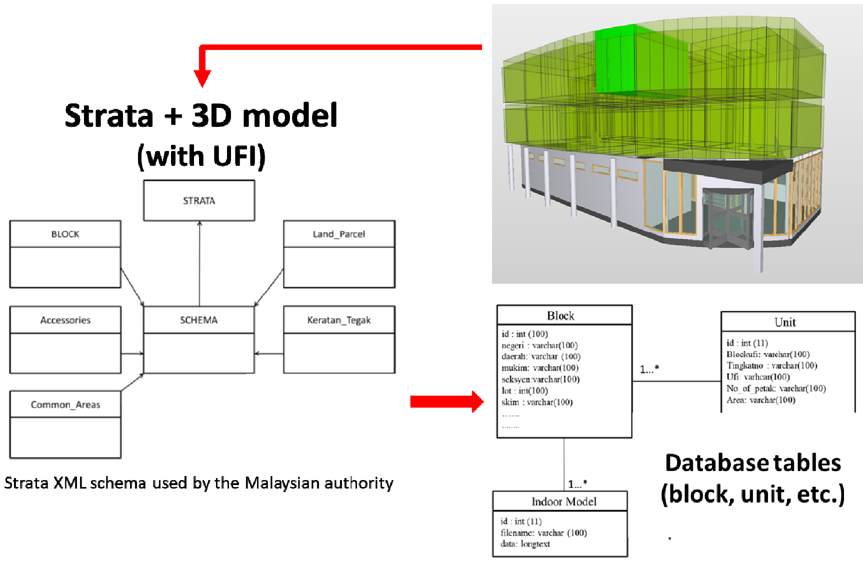

Figure 5: Process of linking the extracted 3D physical geometry with the strata objects (legal data) via the utilization of UFI.

The Malaysian Strata XML consists of *block*, *strata*, *land_parcel*, vertical section (*keratan_tegak*), *common_areas*, and *accessories*. The 3D physical space is assigned with the ID to the strata schema via UFI linkage. Then, the linked data (Strata XML and 3D model) is output into the destination format (i.e., CityGML) enriched with the physical and legal information.

4. DISCUSSION AND CONCLUSION

This paper proposed a method for converting BIM data to CityGML for 3D cadastre purposes that utilized the rich structural information in IFC model to support the legal ownership boundaries, cadastral attributes, and 3D visualization of the strata units. Figure 6 shows the strata units based on the integration of BIM model and Strata XML.

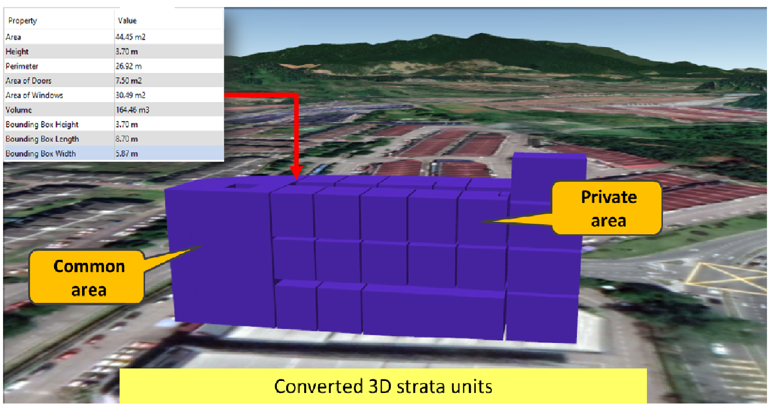

Figure 6: The strata units based on the integration of BIM model and Strata XML.

In this method, the flexibility of IFC as a standard for BIM was utilised to harness the rich data for the conversion such as *IfcSpace* and *IfcZone* as source elements suitable for 3D cadastral objects modelling due to their versatility for geometrical aspect of 3D cadastral objects, for example, walls, floors (upper and lower), doors, and window, also, *IfcLocalPlacement* and *IfcProductDefinitionShape* for the location and shape of the objects respectively. The conversion able to produce strata data into CityGML based format building with several floors and strata units. Furthermore, especially the ownership of a strata unit can be identified such as blocks, buildings, accessories, land parcels and common area information as indicated in Figure 6.

This paper strongly believes that the work obviously requires more attention in the aspect of physical geometry data filtering, and semantic data mapping (different coordinate systems). Other recommendation, such as modification of the data structures of geometry and semantic information of the two models (IFC and CityGML). Important aspects of 3D cadastral such as RRRs (Rights, Restrictions, and Responsibilities) will be investigated further in the near future. Currently, the paper focuses on the modelling and the Rights aspects. Apparently, innovative conversion from 3D cadastral to BIM could be investigated further such as for updating purposes.

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BIOGRAPHICAL NOTES

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3D Cadastre in the Case of Engineering Objects, such as Bridges and Road Viaducts

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Key words: 3D cadastre, road viaduct, bridge, layer approach

SUMMARY

At present, the implementation of cadastral registration of transport investments (such as railway lines on bridges and on viaducts, roads on viaducts, etc.) is performed in the so-called "layer" system. This means that many objects are constructed at different levels (layers) within the space of a given parcel. Several parties may be interested in developing certain fragments of the parcel space; each of them is interested in acquiring rights only to a specified part of the parcel (its specified layer), in which given investment is implemented by that party. The legal conditions binding in many countries do not allow for implementation of such type investments within the space of a someone else's cadastral parcels, based on the ownership right. This is due to the fact, in accordance with the "superficies solo cedit" rule applicable in many EU countries, the ownership right extends above and below the parcel space and cadastral systems do not allow for vertical division of a real property. The conventional 2D cadastre, which does not allow vertical division of the parcel space, forces an investor to buy a whole parcel or to get other rights which allows using a specified space of someone else's parcel, such as easiment rights. Buying of an entire parcel in which space bridges and road viaducts investments will be performed and not being able to divide the land space vertically makes it practically impossible to sell the parcel under a viaduct because following the rule above the viaduct is part of the land parcel. Therefore, the space is not optimally utilised. The easement right has some disadvantages, as it cannot be encumbered with a mortgage; therefore it is not the basis of crediting a given investment. The 3D cadastre allows delineating 3D parcels (from the space of existing 2D parcels) that cover specified fragments of the space and to relate ownership rights to those delineated fragments.

Within a 3D cadastre system, such objects can be registered as separate cadastral objects. This allows for the implementation of a line investment in the above-ground space in a flexible way, i.e. it is possible to get financing of an investment based on the mortgage charge of a 3D property and market transactions of the remaining space after delineation of the 3D parcel, covering the bridge or viaduct. This paper focuses on approaches to registration of real property rights in the case of engineering objects, such as bridges and road viaducts, in different EU countries: Austria, Bulgaria, Czech Republic, Croatia, Greece, Poland, Slovenia and Sweden.The authors review the current solutions for the registration of engineering objects in the cadastre, including its effectiveness in ensuring appropriate property rights to construct and exploit such objects, and make a comparison between the countries.

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1. INTRODUCTION

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This paper focuses on approaches to registration of real property rights in the case of engineering objects, such as bridges and road viaducts, in different EU countries: Austria, Bulgaria, Czech Republic, Croatia, Greece, Poland, Slovenia and Sweden. The authors review the current solutions for the registration of engineering objects in the cadastre, including its effectiveness in ensuring appropriate property rights to construct and exploit such objects, and make a comparison between the countries.

2. REGISTRATION OF BRIDGES IN EU COUNTRIES (NATIONAL SOLUTIONS)

2.1.Austria

The Austrian system does not support the registration of 3D property. A viaduct can be modelled like a building. The areas required for the viaduct are separate parcels. Street crossings are separate parcels where road and bridge intersect.

The situation for bridges is slightly more complicated. Bridges may be close to the surface like in the Stadtbahn example. However, they may also be high in the air. An extreme case is the Europabrücke in Tyrol (see Fig. 1 left), which has a maximum height above ground of 190m and a length of 777m. The pure cadastral boundaries only show the footprints of the pillars (Fig. x4 right). The bridge is marked in the cadaster only as a land use type. Fig. 2 shows a detail of the area with parcel 593 in the center. The parcel has a total size of 24,319m2 and 4,077m2 of them are used for traffic infrastructure. However, the owner of the total parcel is not the operator of the highway. The legal basis of the construction is an easement based on an administrative decision and inscribed in the land register. The text is "*Easement of the superstructure, the maintenance and the operation of the Europabrücke on Gst 593 598/15 601/10 in accordance with decision 1984-12-13 for Republic of Austria (Bundesstraßenverwaltung - A)*". Accessing the original legal document is difficult since it either requires a visit at the locally responsible land register or a search for the decision itself. It is thus not obvious who the owner of the construction is. It could be the Republic of Austria, it could also be ASFINAG, the Motorway and Expressway Financing Corporation, a company owned by the Republic of Austria, which was founded in 1982 and operates the highways in Austria.

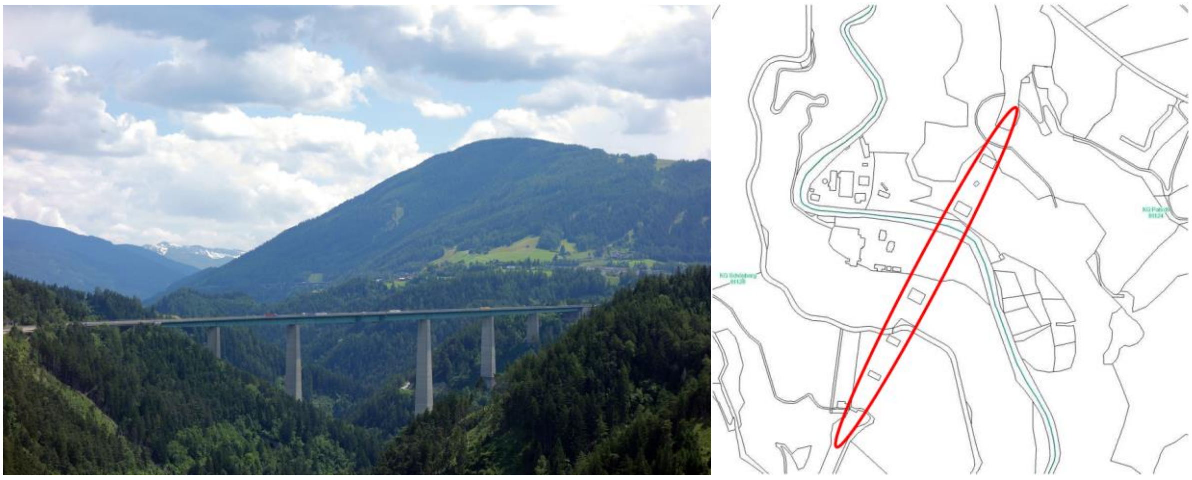

Figure 1. left: Europabrücke in Tyrol, Austra (Source: Von Mnolf - Eigenes Werk, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=27116002, 2013); right: cadastral boundaries in the area of the Europabrücke, red ellipse marks the area of the bridge (Source: BEV)

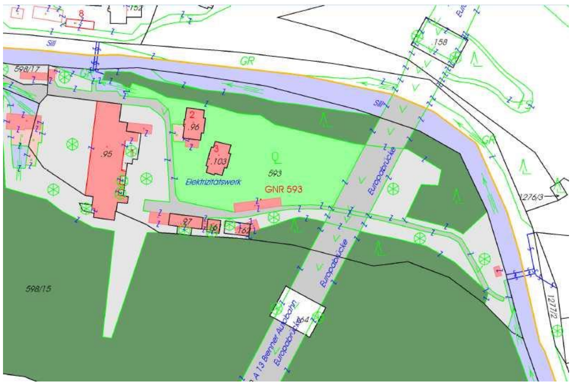

Figure 2. Cadastral map including the land use types (Source: BEV)

2.2.Bulgaria

The first cadastral law with an objective to determine the legal and physical property boundaries aiming for correct geolocation and fair taxation was passed in 1908. Bulgarian Civil Law incorporating the deed registration system was built following the Roman legal system. In 1990 nearly 90% of the territory of the country was restituted. This action was followed by the creation of a new Law on Cadastre and Property Register (LCPR) in 2000, clarifying the rules related to the data collection, exchange, and maintenance between the property register of the Ministry of Finance, register of people and companies. The Agency of Geodesy, Cartography and Cadastre is the one responsible for cadastral data production and maintenance.

The produced cadastral maps include data related to the ownership, property rights over the immovable properties, state and land property boundaries. Moreover, it is shown if the land is urban, agricultural, forestry or other. The Cadastre and the Property Register, which keeps data on property transfers, maintain a constant link. All property transactions in Bulgaria are done with the help of private notaries and licensed surveyors and are registered in the Registry Agency. The Bulgarian cadastral system manages data in 2D format, however for certain complicated situations, additional 3D materials are attached. In Bulgaria, some bridges are visualised in the cadastral map without a unique identifier as shown on Fig 3 since they are not considered cadastral objects.

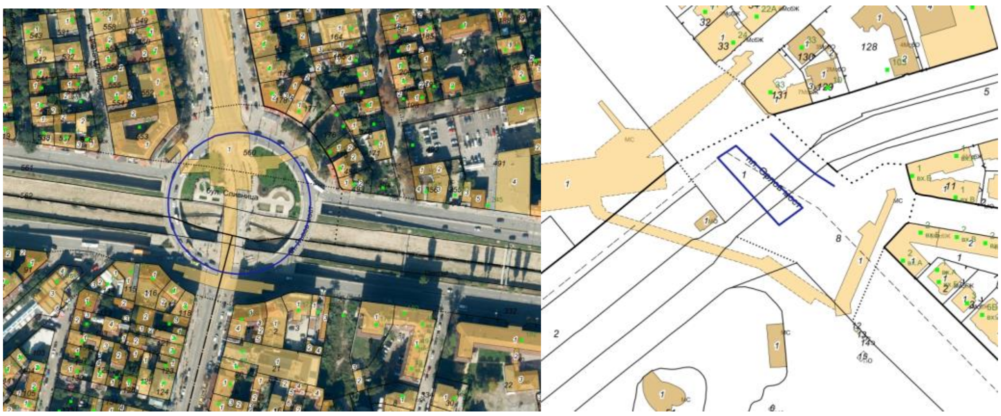

Figure 3. "*Luvov most*" and "*Orlov most*" in Sofia. (www.isofmap.bg)

They are either state or municipality property and fall under the laws related to the transport, technical infrastructure and their facilities. This means that activities related to their construction and maintenance are responsibilities of the state or the municipality. Special approval for their building, including technical specifications and specialised schemes, is needed. Data for creating such specialised maps are retrieved from the central administration system. Usually, it is obtained from the cadastral agency in digital form and contains information about the spatial location (state borders), boundaries, the way of use, ownership, rights, restrictions and responsibilities. In the law, it is written that the underground and common surface networks and facilities of the technical infrastructure should be designed and constructed on municipal and state landed properties. In case this is not possible, they should be constructed in properties owned by individuals or corporate bodies (art. 199 or 205).

After applying for many years the Cadastral Law created in 2000 due to observed challenges in registration of certain complicated urban situations, changes in the law have been done in 2014. One of the changes was related to the registration of infrastructural objects (e.g. bridges) in the cadastral map. A typical complicated example is when there are commercial structures positioned on top or under infrastructural objects such as bridges. With the acceptance of this law, it is currently possible to register such objects independent from the utilities and infrastructure.

2.3. Czech Republic

There are some kinds of 3D objects schematically displayed on the 2D digital cadastral map, but in fact not officially registered in the cadastre, which is also the case of bridges. Fig. 4 displays a combination of the digital cadastral map (and the outlines of the bridge in the center) and the orthophoto map. The bridge is owned by a private person, but the cadastre does not contain any information about the ownership. According to the Civil Code, the ownership is proved just by the purchase contract.

Figure 4: The private bridge schematically displayed in the digital cadastral map. (Czech Office for Surveying, Mapping and Cadastre).

Sometimes the digital cadastral map contains only these parts of the bridge, which are directly connected with the ground (Fig. 5) and sometimes the bridge is completely missing.

Figure 5: The bridge near Pilsen which is a part of the highway from Prague to Pilsen. Only the parts of the bridge connected with the ground are graphically displayed. (Czech Office for Surveying, Mapping and Cadastre).

2.4.Croatia

In the Croatian Land Administration System, there are special topographic signs for 2D maps showing 3D situations such as buildings overlapping other structures (e.g. tunnels, roads, or other parcels with building parts crossing the parcel boundaries either above or below ground level). Additionally, there are also special signs that represent underground buildings on cadastral and topographic maps (Fig. 6). Cadastre can register underground buildings only on cadastral maps and in the written part of cadastral documentation, but without area information, which can be documented in the land register. Many new underground buildings were built in Croatia during the last twenty years, which is the reason behind the consideration of new regulations by the State Geodetic Administration of the Republic of Croatia that will enable the registration of underground buildings with area and other attributes into the cadastre.

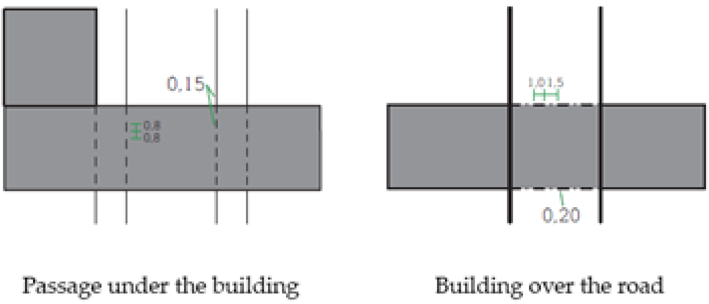

Figure 6. Example of topographic signs for buildings.

City of Neum (Bosnia and Herzegovina) divides Croatian territory into two parts. In July 2021 after a long time, Croatian territory was united by making a new bridge (Figure 7). The Pelješac Bridge is a bridge in the Dubrovnik-Neretva County in Croatia that bridges the Mali

Ston Bay between Komarna on the mainland and Brijesta on the Pelješac peninsula and thus achieves the continuity of the territory of the Republic of Croatia interrupted by a narrow corridor that leads Bosnia and Herzegovina to Neum.

Figure 7: Pelješac bridge (Https://www.obserwatorfinansowy.pl/wp-content/uploads/2020/01/Croatia-Peljesac-bridge-map-kwadrat-1-290x290.jpg (left); https://static.euronews.com/articles/stories/05/93/97/68/808x532_cmsv2_9ebb3473-bee3-55dc-865d-16d92f1d232b-5939768.jpg (right)_

The bridge is a suspension type, with a total length of 2404 m with six main pillars and thirteen spans of steel with a length of 72 to 285 meters. At a height of 55 meters, the request of Bosnia and Herzegovina to ensure the unimpeded passage of ships to Neum was met. The depth of the sea under the bridge is almost constant 27 meters, and due to the soil composed of thick layers of clay and silt, the entire bridge is based on a hundred meters long steel pipes with a diameter of two meters driven into the seabed. The location of the bridge is subject to strong winds and is in a zone of significant seismic activity. The bridge is located in a sensitive ecological area of the Mali Ston Bay, which was declared a nature reserve in the sea in 1983, and is also protected by the ecological network Natura 2000. Pelješac bridge is not registered in the Land cadastre and Land registry due to the missing laws regulating that matter, but State Geodetic Administration working on bylaw for all tunnels, roads, or other parts of parcels with building parts crossing the parcel boundaries either above or below ground level to be registered in Land administration system.

2.5 Greece

Greece belongs to the legal family of Civil Law. Real property is regulated by the Greek Civil Code (Book 3, Property Law). Land ownership comprises everything that is attached to land (art. 948), and extends to the space above and below the land surface. However, the land owner may not forbid an action taking place high or low enough to be of interest to him/her (art. 1001). Stratification of real property can be achieved through the establishment of servitudes, horizontal ownership rights (apartment rights/condominium), vertical ownership rights (the land owner has the right to create and register titles of independent properties that will be erected on the parcel in the future) and the right of superficies. Stratified real property objects pre-existing the introduction of the Greek Civil Code in 1946, known as special real property objects (SRPO), also constitute cases of 3D real property.

For the establishment of utilities, the Greek Civil Code provides that the land owner of a land parcel is obliged to allow utility networks to cross on, above, or below his/her land parcel after compensation (art. 1031). As regarding to major infrastructures, apart from the provisions of Property Law, special provisions can be made by legal statute (e.g. Law 2882/2001 (Expropriation Code) or Law 2714/1999 for the establishment of the subway line of the city of Thessaloniki in Greece that regulates issues of real property rights on and below the land surface). Bridges and viaducts are considered as public spaces, owned either by the State, or by the municipalities. Such types of objects are registered to the Hellenic Cadastre database and are assigned a unique cadastral number (KAEK). In order to avoid ambiguities and identify overlapping real property objects, the Hellenic Cadastre uses separate thematic layers for the spatial representation of mines (Rokos, 2001; Arvanitis, 2014). However, this solution was not extended in case of bridges and viaducts, due to their direct relation with their surrounding real property objects. Consequently, the real property object that is lying on top of the other is presented on the cadastral map, while the objects lying at a lower level are split based on the projection of the above lying real property object (Fig. 8).

Figure 8: Viaduct in the region of Attiki in Greece, as shown in the Hellenic Cadastre map (left) and real property units of the viaduct and its surrounding roads (right) (Hellenic Cadastre web services for professionals)

This introduces ambiguities in representing the real situation on the cadastral map. Reference pointers (tags) relating cases of overlapping real property rights that are used especially for SPROs are also implemented in case of real property objects situated below bridges or roads (Sioula, 2011). Overlaps due to the existence of bridges and viaducts can be distinguished in two categories. The first comprises those that the real property objects below the bridge/viaduct are owned by the state (most commonly the Ministry of Infrastructure), or the municipalities and the regional authorities. In this case, there is no specific provision for the distinction of the overlapping parts as regarding registration or presentation to the cadastral map, since it is considered that both of the overlapping volumes serve the public benefit. The second type of overlaps refers to bridges/viaducts situated above privately owned land. This case is more complex since the existence of the bridge/viaduct significantly affects the below-lying land parcel's exploitation and use. This issue has again been brought to debate, within the context of the ongoing cadastral survey of the rural part of Greece, where about 6,000 bridges of more than 6 metres length can be traced to the Greek national road network, in a total of about 17,000, if bridge openings less than 2 metres are included (Plessias et al., 2019).

2.6 Poland

In Poland according to the Ordinance of the Minister of Development, Labor and Technology of 23 July 2021 on the database of topographical objects and the basic map (Ordinance, 2021) – bridges, viaducts and other engineering objects are registered in this database (Fig. 9), called in short BDOT500. According to paragraph 4 (Ordinance, 2021), the attributes common to all objects of the BDOT500 database are:

- method of obtaining information about the facility;
- the date of admission to the state geodetic and cartographic resource;
- number of the technical report under which the object was entered into the BDOT500 database.

In the category of objects "communication" can be distinguished, among others: OTKM bridge, OTKZ bushing, OTKW Viaduct, OTKE flyover, OTKT track, OTKN platform.

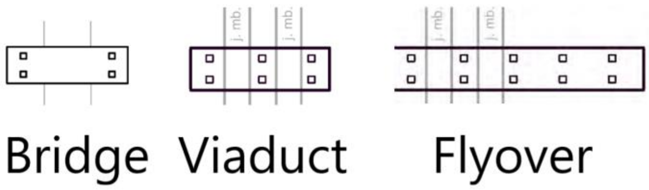

Figure 9: Symbol of bridge and other communication objects on base map and in BDOT500 database (Ordinance, 2021)

Bridges are not registered as objects in the real estate cadastre. The bridge symbol is visible in the BDOT 500 database and on the base map, which contains a cadastral data layer, including boundaries of cadastral parcels. Regardless of registration, In Poland, there is still an old Roman rule related to the perception of the scope of the property right of superficies solo cedit. Art. 46 Civil Code states that, Real estate is the parts of the land which constitute a separate object of ownership (land), as well as buildings permanently attached to the land related or parts of such buildings, if under specific provisions constitute an object of ownership separate from the land. Especially art. 48 states, also that to the part The components of the land include, in particular, buildings and other permanent devices connected with the land. Art. 143 defines the range of property rights. It states that, within the limits defined by the socio-economic land use, land ownership extends to the space above and below its surface. This provision is without prejudice to the provisions governing the rights to water. As a result of such legal and technical solutions, the ground in the plot of land (parcel) in which a given engineering structure is located, e.g. a bridge, cannot be divided vertically, i.e. in layers.

Pursuant to the Act on Public Roads of March 21, 1985, a road is a structure together with road engineering structures, devices and installations, constituting a technical and operational whole, intended for road traffic, located in the road lane. The bridge structure or tunnel is part of the road and is managed by the road administrator. It should be mentioned that there are bold architectural designs which, in addition to technical barriers, also encounter legal barriers in terms of establishing separate ownership rights in a stratified structure. An example is the museum of Polish history. It would originally be located on a huge platform above the Łazienkowska Route. The museum building would look like a glass bridge.

The draft assumptions of the draft act on separate ownership of buildings construction objects planned in 2010 would legally support the implementation of this type of investment plans. It was mentioned in its content in the section "Current state of social relations in the field of separate ownership of buildings construction".

The Ministry of Infrastructure proposed in 2010 the introduction of a new category of objects that may constitute a separate real estate. The goal of the proposed regulation was to allow for the establishment of separate ownership of objects construction works carried out above or below the ground, not directly related economically with this land property. At the same time, an important premise of the separation of such real estate is the fact that it does not deprive the owner of the rights to the land and does not exclude the possibility of using this land. The subject of separate ownership of construction works was to be in particular: construction works or construction equipment erected above or below public roads, railroads, flowing waters, including buildings, structures, tunnels, viaducts, bridges, overground and underground car parks (see Ministry of Infrastructure (2010)). The draft assumptions of these legal regulations remained at the proposal stage and no similar solutions have been adopted so far.

2.7 Slovenia

As for the registration of land rights for the case of bridges, we must remember the basic legal principle of the Slovenian land administration system, which is "superficies solo cedit". This principle means that ownership of land generally means also ownership of all constructions built-up on the land. Exceptions to this principle are (1) the right of superficies (the right to own a building above or below the land owned by a third person) and (2) apartment ownership (condominium). The right of superficies and condominiums separate the ownership of physical objects from the land itself. For the registration of buildings and parts of buildings, an additional database, i.e. Building Cadastre, was established on the basis of the legislation from 2000, which is linked to Land Cadastre (Pogorelčnik and Korošec, 2001; Drobež et al., 2017). Based on the experience of more than ten years of operational use, the Building Cadastre was partly modified in 2018. The changes concerned the classification of the use of parts of buildings, the submission of digital data and the requirements for geometric data. Regarding the latter, floor plans are now georeferenced and submitted in digital format (GeoJSON), enabling 3D visualisation. It is planned that the Land Cadastre and the Building Cadastre will be merged into a single Real Property cadastre by 2022 (Real Estate Cadastre Act, 2021).

However, these two rights have been introduced for buildings and not for other construction objects, such as bridges. Following the principle “superficies solo cedit”, the ownership of bridges “share” the same ownership of land under the bridge. The legal solution on how to protect the rights of the objects of (public) infrastructure has been the topic of several professional and political debates in the last two decades. The Surveying and Mapping Authority established a database on public infrastructure, i.e. Cadastre of Public Infrastructure, that was designed in 2004. The main purpose has been to provide the state, local communities and other users with the georeferenced data on public infrastructure in a centralised and standardised way. An additional aim was to prepare a reliable database on public infrastructure to support the registration of rights, restrictions and responsibilities on the objects of the public infrastructure. However, this legal challenge has not been solved yet.

Focusing on bridges, several approaches can be found in practice. In particular, in the case of “water land”, which is, according to the Slovenian legislation, a public good, the ownership of the land cannot be changed, and the bridge is officially owned by the state. In the case of new bridges/viaducts, where private or public land is beneath the bridge, there are two main practices (i) the investor buys the land under construction or (ii) easements are registered in the land registry for land parcels and parts of land parcels that are under construction. These approaches are then reflected also in the land parcel structure (Fig. 10, Fig. 11).

Figure 10: Land parcel structure for the case of bridge: land parcel boundaries (green) and boundaries of cadastral municipalities (red) on state orthophoto (Surveying and Mapping Agency of the Republic of Slovenia)

Figure 11: Land parcel structure as presented in the field book on land subdivision from 2012 (Surveying and Mapping Agency of the Republic of Slovenia)

In addition, the solutions regarding the land ownership registration for land under bridges might also vary in terms of their heights above the ground. Bridges may be close to the surface, but there are also cases where a maximum height above ground is more than 50 m. In these cases, the practice varies as well. In the case of acquisition of land for this infrastructure object, this is reflected in land parcel structure, while in the case of an easement, this right/restriction is only registered in the Land Registry at the court. The new legislation from 2021 has foreseen that the spatial extension of easements should also be registered in the land cadastre as part of land parcel(s).

2.8 Sweden

The possibility of forming 3D property units was introduced in 2004, as an addition to existing 2D property formation (SFS, 1970). One purpose for this new type of property was the implementation of major infrastructure projects, which was specified as a need for the introduction of 3D property formation (Eriksson, 2005, p. 12).

The traditional 2D property has no fixed delimitation of the property volume above or below the ground surface, and it is possible for the property owner to construct infrastructure facilities above or below ground within the property volume. Constructing such facilities can also be done by another party, with the consent of the owner or through expropriation means if there is no consent, normally providing compensation for the take.

During the investigations before the 3D property legislation was introduced, 3D property formation was considered a valuable tool for solving complicated problems within building projects and for various purposes (Proposition 2002/03:116, pp. 31-32). Among the purposes mentioned were covering railway areas with buildings for housing and offices and using space below ground for garages and archives, as well as for dividing ownership within different communication areas with terminals, bridges, railway stations, etc.

The Swedish 3D property is defined as a property unit, which in its entirety is delimited both horizontally and vertically (SFS, 1970, Chap. 1, s. 1a). The 3D property may also extend over or under several ground parcels, and is thus not bound to be located within one two-dimensionally delimited property unit. In the regulations of the 3D property formation, it is prescribed that 3D property formation is only allowed if the 3D property accommodates, or is intended to accommodate, some kind of construction, such as a building or other facility or a part of the same. However, there are no specific regulations regarding where the boundaries surrounding the 3D property unit should be drawn. This is rather decided in the specific case, although recommendations are provided for. The recommendations (Lantmäteriet, 2003), however, provide that there is no need for the boundaries to exactly follow the delimiting area of the construction, but can include some volume of space for protruding parts, use and management. It is also possible to include in the 3D property unit a larger volume around the facility in order for it to be used for its purpose and to accommodate everything needed for its operation. This is the case for e.g. bridges and viaducts. The recommendations (Lantmäteriet, 2003) also give the possibility to include a protective area around the facility within the 3D property unit, in order to prevent damage by surrounding properties or for management purposes. Another possibility is to create a 3D easement as a protective volume, but included in the surrounding property unit.

The 3D property units are registered in the cadastral index map as part of the national Real Property Register, as well as in the textual part of the register (Lantmäteriet, 2004). For each 3D property unit, the type of space is also indicated, of which 'bridge' is one such type. Today, in total 15 3D property units are registered with the purpose "bridge" in the real property register. However, there are no bridges or other such constructions that constitute pure 3D property units, although they are facilities that are connected with traditional 3D property units. For facilities in the air that lack contact with the ground, such as bridges or viaducts, the vertical location should be specified in the form of coordinates or measurements, in addition to maps and textual descriptions to show the location of the 3D property unit (Lantmäteriet, 2003). The register also indicates the traditional 2D property units within the volume of which the 3D property unit is located.

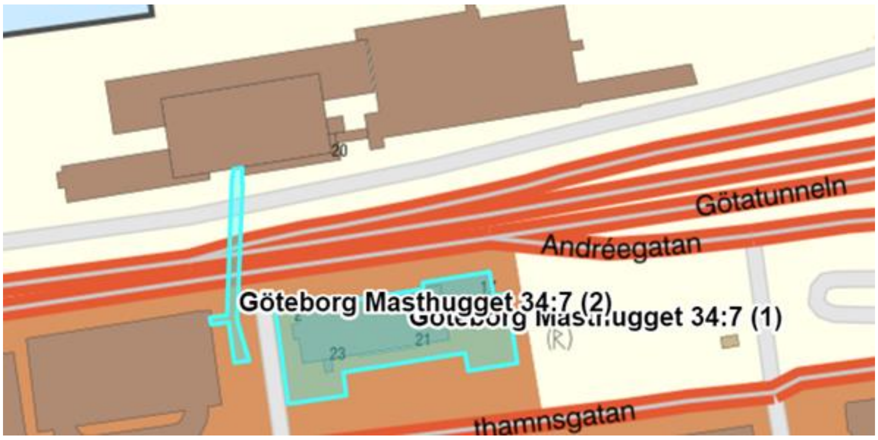

Figure 12. Example showing a 3D real property consisting of two parts. The left part, no 34:7 (2), is a bridge. Extract from the Swedish Digital Index Map. Lantmäteriet, The Swedish mapping, cadastral and land registration authority.

3. DISCUSSION ON LESSONS LEARNED FROM THE EXAMPLES AND CONCLUSIONS

This work examines the approaches regarding legislation and registration of 3D infrastructure objects, especially bridges and viaducts, in 8 European countries. All examined countries are based on the Civil Law legal tradition, specifically the Scandinavian and the Germanic Civil Law. Among the examined countries, Sweden has an operational 3D cadastral system, where 3D real property units can be established, while the rest operate under the Roman principles on the extent and the content of real property ownership. The downside in Sweden is the slightly increased effort during preparation for the registration.

Apart from the Swedish case approach that was developed considering the implementation of infrastructure objects, the rest of the examined countries implement different solutions. Similarities can be traced partially between different aspects of registration. For example, specific annotations used in Croatia are close to the tag concept that applies, in several cases, in Greece. At the same time, the representation of bridges without being officially registered can be traced in several cases both in Bulgaria and Czechia, often also in Slovenia. The easement/servitude solution is a concept shared by Austria and Slovenia.

However, there are three countries that have been motivated to modify their legal framework due to the limitations deriving from the overlapping rights of private and public rights in case of major infrastructures (Greece, Poland and Slovenia), ranging from discussions on technical level for cadastral survey requirements (Greece), (not yet implemented) legal proposals (Poland) and new legislation (Slovenia – cadastral registration of easiments).

On the other hand, the Swedish system of 3D real property units provides already 15 cases of bridges established exploiting the 3D real property unit concept, while also providing other three-dimensional solutions for the construction and maintenance of major developments (e.g. 3D easements). Although the Swedish solution is the most innovative and is based on well-established cadastral procedures among the examined countries, the limited number of 3D real property units used within a period of 17 years after the introduction of 3D property units needs to be considered for further communication of the 3D real property unit concept and the capitalisation of its merits.

It is obvious from the national cases, that the Roman principle superficies solo cedit still affects the legislation in many European countries (e.g., Austria, Slovenia, and Poland). This principle has benefits in case of low construction density, when a 2D representation is sufficient. Then it provides simple rules and leads to legal security. However, when vertical separation becomes relevant, the principle creates problems. Several solutions have been implemented for bridges:

- Do not document them at all
- Document them in a register outside the cadaster
- Show them in the cadaster as additional information but not as cadastral objects
- Show them as separate land use
- Register them as easements

A problem with these solutions is that detailed regulations on responsibilities might not be part of the cadastral description but stored in separate documents. These documents may be difficult to acquire even if geometrical, technical, and legal data are in principle publicly accessible as shown by the Austrian example. The Swedish cadastre is the farthest among the investigated countries in the development of 3D cadastral structures, such as the surveying effort. The advantage is obviously the easier registration of rights, restrictions, and responsibilities, because there are well defined objects that they are attached to. This leads to simpler decision making in case of dispute. The downside is the increased effort during preparation for the registration.

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Modelling 3D underground legal spaces in 3D Land Administration Systems

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Key words: 3D Land Administration Systems; underground objects; LADM; BIM; IFC

SUMMARY

Two dimensional (2D) Land Administration Systems (LASs) do not adequately represent 3D underground objects. It is not easy to identify the owners of these objects and the relations between objects below and above the surface are not explicitly provided. A 3D LAS can however facilitate a better understanding, as well as a more efficient registration and clear visualisation of the Rights, Restrictions and Responsibilities (RRRs) of the 3D underground objects. To represent 3D underground objects, BIM/IFC (ISO 16739:2018) models can be used from design. The LADM (ISO 19152:2012) standard should be used to provide a formal language to register spatial and non-spatial information in LASs. In this paper a literature review is performed to develop a standardised workflow to model the legal spaces of BIM/IFC models of 3D underground objects according to the LADM in 3D LASs. With this workflow the user is provided with a general framework, where adherence to the BIM/IFC and LADM standards enhances interoperability, increases efficiency and reduces costs. More research needs to be done on validating the workflow with use cases.

Modelling 3D underground legal spaces in 3D Land Administration Systems

Rohit RAMLAKHAN, The Netherlands, Eftychia Kalogianni, Greece, Peter van Oosterom, The Netherlands

1. INTRODUCTION

Urbanisation and a shortage of accessible land has resulted in increased development of multi-level properties worldwide (Kim et al., 2015). The implementation of these properties in Land Administration Systems (LAS) requires 3D objects above and below the surface of the Earth, that 2D parcels cannot adequately support (Stoter et al., 2016). When 2D parcels are used to represent objects below the surface it is not easy to identify the owners of these objects, while the relations between objects below and above the surface are not explicitly provided (Yan et al., 2019). 3D LAS clearly defines the relationships between Rights, Restrictions, Responsibilities (RRRs) and spatial units (3D objects), while the registration of the objects in the third dimension (3D) facilitates a better understanding, as well as a more efficient registration and clear visualisation of the RRRs (Kim et al., 2015; Atazadeh et al., 2018, 2019).

To digitally represent a physical model of the 3D objects, a Building Information Model (BIM), which comprises the geometry and semantic information of an object during the whole building lifecycle, can be used (Kalogianni et al., 2020a). The most commonly used BIM format is the Industry Foundation Class (IFC), EN ISO 16739:2018. IFC is an open standard developed to stimulate interoperability of different types of BIM models (ISO, 2018). Enhanced interoperability facilitates data sharing and integration and stimulates the reuse of the data, especially from the design stage. The need for data exchange and interoperability within the Architecture, Engineering, Construction, Owner Operator (AECOO) community, as well as the rapid demand and even mandate from industry and the governments around the world has resulted into the increasing use of BIM/IFC models (Kalogianni et al., 2020a).

The ISO 19152:2012 Land Administration Domain Model (LADM) is an international standard, a flexible conceptual model that provides a formal language for describing both the spatial and non-spatial information in the land administration domain. Compliance with this standard leads to a more efficient LAS, where data can be exchanged and the quality of data ensured, sustained and effectively managed (Lemmen et al., 2015). Recent research is being carried out to investigate the implementation of the LADM in a 3D LAS, with the use of BIM/IFC models as input for apartment buildings and infrastructure objects. The result is that the RRRs of underground objects can easily be determined by applying the legal aspects from the enriched BIM/IFC model. This is especially important when the physical models and their legal spaces need to be compared as could be the case with complex built structures, such as underground objects (Atazadeh et al., 2018).

The use of standards has supported the development of 3D LAS by enhancing the interoperability of the models, although several challenges and incompatibilities still remain.

3D LASs around the world may vary, since they depend on various aspects, such as the socioeconomic situation, scope of the LAS, existing situation on land registration, data availability, standards, vision for future LAS, etc. This mosaic results in different requirements for the collection, validation, registration and visualisation of 3D underground (cadastral) data. For that reason, research is carried out regarding registering the legal spaces of 3D underground objects, and investigating the relation between the 3D underground objects and the affected 2D parcels on the surface of the earth (Kalogianni et al., 2020a).

In this scene, this paper investigates good practices and milestone projects for the registration of underground properties at an international level and presents a comprehensive standardised workflow that will be able to: (1) collect, process, store, validate, visualise, disseminate and query 3D underground data in a 3D LAS according to ISO 19152:2012, (2) model the relations between the underground objects and their legal spaces, (3) model the relations between the underground legal spaces and the 2D parcels on the surface and (4) connect the workflows from AECOO community to a 3D LAS via a BIM/IFC model.

The paper is structured as follows. Section one presents the introduction. Information on the modelling of underground legal spaces in the countries around the world and on standardised data models is then provided. Hereafter, the procedures that were followed in order to develop the workflow are presented. Section four presents the workflow and elaborates on the different phases. The paper concludes with the discussion and conclusions.

2. RELATED WORK

2.1 Modelling of underground legal spaces in the Netherlands

In the Netherlands, there are three types of cadastral objects: parcels, apartments and utility networks. Utility networks are registered as legal objects in the Dutch Cadastre separate from the parcels, and as physical objects by the utility network companies (Stoter et al., 2012).
Other underground objects are not legal objects but their property rights can still be registered with the use of limited rights on 2D parcels. These limited rights are the right of superficies, the right of long lease and easements (Stoter et al., 2012). The right to superficies provides the right to construct buildings or other non-utility structures above or below other structures or land that is owned by a different owner. This makes it possible to register the ownership of tunnels, parking garages and other underground objects. The right of long lease gives the right to use an object but not legally own it. The long lease can apply to (parts of) a property or space, for example, the parking garage can be leased but not the building that is built on top of it. An easement is a burden on a parcel, where another parcel has certain rights over. Examples are the extension of a tunnel from one parcel to another or prohibiting that one parcel builds pipes and cables near the other parcel (Stoter et al., 2012).

To register the legal spaces of the 3D (underground) objects with the attached limited rights, the Dutch Cadastre adheres to the '*specialty principle*'. This principle states that "*if a limited right is attached to a part of a parcel then the whole parcel needs to be divided in a manner that no parcel with the limited right intersects with parcels that do not have the same right* *attached to it"*. Applying the specialty principle may result in the occurrence of many small parcels (Stoter et al., 2016; 2017).

A new workflow has been developed by Stoter et al. (2017), regarding the registration of multi-level properties (with underground structures) in 3D. In this workflow, legal volumes are created from BIM models and validated. With the use of a 2D cadastral map a 3D-PDF is created for the visualisation of the legal volumes and is used as a legal source document (see figures 1,2). The legal volumes created from the BIM models are also stored in the Dutch cadastre for the 3D geometry and could be updated in the future by surveying the legal volumes (Stoter et al., 2017). However, it is not possible to extract coordinates from a 3D PDF, thus, the use of BIM/ IFC models is preferred.

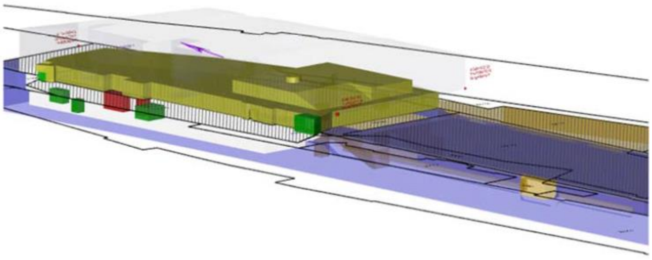

Figure 1. Visualisation of the different legal spaces of the Delft station, The Netherlands (Stoter et al., 2017)

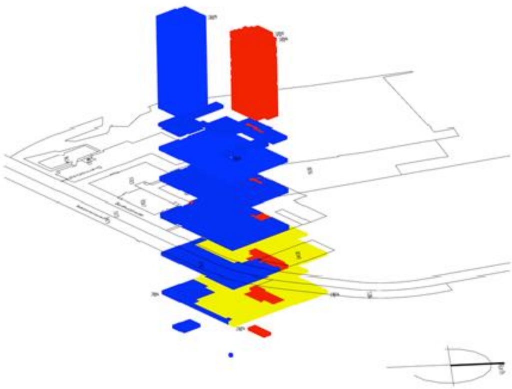

Figure 2. Visualisation of the different legal spaces of the congress hotel Maritim, Amsterdam, The Netherlands. Red: residential building, blue: congress centre; yellow: underground parking garage (Stoter et al., 2017).

2.2 Modelling of underground legal spaces worldwide

Due to urbanisation, cities around the world are being extended below ground and are developing their underground spaces for optimal usage. For example, Singapore plans to increase the use of underground space and has initiated the Digital Underground project to survey and map the subsurface utilities in order to acquire precise information of the underground space (Singapore-ETH Centre, 2019). What is more, the United Kingdom runs a similar project, the "Project Iceberg", in which, not only the subsurface utilities will be mapped, but also the conditions of the ground (BGS Research, n.d.).

A review of how selected countries around the world currently model (specific) underground objects in LASs and registries, as well as the recent research that is being carried out in order to improve this registration, is presented in this section.

In Poland, the current cadastral system consists of two registers: one for the location and the geometry of the land (parcels) and buildings and one for the legal information (Bieda et al., 2020). The registration of underground objects can be complicated, since these objects can have different owners than those of the objects on the surface. The underground objects therefore need to be registered separately. Bieda et al. (2020) propose to extend the current cadastral conceptual model with new classes to support a 3D cadastre. The “object-oriented spatial plot” is a concept proposed in Poland to register underground objects. In this concept the underground object, as well as the spatial plot that it occupies, is described and separately registered in three dimensions. It is highlighted that amendments in the Polish real estate law are necessary to implement this concept (Matuk, 2019).

Moreover, in Korea, land administration is based on a 2D cadastral system and on ISO 19152 LADM standard that registers the boundaries and other geometries of the cadastral objects, while a real property registration system registers the legal information. Due to its two-dimensional character the cadastral system is not able to register 3D underground objects. The real property registration system can register these objects by defining certain extents of the legal space underground. In order to prepare the system for 3D underground objects, Kim et al. (2017) propose to extend the cadastral model with two packages: one for the surveying and mapping of the underground objects and one for the 3D underground parcels. Research by the same authors presents a framework in which 3D underground parcels can be registered. In this framework firstly the parcel is prepared by collecting data from surveying and existing 2D maps. Then, the 3D underground parcel is defined by modelling the legal spaces and taking into account the absolute or relative height. At the end, the legal rights to the 3D underground parcel are registered. To make this framework possible, Korean law does need to be altered (Kim et al., 2019).

In Singapore, land owners in general own the land up to 30 meters below the mean sea level, although the law makes it possible to acquire a specific part of underground space if necessary (Yan et al., 2019). The underground spaces are registered in the cadastre as subterranean lots based on the 2D drawings. Additional surveys can take place which are registered in 2D with the addition of the elevation relative to the mean sea level. Due to the complexity and overlap of the 2D drawings of the lots, there is a need for a 3D cadastre (Khoo, 2011). With regards to the utilities, a method has been proposed to develop an underground utility 3D data model based on the LADM in order to better register and manage the utilities and their networks in Singapore (Yan et al., 2019; 2021).

The Serbian cadastre registers underground objects, that are part of a building, as building units. These building units are not visible on the cadastral map but data and attributes are stored in the database. Underground objects that are independent of a building or other structure are linked to the parcel on which the entrance to the object is located. For the registering of utilities, there exists a separate cadastre. The existence of these two cadastres prevent the overlapping of information on cadastral maps (Visnjevac, N. et al., 2018). However, both cadastres use different semantics, software, data storage etc. resulting in a lack of interoperability and slow information processing. Research has been done in developing a country based LADM profile that will be extended with utility network elements to create a unified data model for both cadastres, solving the lack of interoperability (Radulovic, A. et al., 2019). A 3D cadastre has also been proposed in which the two cadastres can be integrated to one system, and where, due to the three-dimensional aspect, the overlapping of information would not be a problem to visualise (Visnjevac, N. et al., 2018).

2.3 Standardised data models for underground infrastructure objects

There are several types of data models used to standardise the modelling of underground objects. The INSPIRE utility networks is the European application schema for utility networks where the focus lies on defining a 2D topological relationship between the network elements. The information model for cables and pipes (in Dutch: Informatiemodel Kabels en Leidingen, IMKL) is a Dutch data model for all types of utilities where each utility network is described by the location and the topology of the network elements (Den Duijn, 2018). Another data model is MUDDI, the Model for Underground Data and Integration. MUDDI consists of a standard part for the geometry of underground objects, where other modules can be connected to for specific use cases or for interoperability with other data models (Lieberman et al., 2020). In the next section however, the most common data models, LADM, CityGML and IFC will be discussed as well as the integration between these models.

2.3.1 ISO 19152:2012 LADM

The Land Administration Domain Model (LADM) is a conceptual data model and ISO standard (ISO 19152:2012) offering a core structure and vocabulary to be used as fundamental of any Land Administration System, which can be extended with classes and attributes that are specific to each country (ISO, 2012; Lemmen et al., 2015). The LADM covers all basic aspects of land administration including those over water and land, and elements above and below the surface of the earth. These aspects concern the Rights, Restrictions and Responsibilities (RRRs), but also all the legal, administrative and spatial information. The LADM consists of three main packages: party; administrative and spatial, as well as a subpackage of surveying and representations.

Currently, the revision of its first edition is ongoing in order to improve and refine the modelling of the land and property rights, as well as to widen the scope of the standard (Lemmen et al., 2019). An important aspect of this revision is that first, the definition of land administration will change to: "*Land administration is the process of determining, recording and disseminating information about relationships between people and land - informal, customary and formal use and property rights - and about value and use of land*." (Lemmen et al., 2020). What is more, the following aspects are included in the revision: (1) the extension of the scope, (2) the improvement and refinement of the current conceptual model, the (3) the inclusion of technical models and (4) the integration of processes(Lemmen et al., 2019; 2020). The scope will be extended by, among other things, adding more information related to the valuation domain through a Valuation Package, facilitating the link between the legal and physical objects and increasing the support for different types of legal spaces, (i.s. utilities). Indicatively, the improvement of the conceptual model of the LADM Edition I will

be through the enrichment of the semantics of LADM codeLists and by extending the survey model to support multiple surveying techniques. Some of the technical models that will be included in the revised version of LADM are: BIM/IFC, CityGML and InfraGML. Processes that will be integrated in the new model will deal with the updating of maps and the survey procedures. Next to this, there will also be a methodology incorporated to develop LADM country profiles (Lemmen et al., 2019; 2020).
The revised LADM will consist of six parts: (1) Land Administration Fundamentals, (2) Land Registration, (3) Marine Space, (4) Land Valuation, (5) Spatial Planning and (6) Implementations. Part 1 (Land Administration Fundamentals) and part 2 (Land Registration) will integrate the ISO 19152:2012 LADM standard, making the revised version backwards compatible (Lemmen et al., 2019; 2020). It is expected that the new edition of the LADM will be ready and published in 2022 (Kalogianni et al., 2020a).

2.3.2 CityGML

CityGML is an open data model and XML encoded schema used for the storing and exchange of 3D city models. CityGML describes the geometry and attributes of typical 3D objects in cities, for example, buildings, roads, tunnels, as well as the relations between these objects.
The Application Domain Extensions (ADEs) of CityGML are extensions which can be used to adjust the model to fit certain use cases. The Utility Network ADE is used to store data on the geometry of the utilities and the relations between them (Biljecki et al., 2021). Although CityGML is able to store the geometry of underground objects, for example, tunnels and utility networks, through the standard modules and ADEs, the models are less detailed compared to BIM/IFC models, which can be necessary for registering legal information (Arroyo Ohori et al., 2018) .
Due to a need for better usability and interoperability with other standards, CityGML is being updated. CityGML 3.0 is composed of a conceptual model and an encoding specification. The same modules used in CityGML 2.0 are part of 3.0, although some of them have been revised. New modules have been introduced, for instance, the Construction module that incorporates the classes present in the Building, Bridges and Tunnel module. CityGML 3.0 is based on several ISO standards which allows for it to automatically obtain application schema's from the conceptual data model, thereby following a model-driven approach. The conceptual model of CityGML 3.0 has already been finished, while the encoding specification has not (Kutzner et al., 2020).

2.3.3 BIM / IFC

A Building Information Model (BIM) is a model where information on buildings and other (infra)structures is created, stored and maintained for the design, construction, operation and other processes and applications (Kalogianni et al., 2020a). The Industry Foundation Classes (IFC) are an ISO standard (ISO 16739-1:2018) for BIM data and developed to stimulate interoperability in the construction industry. IFC contains requirements for data applied to buildings throughout their life cycle. The ISO 16739-1:2018 IFC standard is encoded in the EXPRESS and XML schema's and consists of many classes to store and exchange data of buildings (ISO, 2018; Atazadeh et al., 2019). Due to the increased use of BIM, explained by the advantages of a reduction in cost and better management of buildings throughout their life cycle, more BIM/IFC files are produced. These IFC files made during the design phase of constructing a building or other structures could be reused for land administration purposes, since they contain geometrical and other data that is necessary for registering property rights. If the IFC files were to be shared throughout the building lifecycle among all stakeholders of the AECOO community, then this would lead to a reduction in costs, higher efficiency and better decision-making (Kalogianni et al., 2020b). The current version of the IFC is 4.0, while the next version, IFC 4.3, is under development. The motivation for this update was to improve the representation of infrastructure objects (buildingSMART, (n.d)a).

3. RESEARCH METHODOLOGY

In order to search for information with regards to the modelling of legal spaces of 3D underground objects in 3D Land Administration Systems (LASs), a literature review was performed. With the knowledge gained from this review, requirements for a standardised workflow to model the legal spaces of 3D underground objects, were defined.

Articles were retrieved by conducting an online search through relevant journals (e.g. International Journal of Geo-Information), educational and research repositories (e.g. TU Delft Education and Research repository).

The articles were selected by assessing their relevance to this research. Important aspects here to consider were: (1) the enrichment of BIM/IFC models of underground objects with legal information according to LADM, (2) the storage of the legal and physical data of underground objects in a 3D database and (3) the visualisation of the whole integrated model. The first selection of the articles was done based on the titles and abstracts. Then, after reviewing the full-text versions of the selected articles, those with the highest relevance were selected for further use. The references of these articles were also evaluated and if articles were deemed to be relevant, then these articles were also included.

4. RESULTS

The modelling of 3D underground legal spaces in 3D Land Administrations Systems (LASs) can be done through the execution of the workflow presented in this section and is based on earlier research by Oldfield et al., 2017, Atazadeh et al., 2018, 2019, Cemellini, 2018 and Meulmeester, 2019. An overview of the workflow is shown in figure 3. The workflow consists of three phases: (1) conceptual modelling, (2) physical modelling and (3) visualisation.

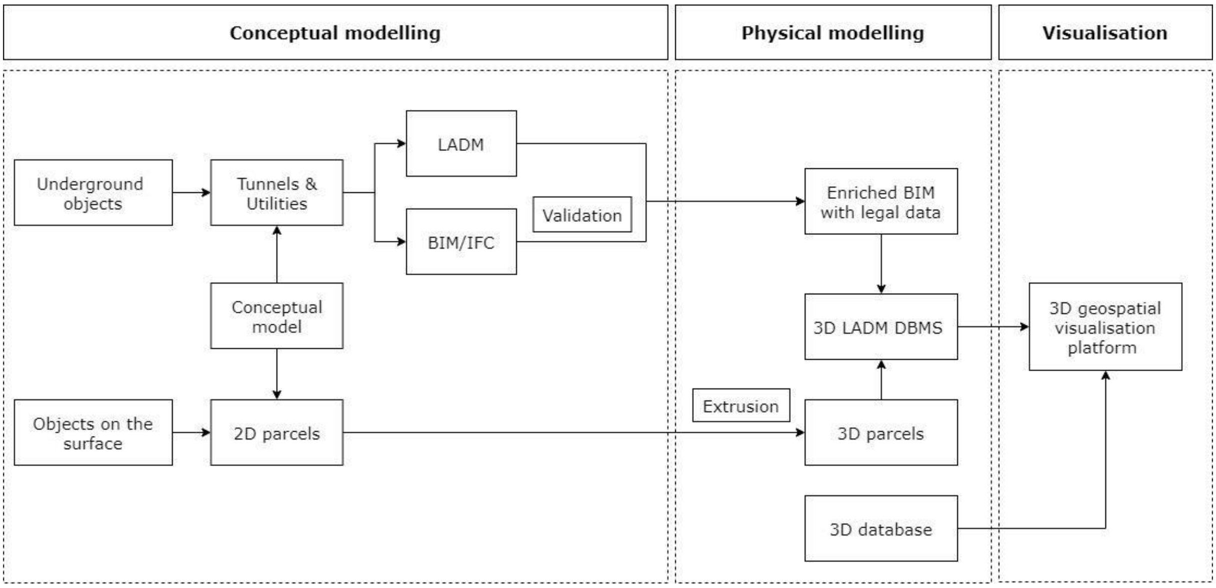

Figure 3. Overview of the workflow

4.1 Conceptual modelling

A UML model describing the relations between the underground objects, for example, tunnels and utilities and the 2D parcels is first created.
Then, BIM/IFC models of the underground objects are collected, investigated and validated. The validation of the BIM/IFC models can be done in three steps. The first step is to assess if the model complies with the IFC schema. The second step is to evaluate the BIM/IFC models according to criteria from the guidelines provided by governments (Meulmeester, 2019). Registering legal information in a cadastre requires the use of geographical coordinates. The third step is thus inspecting if *IfcSite* has (the correct) values of RefElevation, RefLatitude and RefLongitude. The parcels (2D or 3D) of which the relations to the 3D underground objects are modelled are to be retrieved from the cadastre.
After validating the BIM/IFC models, the LADM classes are mapped to the IFC elements in order to enrich the BIM/IFC models. Several types of IFC elements are selected to store the legal information of spatial units, of which *IfcSpace* is the most important (Oldfield et al., 2017; Meulmeester, 2019). *IfcSpace* is *"a space that represents an area or volume bounded actually or theoretically. Spaces are areas or volumes that provide for certain functions within a building."* (buildingSMART, (n.d)b). This property makes it possible for *IfcSpace* to store the legal information, although attributes do need to be added with the use of *IfcLabel* (Atazadeh et al., 2018). The same legal spaces can be grouped into one zone, defined by the IFC element *IfcZone* (Atazadeh et al., 2019).

4.2 Physical modelling

The relational database management system (DBMS) PostgreSQL is set up and extended with the spatial extension PostGIS, resulting in a spatial DBMS. In this DBMS the 3D parcels and the enriched BIM/IFC model will be stored.
If the objects above the surface are stored as 2D objects in the parcels then these objects first need to be extruded to 3D with the use of the data integration platform FME.

The enriched BIM/IFC models are stored in the DBMS in two tables, one for the legal model with the legal information according to the LADM and one for the physical model with the BIM/IFC data.
Another 3D DBMS can also be set up to contain a (local) Digital Terrain Model (DTM) since these are more accurate than the global terrain models that are used or a 3D city model to be used as a reference.

4.3 Visualisation

CesiumJS, a 3D geospatial visualisation platform is used for visualising the whole integrated model. 3D geospatial visualisation platforms often do not visualise the underground surface well. There are three solutions to overcome this challenge: (1) performing a ground-push, where a rectangle pushes an area of land down in order to visualise what is below, (2) creating a fake surface above the ground by copying the terrain and placing it higher than the ground surface, making it able to see what is below, and (3) making the terrain transparent to see the underground (Cemellini, 2018). The most recent releases of CesiumJS should be able to visualise the underground surface, although this is not verified by the authors of this paper.

5. DISCUSSION AND CONCLUSIONS

This paper is about initiating a discussion on the registration of 3D underground objects on 3D LAS by reusing information from previous stages of the Spatial Development Lifecycle.
Defining the ownership of underground objects has become more important due to an increase in development of underground space and multi-level properties. These developments have made it necessary to model the legal spaces of 3D underground objects in a standardised manner in a LAS. A comprehensive standardised workflow is presented in this paper that provides the user with a general framework on how to model the legal spaces of 3D underground objects in a 3D LAS, where the adherence to the BIM/IFC and LADM standards enhances interoperability, increases efficiency and reduces costs.

The upcoming revisions of the LADM and IFC standards were not taken into consideration in developing this workflow. It is thus not clear if the workflow can also be applied to revisions of the LADM and IFC standards. In order to optimally use the workflow BIM/IFC models of underground objects are needed. Although more existing underground surfaces and objects are being surveyed and mapped, most of them are not. Obtaining BIM/IFC models of existing underground objects can be challenging.

This research is a literature review and provides information and a workflow on the modelling of legal spaces of 3D underground objects in a 3D LAS. There are however no use cases provided and analysed due to a lack of adequate BIM/IFC models of underground objects, making it not possible to validate the workflow.

This workflow is an initial attempt at developing a standardised manner to model the legal spaces of 3D underground objects in 3D LAS. To further developing and improving the workflow, more research can be done by:

- validating the standardised workflow with use cases of BIM/IFC models of underground objects
- investigating the option to include data formats of 3D underground objects other than BIM/IFC in the workflow
- investigating and improving methods to convert other data formats to BIM/IFC
- assessing the impact of the revisions of the LADM and IFC standards on the workflow
- investigating how the workflow can be adapted in order to comply with the revisions of the LADM and IFC standards

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BIOGRAPHICAL NOTES

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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' group at the Digital Technologies Section, Department Architectural Engineering and Technology, 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'. He is co-editor of the International Standard for the Land Administration Domain, ISO 19152.

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BIM Models as Input for 3D Land Administration Systems for Apartment Registration

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Key words: 3D Land Administration System, Building Information Model, Industry Foundation Classes, Land Administration Domain Model, Rights, Restrictions and Responsibilities

SUMMARY

The growth of cities and the pressure on land worldwide leads to more complex and multilevel structures with different space interrelations. For the registration of complex spaces mostly 2D Land Administration Systems (LAS) are used, while a representation of space in 3D could provide a clearer insight. Concurrently, technological advancements rapidly improve methods to collect, create, visualise, register, store and disseminate 3D data. In this context, much research is now being carried out at the sources and data used as input in 3D LAS and the various methods for their collection. In this scene, the approach to reuse data from the design phase is gaining ground. Specifically existing Building Information Models (BIMs), usually encoded in the non-proprietary Industry Foundation Classes (IFC) format (EN ISO 16739:2018) are considered a promising source for 3D LAS.

Previous research has shown promising results using BIMs as input for 3D LAS. However, the use of BIM/IFC-models from practice has not yet been tested adequately. This paper investigates the technical issues that are encountered when using real-world BIM/IFC-models as input for the registration of apartment rights in a 3D LAS and how that process can be improved. In the context of this paper, BIM/IFC-models are iteratively being validating against technical requirements. Five real-world BIM/IFC-models are collected. They are tested on the existence of IfcSpace, geometric validity, overlap and the ability to georeference the BIM/IFC-models.

The results of these validation show that the collected BIM/IFC-models lack the ability to be georeferenced. Additionally most BIM/IFC-models did not contain IFCSpace, or reference to essential attributes for identifying legal units in the Dutch 3D LAS. Recommendations and guidelines are formulated to address these issues. The BIM/IFC-models are placed in a 3D LAS at conceptual level, in which the legal spaces are enriched with information of the Rights, Restrictions and Responsibilities (RRR's) to those spaces in line with the LADM.

BIM Models as Input for 3D Land Administration Systems for Apartment Registration

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1. INTRODUCTION

The growth of cities and the pressure on land worldwide leads to more complex and multilevel structures with different space interrelations. For the registration of complex spaces mostly 2D Land Administration Systems (LAS) are used, while land administration is challenged by an unprecedented demand to utilise space above and below earth's surface. The relationships between people and land in vertical space can no longer be unambiguously represented in 2D, while a representation of space in 3D could provide a clearer insight. Concurrently, technological advancements rapidly improve methods to collect, create, visualise, register, store and disseminate 3D data.

In this context, much research is now being carried out at the sources and data used as input in 3D LAS and the various methods for their collection. In this scene, the approach to reuse data from the design phase is gaining ground. Specifically existing Building Information Models (BIMs), usually encoded in the non-proprietary Industry Foundation Classes (IFC) format (EN ISO 16739:2018) are considered a promising source for 3D LAS. BIM is widely recognised as a common data environment for 3D lifecycle management of buildings. The IFC format (ISO 16739-1:2018) and the ISO 19152 Land Administration Domain Model (LADM - ISO 19152:2012) both are international open standards that have a significant impact in their own domain. Reusing existing models is cost-effective and in line with the Spatial Development Lifecycle (Kalogianni et al., 2020a). Previous research has shown promising results using BIMs as input for 3D LAS (Andrianesi & Dimopoulou, 2020; Meulmeester, 2019; Oldfield et al., 2017). However, the use of BIM/IFC-models from practice has not yet been tested adequately, as there are various aspects that need to be addressed.

This paper investigates the technical issues that are encountered when using real-world BIM/IFC-models as input for the registration of apartment rights in a 3D LAS and how that process can be improved. In the context of this paper, BIM/IFC-models are iteratively being validating against technical requirements and placed in a 3D LAS at conceptual level, in which the legal spaces are enriched with information of the Rights, Restrictions and Responsibilities (RRR's) to those spaces in line with the LADM.

2. BACKGROUND

Land administration consists of land registration and cadastres, where the former concerns the registration of Rights, Restrictions and/or Responsibilities (RRR) of land, whereas cadastres register and map parcels. Concurrently land registration is defined as "*the process of recording legally recognized interests [...] in land*" and a cadastre is defined as "*an official* *record of information about land parcels, including details of their bounds, tenure, use, and value*" (Zevenbergen, 2002). A Land Administration System (LAS) is the combination of both land administration and land registration: a system that both measures the parcels of land and registers the relation in terms of RRR's of parties to the land. LAS is the definition that will be used since the proposed 3D LAS consists of both the registration of RRR's as well as the 3D representation of parcels. The growth of cities and concurrently complex 3D properties, as well as technological developments, have led to an interest and research of 3D LAS the past two decades (Dimopoulou & van Oosterom, 2019). The following sections describe the background of this research and give an overview of current rights in the Dutch LAS (2.1), BIM/IFC models (2.2) and the LADM (2.3).

2.1 The Dutch LAS "Het Kadaster"

The Dutch LAS, "het Kadaster", consists of both land registration and a cadastre. Formally the Dutch LAS is tasked to acquire, geometrically register, maintain and cartographically visualise public registries. The Dutch LAS has different RRR's which can be registered. First the right of ownership (eigendomsrecht). This ownership includes in theory not only the land itself, but also the space upwards and downwards from the parcel according to the principle of the rule of accession (superficies solo cedit). Next to complete ownership, there are forms of limited ownership rights. The right of superficies (opstalrecht) allows to own or place immovable property in, on, or under property of another party. The right of long lease (erfpacht) is a right to use the land, i.e. a municipality provides long lease to a party, which owns the building on the land, in exchange for a one time or reoccuring fee. The right of easement (erfdienstbaarheid) is a right of which the owner has the responsibility to allow access to his land to serve another party. The apartment right (appartementsrecht) is a right to part of a split parcel. This right is used for multi-level apartments. Since 2D parcels do not define exclusive ownership of apartments, the ownership of a residence in an apartment building is required to have the boundaries of properties in a deed of division (splitsingsakte), part of this deed is a 2D drawing with a graphical representation of the boundaries (Figure 1; Stoter et al., 2013).

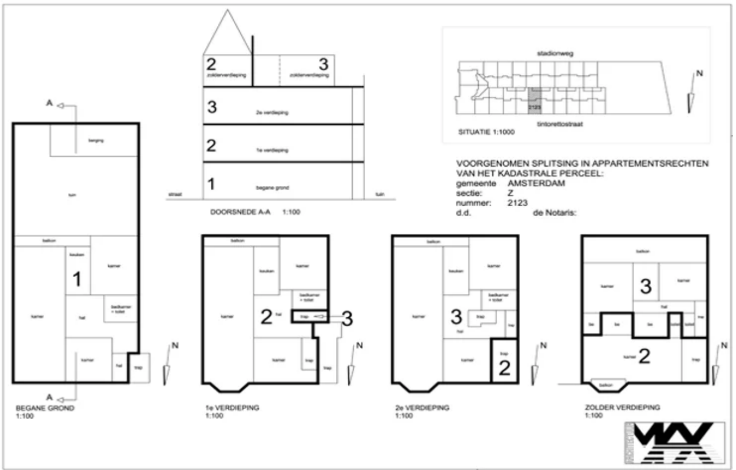

Figure 1: A splitsingstekening (division drawing) (Max Architectuur BV, 2021)

Even though rights are not registered in 3D, some of the limited rights allow for a division of rights in 3D situations. The apartment right being the most apparent, as it deals with vertical split property. Next to the apartment right, the principles of vertical and horizontal accession (vertikale en horizontale natrekking) apply in the Dutch LAS. This principle defines the ownership of a property when it is part of, and cannot be divided, even though it may be on, go over or under the ownership of someone else. Examples of horizontal and vertical accession are tunnels, bridges and underground infrastructure.

The representation of parcels in 2D maps in case of multi-level property which overlap, is handled by dividing the map into multiple parcels. For each parcel the multiple rights are represented. This representation might be clear for the people who are involved in registering the property, however it is hard for people who are not familiar with the real-life situation to interpret these maps. An example of a complex 3D situation represented on a 2D map is the Unilever building as shown in (Figure 2).

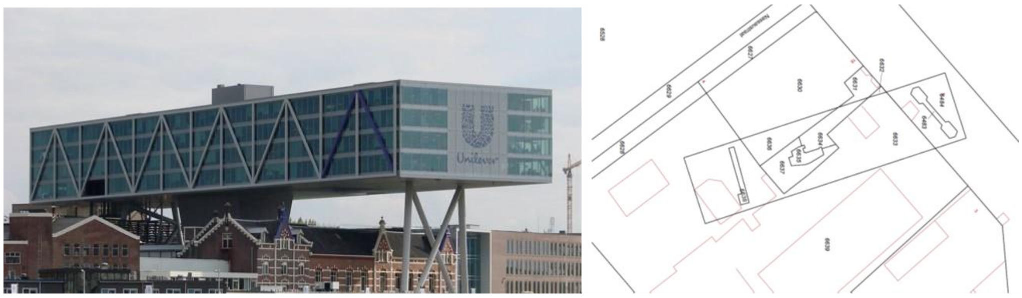

Figure 2: The Unilever building and its representation on a 2D parcel map (Stoter et. al, 2013)

In the Netherlands, research has been conducted on the possible layout of a LAS in which 3D representations can be incorporated. Stoter et al. (2016) implicated a 3D model of the train station in Delft to be registered in the Dutch LAS. A 3D pdf is added as a division drawing, instead of a 2D drawing. The 3D representation is added in the existing LAS and legal framework. The use of a 3D representation allowed for a better presentation of a 3D complex situation, however, the 3D representation cannot be linked to surrounding parcels. Cemellini (2018) developed a system architecture prototype for a 3D LAS, which focused on 3D data storage, dissemination and visualisation through a web-viewer. It is extended by Meulmeester (2019), who researched the possibility of BIM/IFC models as input in a 3D LAS, enriched with legal information required by the Dutch LAS. However this has not been tested with real-world BIM/IFC-models.

2.2 BIM/IFC models

The concept of BIM is about storing and maintaining data in the form of a 3D model through the entire lifecycle of a building. For this purpose BIM models contain both 3D spatial information (geometry), as well as semantic information about the building (Kalogianni et al., 2020a). It fits with the principle of Life Cycle Thinking (LCT), which focuses on the collaboration between parties and the reuse of sources. The collaboration of different parties in the design stage of a BIM can prevent building mistakes by using clash detection, hence combining models of different disciplines and notice if there are overlaps between objects which cannot exist in real-life. Detecting these clashes in the design phase prevents the costs that occur when these mistakes would be noticed in the building phase.

However the circular approach does not stop after the designing phase, BIM can also be used during maintenance, renovation and demolition. Hence BIM can be used from the design, through maintenance, through possible renovation, until the demolition phase. Concurrently there is potential in using BIM for permitting buildings, as well as register 3D spatial units with related RRR's in a LAS.

2.3 ISO 19152 Land Administration Domain Model (LADM)

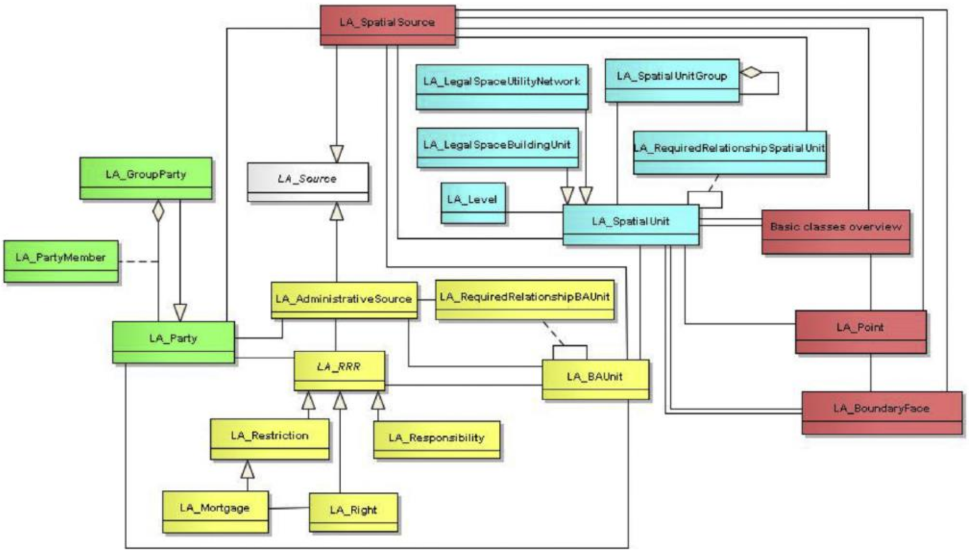

Figure 3: Land Administration Domain Model (Lemmen et. al., 2015)

The LADM is an international knowledge domain specific standard capturing the semantics of the Land Administration Domain. It provides a common, standardised, global vocabulary, ontology and semantics aiming to stimulate the development of software applications and accelerate the implementation of land administration systems that support sustainability objectives (van Oosterom & Lemmen, 2015). The LADM is a conceptual model and one of the first spatial domain standards within ISO TC211, aiming to support "*an extensible basis for efficient and effective Land Administration Systems*" (Kalogianni et al., 2020b). The LADM has a wide use and interest, with several countries investigating and/or applying LADM in their LAS (Kalogianni et al., 2018). For example Croatia (Mader et al., 2018), China (Ying et al., 2018) and Israel (Adi et al., 2018). Currently the development points for the LADM are modelling, storing, visualising, and maintaining spatial units.

Figure 3 shows the UML model of LADM, which consists of three main packages. The party package (green) consists of classes which represent a party, which can be a person or organization such as a municipality or a company. This can also be a group of parties. The administrative package (yellow) stores the RRR's to a basic administration unit (LA_BAUnit) and is linked to the parties and building units. The basic administration unit is linked to the spatial unit package (blue) which contains classes to store spatial information of the basic administration unit. This can be a verbal description, a 2D map, and also a 3D model, among others. To support the spatial unit package for storing geographical information, the representation and survey package (red) contain classes to store surveying and other geographical data.

3. METHODOLOGY

The research objective of this paper is formulated as follows: *How should BIM/IFC-models be designed to effectively be reused as input for 3D LAS?* This can be further sub-categorised to the following research sub-questions: 1. Which technical complications are encountered when using BIM/IFC-models as input for 3D LAS?; 2. Which solutions are recommended for those complications?; 3. What are the different interests and benefits of user groups when using BIM/IFC-models as input for 3D LAS? 4. Which of the technical complications are encountered when testing real-life BIM/IFC-models as input for the Dutch LAS, and how can they be resolved?

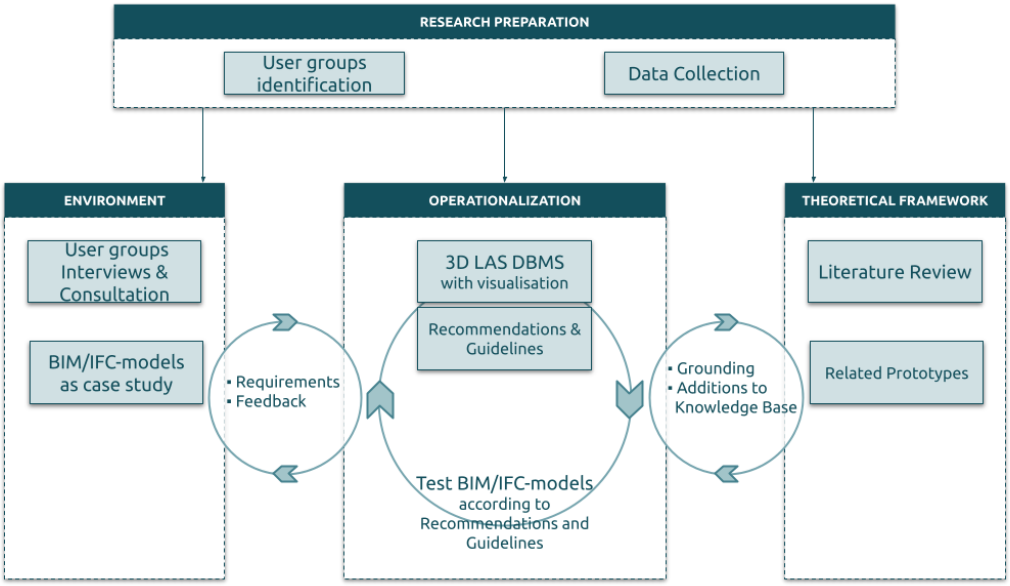

Figure 4: Methodological Steps

Based on the Design Science Research approach the following methodological steps are executed (Figure 4): First research preparation is conducted by identifying user groups and collecting real-world BIM/IFC models (3.1.1). Secondly user groups are consulted to give input for the 3D LAS DBMS and give insight in their use of BIM (3.1.2). A literature review is conducted to assess known complications and previous work on using BIM as input for 3D LAS (Chapter 2). Lastly the BIM/IFC models are validated (3.2), and a 3D LAS DBMS prototype is built (3.3).

3.1 Data Collection and user group identification

The BIM/IFC-models are collected for the purpose of this paper with the following criteria: the BIM/IFC-model concerns a building; concerns a real-world model; is located in the Netherlands; has multiple property rights. Hence, five IFC-models are obtained (Table 1).

Table1: Collected BIM/ IFC-models

Name	Supplier	Location
1. Central Park	Municipality of Utrecht	Utrecht
2. Westflank	Municipality of Utrecht	Utrecht
3. Pontsteiger	Menno Mekes	Amsterdam
4. Schependomlaan	Virtual Systems	Nijmegen
5. Central Library	Virtual Systems	Rotterdam

3.1.1 Case Studies

The Central Park and Westflank models (Figure 7) are both part of a development 'cu2030' in the station area of Utrecht. This area is an area of mixed functions as well as different owners. At its core is the Central Station of Utrecht, a large transfer hub. Next to a transport function, other functions include retail, offices, residential as well as leisure. The largest stakeholders in the area are the municipality of Utrecht, the Dutch railways (Nederlandse Spoorwegen) and Prorail, the railway manager in the Netherlands, but other parties own ground as well. The area is of interest because of the variety in function and owners, as well as the complex 3D structures that are joined with this project.

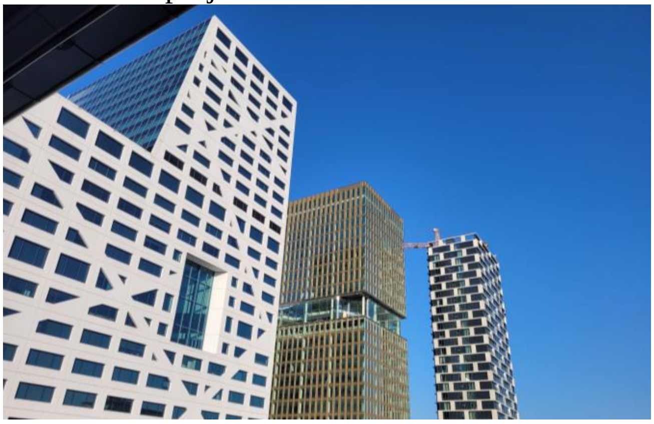

Figure 5: Central Park building (middle) under construction (own photo, 2021)

The Westflank model contains an apartment building to be built. Central Park contains offices which can be rented. A remarkable feature of this building is the park in the middle of the building, which is to be used as a shared space. The Central Park BIM/IFC-model (Figure 5) consists of an aspect model of the inside and the frontage. Other BIM/IFC-models containing stairs to the station area and a parking garage are also collected. They are included for context but are not validated in this research. The Pontsteiger building (Figure 6) has a complex geometry: it contains two towers which are connected through a bridge. It is located in Amsterdam and built in 2015. The building has multiple functions. Apartments are located in the building, as well as a hotel. The Central Library BIM/IFC-model represents the Central Library in Rotterdam. The Schependomlaan BIM/IFC-model represents an apartment building in Nijmegen.

Figure 6: Pontsteiger building (wikimedia creative commons)

3.1.2 User groups

The expected users of a 3D LAS include the public, land registries, land surveyors, notaries, AEC industry, urban planners, local government, real estate agents, contractors, banks, valuators, engineers who issue permits and architects among others (Kalogianni et al., 2020a). Experience from practice is discussed with the architect of the Pontsteiger and an employee of the municipality of Utrecht who is contributing to a digital twin of the municipality of Utrecht.

The architect experiences hurdles in the reuse of BIM/IFC-models leading to data loss after the building was built. For example a BIM is supplied to a municipality or other organization, but the workflow of that organization is based on 2D data. Concurrently, the BIM is transposed to 2D data, and the original 3D data is not maintained. The architect stated that in his work field 3D models of surrounding buildings are often used in the designing phase of new buildings, especially when designing high-rise in urban environments. Windflow and sun studies are made, and these could benefit from the use of accurate 3D models.

Figure 7: The Westflank (left) and Central Park (right) BIM

The employee of the municipality of Utrecht mentions that even though he sees an added value of adding BIM/IFC models to the digital twin, a conversion is required to simplify the model. This is needed to decrease the file size, but also to reduce the level of detail, as the level of detail in BIM/IFC-models is often not wanted for a digital twin. However conversion, i.e. simplifying BIM/IFC-models is time-consuming, as hardly any model is built the same and thus requires manual labour to adjust to make the model suitable for a digital twin. Hence he would benefit from designers adhering to standards to be able to automate the process of simplifying BIM/IFC-models for input in a digital twin.

3.2 Data Validation

Important technical requirements based on the literature review include:

- The availability of uniquely identifiable volumes, including the representation of rooms as IfcSpace, to define legal units which can be linked to the RRR's of the legal unit (3.2.1).
- The geometries to be valid (3.2.2).
- The IfcSpace volumes to contain no overlaps or gaps, as spaces should be mutually exclusive (3.2.3).
- The ability to georeference the BIM/IFC-model, as the geographic location of a building is necessary in the context of a LAS (Cemellini, 2018; 3.2.4).

3.2.1 Legal spaces

The BIM/IFC-model contains uniquely identifiable IfcSpace entities which represent rooms. These rooms can be grouped to form a unit, this definition is stored in the BIM/IFC-model. Rooms can be defined in BIM/IFC-models as IfcSpace, yet IfcSpace is not always included in a model. The first step in the validation of legal spaces is to check if IfcSpace entities are present. The outcome does not inform whether the IfcSpace is a complete set of all rooms. This is validated through the overlap/gap analysis (3.2.3). Concurrently, the IfcSpaces are uniquely identifiable so that they can be linked to legal building units, additionally they can be grouped into legal units, i.e. an apartment which consists of multiple rooms. The former is checked by validating the existence of a IfcGloballyUniqueId (GlobalId). For the grouping of rooms there are no mandated standards. Meulmeester (2019) proposed the addition of a propertyset to IfcSpace to include the Dutch LAS indexnumbers etc., however this proposal has not been implemented in standards. Additionally groups of rooms can be defined by groups in the model, such as IfcZone. Lastly a relation between rooms can be implied by the name of spaces, i.e. spaces which belong to the same apartment have the same prefix.

Concludingly checks are made on the presence of IfcSpace and unique GlobalId's, these are integrated in a FME workspace (Appendix A). Thereafter it is validated by inspecting the BIM/IFC-model whether: IfcSpace contains a propertyset which contains attributes required by the Dutch LAS; groups of rooms are defined in the model; a relation between rooms is implied in the name of IfcSpaces.

It should be noted that next to the rooms, a legal unit contains the interior building elements, and often the exterior elements adjacent to the rooms. Current practice in the Ducth LAS do not model the boundaries, such as walls and floors, as property. The reason for this is that the graphical representation, a 2D drawing of the building, is not legally binding. Rather it is a graphical representation of the building and where the building is located. Therefore the modelling of building elements such as walls and floors is not possible for the Dutch LAS, and only the rooms are defined as legal units (Meulmeester, 2019).

If a LAS does allow building elements to be modelled as property, it should be defined in the BIM/IFC-model to which legal unit they belong. When these links are not integrated in the BIM/IFC-model, some links can be calculated by adjacency to a legal unit. Interior elements, such as walls dividing two legal units, however result in a conflict. Hence to define the ownership of building elements manual adjustments might be needed. Alattas et al. (2021) describe the process of subdividing a building with its building elements into private, common, and exclusively common spaces.

3.2.2 Valid Geometries

It was assessed whether the features of the BIM/IFC-model are compliant with OGC 1.2.0. When calculating spatial relations between objects, invalid geometries may result in errors or an incorrect calculation. Therefore the geometry of features is validated using a FME Workspace (Appendix C). Additionally a check is made for non-planar surfaces and correct orientation of surfaces. If non-planar surfaces are found they are triangulated. Incorrect oriented surfaces are realigned.

3.2.3 Spatial relations

It was assessed whether the IfcSpace volumes do not overlap. For the Dutch LAS, parcels have to be mutually exclusive. Hence overlap between parcels is not allowed. The touching of geometries is expected, as two adjacent spaces can touch on the bounding surface. Figure 8 shows possible DE-9IM relations for 3D geometries. For the Dutch LAS spaces have to be mutually exclusive, hence geometries may not equal or overlap each other, since that contradicts the premise of legal units being mutually exclusive.

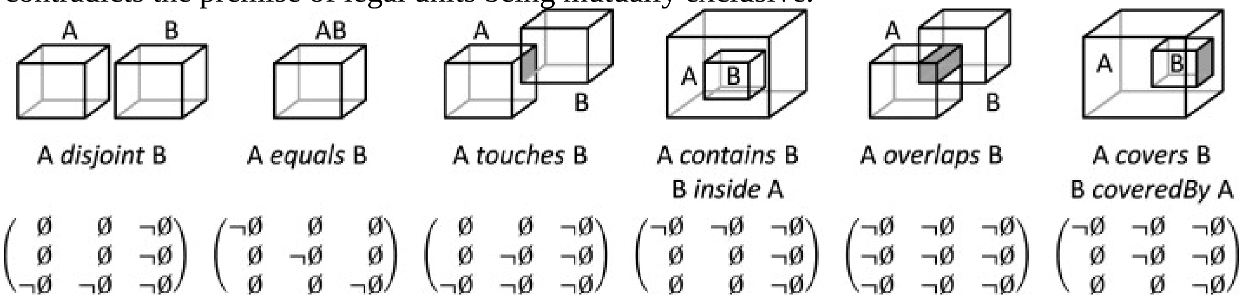

Figure 8: Eight predicates defining the possible topological relationships between two solids in 3D (Daum & Borrmann, 2014)

Defining spatial relations between 2D geometries is well integrated in the used software. FME Desktop and PostgreSQL with the extension of PostGIS have tooling to create a DE-9IM matrix which represents the spatial relation between 2 geometries. However this tooling is not yet able to deal with 3D geometries. Collection of polygons, i.e. a geometrycollection or multi-polygon, can be used as input, however the outcome still represents the 2D relations, not taking into account a Z-coordinate.

For validating whether there is overlap a method is used which utilises the ST_3Dintersection function of the SFCGAL PostgreSQL extension (Postgis, 2021). This method extracts the shared portions between 2 3D geometries. However touching surfaces are also extruded. To exclude these false positive results, surfaces (geometries with a 0 volume) are excluded and not counted as overlap. The geometries are compared to each other using a materialized view (Appendix G). The query does not utilize a spatial index, which has a negative impact on the execution time. Concurrently only geometries which have a distance of less than 10 meters are compared. The outcome of the materialized view is analyzed within FME (Appendix B).

3.2.4 Georeferencing

BIM/IFC-models are designed in local coordinate systems (LCS), rather than coordinate reference systems (CRS). Hence, to georeference a model to the correct location a transformation has to be made and stored in the model. Clemen and Görne (2019) give an overview of the different ways to store attributes, which facilitate the georeferencing a BIM/IFC-model. It should be noted that the existence of these attributes are dependent on whether or not the designer included them in the model. Additionally, the latter LoGeoRef50 is based on attributes which are introduced in IFC 4, whereas older models, including the ones validated in this research, are IFC 2x3 and do not support these attributes.

Table 2: Synthesis of LoGeoRefs as defined by Clemen and Görne (2019) Adjusted from Noardo et al., (2021)

LoGeoRef	Supported CRS	Storing Entities
LoGeoref10	No CRS, approximate location by means of the address	'IfcPostalAddress' referenced by either 'IfcSite' or 'IfcBuilding'.
LoGeoRef20	WGS84 EPSG:4326	'RefLatitude', 'RefLongitude', 'RefElevation' attribute of 'IfcSite'.
LoGeoref30	Any Cartesian CRS, including projected coordinates (CRS not specified in the file)	'IfcCartesianPoint' referenced within 'IfcSite' (defining the projected coordinates of the model reference point); 'IfcDirection' attribute of 'IfcSite'.
LoGeoref40	Any Cartesian CRS, including projected coordinates (CRS not specified in the file)	'WorldCoordinateSystem' storing the coordinates of the reference point in any Cartesian CRS and direction TrueNorth.
LoGeoref50	Specific projected CRS, specified by means of the EPSG code	IFC v.4 - Coordinates of the reference point stored in 'IfcMapConversion' using the attributes 'Eastings', 'Northings' and 'OrthogonalHeight' for global elevation. Rotation for the XY-plane stored using 'XAxisAbscissa' and 'XAxisOrdinate'. The CRS used is specified by 'IfcProjectedCRS' in the attribute 'Name' by means of the proper EPSG code.

The BIM/IFC-models are validated by investigating the existence and contents of the attributes stated by Clemens and Görne (2019; Table 2). The tool IfcGeoRef (Clemens & Görne, 2019) is integrated into the FME workspace (Appendix A), and is used to assess the georeferencing capabilities of the BIM/IFC-models. Each model it is assessed if it complies with LoGeoRef10-LoGeoRef50, and if so the contents of the attributes are exposed.

3.3 Development of prototype

The prototype consists of the validation workflow to validate the BIM/IFC-models, a PostgreSQL database which stores the BIM/IFC-models in a LADM compliant DBMS, and a Cesium webviewer. After the validation of the BIM/IFC-models, the BIM/IFC-models are put in a DBMS through an FME workspace (Appendix D). The IfcSpace entity is represented as LA_LegalSpaceBuildingUnit. For the BIM/IFC-models where a grouping of IfcSpace is present, the groups are defined as LA_BAUnit. For models where the grouping is not present, single LA_LegalSpaceBuildingUnits are also defined as LA_BAUnit. The BIM/IFC-models do not contain information about the RRR's to the legal units. For the purpose of building a prototype 3D LAS, fictitious parties and RRR's are put in the DBMS as LA_RRR and

LA_Party. The contents of the 3D LAS DBMS are converted into cesium tiles with FME Desktop (Appendix E) and uploaded to an online cesium viewer.

4. RESULTS

4.1 Results of validation

4.1.1 Legal spaces

In 2 out of 5 BIM/IFC-models IfcSpace is present (Table 3 - a). The Central Park, Westflank and Central Library model do not contain IfcSpace. Revit is used to automatically generate rooms in the BIM/IFC-models with no IfcSpace. However not every room is recognized, and some building elements such as columns, or incorrectly defined as room. The Central Park, Westflank and Central Library models contain no information required for the Dutch LAS. The Schependomlaan model contains names of rooms which imply a relation. The Ponsteiger model contains no information such as a LAS index number either, but groups are defined which represent legal units, such as ‘bnr. 100’. Concludingly the lack of IfcSpace in some models, and lack of Dutch LAS information are insufficient for placement in a Dutch LAS.

4.1.2 Valid Geometries

All geometries in the BIM/IFC-models are compliant with OGC 1.2.0. (Table 3 - b) In mainly the IfcWindow, IfcDoor and IfcBeam elements multiple non-planar surfaces and incorrect oriented geometries were detected, these are triangulated and repaired.

Table 2: Results of validation

		a) Legal Spaces					b) Valid Geometries				c) Overlaps	d) Georeferencing				
BIM/IFC-model	**IFC version**	Contains IfcSpace	Unique GlobalId's	LAS propertyset	Groups	Implied relation in name	OGC pass	Passed	Repaired	Failed	Overlaps	LoGeoRef10	LoGeoRef20	LoGeoRef30	LoGeoRef40	LoGeoRef50
1. Central Park	2x3	No	Yes	No	No	No	100%	97%	3%	> 1%	-	False	True	True	False	False
2. Westflank	2x3	No	Yes	No	No	No	100%	80%	20%	> 1%	No	True/False	True	False	False	False
3. Pontsteiger	2x3	Yes	Yes	No	Yes	Yes	100%	96%	4%	> 1%	Yes	True/False	True	False	False	False
4. Schependomlaan	2x3	Yes	Yes	No	No	Yes	100%	84%	16%	> 1%	No	True/False	True	False	False	False
5. Central Library	2x3	No	Yes	No	No	No	100%	97%	2%	1%	No	True/False	True	False	False	False

4.1.3 Spatial relations

For the Pontsteiger model, overlap is present. This is due to the grouping of spaces, in which the group of spaces is also defined as a space, which overlap with the containing spaces. In the Westflank model the 3D intersection function resulted in a collection of geometries, however none of them contained any volume, i.e. they represent surfaces, which indicates a touching relation between two adjacent geometries. No overlap is found in the Central Park of Central Library model, however none to only a few rooms are present in those models. The Schependomlaan model contained no overlap either, although it should be noted that not all IfcSpace geometries could be correctly extracted.

4.1.4 Georeferencing

An analysis is done through IfcGeoRef to assess which georeferencing attributes the BIM/IFC-models contain (Table 3 - d). LoGeoRef10 information is present in 4 out of 5 models, however in these attributes, IfcPostallAdress, incomplete or incorrect adresses are stated. All models contain Reference points according to LoGeoRef20. These include RefLatitude, RefLontitude and RefElevation which reflect a single reference point in the WGS84 (EPSG:4326) CRS. However these points do not reflect the actual location of the buildings. For example, the Ponsteiger reference point is in Canada. The Central Park, Westflank and Central Library models all contain a reference point close to, but not exactly at the real location of the building.

The Central Park model contains a reference to a cartesian point (LoGeoRef30). However, it is not clear which CRS is referenced. The remaining 4 models do not contain attributes according to LoGeoRef30. Concurrently, all models do not contain attributes concurring with LoGeoRef40, i.e. they do not contain other coordinate reference points. As expected attributes for LoGeoRef50 are missing in all models, since those attributes are incorporated in IFC 4, while all validated models are IFC 2x3.

In conclusion, none of the BIM/IFC-models contain sufficient attributes for georeferencing. Even though manually affining the BIM/IFC-models is not the optimal solution, the 5 BIM/IFC-models are placed on their approximate position by affining using a 3D Affiner in a FME workspace (Appendix B).

4.2 Prototype and its visualisation

The BIM/IFC-models are put in a DBMS. Additionally tables are created for LA_BuildingUnit, LA_RRR and LA_Party. For the visualisation of the DBMS, the contents of the DBMS are converted to a Cesium Tileset, and uploaded to a web viewer[1](Figure 9).

Figure 9: Online 3D LAS viewer

[1] http://broekhuizen.link/ces/3dlas.html, http://broekhuizen.link/ces/3dlasspace.html

5. DISCUSSION AND CONCLUSIONS

5.1 Discussion and Conclusion

For this research 5 BIM/IFC-models were collected, validated and used as input for a prototype 3D LAS. The built 3D LAS prototype includes LADM components, however LADM is not fully integrated. Furthermore the BIM/IFC-models used as input are mainly as designed BIM/IFC-models. In a 3D LAS the used BIM/IFC-models should be as-built, as this reflects the real-world situation. In the prototype 3D LAS only IfcSpace entities are modelled as legal units, as the Dutch law does not allow walls and other building elements to be included as legal units. However, with the technological developments, and further research into a 3D LAS, it should be reconsidered if building elements could be included as legal units.

Multiple technical complications are encountered as result of the validation of the BIM/IFC-models. The most important are the lack of rooms in the form of IfcSpace, the lack of identification for linking the legal units with the Dutch LAS and the lack of attributes to georeference the models. For effectively designing BIM/IFC-models to reuse as input for a 3D LAS, recommendations and guidelines are formulated as:

- Rooms have to be included in the BIM/IFC-model as IfcSpace
- IfcSpace should contain a propertyset which include the apartment index number, cadastral parcel number, complex number, space type and municipality.
- Concurrently IfcSpace can be grouped, but these groups should not be included as a (duplicate) IfsSpace volume.
- Attributes for georeferencing should be included in the BIM/IFC-model. It is recommended that IFC4 files with attributes for georeferencing are preferred above the IFC2x3 files. For existing IFC 2x3 models it is necessary to enrich the IFC files with attributes complying to LoGeoRef30 and/or LeGeoRef40 (Table 2).

5.2 Future Work

For this research 5 BIM/IFC-models were collected. A larger dataset of more BIM/IFC-models, with a wider variety in designers, would give a better insight in the ability of real-world BIM/IFC-models as input for 3D LAS. The availability of open BIM/IFCmodels however is low, it should be assessed which incentives can be used for designers to share their BIM/IFC-models for research. Concurrently BIM/IFC-models of other countries could also be tested against the used validations.

All collected models are IFC 2 x 3, which have known issues with georeferencing. For the validation FME Desktop and PostgreSQL were used. Spatial relations are defined by executing an intersection function. A DE-9IM matrix could give better insight in spatial relations, and also define the type of relation. It should be further assessed which software tools allow for this analysis. In addition, for 3D LAS boundaries, and the direction of boundaries are important. Future research could focus on the validation of topology and boundaries.

The focus of this research was on the technical challenges that arise when using BIM/IFC-models as input for 3D LAS. However to implement the given recommendations and guidelines legal and organizational challenges should be addressed. A legal mandate, combined with standards, have the possibility to direct user groups when designing and exchanging BIM/IFC-models.

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BIOGRAPHICAL NOTES

Marjan Broekhuizen is a MSc student in Geographical Information Management and Applications, a joint masters programme of the Delft University of Technology and three other Dutch universities. She is currently working on her Thesis under guidance of Eftychia Kalogianni and Peter van Oosterom, the research topic being 'BIM/IFC files as input for 3D Land Administration Systems'. The contents in this paper are based on this Thesis research. She works at a consulting company as a GEO-ICT consultant, focusing on the development of applications with FME.

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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' group at the Digital Technologies Section, Department Architectural Engineering and Technology, 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'. He is co-editor of the International Standard for the Land Administration Domain, ISO 19152.

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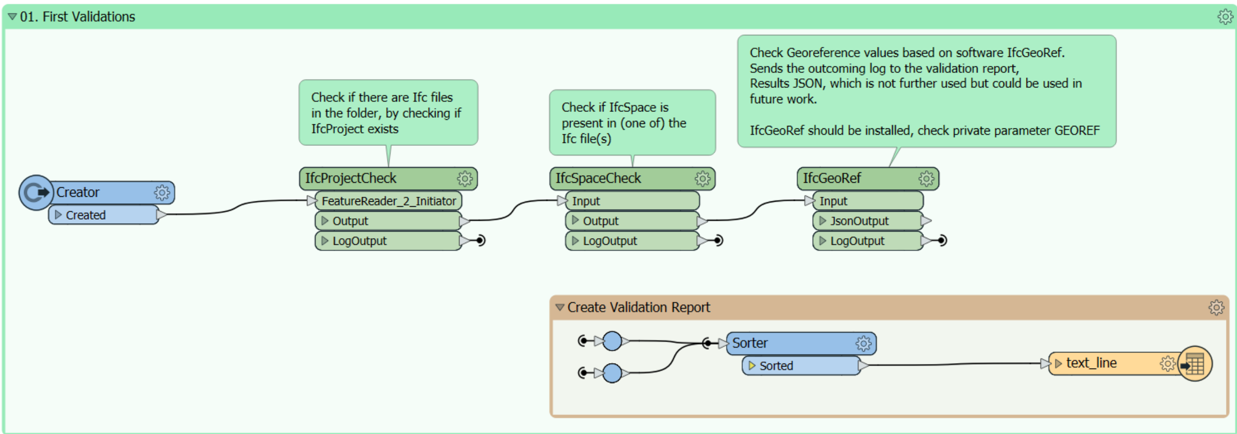
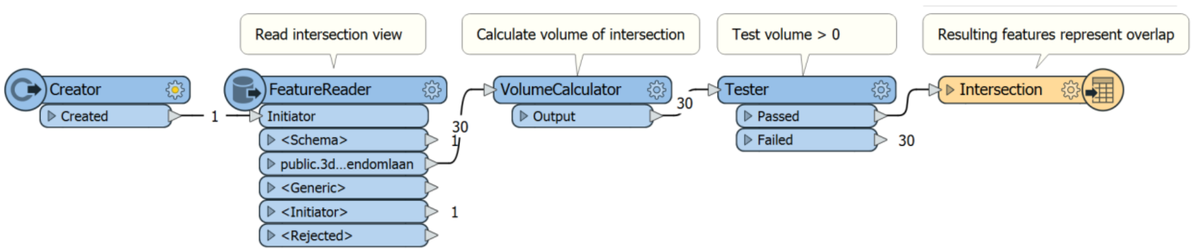
APENDICES

The FME workspaces, PostgreSQL dll, HTML-code and Cesium.js code are available at: https://github.com/superjumpylion/BIMIFCto3DLAS

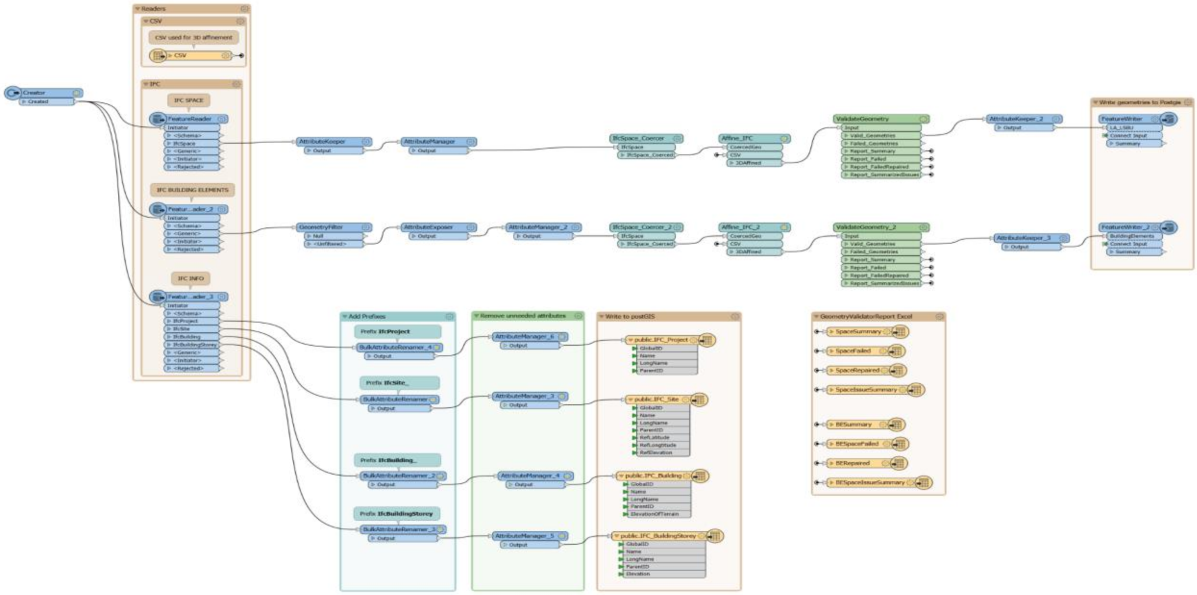
A - 1_IFCspaceAndGeoRefCheck - Validates if IfcSpace is present and generates a IfcGeoRef report containing information about georeferencing capabilities.



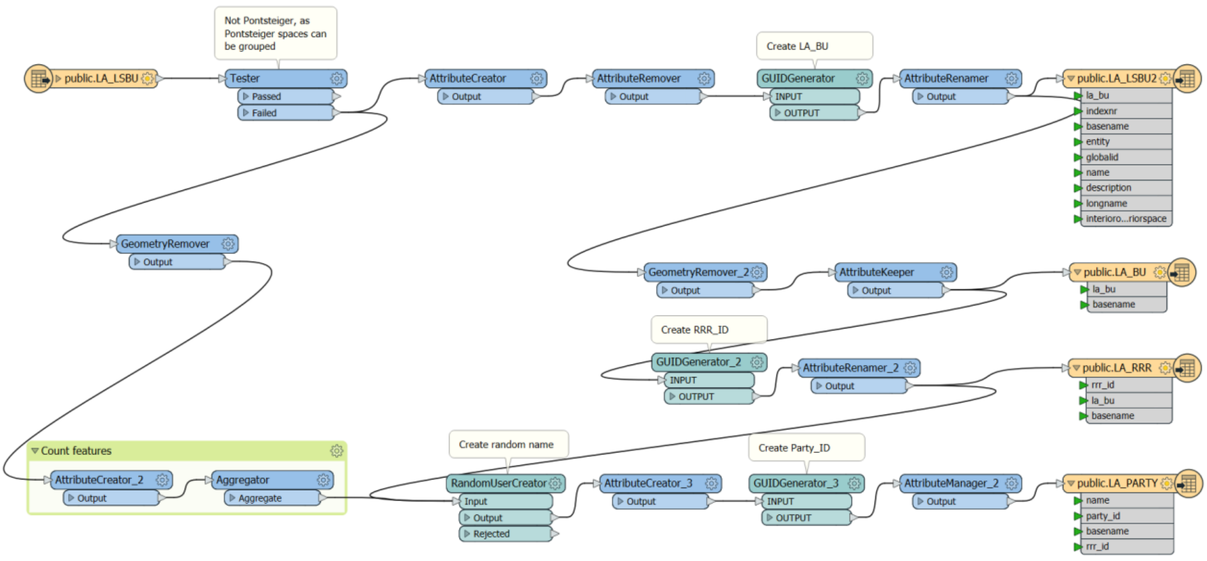
B - 3_Intersection - Reads the 3D intersection view from the DBMS, calculates volumes and results volumes > 0 as overlap.



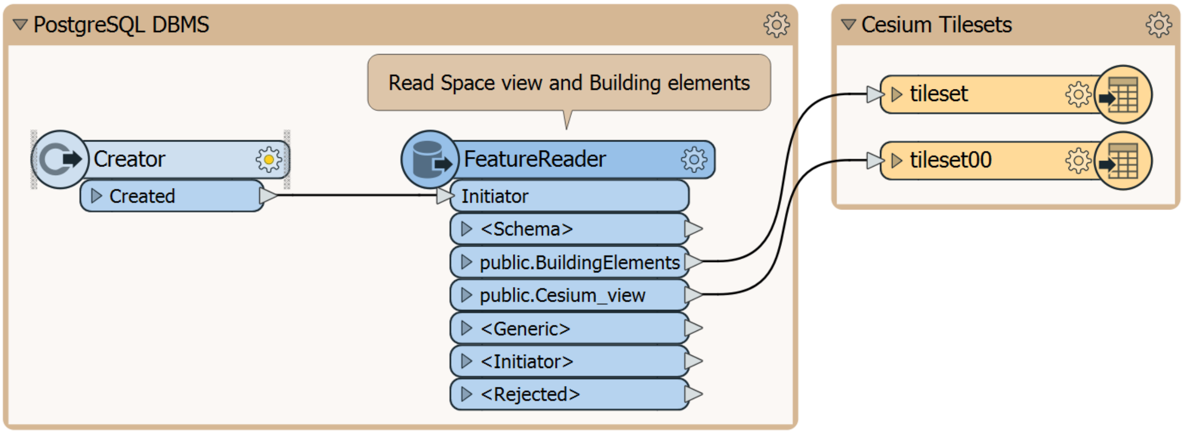
C - 2_BIMIFCtoDBMS - Coerces geometry, validates geometry, and inputs valid geometries in DBMS



D - 4_FictiveLADMa - Reads LA_LegalSpaceBuildingUnits and generate fictive parties and relations



E - 5_DBMStoCesiumtiles - Read Cesium_View from DBMS and write to Cesium Tiles



F - Adresses to find the BIM/IFC models in the viewer

1. Central Park - 5.104487, 6.112662 (this model was not affined correctly)
2. Westflank - Soerabayastraat, Utrecht, Netherlands
3. Pontsteiger - Pontsteiger, Amsterdam, Netherlands
4. Schependomlaan - Houtlaan, Leusden, Netherlands
5. Central Library - Centrale Bibliotheek, Rotterdam, Netherlands

G - 3D intersection query

```
SELECT concat(t1.globalid, t2.globalid) AS id_comb,
   t1.globalid AS gid_1,
   t2.globalid AS gid_2,
   t1.basename,
   st_3dintersection(t1.geom, t2.geom) AS intersectgeom
FROM "LA_LSBU" t1
   CROSS JOIN "LA_LSBU" t2
WHERE t1.globalid <> t2.globalid
  AND t1.basename::text = t2.basename::text
  AND st_3ddistance(t1.geom, t2.geom) < 10::double precision
  AND geometrytype(t1.geom) IS NOT NULL
  AND geometrytype(t2.geom) IS NOT NULL
```

Linking LADM with BIM/IFC standards for mobile-based 3D Crowdsourced Cadastral Surveys

Maria GKELI and Chryssy POTSIOU, Greece

Key words: Crowdsourcing, 3D Cadastre, BIM, IFC, LADM

SUMMARY

The ongoing urbanization has led to the emergence of several complex constructions and multi-dimensional property rights. Traditional cadastral procedures cannot meet the demands of this new reality, leading to increased costs and long delays. Exploiting the capabilities of the latest technologies, mobile services (m-services), Building Information Models (BIMs), open-source software (OSS) and the international standard of Land Administration Domain Model (LADM ISO 19152), the development of a reliable, qualitative and affordable solution for the implementation of 3D Cadastres, is feasible. The utilization of crowdsourcing techniques for the implementation of fit-for-purpose 3D cadastral surveys, utilizing the currently available 2D geospatial infrastructure, has already been proved to provide qualitative results. Integrating BIM data with cadastral information derived from crowdsourcing techniques, may significantly speed up the implementation of 3D Cadastres, providing a better visual understanding of 3D property rights. In this paper a LADM-based technical solution for the initial acquisition, registration and representation of 3D crowdsourced cadastral data (re-)using existing BIM and m-services, is developed and presented. A practical experiment is conducted for a multi-storey building in an urban area of Athens, Greece. The main conclusions refer to the usability, the perspectives and the reliability of the proposed framework, are discussed and presented.

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1. INTRODUCTION

As the phenomenon of rapid urbanization is growing during the years, it is estimated that by 2050 the two-thirds of the population will be living in cities (United Nations, 2018). This exerts great pressure on the existing urban structures and land uses, forcing the 3D spaces in cities to be optimized into multiple individual property units, with legal and physical subdivisions in both vertical and horizontal dimensions. Buildings with several uses referred to the same building footprint, may present a complex equation of overlapping interests, which must be properly managed. Current 2-Dimensional (2D) Land Administration Systems (LASs) are still based on 2D drawings not being able to cope with this new complex stratified reality. Incorrect registrations, mistaken declarations, misunderstandings and multiple disputes concerning these property rights, are only some of the consequences of the poor management of the increasing multidimensional property rights.

To get closer to resolving these issues a 3D LAS is needed in order to provide Accurate, Assured and Authoritative (AAA) information about the multi-dimensional property Rights, Restrictions and Responsibilities (RRR). With the advent of 3D Cadastres, 3D property RRRs of stratified objects may be described in detail, creating a secure and transparent framework for more effective management and use of 3D space. During the past few years, several 3D Cadastre attempts have been initiated worldwide, including a wide variety of potential solutions and important findings, regarding subdomains such as the data type, data modelling, system architecture and visualization (Vandysheva et al. 2011a,b; Stoter et al. 2012; Stoter et al. 2016). With the emerge of the international standard of Land Administration Domain Model (LADM ISO 19152) in 2012, researchers interest focusing in linking the legal and physical parts of 3D cadastral objects, utilizing several technologies, application schemas and technical models such as CityGML, IndoorGML, BIM/IFC, LandXML, InfraGML, etc. (Thompson et al., 2016; Kitsakis et al., 2016; Atazadeh et al., 2018; Alattas et al., 2018; Gkeli et al., 2018; Kitsakis et al., 2019; Gkeli et al., 2019).

However, the considerable costs and required time, for traditional 3D cadastral surveys prevent the immediate completion of such a property registration system intensifying the current problems and forbidden the well-function of property markets in several countries. A fit-for-purpose approach may constitute a potential solution, ensuring that both the developed and developing countries may appropriately built functional land administration systems within a relatively short time frame and affordable costs, in order to meet the 2030 UN Agenda SDGs (Enemark et al., 2014). Recent research has shown that by utilizing modern Information and Communication Technology (ICT) tools, low-cost equipment, crowdsourcing techniques, web services, mobile services, open-source software, the development of a reliable, qualitative and affordable solution for the initial implementation of a 3D cadastre is feasible (Vučić et al., 2015; Ellul et al., 2016; Gkeli et al., 2017 a,b,c,d; Gkeli et al., 2018; Gkeli et al., 2019; Potsiou et al., 2020a,b; Gkeli et al., 2020a,b; Gkeli et al., 2021a,b). Also by reusing the existing rich content of data models, such as BIMs, may significantly reduce the costs and speed up the processes for the implementation of 3D Cadastres (Oldfield et al., 2017). Linking cadastral information to 3D digital representation of the urban environment could be a promising approach in order to define and visualize both 3D physical and legal spaces. Among 3D data models, Industry Foundation Classes (IFC) file format provides the potential capabilities for modelling legal and physical dimensions of urban properties (Oldfield et al., 2017; Barzegar et al.,2021).

The main objective of this research project is to provide a practical technical tool and a crowdsourced methodology for the initial implementation of 3D cadastral surveys in a fast, cost- effective and reliable way. Thus, through such a solution the initial establishment of a functional 3D cadastre is feasibly in a short time-frame, supporting the government administration to provide an effective and transparent system capable of securing property rights, facilitate property valuation, managing real estate markets in modern cities, as well as other necessary urban reforms. This work explores the opportunities for (re-)using available BIM data as registration background for the initial implementation of 3D crowdsourced cadastral surveys. This attempt is part of the wider context of our effort to develop a technical framework that can be adapted to the available cartographic infrastructure of each country or even it can be implemented reliably in the absence of an accurate basemap.

Chapter 2 presents background information regarding the technical framework of the proposed crowdsourced solution. Chapter 3 describes the proposed crowdsourced methodology for the compilation of 3D cadastral surveys, utilizing the proposed technical framework. Chapter 4 presents the implementation test of the developed system in one multi-story building in an urban area of Athens, Greece. Chapter 5 presents an overall evaluation of the proposed technical solution. Finally, Chapter 6 presents the main conclusions referring to the perspectives, the geometric accuracy, the cost, the duration and the reliability, of the proposed crowdsourced solution as a basis for the compilation of a well-functioning fit-for-purpose 3D Cadastre, as well as some thoughts about our future work in this field.

2. BACKGROUND INFORMATION

2.1 Related Work

Nowadays, the main source for 3D building information of new buildings is Building Information Model (BIM). BIMs present the geometry of the complex physical buildings' spaces (rooms, corridors, walls and floors), used mainly for planning, design, construction, maintenance, etc. BIM data in combination with IFC data structure, can provide input to 3D cadastre for both each individual property as well as its surrounding properties, allowing the obtainment of clearer picture regarding properties RRRs. Until now, several researches regarding the use of BIMs in 3D cadastres have been made.

The potential use of BIM and IFC as a future data source for 3D Cadastres, is stated by Oldfield et al. (2016). IFC data structure may support the requirements of cadastral legal spaces, while it can be enriched with additional attributes describing the necessary characteristics of legal spaces. As BIMs are widely used and already existed in several fields, their (re-)usage may reduce the cost of the cadastral procedure and speed up the process for the implementation of 3D cadastres. Towards this objective, Oldfield et al. (2017) developed a workflow trying to establish a connection between BIM/IFC and GIS, aiming to incorporate the information of 3D spatial ownership RRRs as input data for the land registry in the

Netherlands. Sun et al. (2019) present a similar approach, investigating the potential integration of cadastral information, BIM/IFC data and GIS, aiming to set a link between physical and legal spaces for cadastral visualization on building level in urban environments. BIM data have claimed a place as an important and detailed data source for the establishment of 3D spatial units. Janecka (2019) highlights the importance of transforming mechanisms between BIM data in the GIS (Geographic Information System) projects, especially regarding the smart cities. It states that within the ongoing international standardization activities, there are activities focusing on 3D Cadastre and BIM, confirming the significance of such connection.

El-Hallaq et al. (2019) proposed a different approach, trying to present and analyze the current capabilities and situation of modern cities and formulate a future vision. They developed a GIS web-based 3D database, including city elements such as buildings, services and other facilities. The main objective of this investigation is the development of a 3D geometric and descriptive database facilitating documentation, transparency and help in the decision-making process. A similar web-based cadastral-oriented approach, is proposed by Andrianesi and Dimopoulou (2020). The main objective of this investigation is to combine BIM and GIS, for the effective management of 3D cadastral information and building data. A web-based application is developed while the IFC standard is used for the exchange and linkage of the 3D spatial information between the two systems. Finally, one of the most recent investigation is presented by Barzegar et al. (2021), trying to resolve the weaknesses of IFC files, concerning the differences between geometry of 3D data in IFC and in a spatial database. To support required spatial analysis, they development an IFC-based spatial database for 3D urban land administration purposes.

2.2 Crowdsourcing in 3D cadastral surveys

During the past few years, crowdsourcing has emerged as a valuable and reliable tool for cadastral data acquisition. The active participation of citizens and more specifically of the right holders, in cadastral surveys, can minimize the time, costs and the gross errors, as they know better than anyone else the boundaries and location of their properties. As this field is newly emerging, the range of the existing investigations is limited. The majority of these researches is based on the identification and delimitation of 3D cadastral objects, on existing 2D cadastral maps, orthoimages and architectural floor plans. Modern technological achievements gain the role of data collection tools by managing and delivering all the necessary proprietary information into the cadastral systems.

An interesting crowdsourced approach for 3D cadastral data capturing, is developed and presented by Vučić et al. (2015). A mobile device is utilized, for the submission of the necessary geometric information regarding the property unit's attributes, such as the height, the reference point and the surface relation. These data are combined with existed 2D official information about the property's premises, allowing the partly establishment of 3D cadastre and its' visualization. Ellul et al. (2016) follow a different approach, trying to implement the cadastral registration procedure by simplifying the recognition and selection of the situations in which the land and property ownership situations belongs to. Utilizing a web-based application, citizens may select their situation through several different groups presenting different types of land ownership. The different ownership situations are sketched by the research team, enabling citizens to comprehend the form of their case.

Besides the descriptive and indirect determination of the 3D cadastral objects, it is important to determine and create their geometry in the 3D space. In Gkeli et al., 2017d it is stated that the utilization of parametric modelling techniques (Model-driven methods) may be the best option to proceed with 3D modelling of real properties, allowing the rapid implementation of 3D crowdsourced cadastral mapping, in a cost-effective, reliable and simple way. Model-driven methods are characterized by high robustness and maintenance of topology and can be adopted by people/citizens without any specific photogrammetric skill. With that in mind, Gkeli et al. (2018) proposed a LADM-based cost-effective technical solution for the acquisition of 3D cadastral data and the visualization of the real properties, as block models (LoD1), both above and below the land surface. They developed a cadastral mobile application able to process the inserted geometric data and provide the block models of the declared real properties, following a prototype modelling algorithm. The key step of the proposed framework is the digitization of property units' 2D boundaries on the available basemap, and the declaration of important geometric descriptive information regarding the height and the floor where the studied property is located, through the developed mobile application. A similar but more sophisticated approach is presented in Gkeli et al. (2019). The mobile application is upgraded. More functionalities are added, while the crowdsourced methodology is enhanced by upgrading the role of team leaders in the overall registration process.

As satisfactory these approaches may be, it should be emphasized that they are based on ideal conditions of accurate basemap availability. In the absence of an accurate basemap, other mechanisms and technologies may be used. The utilization of the smartphone's GPS sensor, with an accuracy of a few meters, or the utilization of external support GNSS (Global Navigation Satellite System) tools and resources, achieving high positioning accuracy, may constitute a potential solution supported by some researchers (Molendijk et al., 2018; Cetl et al., 2019; Potsiou et al., 2020a). However, the efficiency and effectiveness of such systems is reduced significantly as we move towards the interior of buildings. To overcome this limitation, Gkeli et al. (2020b) followed an alternative approach, utilizing a mobile application enriched with multiple geometric tools, enabling the identification of properties boundaries. Furthermore, a more innovative approach is proposed by Potsiou et al. (2020b). This investigation explores the potential combination of mobile services, Bluetooth technology and innovative machine learning techniques for indoor cadastral mapping. Aims to automatically provide the position of indoor cadastral spaces and create a plan-free solution for the initial implementation of 3D indoor cadastral surveys, mainly in urban areas.

An extension of this technical framework is suggested by Gkeli et al. (2021a,b) trying to integrate BIM in the process for the initial implementation of 3D Cadastres. Through the development of a web-based application, the possibility of (re-)using rich BIM data, as registration basemap for the implementation of 3D crowdsourced cadastral surveys, is explored. The first results are very promising, enabling better communication and understanding of 3D space, while speeding up the necessary cadastral processes. However, the utilization of wireless services in combination with the mobile application, are inclusive and preferable as not everyone has access to a cable internet. Thus, the potential integration of BIM data, crowdsourced techniques, mobile services and LADM standard, for the registration of property's RRR has not been implemented yet, being an interesting aspect for further investigation. The integration of all these factors in a single approach, may expand the range of alternatives for the immediate implementation of 3D Cadastres everywhere.

3. PROPOSED TECHNICAL FRAMEWORK

The proposed crowdsourced approach tends to enrich the previous research on 3D crowdsourced cadastral surveys (Gkeli et al., 2020a,b; Gkeli et al., 2021a,b), aiming to speed up the processes for establishing 3D cadastres, reducing the requires financial resources and increasing the reliability of the collected data. This attempt enhances citizens' role and participation, as right holders are called to be responsible for the identification of their property, either by digitizing its boundaries on an available basemap, or by locating and selecting their property on an existing BIM. The main idea of the of the proposed approach is based on (Gkeli et al., 2020a;b), while it is upgraded by enabling the integration of BIM/IFC data as a potential data source of 3D cadastral information.

The main objective of the proposed technical framework is to provide a modern approach and an alternative technical tool for the future acquisition, management, registration and representation of 3D property rights, mainly in urban areas. It consists of two complementary parts: the technical part and the procedure to be followed. The first part includes the technological sub-systems that need to be developed. The procedure deals with implementation process of the 3D crowdsourced surveys through the developed systems.

3.1 Technical Aspect

The architecture of the developed technical background is composed of two connected parts: the server-side and the client-side. These two parts are communicated through a network connection. The first refers to the web server and the Database Management System (DBMS) where the collected data are stored and maintained. The client-side refers to the data capturing tool, which in this case is preferred to be a mobile device. In order to follow the global directions for the development of 3D cadastral systems, a database schema based on LADM standard is generated. For client-side an open-sourced mobile application for Android devices, is developed, while the storage and management of the collected data is conducted through the server of ArcGIS Online (ESRI, 2021).

3.1.1 Data Model

The proposed DBMS conceptual schema was developed through Enterprise Architect (EA) UML modeling tool from Sparx Systems, which supports the Geography Markup Language (GML) application schemas and the modeling of ArcGIS geodatabases, utilizing Model Driven Generation (MDG) Technologies. EA allows the generation of geodatabase conceptual schemas empowering the development of GIS applications. The developed geodatabase is based on our previous work, presented in Gkeli et al. (2019) following the LADM standard's specification, while some new classes are generated in order to support the BIM/IFC aspect. More specifically, LADM's basic classes of LA_Party, LA_RRR, LA_BAUnit and LA_SpatialUnit, are preserved (Figure 1). A new class named BuildingUnit3D, is generated in order to function as the receptacle of all potential geometries that can be managed by the DBMS).

According to LADM specifications, a "true" 3D representation of a spatial unit consists of arbitrary oriented faces. As the definition of the acceptable 3D geometries and representations for the 3D cadastral objects is still challenging (Ying et al., 2015), there is a wide range of geometric choices that may potentially utilized. Gkeli et al. (2019) proposed a different geometric approach, based on the fact that a real 3D cadastral object may be defined as a valid volumetric object that can be represented by one closed polyhedron refined by a set of connected faces (Ying et al., 2015).

As BIMs are widely used in modern cities, in many application areas, their (re-)use should be integrated into the future procedures for the implementation of the 3D Cadastres. However, before that happens, some limitations concerning the linking process between BIM and LADM should be settled. BIM consists one of the most detailed and comprehensive object-oriented method of modelling buildings, providing in detail the geometry of the complex physical buildings' spaces, such as rooms, corridors, walls and floors. This may suffice to define the 3D cadastral physical spaces, but not the 3D cadastral legal spaces. A legal space needs to be related with only one space consisting the ownership boundary of a single property, where the corresponding RRRs are assigned (Gkeli et al., 2021b). Thus, for defining the 3D cadastral legal spaces through BIM, a number of physical spaces should be united into single entity, which will describe the legal space of ownership rights. Thus, a 3D spatial representation derived from a BIM may present an apartment which spread across multiple rooms but belonging to one owner (Gkeli et al., 2021b). With IfcSpace entity, the representation of volumetric cadastral spaces inside a building is feasible. Thus, the interior structural elements can be included into this entity, forming the legal spaces of the cadastral objects, where the RRRs will be assigned.

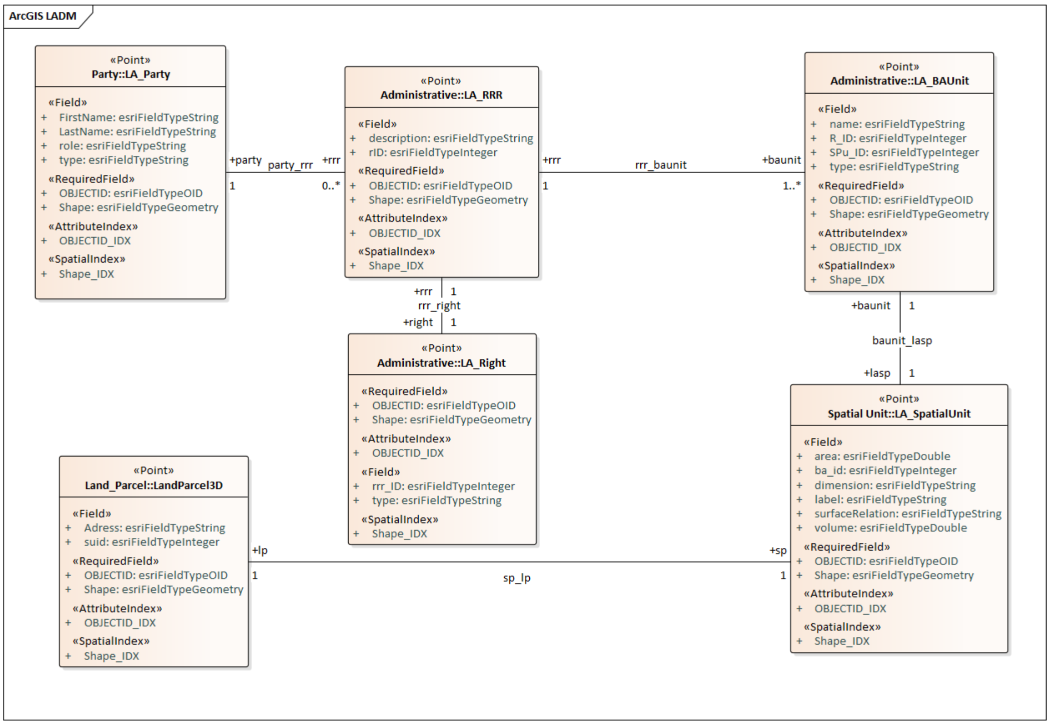

Figure 1: Conceptual DBMS schema of the developed data model, based on the main classes of LADM: LA_Party, LA_RRR, LA_BAUnit and LA_SpatiaUnit

The representation of BIM legal spaces may be achieved utilizing open BIM exchange models, such as the Industry Foundation Class standard (IFC), which is one of the most widely used standard. IfcSpace entity, enables the representation of volumetric (legal) spaces inside a building. With that in mind, a new class named BIM_BuildingUnit3D is created (Figure 2), describing the BIM's cadastral legal spaces. BIM_BuildingUnit3D class is directly linked with BuildingUnit3D class, preserving the necessary information regarding the definition of the volumetric/multipatch geometry of a building unit (property).

Finally, the developed database scheme is exported from EA as a Geodatabase Workspace XML Document (containing the ArcGIS schema) in order to be imported into ArcGIS Pro software. Subsequently, the produced geodatabase is uploaded on ArcGIS Online platform in order to be able to be linked with the rest of the elements of the proposed technical solution.

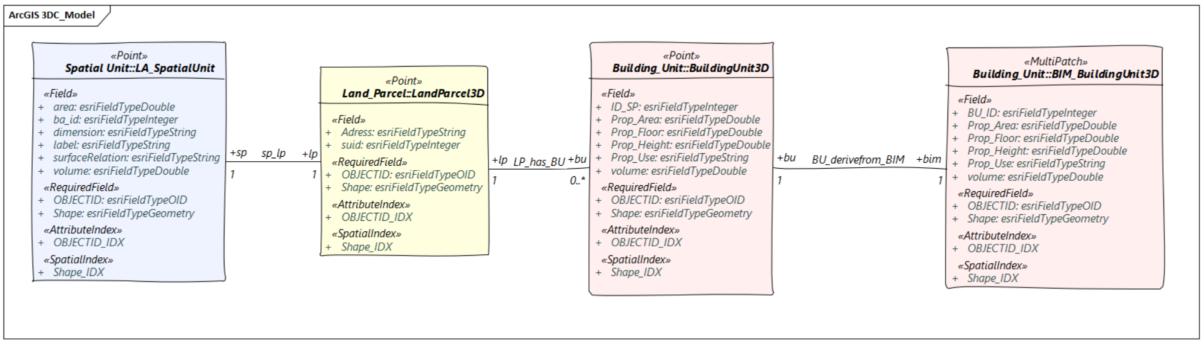

Figure 2: Conceptual DBMS schema of the developed data model, describing the new classes of Land_Parcel, BuildingUnit3D and BIM_BuildingUnit3D; the relationships between them, as well as with the LA_SpatiaUnit class of LADM

3.1.2 <u>Developed Mobile Application</u>

An open-source prototype for Android mobile devices is developed to support the client-side of the proposed technical solution (Figure 6). This research domain is newly emerging, providing promising results for the compilation of a preliminary 3D cadastral database directly by the citizens/rights holders. The developed application is based on the results of earlier stages of the current research (Gkeli et al., 2019; Gkeli et al., 2020a,b), including more functionalities for BIM/IFC manipulation. The mobile application enables the collection of 3D crowdsourced information by non-professionals; the registration of the cadastral data and their relationships within a LADM-based cadastral geodatabase; the automatic generation of 3D property unit models as block models (LoD1), using Model-driven approach; the manipulation of BIM/IFC descriptive data; and the objects visualization in real-time.

For the development of the mobile application a set of software tools were utilized: (i) the Integrated Development Environment of Visual Studio 2013 (IDE); (ii) the Java Deployment Package Oracle JDK 8 (Java Development Kit); (iii) the Android SDK Manager (for API level 19); (iv) the add-in ArcGIS Runtime SDK for .NET (100.0.0) of ESRI, which adds the function of ArcGIS to the application via libraries (with a wide variety of methods and functions); (v)the add-in Xamarin 4.5.0 for Android Support Library that allows developers to build Android, iOS, and Windows apps within the IDE using code completion and IntelliSense; (vi) the Server of ArcGIS Online (cloud of ESRI), for the storage and management of data (ESRI, 2019); and, (vii) the programming language of C#.

The user interface is simple and appropriately configured in order to lead the registration procedure. It simulates the 3D real world utilizing a Digital Terrain Model (DTM) offered by ESRI. The user may be oriented in 3D space utilizing the GPS (Global Positioning System) of the mobile device. However, the GPS is used only for a rough positioning in order to avoid gross errors during rights holder’s orientation in the 3D space. As registration basemaps, the available spatial infrastructure (2D architectural plans, orthophotos, aerial photos, BIM data) may be utilized.

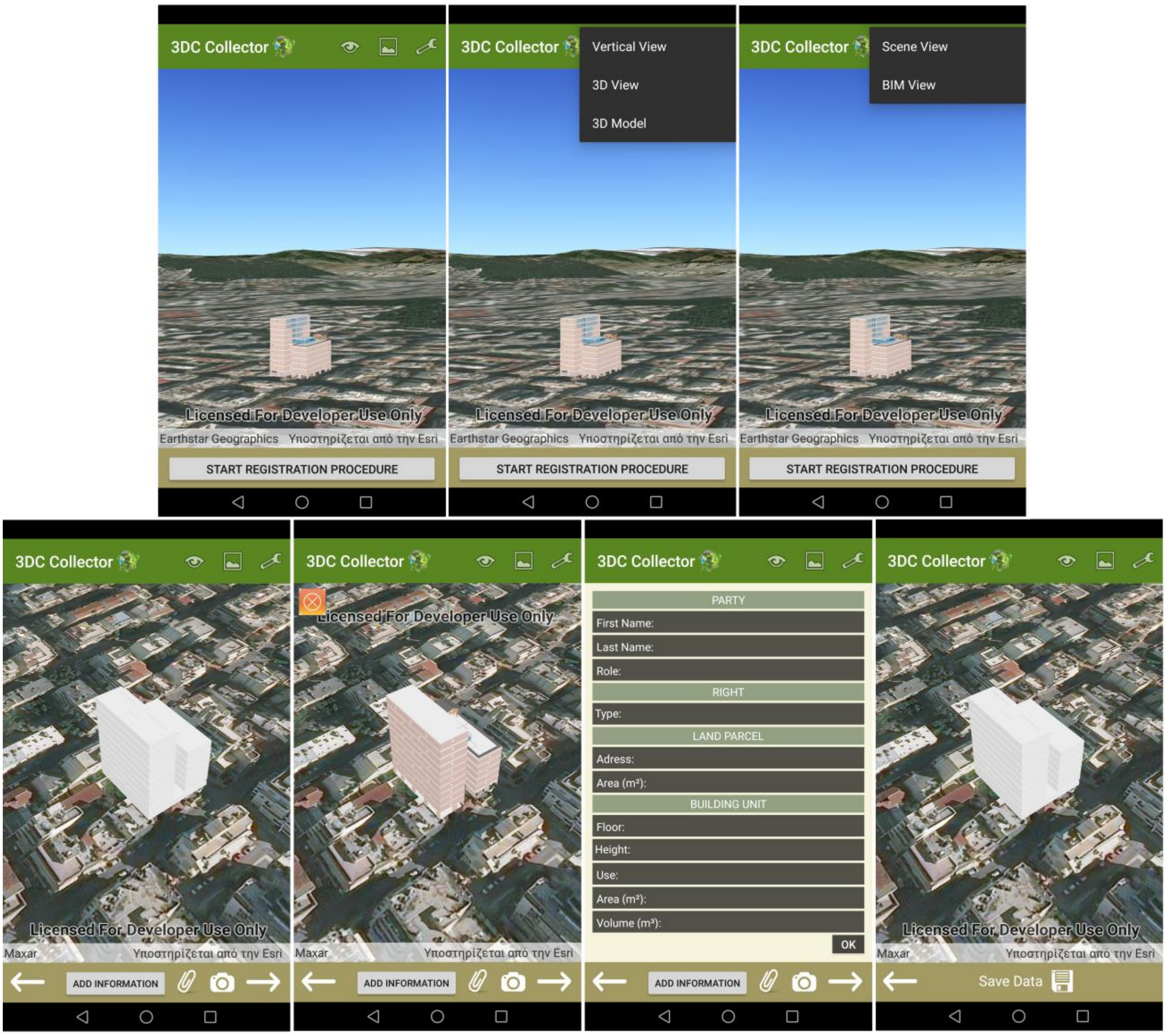

Figure 3: Users interface overview of the developed mobile application

If BIM data describing user's property unit is available, the user may proceed with the cadastral registration process (Figure 3). He/she may navigate throughout the 3D scene, locate his/hers property unit on BIM and select it, by tapping it on screen. Following, the user may enter all the necessary cadastral information included in the information form, which the application will ask him/her to complete. During the registration process, the user may enable or disable the physical (LoD4) or legal view (LoD1) of the property units presented in the available BIM, through the BIM view tool, provided by the mobile application (Figure 3). Finally, the user can store the collected data in the cadastral database, updating the system with the new records and the corresponding 3D property unit model, in the server of ArcGIS Online. It is noted, that in this study we investigate the potential use of available BIM data in order to proceed with crowdsourced cadastral surveys, utilizing mobile devices as data capturing tool. In the absence of BIM data, other methods and techniques may be utilized.

These alternatives solutions have been tested in previous research, leading to satisfying and promising results (Gkeli et al., 2018; Gkeli et al., 2019; Gkeli et al., 2020a,b). A hybrid solution including all the proposed alternatives is tended to be developed in the next step of this research project.

3.2 Crowdsourced Methodology

The proposed methodology for the initial implementation of 3D cadastral surveys, is based on our previous work presented in Gkeli et al. (2020a,b) and Gkeli et al. (2021a,b) (Figure 4). The main objective of the proposed procedure is to reduce time, costs and simplify the most expensive and time consuming phase of cadastral registration process, which is the 3D cadastral data acquisition. By utilizing low-cost technology, (re-)using existing rich data models, and enhancing rights holders' participation during this phase, the collection of the necessary geometric and semantic information concerning the ownership status and other rights, is accelerated with data reliability to be increased. This investigation aims to explore the potential use of BIM data, as a basemap for the initial acquisition of 3D cadastral information, by the rights holders. The visualization of the real properties through BIM, facilitates the identification and selection of the desired property/building unit, simplifying the overall process. As data capturing tool, a mobile cadastral application is suggested to be used.

The first phase of the proposed crowdsourced procedure starts with the declaration of a specific area under cadastral survey, by the National Cadastre and Mapping Agency (NCMA). The preparation of a draft registration basemap is conducted, through collecting all the available cartographic/ geospatial, cadastral information and BIM data - if existing (Gkeli et al., 2020a;b). In the next phase, the area under cadastral survey is divided to sub-regions and each one of them is assigned to a local team leader, who has an auxiliary and organizational role during the process. The team leader may be a professional surveyor or a trained volunteer, responsible to assist the overall data collection procedure and help the right holders with any question or difficulty concerning the process or the used software. In the third phase, team leaders are responsible to inform rights holders about the benefits of the cadastral crowdsourced project and train them on how to use the cadastral web application. Besides that, NCMA should provide informative videos and detailed explanatory documents, describing the necessary processes.

The responsibilities of the leaders also include the collection of the available basemaps and BIM data, the utilization of the necessary pre-processing steps for their insertion into the cadastral server, and therefore, for their usage by the cadastral web application. Next, the 3D cadastral surveys are performed by rights holders through the cadastral web application. Each right holder, identify and select his/hers property based on the BIM/IFC representation and insert all the necessary cadastral information. Finally, the examination and assessment of objections and the correction of data is conducted by professionals, leading to the compilation of the preliminary 3D cadastral database.

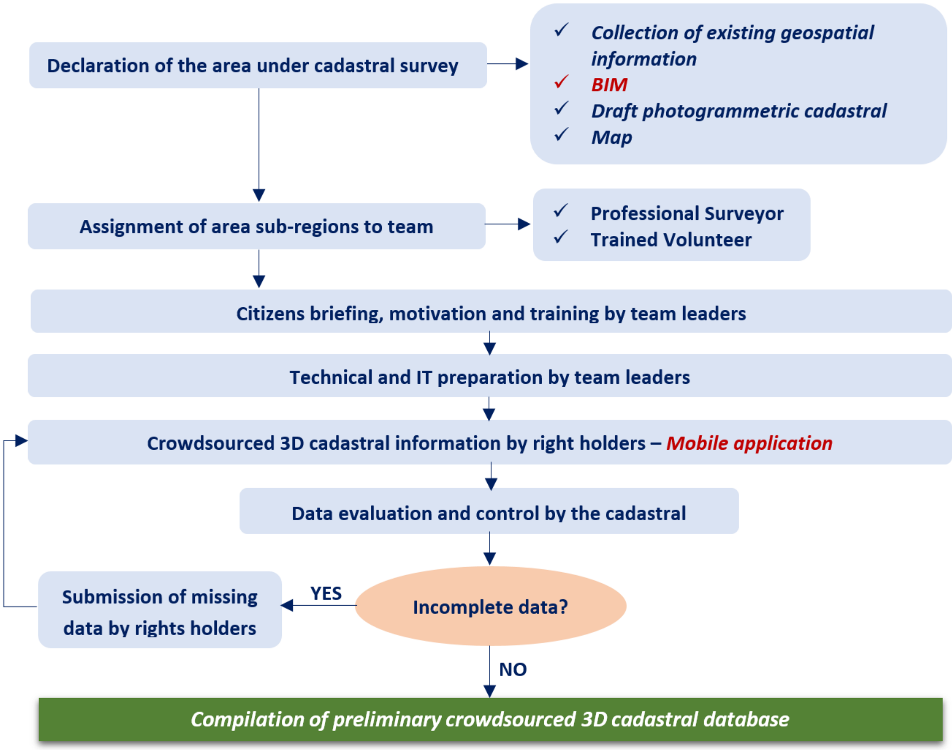

Figure 4: Proposed crowdsourcing methodology for 3D cadastral surveys up to the stage of the compilation of the preliminary 3D cadastral database

4. PRACTICAL IMPLEMENTATION

The proposed technical framework was tested in a densely structured urban area of Athens, Greece (Figure 5). The 3D building models of a building block were utilized as registration basemap. The models were in LoD4, describing in detail the physical characteristic of the buildings' exterior. In this section, a number of pre-process steps enabling the insertion and exploitation of the BIM data into/from a GIS system, and therefore their integration with the generated LADM database and the developed mobile application, are discussed and presented. Finally, the practical experiment is described, and the first results of the proposed crowdsourced approach are presented.

Figure 5. The aerial photo depicting the test area

4.1 Pre-processing steps

For this particular case study, 3D building data available from a previously successfully completed project conducted by a research team of the National Technical University of Athens, were used (Ioannidis et al., 2015). For the creation of the BIMs of the studied area, the Autodesk's Revit software was selected, while a set of available georeferenced floor plans were utilized as reference data. In the first step, the physical spaces were created in LoD4, and then the legal spaces were generated utilizing the Area and Schedule function of Revit. The utilization of Area tool enables the identification of the 2D boundaries for each 3D legal space which is a debatable topic among researchers, as their proper identification varies according to the current legislation of each country. In this investigation, we assume that the 2D and 3D legal boundaries of the studied properties are correctly sited.

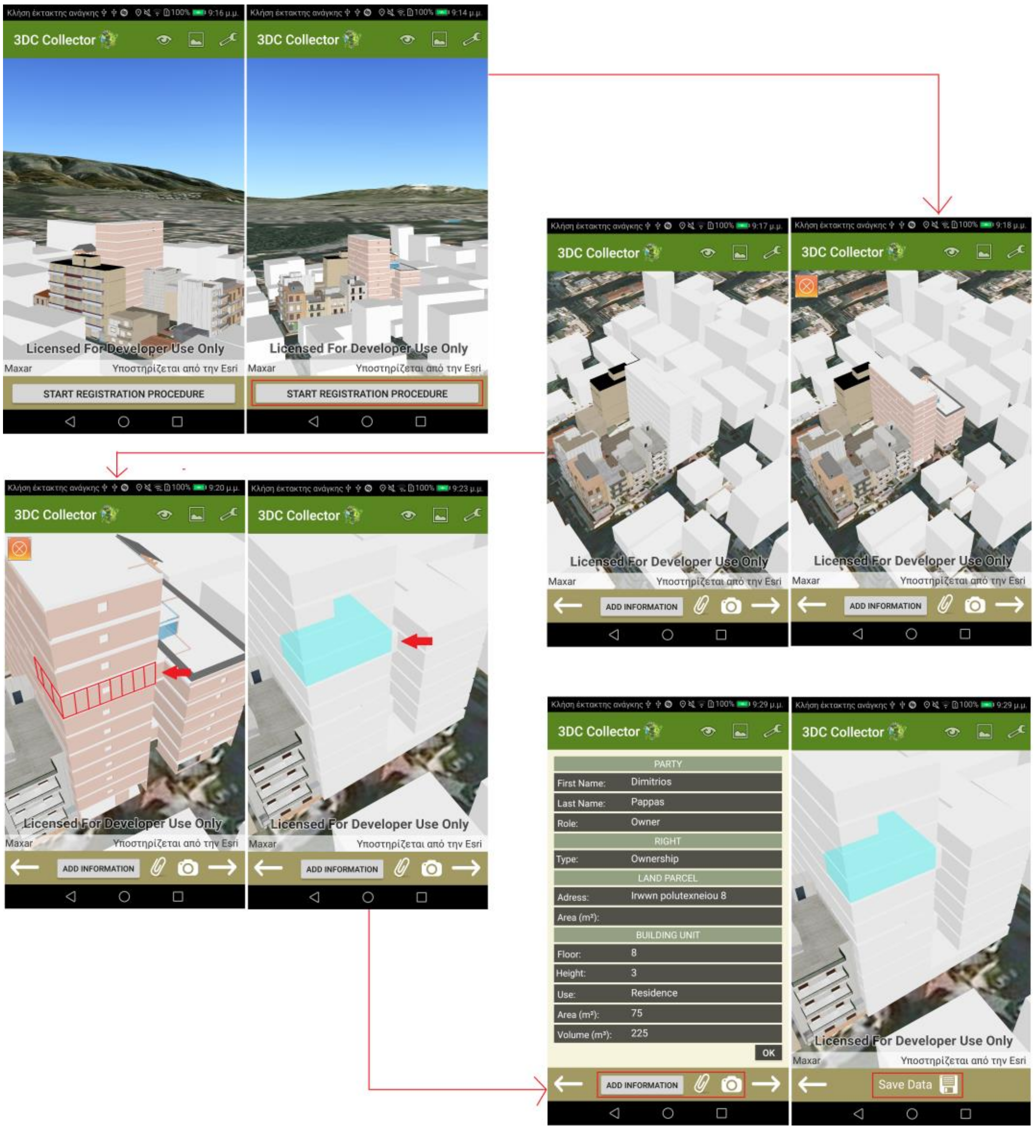

Figure 6. Example of the registration process through the developed mobile application, including: (first row) navigation throughout the 3d scene, (second row) visualization of physical and legal view of the studied building, (third row) the identification and selection of the desired property and (fourth row) the insertion of the necessary information concerning the right holder, the land parcel, the building and the building unit; and the storage of the collected data

The identification of the different types of legal objects is outside of the scope of this study, but will be addressed in the next stage of this research project. Subsequently, another useful tool provided by Revit is Schedule, as it enables the insertion of the necessary semantic information concerning the property's RRRs. Thus, the generated 3D legal objects were enriched with several attributes, describing each one of the necessary cadastral information as they are described through the generated LADM-based DBMS schema, presented in Section 3.1.1. Finally, the created 2D spaces were matched with IfcSpace entity in the exported IFC model, which was selected as exchange model in order to translate the BIMs 3D spatial information into the ArcGIS platform.

In the next step, the generated IFC model was imported into ArcGIS Pro environment, utilizing quick import tool from Data Interoperability Toolbox. Thus, the IFC model was translated into a file geodatabase and then the IfcSpace entity was directly connected with the BIM_BuildingUnit3D class of the developed LADM-base geodatabase, which is now enriched with the necessary geometric information concerning the cadastral legal spaces. It should be noted, that despite performing all the necessary steps during the development of BIM with Revit software, its georeference is not properly maintained when IFC is inserted into ArcGIS Pro environment. This is a common issue in the context of BIM–GIS integration. For this particular study, the IFC2x3 version was utilized, which despite the fact that embedded spatial reference information, mismatches may occur when importing the model to a GIS environment (Zhu et al., 2021). However, this issue is solved in the IFC4 version by introducing a new entity that includes and maintains all the necessary elements for the geo-reference of the model (Gkeli et al., 2021b).

For the purpose of this study the model was horizontally aligned close to its correct position with a fixed offset of 17 cm, while its vertical alignment was incorrect, making it appear to be submerged in the ground. To overcome this problem, the model was moved to its correct horizontal position utilizing the editing tools of ArcGIS Online. By the end of this phase, the developed LADM-based geodatabase may be uploaded to the Cloud of ArcGIS Online, so that it can be utilized for the implementation of 3D crowdsourced cadastral surveys through the developed mobile application.

4.2 Implementation and Results

For the practical implementation the proposed crowdsourced methodology was followed. A team of volunteers consisted of NTUAs' students, were assumed as right holders in order to proceed with the 3D cadastral registration. As team leader a member of our research team was selected, in order to inform the volunteers about the objectives of this research project and train them regarding the functions of the developed mobile application. Once the volunteers were familiarized with the mobile application the 3D cadastral registration process was started. Each one of the volunteers was responsible of identifying a specific number of property units in the BIM and declaring the necessary information through the developed mobile application.

The user was able to navigate throughout the 3D building scene and view the structural and realistic characteristics of the building by enabling the physical view (LoD4) through selecting the respective tool provided through the mobile application. Once the volunteer identified the desired property unit, he/she may close the Physical view and view only the 3D legal objects (LoD1) of the studied building. By tapping on the BIM at the position that he/she assumed that his/her property was located, the 3D volume presenting the legal space where the RRRs are assigned was highlighted. Then, the user was inserted the required cadastral information utilizing the Add Information tool. For this experiment, as inserted data, the descriptive information about the rights holder (first name, last name, and type of right); and the property unit (address, area code, and use), were selected. Simultaneously, the volunteers may attach images and legal documents (in an official procedure) proving their rights, in order to verify their declaration. Once the volunteers collected the required data, they submitted their declarations, which were stored in the cloud of ArcGIS Online, updating the system with the new records. An example of the described registration procedure is presented in Figure 6.

Thus, following this sequence of registration steps, the volunteers were able to complete succesfully the registration procedure, through the mobile application. The mobile application was easy to use, with the registration of each property accomplished in about 7–15 min (on average), depending on the location of the property in the BIM and the familiarity of the user with the application. The collected cadastral data have been correctly assigned to the 3D cadastral legal objects presented through BIMs, and stored successfully in the cloud of ArcGIS Online. The proposed technical solution seems to lead to reliable results requiring less time and financial resources in contrast with traditional cadastral procedures. However, this study consists only a first step towards this objective. A more in-depth investigation is needed in order to highlight any weaknesses or problems regarding the proposed framework and the mobile application itself.

5. DISCUSSION AND CONCLUSIONS

In light of rapid urbanization, the cases of multiple use of the space with overlapping and complex property right are increasing, requiring proper management. The establishment of a 3D cadastral system aims to support the government administration in order to provide an effective and transparent system capable of securing property rights, facilitate property valuation, managing real estate markets in modern cities, as well as other necessary urban reforms. Despite this need, traditional cadastral systems remain based on 2D maps complicating the definition and management of multi-dimensional property rights. At the same time, traditional cadastral procedures are time-consuming and elaborated, delaying or even preventing the completion of field surveys, increasing simultaneously the costs of the required procedures (Basiouka and Potsiou, 2012; Molendijk et al., 2018). This results in an increasing need for the development of modern innovative approaches for the compilation of 2D and 3D cadastral surveys. Until now, crowdsourcing has claimed a critical role as a reliable methodology with huge potentials regarding the realisation of 2D and 3D cadastral registration, both affordable and fast. Gross errors may be reduced as the rights holders can better identify their properties without making assumptions about the property boundaries or the names of the owners (Gkeli et al. 2016; Mourafetis et al. 2015).

BIM consists without a doubt one of the most detailed and comprehensive object-oriented method of modelling buildings. Its utilization and more precisely its potential (re-)usage may be of significant importance for the declaration of the physical and legal cadastral objects in 3D Cadastre. The utilization of BIM for cadastral purposes is very beneficial as provides a realistic view of 3D buildings and therefore of 3D property units, enabling the fast and reliable registration of 3D cadastral objects, minimizing the gross errors which are usually inserted in traditional cadastral surveys due to the misinterpretation of property unit's position and boundaries. Though the exploitation of BIMs and the IFC standard the definition and visualization of 3D legal boundaries in LoD1, is feasible. The visualization of 3D cadastral legal spaces provides a better understanding of properties boundaries as well as of the extend of the RRRs, ensuring clarity and avoiding improper behaviors and disputes between the right holders (Barzegar et al., 2021). As resulted from the test implementation, the registration process using BIMs was enjoyable, increasing the receptivity of the volunteers to perform and complete the necessary steps for the implementation of the 3D crowdsourced cadastral surveys.

Of course, another important factor strongly influencing the effectiveness of the proposed technical solution, is the ability of the user to manipulate the developed cadastral mobile application. In this particular test implementation, the users/volunteers were young adult people with advanced digital skills (engineering or technical skills) as they are students from various NTUA Schools and/or young surveyors, and they are well informed about the use of smart phones. However, as it has been proven at earlier stages of our research such mobile applications or even more complicated mobile applications can be managed by older people with limited digital skills (Gkeli et al., 2021c). Through proper training of the rights holders and real-time support from the team leaders, the effectiveness and reliability of the proposed procedure will be increased and assured.

Beyond these matters, the adoption of an international standard in order to structure the collected data, consist a valuable feature of the proposed technical solution. The adoption of LADM standard, establishes a standardization in cadastral data management and facilitates the communication between the involved parties within one country or between different countries ensuring transparency, cross-border trade, and in general data exchanging in heterogeneous and distributed land administration environments (Janecka et al., 2017). Until now, there are several different approaches presenting a potential integration schema between BIM/IFC and LADM and there is still much room for improvement. So far, the research in this field has been proven that BIMs potentially can serve well as an important and detail source of data for such 3D spatial units. Their connection with LADM and GIS may expand even more their potentials and provide interesting solutions for the fast and reliable implementation of 3D cadastral surveys.

The proposed LADM-based crowdsourced technical approach provides an alternative solution for the initial acquisition of 3D cadastral information, utilizing the rich content of (existing) BIMs. The proposed framework aims to save time and funds, simplify the registration process, enable communication, data exchange, and increase reliability of the collected data, by enhancing the role of right holders during the cadastral surveys. The selection of a mobile application as the main data capturing tool, is very helpful as a mobile device allows the rights holders to move throughout the property using the GPS sensor and oriented in 3D space and 3D visual environment, simultaneously. Also, the utilization of wireless services in combination with the mobile application, are inclusive and preferable as not everyone has access to a cable internet (Gkeli et al., 2018). The developed mobile application enables the collection of the required data in a short time, with the registration of each property unit to fluctuate between 7-15 minutes (average) and leads to reliable and accurate results. Thus, the proposed approach may constitute the basis of an initial implementation of a 3D cadastral system, speeding up the processes for the implementation of 3D Cadastres.

As a next step of this research, the investigation and identification of the different types of legal objects will be carried out, in order to investigate in detail, the weaknesses and challenges of the proposed technical framework and to proceed with the necessary corrections. Also, a hybrid mobile application including all the proposed alternative data and tools for the identification and digitization of properties boundaries (in cases of limited data sources) is tended to be developed in the next step of this research project, providing a more solid technical solution for the initial implementation of 3D crowdsourced cadastral surveys.

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4D Musrenbang: Designing User Experience (UX) to Support Public Participation in Spatial Planning for Indonesia

Nur An Nisa MILYANA, Indonesia, Bastiaan VAN LOENEN, Willem KORTHALS ALTES and Hendrik PLOEGER, The Netherlands

Key words: spatial planning, participation, Indonesia

SUMMARY

Public participation is an important prerequisite for the success of spatial planning. Technology can help improve the quality and amount of public participation in spatial planning. This paper describes the development of the User Experience (UX) design guideline named '4PHASE toolkit'. The toolkit was used to create a web-based GIS prototype, applied on the spatial planning practice in Indonesia. In Indonesia the spirit of community involvement is incorporated into the spatial planning process using a bottom-up approach.

The so-called Musyawarah perencanaan pembangunan (Musrenbang) is the traditional tool in participatory planning during the plan-making process. Meanwhile, as technology development is used as communication strategy for the government, 4D Open Spatial Information Infrastructure (4D PUPM) has emerged as a modern tool to monitor the implementation of land use plans. The exploration of both traditional and modern tools is done to get valuable information about what needs to be added for building the prototype. Our research resulted in a 4D web-based GIS prototype named 4D Musrenbang, while building on 4D PUPM to facilitate citizens participating in the spatial planning process in Indonesia.

4D Musrenbang: Designing User Experience (UX) to Support Public Participation in Spatial Planning for Indonesia

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1. INTRODUCTION

In modern-day spatial planning, the role of public participation becomes more and more important in order to find a balance between two major actors: the government as the powerholder and citizens as the individual affected by planning decisions (Vitálišová et al., 2021). As a result, the concept of Public Participation Geographical Information Systems (PPGIS) has emerged in the spatial planning domain as the collaborative approach to link citizen participation and spatial information by involving non-expert stakeholders in the decision-making process leading to the land use plan (Kahila-Tani et al., 2016).

Along with the smart city agenda, and based on the insight that providing open data alone is not sufficient (Gagliardi et al., 2017), there has been an increase in the appearance of detailed, multidimensional (3D & 4D) spatial data visualisations, usually described as digital twins, to support citizen participation activity. A web-based GIS application, known as geo-web, is often used to facilitate this participation, making it possible to connect multiple users to virtually share their opinions (Atzmanstorfer et al., 2014). However, achieving a well-functioning solution that satisfies the needs of citizens is less obvious than one might expect.

While on one hand researchers argue that 3D visualisations, compared to traditional 2D maps, can significantly improve the understanding of non-expert users (Indrajit, 2021), on the other hand research shows that many users cannot handle the mass functionalities provided by geo-web applications (Kramers, 2008; Resch and Zimmer, 2013).

Participatory mapping activities such as sketching can be easy to implement using 2D maps, however the story will differ when we use 3D maps. Not everyone can draw the visualisation of their houses in 3D; thus, it requires special skills that belong to specific users. Kaplan et al. (1989) argue that a simplified model could parallel the user's cognitive structure and reduce the total load to the processing system. In order to grasp a large type of users to participate and avoid social loading and the free-rider effect during the process, there is a need to simplify the complexity of spatial information provided in the geo-web application.

However, while geo-web technologies are emerging trends, there is still a lack of user consideration during the design process, and there is a lack of research on how this can be established (Lafrance et al., 2019). The risk is that GIS technology ends up running into an unnavigable ocean of buttons and 3D visualisations, resulting in users that can easily get lost and become frustrated. In the worst case, users may find themselves unable to use the applications successfully and quit the participation in the planning process altogether. Consequently, many functions provided in technology-oriented GIS approaches are not suitable for most users, primarily because of not including the profiles of future users in the development process.

2. USER EXPERIENCE (UX) DESIGN GUIDELINE FOR GEO-WEB

User Experience (UX), the process of enhancing user satisfaction by improving the overall experience provided by the interaction between the user and the product, is crucial to engage users with spatial planning products and effectively meeting their aspirations. The User Experience / User Interface (UX/UI) describes a set of guidelines and workflows for critical thinking about the design and use of an interactive product (Garret, 2011). Although UX and UI complement each other, they are not the same due to their difference in focus between interaction and interface. The User Interface is what the product looks like at the end, referring to the website's appearance. User Experience (UX) tackles interaction issues before, during, and after using the website. Therefore, the usability of an interface is part of the user experience, which means that a good user experience cannot be achieved by good usability alone (Adikari et al., 2011).

2.1 The 4PHASE Toolkit

The research aims to create a UX design strategy scheme in building geo-web applications for participation purposes. This design structure provides a guideline so that geo-web could accommodate and facilitates active participation from multi-stakeholders in a two-way communication, making optimal use of 3D visualisations. The research led to the development of the User Experience (UX) design guideline named '4PHASE toolkit'. The 'Toolkit' refers to the style guide templates to help to maintain the consistency of participative and user-friendliness of geo-web applications. This toolkit consists of four phases:

- **PHASE 1: Define.** The first phase is based on theoretical insights on the spatial planning process and citizen participation. This research uses the literature review's related characteristics to establish the initial requirement and procedure for intended actors, user roles, and task capabilities through the geo-web application.
- **PHASE 2: Design.** The second phase translates the result of phase 1 into a conceptual UX design. Geo-web as digital mapping can be complex due to the unique spatial information representations to be displayed. UX design can help create efficient and effective user-guidelines flow before, during, and after accessing the interface. The result of this phase will be a mockup consisting of design elements of the platform, however, not yet including functional elements.
- **PHASE 3: Build.** The third phase focuses on filling the proposed mockup with real map datasets and exploring the function element in a geo-web application. The end result is a prototype, which demonstrates the realistic front-end web experience with real datasets in 2D and 3D.
- **PHASE 4: Test.** The final phase focuses on evaluating the platform's usability. The user session will lead to two results: 1) the initial status benchmark compared to the final design and 2) several comments about the participation process's experience through the prototype.

3. IMPLEMENTATION TO INDONESIA'S CASE

The toolkit was used to create a web-based GIS prototype, applied to Indonesia's spatial planning practice, especially on the so-called *Musyawarah perencanaan pembangunan* (Musrenbang), being the traditional tool in participatory planning during plan-making process.

Both the formal-institutional forces and the informal-cultural forces are the drivers of Indonesia's spatial planning system. While the top-down governmental structures and legal frameworks formalise the formal-institutional forces, the informal-cultural forces associate with the bottom-up native culture, which constructs traditional participatory discussion mechanisms in customary practices of consensus decision-making (referred to as *musyawarah*) (Bowen, 1986). As a result, the law encourages citizens to participate in the spatial planning process.

Participation in the planning process itself is stated in Government Regulation 68/2010. According to art.2 'citizens contribute to the process of the plan-making process (*perencanaan tata ruang*), the utilisation of space (*pemanfaatan ruang*), and controlling the space development (*pengenalian pemanfaatan ruang*) based on their legal rights and obligations'. Art. 9 provides the citizen the rights: (a) to give an opinion about zoning directions and/or regulations, permits, incentive and disincentive distributions, as well as the imposition of sanctions; (b) to participate in monitoring and supervising the implementation of the spatial plan; (c) to report to the government agencies violations of the actual space utilisation in comparison to the spatial plan; (d) to report the irregularities from official statements regarding the development process that is considered to violate the spatial plan. Participation mechanisms from 'the citizen can take form in information delivery, oral suggestions, and writing opinions through various media platforms (print, electronic media, and seminars)' (art. 13). Also, the participation can be carried out by individuals, organisations, and professionals (Government Regulation 68/2010, 2010).

The traditional form of bottom-up level participation on the first stage of the Indonesia planning process is actively seen through Musrenbang (*Musyawarah*: community building, *perencanaan*: planning, *pembangunan*: development). Based on Law No. 25/2004, Musrenbang is a multi-stakeholder participatory planning process aiming to negotiate, reconciliate, and harmonise differences between government and non-government stakeholders to reach the collective consensus on development priorities.

The process starts from the level of the village, district, city, to province. It is usually conducted by Non-Governmental Organization (NGO), researchers, or the local government advocating land ownership that belongs to several local communities. Finally, the outcome will be sent as input for the Local development planning agency (Bappeda) to assign resources to each neighbourhood depending on the available funds based on their needs (Mohamed and Solo Kota Kita, 2012). Based on Law No. 25/2004, Musrenbang aims to draft the annual work plans (RKP Desa) and annual budget preparation (APBD Desa). The two most common participation activities of Musrenbang are participatory mapping and participatory budgeting. The activities include sharing information resources and local spatial knowledge by creating a neighborhood-level map and socio-spatial discussion (Mohamed and Solo Kota Kita, 2012; Akbar et al., 2020). In Musrenbang, the citizen gains a sense of duty to discuss the planning process based on their priorities. However, it is important to note that this process can only be effective if a facilitator fills the knowledge gap about spatial information and spatial planning to the public (Akbar et al., 2020).

3.1 The initial tool: 4D PUPM

In Indonesia, several modern tools have emerged to support digital participation. Among them, 4D Open Spatial Information Infrastructure (4D PUPM) provides modern-day participation tools to put a 3D city model into action to monitor the implementation of land use plans through a participatory process (Indrajit, 2021). The exploration of both traditional and modern tools is done to get valuable information about what needs to be added for building the prototype.

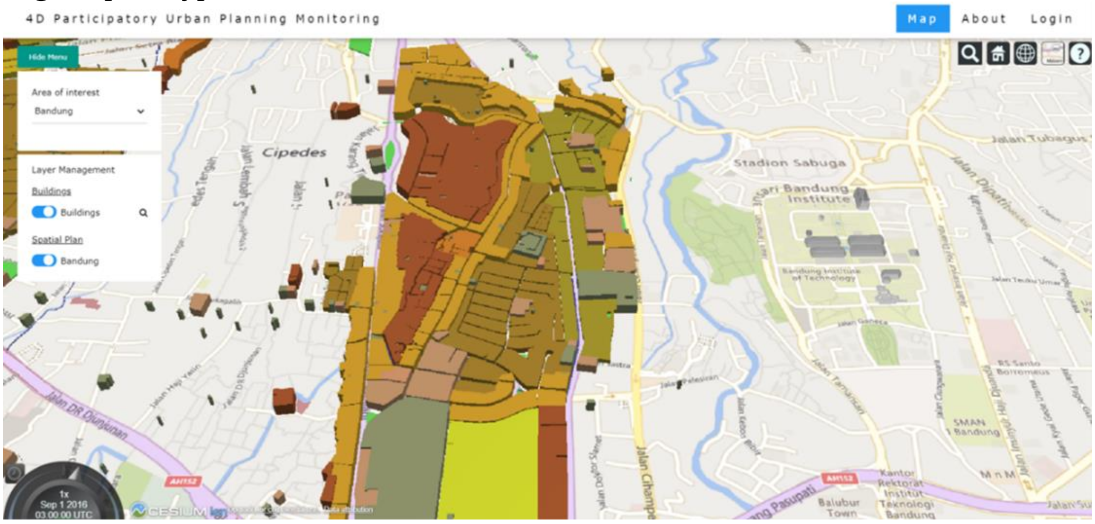

Figure 1. Interface of 4D PUPM

Developed by Indrajit (2021), the 4D Open Spatial Information Infrastructure (4D PUPM) is a geo-web application to monitor through a participatory process the implementation of spatial planning. The platform works under the national mapping agency named Geospatial Mapping Agency and can be accessed on: https://tanahair.indonesia.go.id/pupm. This application shows the 3D spatial zoning from provincial to city level. 4D PUPM aims to provide the citizen a better understanding of the spatial properties of the urban objects. At the moment, the 4D (3D + time) spatial information available on 4D PUPM are the 3D buildings and 3D spatial plans of two cities in Indonesia: Bandung and Jakarta.

The user's roles of 4D PUPM are divided into three types: 1) Contributor Attribute, 2) Contributor Geometry, and 3) Validator. At first, the user has a role as a guest user since (s)he has not registered or logged in to the system. The guest user cannot input any spatial or non-spatial information into the platform. After registration, the user can choose the user role based on preference to access different interfaces and functionalities. Being a contributor attribute, the user has the capability to update (add, delete, or edit) the attribute of a 3D building, together with providing photos and videos. As for contributor geometry, the user also has the same task capability as the contributor attribute with the additional new capability to add new spatial information (geometry) in CityGML format. Finally, the third role, validator, has the capability to update the database and verify whether the input data from both contributors are valid or not. This latter role seems specific for government staff. In practice, 4D PUPM helps to facilitate participation in the spatial planning process using 3D spatial representations.

However, the two main drawbacks of the existing platform are: 1) the intended actors for each user role are not yet defined, and 2) the platform still focuses only on the second planning process: the monitoring. Therefore, in this phase of the toolkit the research added the existing traditional participation activities, Musrenbang, to the first process, the formulation of planning.

3.2. The proposed tool: 4D MUSRENBANG

With the recent development of Web 2.0, further development of GIS has opened new ground for citizens to critically communicate and express their location-specific opinions in the form of a map. As a result, the merging of the Internet with GIS has gradually grown into a medium that provides the broadest sense in various participation activities and sectors of society involved. In this respect, several web-based GIS platforms, called 'geo-web', have reduced technical barriers for a layperson to create maps and spurred various activities that generate geospatial information.

The research resulted in a 4D web-based GIS prototype named 4D Musrenbang, building on the 4D PUPM to facilitate citizens participation in the spatial planning process and resulting in a UX design that combines existing 4D PUPM functionalities with the Musrenbang workflow to maximise the participation process of the platform.

3.2.1. PHASE 1: Defining the Human-to-GIS connection

Geo-web should not be a technical gimmick – instead, it should unpack the theories of participatory planning into a practical solution while also fulfilling the efficiency and transparency of a good decision-making process. Thus, it has brought a paradigm shift of how citizens could engage with spatial planning issues and policy-making processes using GIS technologies. With this in mind, we might ask what an ideal GIS would be like to support participation in the spatial planning process? By exploring the theory of PPGIS, the conceptualisation of geo-web as participation tools in the spatial planning process is created to build a conceptual network diagram that consists of participation task capabilities, space-time settings, and user roles. The research conceptualised the relation of human-map interaction in GIS using the ANT diagram by Latour (1996) and further developed Cvetinovic et al. (2017) for spatial planning context, which emphasises the connection between human and non-human, that is, the GIS, actors to examine how spatial planning participation is manifested.

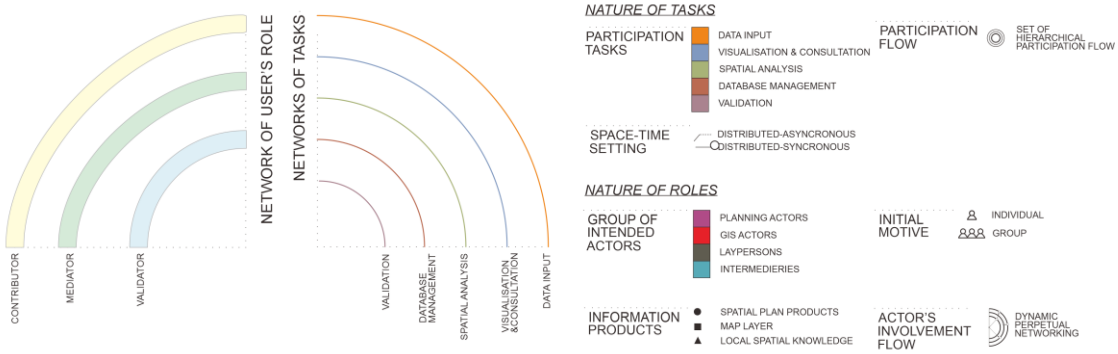

Figure 2. Conceptualisation of human-map interaction in participatory GIS using the ANT diagram

This research develops the ANT diagram (see Figure 2) based on the intended actors as the human actors with GIS application as the non-human actors into two natures:

- Nature of tasks: To answer how participation in GIS operates, this research proposed the nature of networks consisting of participation tasks as the hierarchical circle loop starting from the outer layer as ’Data Input’ to the inner as ’Validation’. Moreover, each task is filled with the space-time setting to see whether the participation flow is ’synchronous’ (same time) or ’asynchronous’ (different time).
- Nature of roles: The nature of roles is displayed to maximise all stakeholders’ involvement during the participation process. These stakeholders’ involvement could act as the individual state or group state, depending on their initial motive to join. By nature, each actor brings new information during the discussion process based on their background of knowledge and skills – thus, splitting it into three information products: spatial plan products, map layer, and **local** spatial knowledge. These actors and their products are then situated to the loops of the nature of tasks in a perpetual networking condition. The final product that reaches the loop’s core is considered the final output from the participation process. At last, each loop is highlighted to conclude what kind of user roles and which actors should be involved in each participation task.

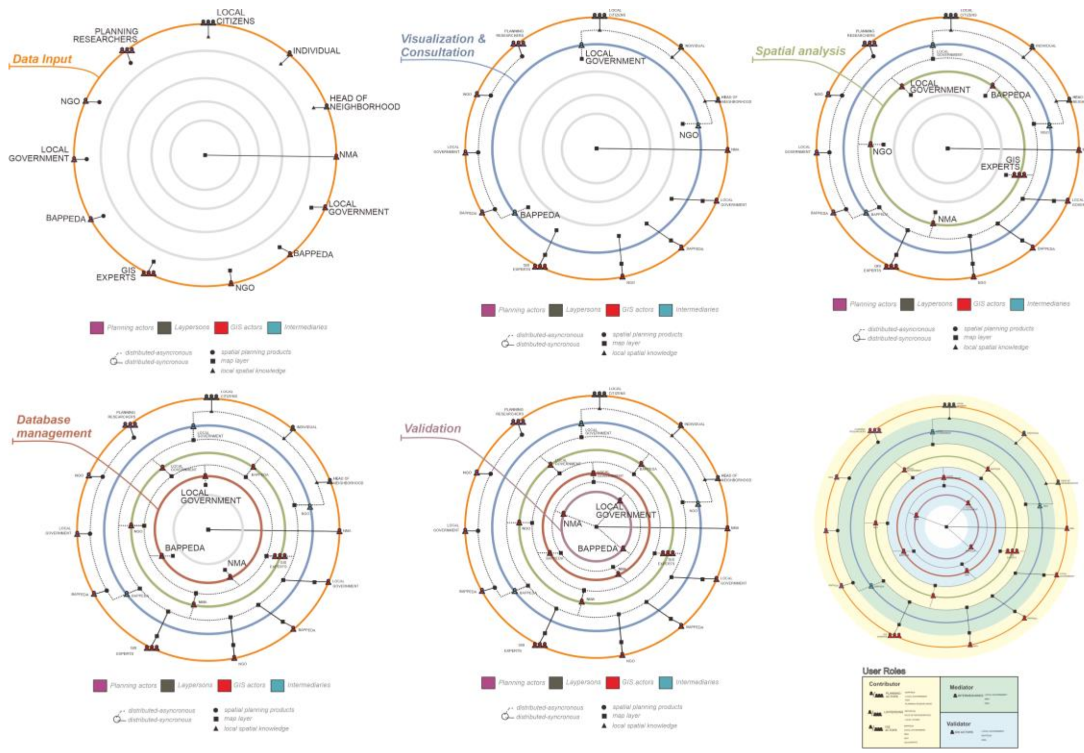

Figure 3. Final result of Phase 1 to define the user roles and participation tasks

As the final result of Phase 1, the user roles conception is made, based on the intended actor's capabilities (see Figure 3). These roles are based on whether they know about spatial planning, GIS, both, or none. This Model visualises the hierarchical layer of the task capabilities in the GIS application's participation network, together with a list of the intended actors and the space-time setting. In the end, the user roles are divided into three types: 1) Contributor, 2) Mediator, and 3) Validator.

3.2.2. PHASE 2: Designing the interface

The research resulted in a 4D web-based GIS prototype named 4D Musrenbang, building on the 4D PUPM to facilitate citizens participation in the spatial planning process, and resulting in a UX design that combines existing 4D PUPM functionalities with the Musrenbang workflow to maximise the participation process of the platform. The result creates a design mockup named '4DMusrenbang' in HTML, Javascript, and CSS format.

Once the targeted user roles and tasks were discovered, the user goals, skills, and frustration, were visualised as the hypothesis personality, or referred to as Persona. Persona is a fictional user to guide the design by setting a potential user's target instead of pleasing all kinds of real users at once (Pruitt and Grudin, 2003). These fictional users are used to decide for whom the design will be targeted. The four Persona that could be distinguished, i.e. Planning Actor, GIS Actor, Layperson and Intermediary, were then grouped based on a group of people that share similar traits.

To break down the platform's whole experience from each persona's type, the 5E Model to translate participation activities into the experience design concept (Richardson, 2010;

Rosenbaum et al., 2017), helps the UX designer understand how users can enter the platform and what they carry with them after they close the platform.

The designer illustrates each step that the users will go through while engaging with the platform by creating a user flow through five elements called the 5E Model. This consists of:

- Entice: How the user becomes aware of the experience and is attracted to it?
- Enter: How does the user begin?
- Engage: What activities immerse the participant in the experience?
- Exit: How does a user complete the experience?
- Extend: What will the user get after the experience has ended?

After creating the 5E Model, the four intended actors are mapped based on the user roles: Contributor, Mediator, and Validator. The contributors can foster both spatial information and local spatial knowledge through sketches, annotations, and existing spatial datasets. This will be visualised on the 'Map Interface' panel during the discussion process. Mediators, which consist of Intermediary actors, provide discussion panels and translate the visualization-and-control-map-layer visualisation during the discussion process. Finally, validators, which consist of GIS actors working on the governmental agencies, cover both Validation and Database Management steps. Validators are in charge of checking the proposal's spatial information and giving feedback on whether the design proposal is approved or rejected. The final result will be shared with all participants after the process ends.

The main challenge of implementing GIS technologies to facilitate participatory planning lies in that users do not understand the GIS. Therefore, UX helps to recognise the need of each involved user, guide users to do a specific task, organise the platform to allow users to achieve their goals, and visualise the process for better user understanding. In practice, 4D PUPM needs to facilitate five different participation activities from four intended groups of actors based on the Phase 1 result. Moreover, the current workflow of traditional Musrenbang also provided an initial flow of the planning formulation step in the 4D PUPM system. Due to this complexity, 4D PUPM needs to consider four phases of building user experience such as 1) Creating Persona based on user roles; 2) Translating all participation tasks into 5E elements; 3) Building wireframes of the web organisation; 4) Designing the final interface based on user-friendliness.

3.2.3. PHASE 3: Building participatory geo-web

One of the main goals from the mockup resulting from PHASE 2 is to re-design the initial 4D PUPM into a fully dynamic map interface to maximise the participation activities. Consequently, the prototype should have the most appropriate 3D geo-web platform available and easy to access by everyone. Therefore, choosing the right geo-web platform is very crucial. For the context of this research, two geo-web libraries were analysed:

- Cesium JS: an open-source Javascript library to create a 3D geo-web application.
- Mapbox: a Javascript library to render interactive maps using WebGL.

These two libraries are selected because of their wide variety of functions and are free to use and access. Since this research focuses mainly on usability, these two platforms are compared based on the most effective way to simulate user experience similar to offline participation situation. User interaction and environment simulations are the key points for the comparison; hence, technical aspects such as spatial validity and database system are not the main priority.

Based on a comparison Mapbox GL JS provides more benefits for supporting user-friendly geo-web applications due to several reasons. First, it provides fast loading map time, which is useful for a seamless participation process between multiple users throughout the platform. Second, it is more feasible to apply design and visualisation requirements from Phase 2 due to its ability to customise the map styling features. However, Mapbox has an important technical limitation: to visualise buildings in 3D, Mapbox is not using pure 3D but 2.5D, which means that the building is a 2D shapefile which then extrude based on its height. This limitation makes Mapbox not suitable for 'stacking' visualisation (for example: visualising 3D building with each floor having different ownership like an apartment building). However, it is still possible to solve this limitation by using a third-party application like Three.js.

In Phase 3, the mockup was developed into a prototype by adding several map functionalities and interactions and adding real 3D datasets. The area of interest is located in Tebet district, Jakarta city, Indonesia. This part of the city is chosen because of its detailed attribute information compared to other districts' datasets. The dataset utilised in the prototype combines 3D spatial plans with building models of Jakarta, Indonesia. The input datasets of the prototype are:

- 2D spatial zoning plans from the province DKI Jakarta's geoportal, recorded as a polygon in 2D shapefile format. The attribute information of each 2D zones provides spatial development guideline such as the function of land or area, urban infrastructure, and the intensity of each zone such as coefficient of the building (KDB), coefficient of the floor (KLB), the height of the building (KB), and coefficient of a green area (KDH).
- 2D building parcels accessed from the official Jakarta city's geoportal and the National Land Agency (BPN), recorded as a polygon in 2D shapefile format. The original dataset is in 2D shapefile format, provided with the building height attribute. Therefore, a data conversion process has been conducted to convert the 3D map in shapefile into a 3D map in GeoJSON, which then later would be inserted to the dynamic map interface.

These 2D datasets were extruded based on their height value from the terrain elevation (set=0; assuming that the base map is in 2D) to gain a 3D visualisation. To simulate the 3D environment in a more realistic way, a sky atmosphere to the space above the mapping horizon was also added using Javascript.

With all these datasets in place, several map functionalities and interactions were developed using a custom script (Javascript) to facilitate the following user's involvement during the participation process:

- **View.** The view control refers to a set of map functionalities on adjusting the map camera for a better 3D navigation experience. This feature could be performed based on two interactions: by mouse and button. Through mouse interaction, the user can manipulate the angle and position of the map using their mouse button. Different functions were assigned to each button on a mouse for facilitating user experience. Mapbox provides these functionalities from default. The functionalities provided are: pan, zoom in and out, and rotate. Button interaction was also provided on the top right of the interface, consisting a of zoom in and out button and a compass. The compass button could manipulate the camera bearing with two modes: 1) single click to reset bearing to the north; and 2) click and hold to customise bearing angle. This feature was added by calling Mapbox API, which defines mapboxgl.NavigationControl plugin in Javascript.

- **Search.** The search box is a map function to allow the user to find a specific location quickly and easily. The search can be based on addresses, coordinates, name of places/landmarks. This function was added by callingMapbox Geocoding API through mapbox-gl-geocoder plugin inside Javascript, then adding map.addControl to display the search button on the interface.Based on the mockup design, the search function was positioned at the top of the map in order to be recognised easily by the user. The user could type an address, a coordinate, or place name; then the closest suggestion will show up. Once the user clicks on the desired suggestion, the map interface would zoom in and pinpoint to the targeted place. The pinpoint would automatically remove once the user clicked on the close (’X’) button.
- **Object selection.** Object selection refers to the user activity when clicking or touching a certain object on the map interface. In this case, the object selection is used to show attribute information of the selected area. The user is only able to click on the dataset layer: the spatial zone. To inform the user, the cursor style would automatically change to a pointer once it touches the datasets, then change back to hand when it leaves. This feature is crucial to avoid the user sending the wrong action to the map. This function was added using a custom script with map.getCanvas plugin from Mapbox API in Javascript.
- **Attribute information.** Attribute information shows the selected layer attribute that is already specified in. It is linked to the object selection function, making the selection action to become more convenient. By using this function, the user could get the administrative information to the area. This function gives an overview to non-expert users about what building type they can/cannot build in the specific area during the participation process.
- **Layer.** Layer is a function that helps the user switch on and off the visualisation of the dataset layers on the map interface. This functionality uses setLayoutProperty to toggle the visibility value of each layer between ’visible’ and ’none. This function is also added to the hidden sidebar activated when the user clicks on the ’Layer’ icon. Then, the user could show or hide the layer when the checkbox is checked.
- **Draw.** The Draw function is developed to simulate the traditional participation activity in Musrenbang. Instead of drawing or sketch on the map, the user can add a 3D building by simply clicking on one of the building options, similar to putting Lego on top of a map. This method is chosen to avoid any errors that might cause by using the sketching method: invalid geometry; polygon does not close, and others. In this case, the user can give a design idea in a straightforward visualisation in LoD1. However, it is important to note that this prototype aims to increase participation by expanding the non-expert user’s involvement during the design process.

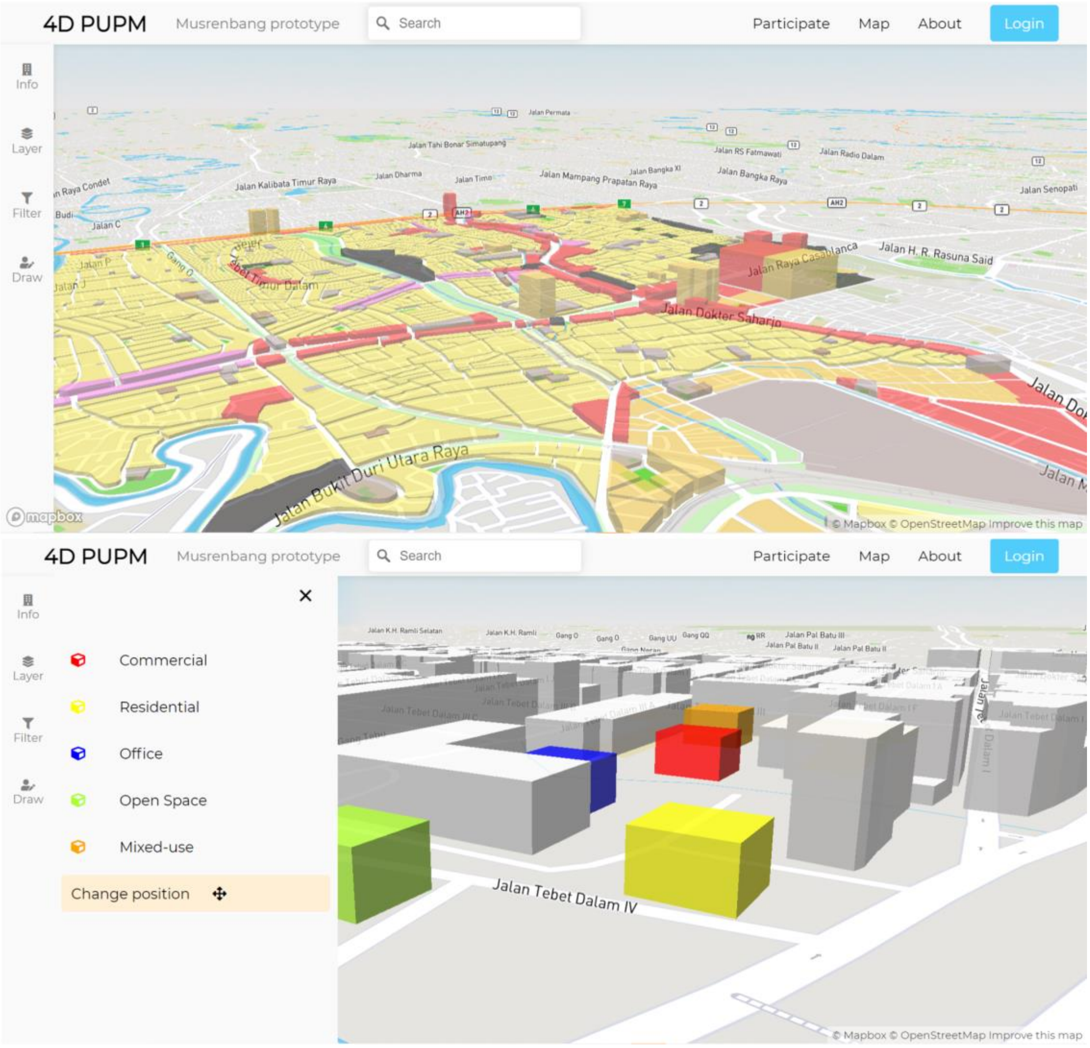

Figure 4. Data visualisation for 3D spatial plan (top) and 4D (3D + time) participatory activity (bottom)

The participation mechanism using these simplified 3D models is also very straightforward (Figure 4). The participant could click on the selected building function then position it on the map. The participation process itself is based on distributed-synchronous, meaning that each participant can simultaneously place the Model at the same time.

Therefore Phase 3 resulted in a prototype, which is called 4D Musrenbang, together with 7 functionalities. Some suggested functions like Filter, Input/Output, and Validation were decided not to be added due to bug issues and time constraints. This prototype is hosted in the Github repository, together with the mockup. It is also available to access via web on: https://nurannisam.github.io/4Dmusrenbang/.

3.2.4. PHASE 4: Testing the prototype

The user test aims to validate the level of participation and the prototype's usability for this research. The user test was taking place online using a video conference application (Zoom) and an online questionnaire. Even though the user test is a crucial step to measure the usability of the 4D PUPM prototype, some limitations need to be taken into account:

- The testing session was conducted in an artificial situation with time and place constraints due to the COVID-19 situation.
- The main goal of the user test is not focused on technological aspects.
- Different type of tests and participants might affect the result: different researchers have their own different methods - therefore, it depends on each individual's ability to identify which user test is the best to conduct.

In total, there were two sessions of the user test: a) pre-test (limited number of users and tests); and the final test. To get the result that fits the best to reality, the user test was performed with participants who matched the initial Persona: Planning Actor, GIS Actor, Layperson and Intermediary. Three participants were invited to the pre-test session, then became five participants for the final test. The users then were split into four study groups based on their Persona background. The participants come from different backgrounds. All participants agreed to share their background, experiences, and quotes during their testing process anonymous.

The users were given the following tasks
- Login according to your user role
- Access the 'Participate' map interface
- Search for an address
- Display information from 3D spatial plan layer
- Switch 3D dataset layer
- 'Draw' 3D building
- Move the added building

The user test has been carried out by inviting some participants related to the persona group. Then test session was started by doing a Persona validation test to see whether the hypothesis skills of the initial actor groups match with the participants. Then, the session continued with a task-based test, letting the participants interacted with the prototype and measured the usability metric based on the effectiveness, efficiency, and satisfaction. A semiconstructed interview was also done while the participants completed their tasks to get their opinion of what they felt when using the prototype. At last, post-interview and rating scale statements were asked to the participant to get how they felt after finishing the task.

Based on the test session, the value for each task were assigned to get a statement of whether the prototype is usable or not. Overall, the usability level of 4D Musrenbang is 71%, meaning that the prototype has successfully achieved this research aim. Although the test was limited, the conclusion, based on the calculation and general thoughts from the interview, designing GIS technology, especially geo-web, using UX could increase the usability and broaden the task experiences during the participation discussion.

4. CONCLUSIONS

Even though many researchers focus on establishing a higher accuracy for 3D spatial information, only a few researchers study how 3D geo-visualization can be developed towards a communication platform for citizens to provide content to planning and express their opinion about the spatial planning process. Meanwhile, designing user experience is a very long and iterative process. We constructed the 4PHASE toolkit to guide the design process of geo-web applications. Toolkit itself means guidance to help to maintain the consistency of participation and user-friendliness of the platform. The 4PHASE toolkit is consisting of four phases of the design methods.

- PHASE 1: Define. Participation is a multi-actors activity, meaning that all individuals with their skills and knowledge join forces in the decision-making activities. In order to make sense of the user roles and participation tasks in a hierarchical GIS process, creating a network of human-to-GIS using the ANT diagram is needed.
- PHASE 2: Design. Once the targeted user roles and tasks were discovered, this research explored user goals, skills, and frustration, then visualised these as the hypothesis personality (or referred to as Persona). The Persona were then grouped based on a group of people that share similar traits. After creating a persona, it constructed user roles, wireframes (sketches of web flow), and the interface. The result of this phase would be referred to as a mockup.
- PHASE 3: Build. In order to convert a mockup into high-fidelity geo-web, 3D spatial datasets and functionalities were fed into the proposed mockup using HTML, CSS, and Javascript. This was done by converting a mockup into a prototype so that users could use and interact with the platform.
- PHASE 4: Test. At last, to check whether the users could use the prototype, the phase was ended with the user test. During this phase, several users were invited to check and see whether the prototype's effectiveness, efficiency, and satisfaction.

Throughout these four phases of UX design, this research has successfully produced two main products: mockup design and geo-web prototype, which is called 4D Musrenbang - the main result of that the five user groups tested and evaluated the overall performance of the prototype as good. The research contributes to bridging spatial planning, GIS, and User Experience (UX) aspects to both Geomatics and its broader functionalities to the Built Environment, specifically to the urban planning formulation. Also, the position of citizens as active contributors toward spatial information was rarely explored before. The research about user experience (UX) for geo-web applications to enable active participation is still in the early stages. At last, the proposed 4PHASE toolkit and 4D Musrenbang as the prototype also could contribute in giving guidance to the design aspect of geo-web or other GIS-related applications with multiple users involved.

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BIOGRAPHICAL NOTES

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Requirements and Opportunities for Web-Based 3D Visualization and Dissemination of Property Valuation Information

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Key words: Property valuation, ISO 19152 Land Administration Domain Model (LADM), Valuation Information Model, 3D visualization, Dissemination.

SUMMARY

The timely and effective dissemination of property values is an essential part of a transparent and efficient property valuation system as property values are required in several land administration processes, such as land acquisition, taxation, transaction, consolidation, readjustment and transformation. In the last decade, a web-based data-sharing system has been increasingly used for dissemination of property values. The 3D visualization of valuation units may be required in order to better communicate with users and provide more effective and efficient dissemination, however, none of those systems share valuation information associated with 3D representation (legal or physical) of property (valuation) units.

The objective of this paper is to reveal the requirements, opportunities and challenges for web-based 3D visualization and dissemination of property valuation information. To deliver this objective, the requirements for U(ser), D(ata), and V(isualization) are investigated. The general public/property owners and professionals are determined as main user groups in this research. For each of the groups specific data and 3D visualization requirements are discussed and a number of suggestions are provided for developing an effective dissemination of property valuation information. These requirements includes the visualization of multi-part properties (e.g. condominium unit, storage unit, car parking), thematic mapping of valuation information, and aggregation of valuation units into valuation units groups. Furthermore, the capabilities of the LADM Valuation Information Model as a schema for storage, and the features and functionalities of 3D visualization platforms (geoweb viewers) in terms of better value dissemination (e.g. altering visual variables, solution for occlusion, visualizing below surface properties) are briefly investigated. Lastly, an initial prototype is developed and presented.

Requirements and Opportunities for Web-Based 3D Visualization and Dissemination of Property Valuation Information

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1. INTRODUCTION

Immovable property value is a key component of land administration systems (UN-Habitat 2021), as it is important for effective land acquisition, taxation, transaction, consolidation, readjustment, transformation and so on. Timely and effective dissemination of property values as well as input information related to valuation processes to general public is an essential part of a transparent and efficient valuation system. Lozano-Gracia et al. (2013), for example, stated that urban transformation is most efficient when land markets are grounded in strong institutions that enable public dissemination of property values across users. Furthermore, the New Urban Agenda encourages the use of geospatial visualization opportunities for dissemination of timely and reliable geospatial information (UN, 2016).

Dissemination of input and output data related to property valuation processes is of vital importance for market transparency and reliability. While input data for valuation is likely to include transaction prices (e.g. sale price), sales statistics, and legal, locational and physical property characteristics; the output data is estimated (assessed) values.

In the last decade, valuation information is increasingly disseminated in digital form through the Web. According to the respondents of a questionnaire (isoladm.org, 2017), which was conducted for creating a worldwide inventory revealing commonalities and differences among property valuation systems, a web-based data-sharing mechanism has been used for dissemination of property values (to all public or only to owner of property) in several countries (e.g. Cyprus, Denmark, Singapore, Slovenia, Spain, the Netherlands and the United Kingdom). It should be noted that none of those web-based mechanisms (systems) share valuation information associated with 3D representation (legal and/or physical) of property (valuation) units. In the Netherlands, for example, assessed values together with valuation dates and some characteristics (e.g. construction year, property function/type, floor size) of residential properties are publicly disseminated through footprints of apartment buildings (see 'WOZ-waardeloket' - https://www.wozwaardeloket.nl/). However, visualization of 3D valuation units may be required in order to disseminate valuation information more effectively and efficiently.

Current property valuation practices seem not to be significantly benefiting from semantically rich 3D building and cadastral models (Isikdag et al., 2014; Cagdas et al., 2016; Kara et al., 2020; Ying et al., 2021). They can be, for example, utilized to obtain characteristics of valuation units in order to improve the results of valuations. Moreover, as 3D building and cadastral models include physical and legal boundaries of property units, they can be used for disseminating of valuation information more effectively. In other words, an identical and/or modified version of a 3D cadastral prototype can be used for disseminating property valuation information. In fact, some of recently developed 3D cadastral prototype examples include value as a characteristic of property units. However, it was not researched whether an identical or a modified version of a 3D cadastral prototype can be considered as an effective tool for dissemination of valuation information.

To the best of authors' knowledge, there is no prototype system designed for effective dissemination of valuation information through 3D valuation units. Moreover, the requirements and possibilities to develop an effective dissemination system for valuation information were not investigated. The objective of this paper is to reveal the requirements, opportunities and challenges for web-based 3D visualization and dissemination of property valuation information. To achieve this goal, the studies specifying the requirements for the purpose of developing a 3D cadastral prototype are firstly analysed in Section 2. Subsequently, specific requirements for visualization and dissemination of valuation information are researched in Section 3. In this phase, a number of suggestions are provided for developing an effective dissemination of property valuation information. Moreover, the capabilities of LADM Valuation Information Model as a schema for storage, and the functionalities of 3D visualization platforms (geoweb viewers) in terms of better value dissemination are also briefly investigated in the same section. The conclusions are given in the last Section.

2. OPPORTUNITIES AND REQUIREMENTS FOR WEB-BASED 3D VISUALIZATION AND DISSEMINATION

Valuation processes require correct, complete, and up-to-date information related to property units (International Association of Assessing Officers – IAAO, 2013). This information includes legal, geometric, physical, locational and environmental characteristics of property units combined with transaction prices. It should be noted that the land and building property rights to be valued is the fundamental and indispensable information for valuation processes (IAAO, 2014). Therefore, it can be stated that land registry and cadastre are the main data sources for valuation processes, as they record the rights, restriction and responsibilities (RRRs) and their associated spatial units. In fact, the concept of cadastre emerged for taxation purposes and its aim was to record the land values of spatial units subject to land tax and to identify the related taxpayers (Silva and Stubkjær, 2002). However, it developed from being a fiscal cadastre primarily as a basis for property valuation and taxation to a legal cadastre late in the 1800s (Enemark and Sevatdal, 1999). Today’s cadastral systems may serve legal purposes or legal and fiscal purposes. Today’s cadastral systems generally store boundaries of property units in 2D and it’s legal information, whereas today’s valuation processes also require 3D property units with detailed characteristics (Cagdas et al., 2016).

In the last decade, several visualization and dissemination prototype systems have been developed for 3D cadastres providing some advantages over 2D, such as better support for complex multi-level properties, more realistic view of real world and more effective communication with users (Pouliot et al., 2018). In some cases, a 3D cadastral visualization prototype can be directly utilized for disseminating valuation information. However, this is not always the case. In some countries, the basic legal units may differ from the basic valuation units (Cagdas et al., 2016). Additional specific features and functionalities may be required to disseminate valuation information more effectively. The requirement analyses conducted to develop a 3D cadastral visualization prototype system can be adapted for design and development of a prototype for valuation information, because they are using identical or very similar spatial units (e.g. parcel, building, condominium, accessory part).

Several studies investigated the visualization requirements for 3D cadastral systems (Shojaei et al., 2013, 2015, 2018; Wang, 2015; Pouliot et al., 2018; Cemellini et al., 2020). Those studies were selected for this research based on expert consultations and recommendations. Table 1 presents the selected 3D cadastral visualization requirements that are compiled from Pouliot et al. (2018), Shojaei et al. (2018) and Cemellini et al. (2020). Pouliot et al. (2018) grouped the requirements into three categories, namely users and user requirements, information to visualize and semiotic/rendering aspect, and visualization platform.

Table 1. Requirements for 3D cadastral visualization

Users and user requirements	- Property registration authorities, lawyers, notaries, engineers, architects, developers, real estate agents, surveyors, general public, etc. - Descriptions of 3D geometric boundaries of property units (e.g. physical and legal spaces and boundaries) can be included and identified - Private and common parts in 3D co-ownership apartment buildings can be distinguished and represented - -D measurements can be performed and processed - Geometry and characteristics can be queried and compared - Interactive 3D user interface is available - Interoperability with other applications (e.g. property valuation) can be supported
Data and semiotics	- Descriptive and/or legal documentation (e.g. data sources) can be included - Temporal aspects of property rights can be managed - Annotations, labelling, and characteristics are supported in a flexible way - Setting graphic visualization is supported (e.g. colour, texture and transparency) - Highlighting techniques (e.g. slicing, cross-sections, wireframe, explode view, discretization) are available
Visualization platforms	- Platform support: Web/desktop, virtual/augmented reality, game engines, open/proprietary, fully functional editing/basic visualization only - Functionality of the platform include zoom in/out, pan, symbol, colour, line style, thickness, transparency, shadow effect, navigation, tooltip, spatial search, attribute query, spatial analysis, underground view, handling massive data)

The first question that arises in defining the requirements of a visualization and dissemination prototype is “who are the users?” (Pouliot et al., 2018; Shojaei et al., 2018; Cemellini et al., 2020). The property registration authorities, lawyers and notaries are specified as the main user groups for 3D cadastral visualization systems in the selected studies. In accordance with the needs and demands of the user groups, the 3D visualization requirements can be specified.

Describing 3D legal boundaries of property units (e.g. parcel, building, and condominium) is specified as the main aim and the initial requirement for a 3D cadastre. Moreover, the boundaries of private and common parts should be properly distinguished in case of apartment (condominium) buildings. Performing and processing of 3D measurements, spatial analyses and querying geometries and attributes of property units is required. For these analyses and queries, the physical boundaries and characteristics of a building are often of the same importance as the legal boundaries of the parcel on which this building is built. Therefore, it is expected from a cadastral visualization prototype to have such features, and to show the results of demanded analyses.

Next appropriate data sources need to be determined. Various data sources have been used to get 3D volumetric objects. However, creation and maintenance of a valid 3D cadastral object is a challenge in practice (van Oosterom, 2013; Ying et al., 2015). Architectural drawings have long been used to represent apartment complexes in cadastral systems (van Oosterom et al., 2018). Meulmeester (2019) compared the use of 3D BIM/IF to the use of 2D drawings of floor plans in the notarial deed to define 3D legal spaces for apartment rights in the Dutch cadastre. Višnjevac et al. (2019) utilized the drawings of floor plans and cross-sections as data source. Similarly, Atazadeh et al. (2017) used 2D architectural floor plans and cross-section diagrams to create 3D building elements (e.g. walls, doors). It is expected that in near future these architectural floor plans as a base for the 3D system for new buildings can be substituted by BIM-models. However it is frequently the case that the implementation of the design in reality differs from the design in architectural drawings (van Oosterom et al., 2018). Therefore, ‘as-designed’ models should be verified after construction since ‘as-built’ models provide ownership boundaries in the real world (Atazadeh et al., 2017).

On the other hand, a number of studies directly utilized surveying data as input for creating 3D cadastral objects. For example, 2D survey plans that provide implicit information to build a representation of 3D cadastral spaces were used by Ying et al. (2011). The information in survey plan documents was converted into 3D geometry as collections of polyhedrons by Cemellini et al. (2020) to develop a LADM compliant dissemination and visualization system for 3D spatial units. Moreover, Li et al. (2016) used 2D layout plans to model the ownership structure of condominium units in 3D. Besides spatial information, the textual (descriptive) characteristics of property units can be extracted from legal documents, such as floor areas, co-ownership shares and use/function type(s). The descriptive information can be visualized as a characteristic associated with relevant property units, using lists, labels, and annotations. It should be indicated that a suitable data schema is required to store both spatial and textual data. For this purpose, ISO 19152:2012 Land Administration Domain Model (LADM) compliant data schemas (an extended version of the LADM with country specific situations) were generated in recent studies (Meulmeester, 2019; Cemellini et al., 2020; Alattas et al., 2021). It is noted that in order to improve the communication level with the users, different highlighting techniques (e.g. slicing and explode view), visual variables (e.g. colour, transparency) and cadastral symbols may also be required (Pouliot et al., 2018).

The last category is on the selection of a suitable visualization platform, considering the above-mentioned requirements of 3D cadastral visualization. Data, users, and usages are important factors to be considered in choosing a visualization technique (Shojaei et al., 2013). In order to display 3D cadastral objects to users, different display modes can be selected, ranging from those available on desktops, standard computers (e.g. gaming engines) or mobile devices (such as a tablets through augmented reality) to those requiring very specialized hardware (Pouliot et al., 2018). On the other hand, web-based display solutions for 3D cadastral visualization prototype systems have been identified as an important visualization requirement among end-users, such as general public and land surveyors (Shojaei et al., 2015). A number of studies investigated the 3D web-based visualization platforms in terms of identified requirements. For example, Shojaei et al. (2013) compared desktop and web-based visualization platforms, while Shojaei et al. (2015) evaluated common 3D web-based visualization solutions, including Web Graphics Library (WebGL) solutions. Moreover, Cemellini et al. (2020) investigated the existing WebGL platforms (e.g. iTowns, Cesium JS, OSM Buildings, WebGL Earth, GeoBrowser 3D, ESRI CityEngine) for developing a 3D cadastre prototype.

WebGL is a royalty-free web standard for a low-level 3D graphics application programming interface (API) (Kronos, 2021). It enables web content to use an API based on the OpenGL for Embedded Systems (GLES) to perform 3D rendering in an HTML canvas in browser. A big advantage of WebGL is that it brings 3D to the Web without any third party plugins since most browser vendors are member of the related WebGL Working Group (Kronos, 2021). As WebGL is a low-level JavaScript API, designing an elementary 3D geometry needs a lot of work; therefore, various open source JavaScript libraries and platforms have been developed to make it easy to use (Shojaei et al., 2015).

From investigation of the recently developed 3D cadastral visualization prototype systems, it is clear that WebGL based libraries and platforms are preferred increasingly. Shojaei et al. (2015, 2018) utilized the Three.js library for developing a 3D visualization prototype. Among the WebGL libraries, CesiumJS is increasingly being used in the cadastral domain (Meulmeester, 2019; Višnjevac et al., 2019; Cemellini et al., 2020; Olfat et al., 2021). It supports 3D tiles enabling to stream massive 3D geospatial data (CesiumJS, 2021). Cemellini et al. (2020) indicated that in addition to being cross-platform and cross-browser, the existence of a big community supporting developers is an advantage of CesiumJS. It should be noted that all functions given in the Table 1 are supported by CesiumJS (e.g. underground view functionality was recently added).

3. SPECIFIC REQUIREMENTS FOR 3D VISUALIZATION AND DISSEMINATION OF VALUATION INFORMATION

To specify specific requirements and extra functionalities of an effective and web-based prototype system for 3D visualization and dissemination of valuation information, the user approach as from the previous section is also followed here. The initial step of the user approach is to determine the users. In our case, main users are considered the appraisers performing private or public valuations and the customers of these valuations, therefore, requirements are specified for the public dissemination of valuation information. These user groups have no specific experience with using 3D models and can therefore be dealt with as "the general public". The importance of 3D systems and 3D data for valuation and mass valuation will grow because of the development of new valuation methods based on Artificial Intelligence (AI). These AI-models make it possible to use the data from the 3D comparison in the estimation of the value.

Similar to the investigated 3D cadastre prototype systems, legal boundaries of valuation units have a great importance for an effective 3D visualization and dissemination of valuation information. Distinguishing private and common parts (spaces) in condominium buildings is another crucial requirement. Moreover, each part of a multi-part property (e.g. condominium unit, storage unit and car parking) should be clearly identified as they may have a separate value. Figure 1 presents an example illustrating the legal spaces (i.e. private, common and accessory) of a condominium unit within a condominium building. It is noted that 3D city and/or building models can also be used to share values of units (e.g. when the basic registration units of a cadastral system are different from the basic valuation units). On the other hand, it should be stated that having option to visualize both legal and physical spaces of valuation units in the same prototype system would further support effective dissemination.

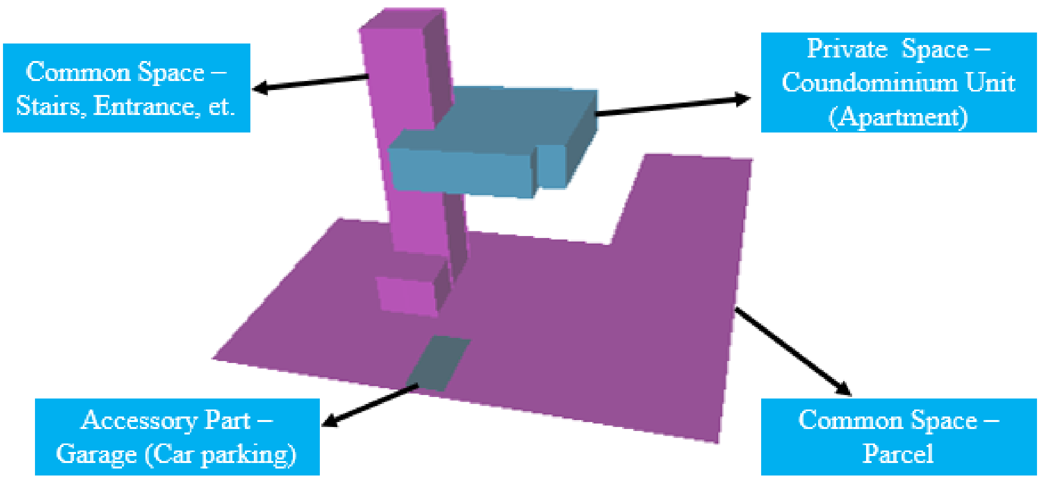

Figure 1. Legal spaces of a condominium unit

In the user requirement phase, the characteristics to be shared should also be determined. The main characteristic to be disseminated is the value of property units. Several different value types (e.g. tax value, investment value, registered value) can be shared via a prototype. However, sharing market value may be preferred over the other value types as the market value can be utilized in different applications which make the dissemination more efficient. The date of valuation can be considered as one of the indispensable characteristics to be shared together with the value. Sharing time series of values of valuation units and valuation unit groups is also expected in an effective prototype.

The valuation units can be aggregated according to use type (e.g. residential, commercial, retail, etc.) and valuation unit group type (e.g. single unit, building, street, neighbourhood, city district, and city) (see Figure 3). Aggregating valuation units into groups (total value of the group, average value per unit within the group) can be considered as the implementation of the level of detail concept in visualization and dissemination of valuation information. At all designated levels, valuation units can be firstly grouped according to use types, and for each use type, for instance the minimum, maximum and average values can be shared.

For the purpose of transparency and accuracy, it is required to disseminate the internal and external property characteristics that are used when calculating values. According to Sirmans et al. (2005), the most frequently utilized internal characteristics in valuation models are building age, floor area, parcel size and accessory parts (e.g. garage space). Therefore, it is needed to include and disseminate those characteristics. By sharing the mentioned characteristics to the public, possible incorrect inputs in calculated values can be eliminated and valuation results may be improved. For the same reason it can also be beneficial to include market data such as sales prices and date of sale in the system. Some of the external property characteristics may also be disseminated as textual data, such as view and distance to important points of interest. A better alternative to this is to develop a prototype that can perform dynamic 3D view and distance analyses. In such a prototype, it is possible to visualize the air space of properties through performing 3D measurements.

After the specification of users and their requirements, appropriate data sources can be determined. Similar to 3D cadastral prototype systems, cadastral plans, surveying plans, floor plans and architectural drawings (or when available BIM models of the buildings) can be utilized to represent valuation units in 3D. The required property characteristics determined above can also partly be derived from those plans and drawings. The actual challenge here is finding ways to visualize all valuation units in 3D, for example, in a neighbourhood or a district. According to the required spatial and textual data specified above, a suitable data schema (application schema) should be produced in this phase. Since the only information model that refines RRRs is the LADM, the data schema should be compliant with it. The LADM can be combined with building models if physical spaces of valuation units are desired to be included in the visualization and dissemination prototype. It should be noted that all the required characteristics of valuation units specified above (e.g. building age, floor area, accessory parts, view, distance) are included in the LADM Valuation Information Model (Kara et al., 2020). Moreover, it covers detailed definitions on valuation units, valuation unit groups and types of usages. Therefore, an extended version of the LADM Valuation Information Model (i.e. country profile) can be directly utilized as a schema for storage of all input and output data used and produced in valuation processes. It can also be used as basis for visualization of legal spaces of 3D valuation units as it is based on the LADM (Kara et al. 2021).

Selecting a visualization platform (geoweb viewer) that conforms to the requirements is the last stage of the user approach. Only WebGL based tools are evaluated in this stage (e.g. CesiumJS, OSM Buildings, ESRI CityEngine, iTowns,) as the aim of this research is to find an appropriate, web-based solution for visualization and dissemination of valuation information. The following aspects are considered as being important when selecting the viewer:

- support for altering visual variables (e.g. colour and transparency) to create coloured 3D valuation maps,
- support for thematic mapping and animations to enable effective dissemination of valuation information,
- support for visualizing below surface properties to identify valuation units below ground level,
- provide some solutions for occlusion to identify valuation units in complex buildings,
- support for 3D measurement to perform spatial analyses (e.g. view),
- support for 3D Tiles to stream massive amounts of data.

According to the above criteria, two geoweb viewers (renderer) came forward, namely CesiumJS and NASA-AMMOS/3DTilesRendererJS. In our case, CesiumJS was selected for visualization and dissemination of valuation information since:

- it provides a complete and end-to-end platform for visualizing, tiling, and analysing 3D geospatial data,
- 3D Tiles formats are also developed by the same group,
- it provides opportunities with 3D analysis tools for distance and area measurement, line of sight, viewshed and visibility analysis,
- it supports time dynamic visualization by means of the CZML format,
- it is widely used in the domain of land administration, it is used by a large group of users.

After the users, users' requirements, data sources, schema for storage and appropriate geoweb viewer are determined, the obtained information is used to create a web-based 3D visualization and dissemination prototype for valuation information. Figure 2 shows a CesiumJS based LADM Valuation Information Model compliant prototype system for valuation information (see: http://3d.araziyonetimi.org/). The legal spaces of valuation units can be identified with the prototype. Moreover, it is possible to distinguish private and common parts of a building. When hovering over a condominium unit, the colour of the accessory part of it (in this case a garage) is automatically changing. When clicking on a condominium unit, valuation information related to the selected unit appears as a table on the left side of the screen.

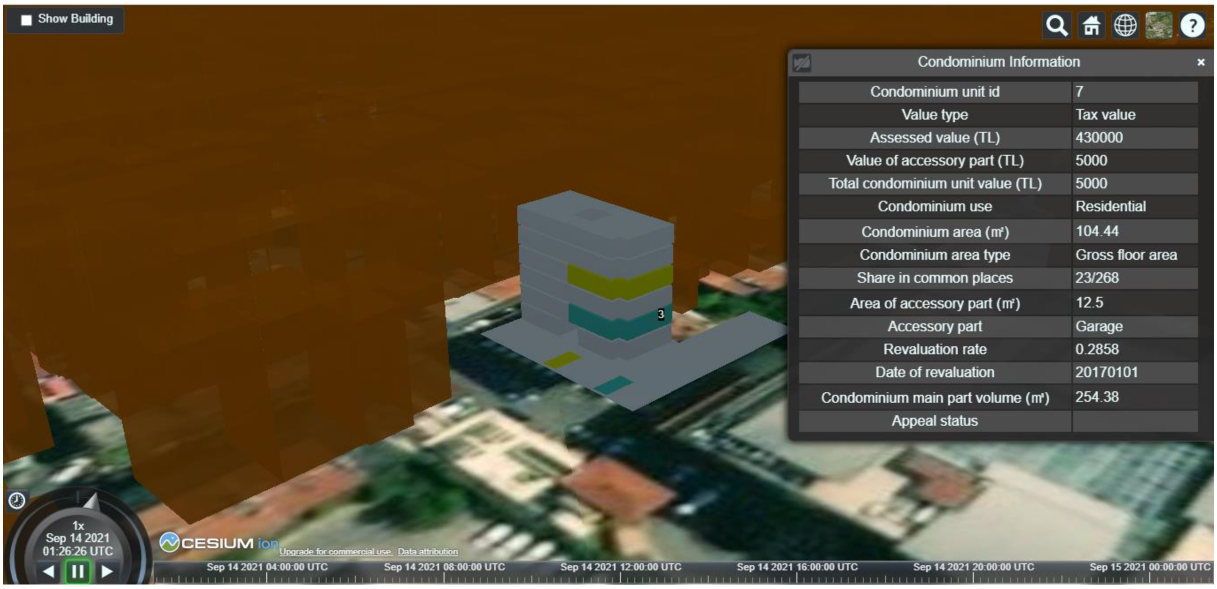

Figure 2. A web-based 3D visualization prototype for disseminating LADM Valuation Information Model compliant valuation information

Besides valuation units, valuation unit groups are also refined in the LADM Valuation Information Model. An application schema that is developed has the capability to store valuation unit groups.

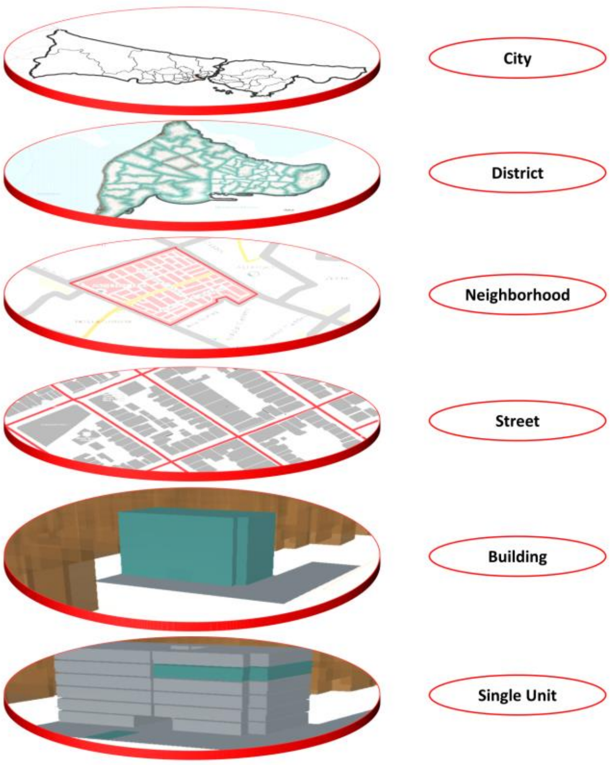

Figure 3. Aggregation of valuation units into valuation units groups

The prototype presented above can also be used to visualize different aggregations of valuation units, if appropriate rules are defined in the prototype. Figure 3 shows a possible classification for the aggregation of valuation units into valuation units groups. It should be noted that since there is not enough data, not all the levels given in Figure 3 are implemented in the prototype.

In Figure 4, the developed prototype is used to create a 3D valuation map for a neighbourhood in accordance with the values of a specific valuation date. The values coloured are aggregations of values of all condominium units in one building (average values can alternatively be used). It should be noted that the building marked with a green circle contains the condominium unit with the highest tax value.

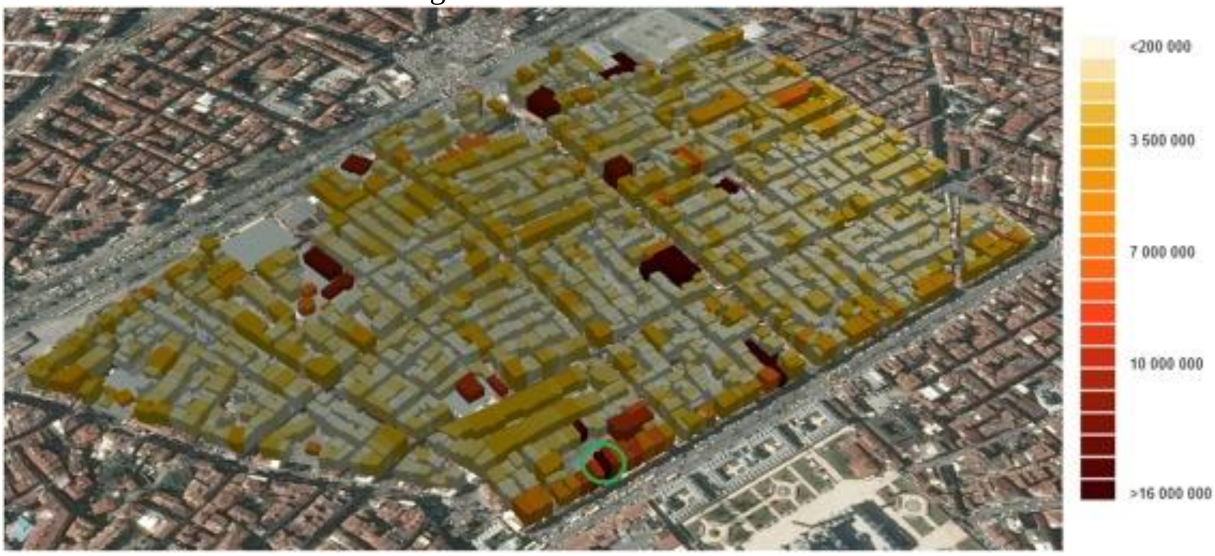

Figure 4. A web-based, 3D and LADM Valuation Information Model compliant valuation map of a neighbourhood (Kara et al., 2021)

4. CONCLUSION

Complete delivery of the 3D land administration theory, together with its practical implementation, is a multi-disciplinary problem (van der Molen, 2002; van Oosterom et al., 2020). One component of this theory is property valuation and this paper focuses on 3D visualization and dissemination of valuation information.

Developing a web-based system for visualization and dissemination of 3D valuation units and their characteristics is a challenging task. To support this task, the defined problem in this paper, which is to search the requirements, opportunities and possibilities for developing a web-based 3D visualization and dissemination system for property valuation information, is broken down into small steps. In the first step, the experience gained from the studies that developed a 3D cadastral visualization prototype are investigated. Subsequently, this experience is applied to valuation information. The general public, without specific experience with 3D models is selected as main user group. This group includes valuers for private valuations and mass valuations as well as their clients. After that the requirements for this user group is discussed together with possible data sources. The requirement analysis shows that the LADM Valuation Information Model compliant schema can be used for data storage and visualization. In the last step, considering the specific functionality requirements, geoweb viewers are investigated and CesiumJS was selected as an appropriate option.

The paper makes a number of suggestions for effective visualization and dissemination of valuation information, such as aggregation of valuation units into groups (e.g. level of detail in visualization of valuation information). Finally, taking into account the requirements analysis, a prototype system is developed and presented. However, it should be noted that the developed prototype is not completed yet and there is a lot still to be done. For example, the prototype system should be enriched with some functionalities and needs to be tested with a more complete dataset.

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BIOGRAPHICAL NOTES

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New Trends in 3D Cadastre Research - a Literature Survey

Jesper M. PAASCH, Denmark/Sweden and Jenny PAULSSON, Sweden

Key words: 3D cadastre, 3D land administration, literature survey, marine space, valuation, BIM, 4D cadastre

SUMMARY

During the last decade, several literature surveys on trends in 3D property research have been published. The latest publication is Paasch and Paulsson (2021), examining 530 research related publications from 2012 to 2020. It showed that 3D cadastre publications mainly have focused on technical and registration issues, even if there is an increase in research concerning legal and organizational topics compared with a similar survey from 2013. The Paasch and Paulsson (2021) survey identified some 3D cadastre topics that have gained increased focus during the investigated period but were not analysed in detail in the study. These research topics are investigated further in this paper. The topics are analysed in the same manner as in the 2012 and 2021 surveys, i.e. classifying them into Legal, Technical, Registration and Organizational classes. The publications are part of the 2021 study but are analysed more in detail in this paper in relation to some of the topics.

This paper is an addition to this study where we have identified areas that we think should be of interest for further research, but not yet investigated in detail. These areas are BIM (Building Information Modelling), 4D cadastre, marine and water applications, and valuation. Out of the 530 publications in the Paasch and Paulsson study, 22 publications were identified as BIM related, 11 as 4D cadastre related, 11 related to marine and water applications, while 8 publications dealt with valuation topics. The paper shows that there seems to be an increased interest for the presented themes, but it is too early to say whether they all are part of trends in 3D cadastre research or whether they are only expressing temporary interests as such for the 3D cadastre community.

New Trends in 3D Cadastre Research - a Literature Survey

Jesper M. PAASCH, Denmark/Sweden and Jenny PAULSSON, Sweden

1. INTRODUCTION

During the last decade, several literature surveys on trends and development in 3D property research have been published. The first study, to our knowledge, was an initial study on the occurrence of legal topics in publications by Paulsson and Paasch (2013), followed by an analysis and classification of 3D research topics by the same authors (Paulsson and Paasch, 2013), also from a legal perspective. Other literature studies on 3D cadastre research during the period are Döner (2021) and Tekavec et al. (2018). The latest publication is, to our knowledge, Paasch and Paulsson (2021) conducting a follow-up study of the eight years that have passed since the 2013 survey covering 2001-2011. Paasch and Paulsson (2021) examined 530 research related publications from 2012 to 2020. The study showed that 3D cadastre publications mainly have focused on technical and registration issues, even if there is an increase in research concerning legal and organizational topics compared with the 2013 survey.

In our previous studies, we have seen that there are some recurring themes and topics in the published research. We thought that it would be of interest to study these research topics more in detail in order to find out what is included in them, where the 3D cadastre research seems to be heading in these fields, and what could be interesting to study and develop further. We chose these topics among those identified in the Paasch and Paulsson (2021) survey, which identified some 3D cadastre topics that have gained increased focus during the investigated period but were not analysed in detail in the study. They are, for example, marine and water applications, valuation, Building Information Models (BIM) and 4D cadastre. These research topics are investigated further in this paper. The topics are analysed in the same manner as in the 2012 and 2021 surveys, i.e. classifying them into Legal, Technical, Registration and Organizational classes. The included publications are part of the 2021 study but are analysed more in detail in this paper in relation to some of the topics.

The aim of this paper is to identify and describe some recent trends in 3D property research, based on a literature survey of publications on 3D property research from the years 2012-2020. The purpose is not to make a full identification and description of all current trends, nor to outline future trends in 3D property research, but rather to show examples of recent trends issues, their contents and other aspects that could be of interest. We noticed that sub-topics appeared with some regularity in the survey and we judged it to be of interest for the scientific community to present a first, preliminary analysis of them to describe some possible current trends in 3D cadastre research. Examples are picked from the publications found in the mentioned literature survey, although there is much more ongoing research.

2. LITERATURE SURVEY

The literature survey by Paasch and Paulsson (2021) made a classification of the surveyed publications into the main groups; legal, technical, registration and organizational. Of the total of 530 publications identified during the analysed years, 77 publications were assigned to the legal category, 254 to the technical category, 165 to the registration category and 25 to the organizational category. The survey also showed that many of the publications could be assigned to more than one of the main categories. The study also investigated the occurrence of some sub-themes such as visualization and standardization. Furthermore, the results were compared with the previous study by Paulsson and Paasch (2013) of the years 2001-2011.

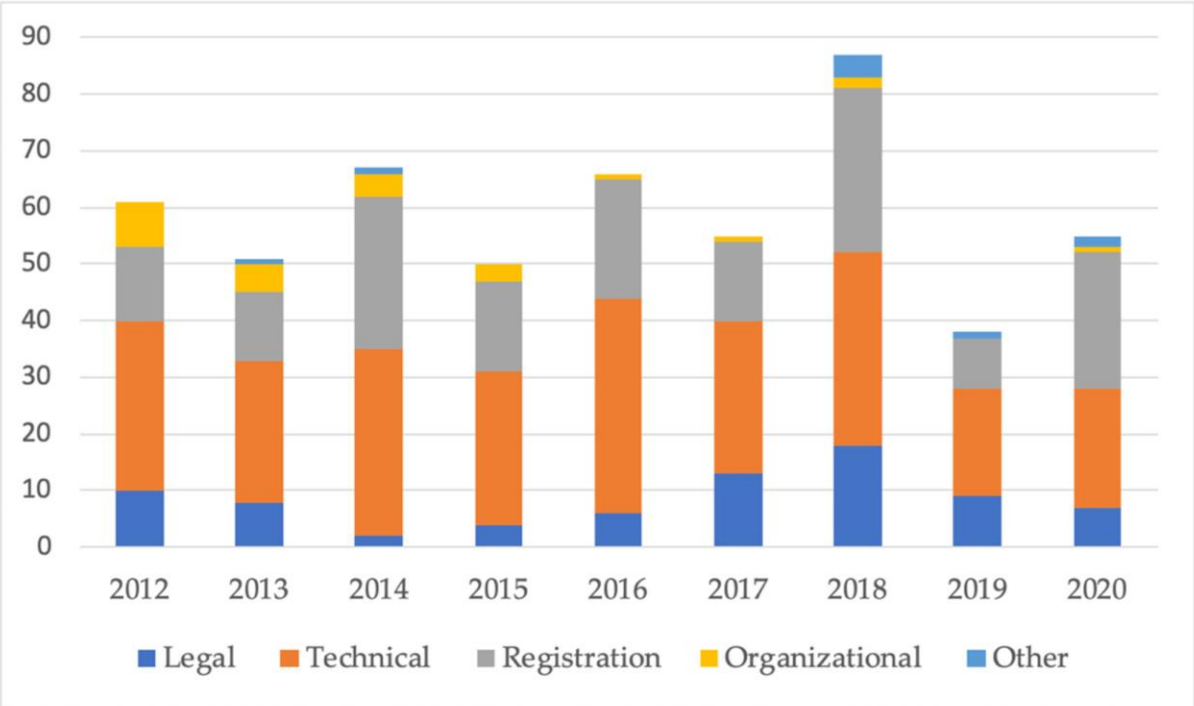

Figure 1. Distribution of main topics in the Paasch and Paulsson survey. Paasch and Paulsson (2021)

This paper is an addition to this study where we have identified areas that we think should be of interest for further research, but not yet investigated in detail. These areas are BIM (Building Information Modelling), 4D cadastre, marine and water applications and valuation. Out of the 530 publications in the Paasch and Paulsson study, 22 publications were identified as BIM related, 11 as 4D cadastre related, 11 related to marine and water applications, while 8 publications dealt with valuation topics. The contents of the selected areas are presented more in detail below.

2.1 BIM

BIM is a relatively modern process for generation and management of digital representations of physical (and e.g. legal and other functional) characteristics of geographic objects. The BIM principle is based on digital information being collected and maintained by numerous stakeholders during the project lifecycle. A number of countries are active within this research topic, such as Australia, the Netherlands, Greece, Croatia, Turkey, Korea, Sweden, Malaysia and Kosovo.

The publications cover a wide field of activities, such as the use of BIM as a tool for property formation, registration and visualization of cadastral information. It is the largest category in the survey with 22 publications, with the first identified 3D cadastre BIM publication in 2014 (El-Mekawy et al., 2014), followed by 1 to 6 publications per year the following years and covering a number of topics. For example, case studies were made concerning the development of a 3D underground cadastral system with indoor mapping for as-built BIM, which has been described in a case study of Gangnam Subway Station in Korea by Kim et al. (2015). Another example is the development from 2D representation of the buildings into cadastral maps towards 3D GIS applications and BIM in Pristina in Kosovo (Loshi, 2018).

Further examples are strategic lessons learned on 3D enabled urban land administration from a BIM initiative in Singapore (Ho et al., 2016) and the description of a BIM-based approach for Swedish 3D cadastral management (Sun and Paulsson, 2020). Considering the classes presented in Paasch and Paulsson (2021), the largest group (9) of the BIM publications belong to the technical class, while six of them can be classified as registration, five as legal and two publications belong to the organizational class.

The publications listed above are representative for the majority of the 22 publications identified as belonging to the BIM theme. Focus in the publications is also on modelling, such as the comparison of three types of BIM-based models for managing 3D ownership interests (Atazadeh et al., 2016), and extending a BIM-based data model to support 3D digital management of complex ownership spaces (Atazadeh et al., 2019). Other topics are the use of open BIM standards to source legal spaces for a 3D cadastre (Oldfield, 2017), how BIM can be used to visualise 3D property (Andree et al., 2018), and using 3D BIM modelling for value-based land share calculations (Simsek, 2017). Further examples are BIM-enabled spatial queries for retrieving property boundaries (Barzegar et al., 2020) and the feasibility to use a BIM-driven approach to support building subdivision workflows (Olfat et al., 2019), providing a mechanism for stakeholders to document, visualize, analyze, share and reuse 3D digital cadastral data.

2.2 4D Cadastre

The 4D cadastre topic focuses on the development of the concept of 3D cadastre by adding a time element. 4D cadastre is, in principle, identical to 3D cadastre but with a time component added. The 11 publications originate from a number of countries active within this research topic, such as Australia, the Netherlands, Turkey, Hungary, China, Indonesia, Argentina, Croatia and Indonesia. One example is Suhari et al. (2020) describing the implementation of the concept of 4D cadastre for land disputes and natural disasters, such as earthquakes, where time is a vital factor for managing these man-made or natural changes in the nation's land management system(s). Another example is Thompson et al. (2019), who discusses the implementation of a data schema for 4D/5D cadastre. They believe that there is a need for time-related information in the cadastre, such as being able to track patterns of subdivision and land use through the past.

The 11 publications identified in the study that belong to this category describe different aspects of 4D cadastre. The identified publications are rather evenly distributed through the investigated period with one publication per year during the first 7 years, except in 2016 where we did not identify any publication focusing on 4D cadastre. The years 2019 and 2020 showed a small increase in publications to 2 and 3 annually. It would make no sense to analyse these few publications statistically, but they may be indicative of coming research interests concerning 4D cadastre. Examples are data and implementation issues from conventional systems to multipurpose 3D and 4D cadastral systems (Paixao et al., 2012). Considering the classes presented in Paasch and Paulsson (2021), the majority (6) of the 4D cadastre publications belong to the registration class, while four of them can be classified as technical and one publication in the organizational class. We did not identify any 4D cadastre publications belonging to the legal class.

A topic within the 4D cadastre area is national studies on implementations of 4D cadastre, such as in Croatia (Vucic et al., 2014), Germany (Seifert et al., 2015) and the conformity of LADM for modeling 3D/4D Cadastre situations in Turkey (Döner and Biyik, 2013). Other topics are LADM related, such as the implementation of an LADM versioned object class for representing spatio-temporal 4D objects (Sulistyawati et al., 2018).

Constructing topological models for three-dimensional and dynamic cadastral management systems based on generalized maps are also focused upon in the studied research, see e.g. Ding and Shao (2020).

2.3 Marine and water applications

The marine and water applications topic is focusing mainly on the different issues that affect the construction of a 3D LADM compliant marine and water cadastre, such as legal and technical aspects, as well as developing an institutional framework and administration system. Out of the 11 publications that were identified in this area, they were distributed rather evenly between the years in the studied period. A few countries are active in this research topic, from countries such as Trinidad and Tobago, Greece, Argentina, Malaysia, Ukraine and Poland. Considering the classes presented in Paasch and Paulsson (2021), the majority (7) of the marine publications belong to the registration class, while two of them can be classified as organizational and one publication each in the legal and technical classes.

The publications present research on different aspects of marine and water applications. The concept of using water cadastre as a subsystem of the 3D cadastre by investigating the contents of water cadastre databases in Poland and possibilities of using them in building the 3D cadastre is also discussed (Mika et al., 2018). The authors present a Real Estate Cadastre model based on synchronisation of the Land Register databases with the water cadastre databases carried out in District Water Management Boards. Hisham Omar et al. (2015) present the Malaysia perspective on sustainable marine space management and propose a method of implanting marine space governance. Dubnytska et al. (2018) discuss 3D cadastre as a tool for water bodies account, analysing the problems of cadastral systems in Ukraine and providing examples of water objects representation in a three-dimensional geoinformation environment. Alberdi et al. (2018, 2020) address modelling of legal land objects for water bodies in the context of 4D cadastre, i.e. considering the time aspect. They describe rivers as legal land objects in the 4D cadastre and evaluate the need to implement multidimensional registers with the example of the Argentine cadastre.

A related question is how the international standards and practices of the land administration domain can be used for managing the marine environment. Sutherland et al. (2016) study the development of LADM-based marine cadastres and assess how applicable LADM as a published cadastral data standard is to marine cadastres. Griffith-Charles et al. (2014) examine the different issues that affect the construction of a 3D LADM compliant marine cadastre in Trinidad and Tobago, with both legal and technical considerations. A profile is proposed to extend the current LADM to incorporate juridical, fiscal, and marine components of the land administration together, incorporating the Social Tenure Domain Model, STDM (Lemmen, 2010), as well as valuing the informal parcels in order to uniquely define a profile for the country (Griffith-Charles et al., 2018).

Athanasiou et al. (2015, 2016, 2017) claim that the complexity of interests in marine space is similarly encountered in land and that the extension of cadaster functions from land to marine space is reasonable. They propose to organize the RRRs included in marine space and to develop a marine administration model, based on LADM, followed by a database implementation. They discuss how the legislation can be included into a marine administration system based on international standards, and how RRRs relating to marine space may be defined and organized. Furthermore, they propose several modifications to the S-121 Maritime Limits and Boundaries (MLB) Standard (IHO, 2018), which refers to the international standard for land administration, LADM (ISO, 2012), with the introduction of class marine resources into the model, the integration of data on legal spaces and physical features through external classes, as well as the division of law and administrative sources.

2.4 Valuation

The valuation topic deals with the use of 3D cadastral data for real estate valuation. The data sources and geospatial analyses can be used to visualize value spatial distribution. The eight publications on valuation from the studied period were distributed rather evenly between the years. The authors of these publications represent countries such as the Netherlands, Turkey, Germany, USA, United Kingdom and Croatia. If applying the classification from Paasch and Paulsson (2021), half of the publications belong to the technical class, and the remaining half is divided equally between registration and organizational. No publication belongs to the legal main class.

Various aspects of valuation are dealt with in the 8 publications from the studied years. Tomic et al. (2012) examines the possibilities of mass real estate valuation based on a 3D Vector Terrain Model created from the digital cadastral map. They claim that data derived from the system can be used for better understanding and explanation of real estate value spatial distribution. Isikdag et al. (2014a, 2014b, 2015) analyze current valuation practices in some countries and explore the role of semantically rich 3D building models and 3D cadastres in relation to valuation and taxation. Furthermore, they investigate the utilization of building/cadastral information models in derivation of valuation-related information and information requirements for valuation related to 2D and 3D geometries and rights, restrictions and responsibilities (RRRs) associated with land lots and buildings. One publication (Asiama and Voss, 2020) looks back at the development of valuation approaches in relation to cadastres, to interrogate the needs for a 3D property valuation approach.

Toppen (2016) describes why and how the 3D CityGML modelling standard can be used in real estate valuation and transaction applications. This is achieved by examining how (3D) Geographic Information Systems (GIS) in real estate is used, e.g. by using 3D city models to visualise information per building storey. Kara et al. (2018, 2020) study the use of 3D data for better property value estimation in the context of the LADM Valuation Information Model and to develop 3D valuation unit profiles. They examine which geospatial analyses, especially 3D analyses, that can be used to provide information about immovable properties including environmental and locational characteristics for property valuation activities. Furthermore, they investigate how property valuation can benefit from data sources including semantically rich 3D building, city and cadastral models for deriving environmental and locational characteristics of property units, and to what extent it is possible and meaningful to include derived 3D characteristics of property units in valuation registries. Asiama et al. (2020) investigate the needs for a 3D property valuation approach in relation to cadastres with the independent 3D property as the basic unit and further need for research on valuation.

3. ANALYSIS AND DISCUSSION

The purpose of the paper has not been to analyse specific problems related to 3D cadastre research, but rather to show some current trends in 3D cadastre research. Of the four topics in focus, BIM accounts for the same number of publications as 4D cadastre and marine and water applications together, while valuation topics has the smallest number of publications. BIM is a popular topic in many fields of research at the moment and therefore the larger number of publications is not surprising. Since BIM is a rather new process that has increased in several different areas in recent years, it can be considered a new development. Valuation, 4D cadastre and marine and water applications are not new phenomena and have been subject to research before, but mainly not that much related to 3D cadastre.

Valuation of real property, including 3D real property, is of vital importance in land management, but research on valuation has, as mentioned above, only in recent years been subject of interest in the 3D cadastre community, judging from the identified publications.

Valuation issues might be discussed more in other research communities than specifically related to 3D cadastre. Valuation is however coming more into focus and we expect to see more publications on this subject in the future. One indicator for such development is that the ongoing revision of the ISO LADM standard on land administration probably will result in extensions of the standard, for example with a section on valuation (ISO, 2021). Marine applications may not be that interesting for countries not in need of a marine cadastre, but the increased interest in managing the seas, e.g. due to an increased focus on climate change and sustainability, makes us assume that we can expect an increased number of publications on that topic as well.

Several of the more popular topics of research within 3D cadastre also constitute separate fields or topics of their own and are discussed in separate conferences, such as LADM and

BIM. BIM has had its own development outside of the 3D cadastre field. Marine cadastre is also a separate topic discussed for several years, and since it is not 3D cadastre related per se, it is not obvious that all research related to this should be included under the 3D cadastre umbrella. Valuation is certainly a topic of its own related to several other fields, such as more economic issues.

It can, in our opinion, be discussed if standardization is to be regarded as a specific topic/group/field or rather a tool in regard to 3D cadastre. Standardization is a wide concept and, for example, the forthcoming revised version of LADM seems to cover other themes than the present version, such as valuation as mentioned above. We may therefore in the future not talk about one LADM standard in general terms, but rather refer to specific parts of it.

There are also subgroups, such as marine cadastre, which can be a specialization of marine and water applications. It is not clear how the contents of such a topic can be classified - e.g. as technical (such as how to build a cadastre), legal (such as the legal content and framework for a marine cadastre), registration or something else, or a combination of classes. We believe that classification aspects have become more complex today than before, e.g. when introducing the rather wide legal, technical, registration and organizational classes first used in Paulsson and Paasch (2013).

Only a limited number of countries are involved in the research analysed in this paper, but the number of publications is too small in order to do any further analysis of the geographical distribution. However, based on the number of publications, there are different countries involved and not just the same authors contributing to most of them.

This study shows that there has been an increase in the number of publications in each topic during the investigated years. BIM is a new topic and not found in the data from our earlier survey (Paulsson and Paasch, 2013) covering 2001-2011. One reason for why BIM related publications have emerged may be that building information modelling is a research and development topic outside the 3D cadastre community in e.g. the geospatial and building industries and thus a driving force for the development of 3D cadastre applications and research. The Paulsson and Paasch (2013) study showed that publications on 4D cadastre, marine and water applications and valuation topics existed, however to a limited extent and as a more isolated phenomenon, but they were not registered as separate classes in the survey. Their numbers have increased in the present investigated period, but as mentioned above, their numbers are limited and do not allow a more detailed analysis.

4. CONCLUSIONS

The paper shows that there seems to be an increased interest for the presented themes during recent years, but it is too early to say whether they all are part of trends in 3D cadastre research or whether they are only expressing temporary interests as such for the 3D cadastre community.

The purpose of the paper is a literature survey and has no intention of finding solutions to the mentioned issues, which would rather be a topic for future research. Considering the development of 3D cadastre research and its alignment with other more general topics and fields, it might be discussed whether we can talk about 3D cadastre (or any similar term representing that field) research as an overall comprehensive term for the research field, since this field has grown to be rather wide and large. Related to this question, it can also be discussed in what form and title future conferences within this field, such as the recurring International FIG Workshop on 3D Cadastres, should be held.

We hope that our results can be an input and inspiration for others on what topic or subtopic to focus on with for example national 3D cadastre solutions and comparative analyses in the wide field of 3D cadastre in the future. Further research could include looking more deeply into some of the other areas that were identified in the literature survey as developing areas with increased research. More comparative research would also be of benefit, involving more countries that could have an interest in 3D cadastre related to these areas, such as including other countries with sea borders in the marine and water applications research.

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Case-driven category analysis of 3D building property

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Key words: 3D cadastre, building property, ground level, earth surface, location, spatial relationship.

SUMMARY

Many immigrants from rural areas pour into urban areas, especially in China, and urban development faces the challenges to provide sufficient space for citizens' acommodation, works and social contacts. So 3D development and use of land and city space become the reality with various complex buildings and constructions with modern architecture and construction techniques. Many underground constructions like mall and subway with stations are built without clear impression comparing to the above reality scenes. Also many buildings above the earth surface show their special characters with either air building / overpass / viadust or "strange" shapes getting our attentions; but actually they bring new challenges of spatial management to handle the 3D property unit, either in describing their relations with reference to earth surface or in performing administrative processes in transactions of planning, approval and management. From the real cases of buildings or 3D property, this paper first details the relations between 3D properties and earth surface, the relative location relations between 3D building properties and earth surface form, and the correspondence between 3D building properties and surface parcel, then classifies the category according to these three profiles, which would promote the understandings of complex buildings and 3D building properties and would enhance the descriptions and the segmentation of 3D building properties.

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1. INTRODUCTION

With 3D utilization of urban land, land administration tends to transform from 2D model to 3D space which is more precise. Modern building and construction technology supported various 3D shapes, and many buildings above the earth surface show their special characters with either air building / overpass / viadust or "strange" shapes getting our attentions. The "parcel" space is divided into different stratas both on the earth surface and above/under the surface and results in multiple strata ownership/usership. Actually, these realistic cases bring new challenges of spatial management and our land administration to handle the 3D property unit, either in describing their relations with reference to earth surface or in performing administrative processes in transactions of planning, approval and management because traditional 2D projection parcel couldn't fit the requirement for clear spatial relationship descriptions. 3D cadastre arises to tailor the new challenges. The cores of 3D cadaster are the descriptions and management of 3D building property.

The State Council of the People's Republic of China issued the document NO.96 to carry out 3D land administration based on core 3D cadastral techniques with the responsibility of Ministry of Natural Resources of People's Republic of China.

Research on 3D cadastre began from the case study (Guo Renzhong et al., 2011; Góźdź et al., 2014). With the case studies, the limitations of 2D cadastre could be clear analysed and corresponding 3D solution project would be framed. 3D property unit is the basic unit in 3D cadastre for 3D land administration and registration (Ying Shen et al.,2018). Research is mostly focused on 3D data structure and data model (Guo Renzhong et al., 2012), topologic reconstruction and maintainance (Ledoux et al., 2011; Li Lin et al., 2012), spatial computation and operations (He biao, 2011) and visualization (Ying shen et al., 2019). Cases and analysis about shape category of 3D cadastre are seldom; only simly classification about 3D cadastral objects is mentioned with division of surface parcel, above-surface parcel and under-surface parcel (Wang Lvhua et al., 2014) or with division of 3D regular shape or 3D irregular shape (Wu Changbin, 2016).

This paper focuses on the realistic cases of 3D building properties and analyses them from morphological aspect. This paper first details the relations between 3D properties and earth surface, the location relations between 3D properties and earth surface form, and the correspondence between 3D properties and earth surface parcel, then classifies the category according to these three profiles, which would promote the understandings of complex buildings and 3D building properties and would enhance the descriptions and the segmentation of 3D building properties and 3D land administration, which would bring about better indeed registration, reducing quarrels and protecting interests.

2. RELATIONS BETWEEN 3D PROPERTY UNIT AND SURFACE BASED ON CASES

Most our behaviors and actions happen on the earth surface, and we have formed the stable understanding about surface reference. When we talk about the buildings, we all knew they are built on the earth surface. Buildings and constructions normally have a plan ground with same surrounding elevation. However, it wasn't always this way. Mountain areas occupy 2/3 land area in China and many buildings and constructions built on unplannar gound, especially in Chongqing City. If we pay our attention on the surface to analyse the buildings, questions are arised: Where is the ground? Is the ground surface same or flat? Buildings in mountain city are built on the slope (Figure 1A), or even the same building connect the surface at different elevations in different directions (Figure 1B). For example, the ground surface of the building in Figure1 in two sides are different. Also, the surfaces among different buildings are curve. Where is the ground level? More amazing, the top of the lower building in Figure 2a is the ground of another higher building; the “current” location is the ground of the skyscraper, at the same time, it is the top of another 28-storey building property. Where is the ground surface for one building property? How to define the the ground surface for SEVERAL group buildings? It is important to make a clear category of the relationship.

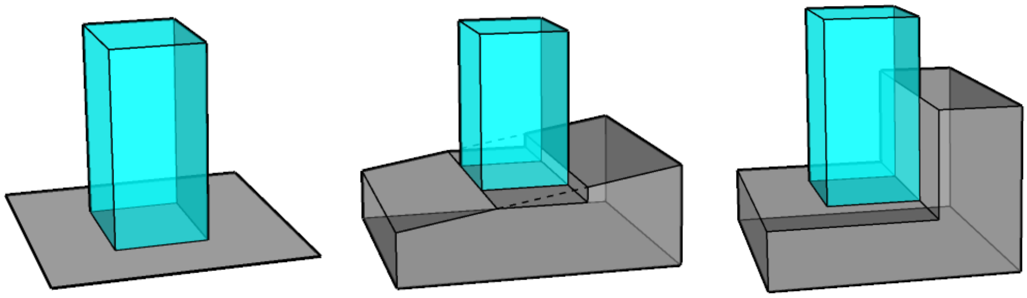
A B

Figure 1. Different grounds in two sides

A B

Figure 2. Different ground levels for different buildings: A) top level to ground level; B) ground level to the top level and middle level.

In order to clarify the relation between the building and earth surface, we divive the earth surface into three types: plannar surface, slope surface and terraced surface (Figure 3). Also, we define two faces: bottom face refers to the lowest bottom face of the building and base face refers to the face where building entrances locate. The entrance, as a key part in building, connects the outside and the inside space which is generally choosed as our daily perception place. Obviously, the based faces for one building may be more than one. As the main node connecting outside, base face / entrance is the important cognitive place that is formulated by “gound” marked with level 1 or level 0. For terraced surface, the building may have multiple base faces with different entrances that influence our cognition about building hight and direction concepts of front/back sides.



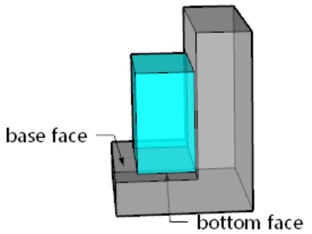
A plannar **B slop** **C terraced**

Figure 3. Different ground surfaces with the building sites

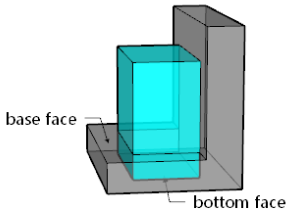
We take the complex terraced surface for example to analyse the category about relationships between the 3D building property and earth surface. Four types can be listed:

- There is only one base face that coincide with bottom face and the terraced top is higher than the building (Figure 4A)
- There is one base face and base face doesn’t coincide with bottom face, also the terraced top is higher than the building (Figure 4B)
- There is multiple base faces and one of base faces coincides with bottom face (Figure 4C). Comparing the elevation between another base face and bottom face, there could be three types as Figure 4C shows. Real case of HONGYADONG in Chongqing City in Figure 5 meets the type in Figure 3c with terraced ground, two main entrance locate at two base faces.
- The building has multiple base faces that is not coincide with bottom face, and this senario happens when bottom face locates underground (Figure 4D).

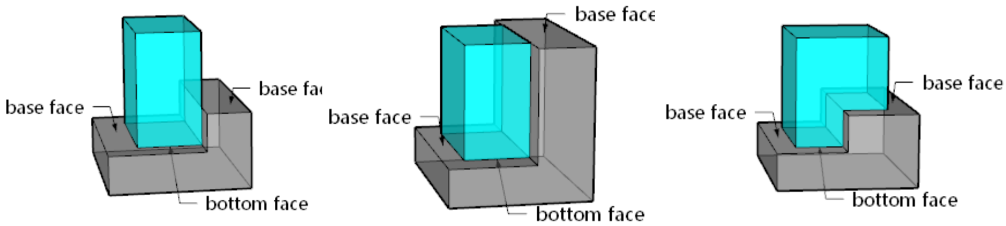
Clear description of the relation between building property and terraced ground can enhance the storey semantics about the building. For Figure 1B, there are two base faces with entrances, and A is marked with L1, then B is marked with LG (lower ground); different levels are sequently marked according to A and B.



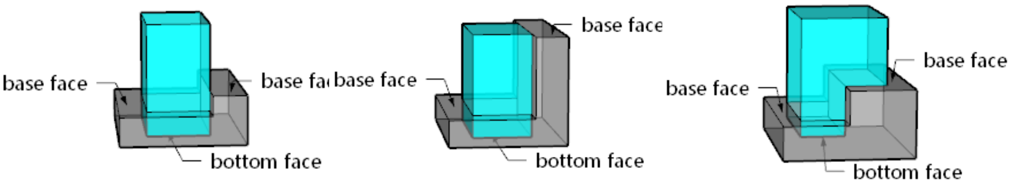
A One base face and one bottom face (coplannr)



B One base face and one bottom



C Multiple base faces and one of them coincide with bottom face



D Multiple base faces and different bottom face

Figure 4. The relationship between 3D building property and terraced terrain (grey color for the surface and red color for building property)

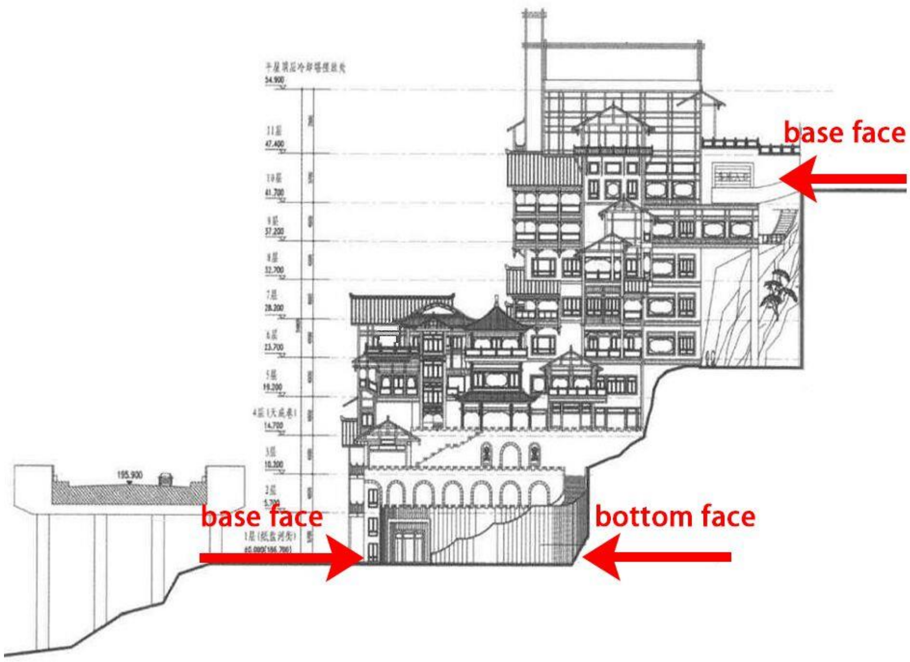


Figure 5. The diagram of relationship between Hongyadong and ground surface

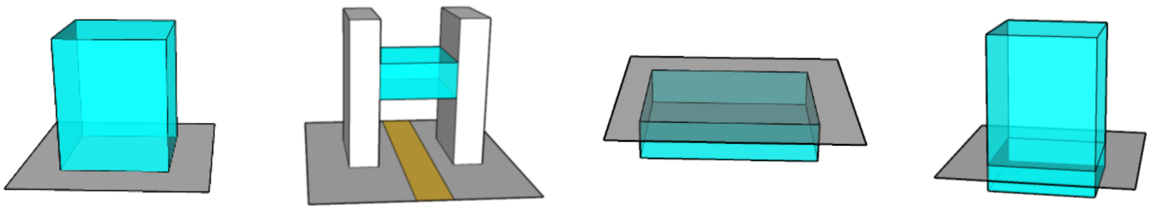
3. EARTH SURFACE REFERENCE

Even the ground levels are there, we still need to understand the air building and underground space, to get correct relative locations comparing to the ground surface. Moder construction techniques support the buildings and man-mad to the air and underground as Figure 6. In China the new Civil Code (2021) stipulated that the ownership/usership can be set up in the air and underground.

A Overstreet building **B Underground street** **C viadust through the building**

Figure 6. Buildings extending into overground and underground space

Spatial location and shape of 3D property in 3D cadastre should be clearly portrayed (Stoter, 2010), also this explicit descriptions should include spatial relationships relative to the earth surface. In full 3D cadastral system, 3D relative vertical locations can be described as Figure 7 in four types: on the surface, in the air, underground and across the surface.



A on surface **B in the air** **C underground** **D across the surface**

Figure 7. Relative locations between 3D building property and the ground surface (grey color for the surface and red color for building property)

4. CORRESPONDENCE BETWEEN 3D BUILDING PROPERTIES AND SURFACE PARCEL

For administrative management, the basic unit is the parcel, mostly 2D parcel. When the focus moves to 3D parcel, it locations and connection with 2D parcels become more complex. One 3D parcel may touch more than one ground 2D parcels, like the overroad building connects two buildings with ground parcels (Figure 6A). When we think the relations in 3D space, one 3D parcel is "inside" in another 3D parcel, for example, the metro goes through the building in 3D space (Figure 6C).

3D parcel in 3D Cadastre is an spatial occupy with RRRs (Ying Shen, et al., 2015), and its indeed registration can be independent of the surface parcel (Shi yunfei, 2009). Taking the general understanding abour surface reference in our daily cognition, it is necesary to describe the correspondence between 3D building property and 2D surface parcel to reflect the vertical overlap between them. We conclude the correspondence between 3D building property and 2D surface parcel in four types: one to one (1-1), one to multiple (1-m), multiple to one (m-1) and multiple to multiple (m-m) (Figure 8).

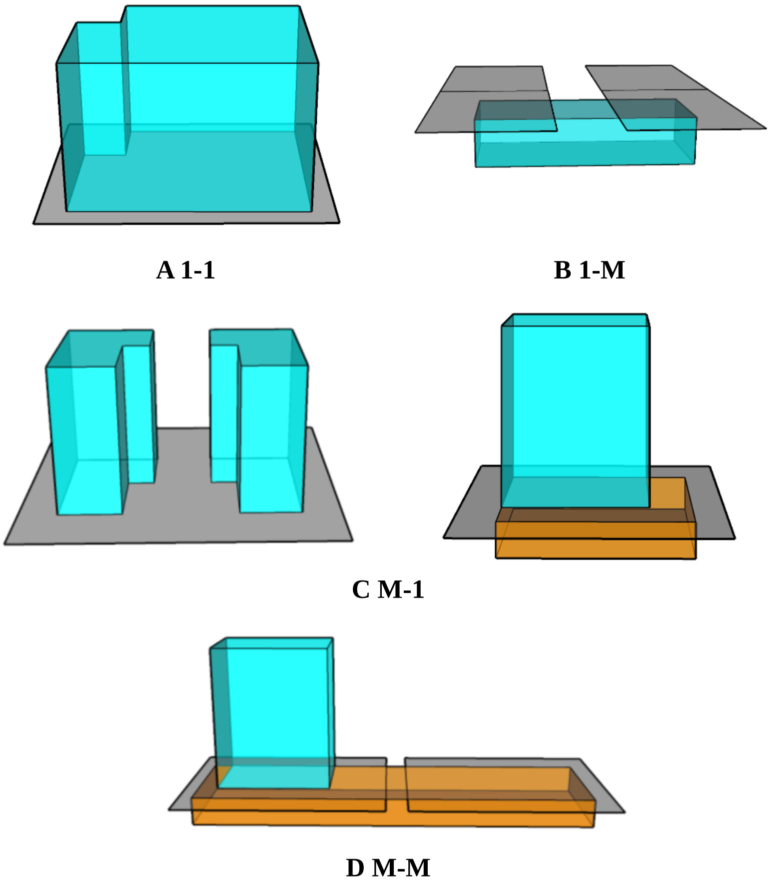


Figure 8. Correspondence between 3D building property and 2D surface parcel (grey color for the surface and red color for building property)

5. CONCLUSION

3D building property is the main object in 3D cadastre, and correct classification and analysis between 3D building property and earth surface would enhance the descriptions and the segmentation of 3D building property and promote the understanding about spatial situations and right analysis for 3D building property. The paper demostrates real cases and analyses the spatial relationships between building property and earth surface, and with these descriptions, further analysis about the consistency between legal geospace and physical geospace of building property, spatial relationships between 3D building properties can be detailed with legal system and RRR constraints.

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BIOGRAPHICAL NOTES

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3D Cadastre in Australian and New Zealand Jurisdictions: Similarities and Differences

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Key words: 3D cadastre, Australia, New Zealand, 3D land parcels, legal boundaries

SUMMARY

Many research studies have been recently conducted in Australia and New Zealand to explore a range of technical, legal, and institutional aspects related to modernisation of 3D cadastre. Most of these studies focus on a particular jurisdiction. This stems from the fact that each jurisdiction is responsible for their own cadastral system. Therefore, the requirements, guidelines, and procedures for implementing 3D digital cadastre are also specific for each jurisdiction. However, the Intergovernmental Committee on Surveying and Mapping (ICSM) develops national frameworks and data models, e.g. ePlan, for cadastral systems in Australia and New Zealand. Therefore, understanding the differences and similarities between existing cadastral systems is critically important to support 3D cadastre at a national level. In the current literature, comparisons of 3D cadastre for some civil law jurisdictions as well as standards have been conducted. Nevertheless, the common law jurisdictions, including Australia and New Zealand, have not been compared in terms of 3D cadastre.

Thus, this research aims to develop an overarching framework comprising differences and similarities in current practices pertaining to subdividing ownership of vertically stratified properties to support 3D cadastre in all jurisdictions of Australia and New Zealand. The study scope is limited to technical aspects of 3D cadastre in these jurisdictions. A survey based on a questionnaire has been conducted to identify the important data elements used in current 3D cadastre practices in Australian and New Zealand jurisdictions. The survey outcomes indicated that there are some similarities in terms of managing 3D cadastral data. One main similarity is that 3D legal boundaries are typically delineated by either referencing physical structures or fixed survey measurements. The differences mainly refer to various types of primary land parcels and secondary interests in each jurisdiction. In addition, similar ownership concepts are named differently in each jurisdiction. For instance, the “Lot” primary parcel, which defines the ownership space of a private property, in Victoria is the same as “Unit” parcel in Northern Territory. Each jurisdiction uses its own representation of 3D cadastral data. For instance, cross section diagrams are used in Victoria while isometric views are used in Queensland. These research outcomes could help with developing a framework for multi-jurisdictional 3D cadastre in Australia and New Zealand.

3D Cadastre in Australian and New Zealand Jurisdictions: Similarities and Differences

Behnam ATAZADEH, Hamed OLFAT and Abbas RAJABIFARD, Australia

1. INTRODUCTION

Cadastral systems have been developed and implemented by governments across the world. These systems are used to assist land and property decision-making across government, businesses, and communities by using land surveying techniques to convey the most complete depiction of land parcel and property boundaries, which is known as cadastral information. Current cadastral systems rely heavily on 2D base maps and survey plans which fall short of meeting future land development demands and community expectations.

As cities in Australia and New Zealand have grown rapidly in the last decades, the demand on land development and use has been tremendous. For these nations' urban areas, this has resulted in the growing dominance of complex aboveground/underground developments. The common examples are buildings with many stories and multiple uses, shopping malls, passageways on top of and below streets, gas pipes, electrical cables, subterranean parking lots or tunnels. In these developments, the spatial dimensions of ownership rights, restrictions, and responsibilities (RRR) are often three-dimensional (3D), invisible and multi-layered spaces.

The problem is that current practices for subdividing urban land and property ownership are predicated on silo-based and fragmented 2D approaches, which do not provide a reliable, unambiguous, and coordinated representation of the legal and physical aspects of underground and aboveground areas. For instance, the inaccuracy and unreliability of 2D as-builts resulted in several delays and disruptions in a railway project in Sydney (see Figure 1). However, if there had been a comprehensive and accurate 3D digital model of underground properties during the planning phase, the railway project could have been completed at least one and a half years sooner, at less cost and a much lower level of risk (Acil Allen Consulting, 2017; Zeiss & Shinoaki, 2020).

In Australia, there are eight jurisdictions: Australian Capital Territory, New South Wales, Northern Territory, Queensland, South Australia, Tasmania, Victoria, and Western Australia. There is a unique method to represent 3D RRR spaces in each jurisdiction. Therefore, there are currently eight types of methods used for 3D cadastre in Australia. Furthermore, New Zealand has its own approach for representing 3D legal limits of RRR spaces. So, depending on the legislations and processes created especially for that jurisdiction, each jurisdiction has different needs when it comes to capturing, curating, and communicating 3D cadastral information.

According to Australian and New Zealand legislations, the legal limits of vertically situated properties are typically delineated on analogue 2D subdivision or survey plans. When it comes to urban developments with basic structural shapes, 2D-based representation approaches are quite effective and efficient. However, a built asset with a spatial and functional complexity raises questions about the efficiency of 2D representations. The communication and management of 3D RRR spaces within vertically placed properties create several issues for long-established 2D-based paradigms. Some consequences of using 2D concepts can be summarised as (Rajabifard, Atazadeh, & Kalantari, 2019):

- It is only the surveyor, who created the initial drawings, can provide a complete sense of the abstract (plan) version of reality.
- Planar, isometric, and cross-section views are difficult to interpret whey they are used to represent complex RRR spaces.
- Multiple pages of 2D drawings are required to accurately reflect the legal extent of all RRR spaces in a high-rise building.
- A variety of technological approaches are now used to register 3D RRR spaces in current 2D cadastral systems; however, technical ambiguities pose critical challenges to the security of tenure in urban areas.

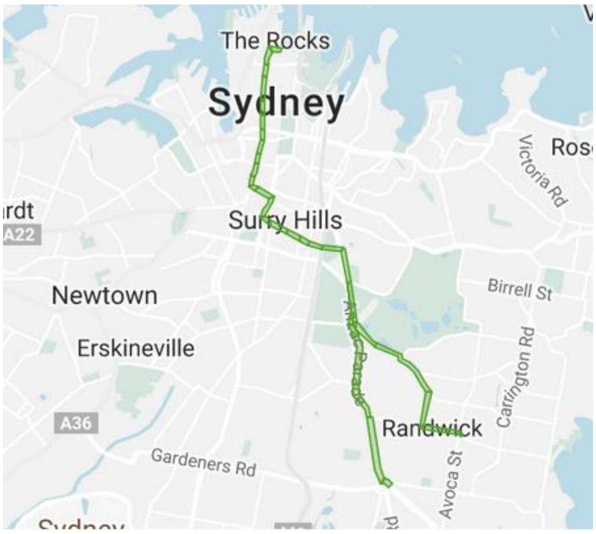

Figure 1. Sydney Light Rail Project, source (Zeiss & Shinoaki, 2020)

Increasingly, 3D digital models are being researched as possible solutions for improving the recording and representation of urban land and property to overcome communication and management challenges in complex urban environments. In the existing literature for 3D digital cadastre, a significant number of studies related to legislative, institutional, and technical aspects have been conducted in different jurisdictions. In an international context, many countries including the Netherlands (Stoter et al., 2016), Sweden (Sun, Mi, Olsson, Paulsson, & Harrie, 2019), China (Ying, Guo, Li, Chen, & Jia, 2018), and Korea (Lee, Kim, Kwak, Lee, & Choi, 2015) have developed different research approaches to showcase the feasibility of 3D digital cadastre.

In Australia, States of Victoria, Queensland, and New South Wales have been active in researching aspects of 3D digital cadastre in isolated investigations. However, there is a lack of research regarding a national approach for 3D cadastre in Australia. In addition, New Zealand jurisdiction is also part of the Intergovernmental Committee on Surveying and Mapping (ICSM) together with Australian States and Territories.

Therefore, there is no comprehensive and holistic approach in advancing knowledge to support a move towards 3D digital cadastre and address the general problem of modelling and managing complex 3D RRR spaces in underground and aboveground developments in rapidly growing built environments of Australia and New Zealand. As these countries are planning to move towards an approach for implementing 3D digital cadastre, this research aims to identify and compare 3D cadastral data elements in these jurisdictions. The expected outcomes of this study include similarities and differences between all Australian states and territories as well as New Zealand to develop a new nationwide framework for 3D cadastre.

2. LITERATURE REVIEW

In this section, a review of 3D cadastre research will be provided with a particular focus on the existing studies comparing different jurisdictions. Investigations in different countries, including Australia and New Zealand, have identified three generic aspects for modernisation of 3D cadastre: technical, legal, and institutional.

The technical aspects of 3D cadastre have been investigated significantly in different jurisdictions including Australia and New Zealand (Gulliver, 2015; Gulliver, Haanen, & Goodin, 2016; Rajabifard et al., 2019; Smart & Priebbenow, 2018). These aspects typically refer to various stages of the digital data lifecycle, namely 3D data acquisition (Jazayeri, Rajabifard, & Kalantari, 2014), 3D data models and standards (Atazadeh, Rajabifard, & Kalantari, 2018), 3D data storage (Janecka et al., 2018), 3D data visualisation (Jacynthe Pouliot et al., 2018), 3D data validation (Asghari, Kalantari, & Rajabifard, 2019; Karki, Thompson, & McDougall, 2013), 3D data query and analysis (Atazadeh, Rajabifard, Zhang, & Barzegar, 2019; Barzegar, Rajabifard, Kalantari, & Atazadeh, 2020). 3D data visualisation and 3D modelling are two of the most used technical solutions for 3D cadastral data management. Developing an integrated approach including the important phases of the full lifespan of 3D cadastral data is still a relatively new field of research that has received little attention (Kalogianni, van Oosteom, Dimopoulou, & Lemmen, 2020; Olfat et al., 2021) .

While various solutions have been developed to address technical aspects of cadastral data lifecycle in a 3D environment, the legal and institutional aspects have been identified as "invisible" constraints and fundamental barriers to shift from 2D to 3D digital environments.
To understand how current land development processes use cadastral information, researchers looked at the spectrum of regulatory, normative, and cultural factors that drive present 2D practices. As part of a study conducted in Australia, researchers found apparent obstacles to a successful transition process and offered viable methods, as well as a road map to help a shift towards 3D cadastre. Research findings from cross-case analysis and syntheses were used to build a new framework of strategic principles to guide key stakeholders in the creation of a transformation path. Development of a roadmap to enable the implementation of 3D cadastre must consider the cultivation of legitimacy as an underlying principle.

One of the earliest studies on analysing international key factors for 3D cadastre has been conducted by Paulsson (2007). Her findings revealed a number of commonalities in 3D property ownership across a variety of cadastral systems in various countries including

Australia (Victoria and New South Wales), Germany and Sweden. Legal boundaries of ownership spaces, common property definition, easement formation, forms of collaboration between units and management and regulation concerns, as well as dispute settlements and insurance solutions were identified as critically important key factors. In another study, Paulsson (2012) did a comparison between the Swedish types of 3D property and the typical types of 3D property prevalent across the world. It was preconceived that the Swedish 3D property types would be different from those used internationally. However, it was found all forms of 3D property ownership are similar in their creation even though there are differences between the legal systems. The identified key factors seem to be crucial for establishing a successful system for 3D cadastre, and these should be taken into consideration while developing new systems and comparing them to existing ones (Paulsson, 2007). More recently, Paulsson & Paasch (2013) analysed a comprehensive number of publications from 3D cadastre literature and identified four categories in this research domain, namely legal, technical, registration, and organisational. One of the main findings was that technical and registration aspects of 3D cadastre have received more attention than legal issues. Comparative studies on 3D cadastre were also found to be of limited interest. In addition, it was indicated that an increase in the number of studies comparing different cadastral systems, as well as a global perspective on the cadastral systems' strengths and drawbacks, would be useful to the scientific community.

Pouliot et al. (2011) recognised the need for comparisons between the 3D representation of vertically situated co-ownership in Quebec and Franc, which would assist to build a 3D solution for cadastral systems in these jurisdictions. The comparative analysis was partly done using Land Administration Domain Model (LADM) standard. It was shown that comparing the spatial representation of vertical co-ownership in Quebec and France may help discover better practices and, ultimately, provide advice on how best to upgrade cadastral systems. The application of LADM enhanced and clarified differences and similarities between Quebec and French jurisdictions. A clear advantage was the ability compare the two cadastral systems visually. Therefore, both systems could be compared side by side, class by class and attribute by attribute (Jacynthe Pouliot, Vasseur, & Boubehrezh, 2013). This facilitated establishing possible linkages between the two jurisdictions. The shared vocabulary provided in the LADM standard helped to identify semantic conflicts regarding the term “lot” in these jurisdictions.

In another international context, the legal foundations of 3D cadastre in fifteen jurisdictions, including Australia, have been reported in a study by Kitsakis et al. (Kitsakis et al., 2018). The study found each jurisdiction uses a distinct set of terms to define 3D legal objects, but national approaches have certain similarities. For example, although apartment ownership is based on 2D registration, it is the most common 3D legal object registered in all of the analysed jurisdiction. A 3D cadastral system requires to redefine property ownership using clear 3D language and develop appropriate legalisations to partition, consolidate, and administer vertically stratified properties in a 3D digital environment, as can be seen from the case studies that have been explored in (Kitsakis et al., 2018). For instance, according to case studies conducted in Australia (Queensland and Victoria) and Sweden, such legislations can provide a clear understanding and interpretation of complex RRR spaces above and below the earth’s surface.

In a more recent study conducted by Çağdaş et al. (2020; 2018), various jurisdictions and land administration standards have been compared regarding co-ownership shares (or common properties) in condominiums. Seven countries (Denmark, Germany, South Africa, Sweden, Switzerland, the Netherlands, and Turkey) were examined in order to evaluate techniques and processes used for the distribution of co-ownership shares in condominium systems. The study found that actors who determine the co-ownership shares differ from one jurisdiction to another. For instance, the co-ownership shares are specified by the project architect in Turkey while the cadastral authority is the actor determining co-ownership shares in Sweden. Moreover, the study found that LADM and the Land and Infrastructure (LandInfra) standards have been compared in terms of their capability to support 3D digital representation of condominiums. The comparison showed that semantically richer entities and code lists, such as condominiumMainPart, condominiumAccessoryPart, jointAccessFacility, and jointOtherFacility, are provided to describe condominium parts by LandInfra. However, LADM provides more general code list class (i.e. LA_BuildingUnitType with individual and shared values) to differentiate condominium parts (Çağdaş et al., 2018). Moreover, in a study by Pouliot et. al. (2019), LADM, LandInfra (InfraGML), and LandXML content were compared using schema matching techniques to see how well they matched.

3. METHODOLOGY

As depicted in Figure 2, the methodology of this study comprises several steps. Each step is explained in the following subsections.

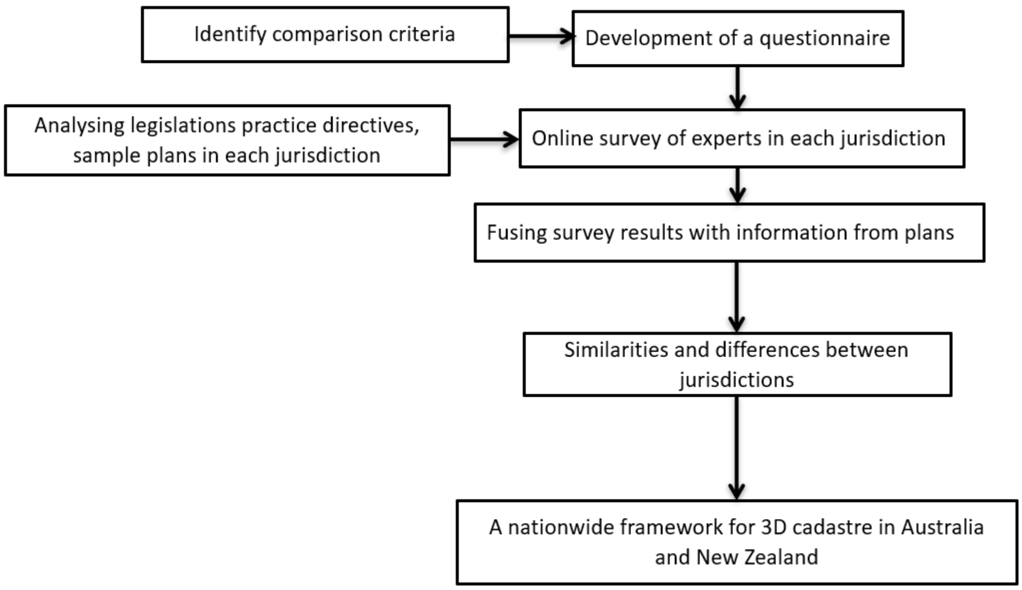

Figure 2. Research methodology adopted for studying 3D cadastre in Australia and New Zealand

3.1 Identification of comparison criteria

The first and fundamental step was development of appropriate criteria for comparing jurisdictions. Based on the current literature and our previous study in the Victorian jurisdiction, the following criteria have been considered as critically important ones for identifying the similarities and differences between jurisdictions:

- Types of primary parcels and their shape
- Types of secondary parcels and their shape
- Spatial relationships between primary and secondary parcels
- Legal boundary types

It is important to note that the above-mentioned criteria do not provide a complete set of cadastral datasets required in each jurisdiction. Survey information such as traverse lines and survey marks may be also considered as part of cadastral datasets; however, this information has already been addressed in the current national ePlan model.

3.2 Development of a questionnaire

By considering the comparison criteria, a questionnaire was developed to seek cadastral experts' input regarding data elements of 3D cadastre in their jurisdiction. To provide a clear explanation of each question, we provided examples derived from Victoria's practices. These examples were given in line with the data elements provided in the ePlan protocol. The questionnaire comprised two parts:

- **Part One - Respondents' details:** In this part, the questions were mainly developed identify the profile of experts participating in this study. The questions of this part mainly asked about the experts' organisations, position title, expertise area and years of experience. The respondents were mainly land registry experts in each jurisdiction.
- **Part Two - Data elements of 3D cadastre:** The questions of this part asked about various questions from the respondents to identify 3D cadastral data elements in their jurisdiction. For each question, the relevant definitions and examples were given to the participant to help them better understand the purpose of the question. The questions for this part are presented in Table 1.

Table 1. Questions developed for identifying 3D cadastral data elements

Question Number	Question
1	What are the possible primary parcels defined in subdividing vertical developments?
2	What defines the 3D spatial extent (shape) of each primary parcel?
3	What are the possible secondary interests considered in vertical developments?
4	What defines the 3D spatial extent (shape) of each secondary interest?
5	How do you define relationships between a primary parcel and a secondary interest in strata developments?
6	What are the legal boundary types delineated in vertical developments?

3.3 Online survey of experts in each jurisdiction

An online survey was conducted using Survey Monkey platform. For this online survey, the following information was given to each participant:

- **The plain language statement:** This document provides a short description of study in a simple language.

- **Consent form:** In this form, it is stated that participation in this research is completely voluntary. Participants had the right to withdraw at any stage, or to withdraw any unprocessed data they have supplied, they are free to do so without prejudice. They also agree that each participant may be identifiable as a participant due to the small sample size. However, the confidentiality of the information they provided will be safeguarded, subject to any legal requirements. It was also mentioned in the consent form that responses and comments provided by each participant will be kept confidential.
- **The questionnaire form:** This form included the questions that each participant was required to answer for identifying 3D cadastral data elements.

The participants firstly read the plain language statement and signed the consent form. Subsequently, each participant was asked to complete the questionnaire.

3.4 Analysing legalisations, practice directives and sample plans in each jurisdiction

In order to enrich our understanding of 3D cadastral data elements in each jurisdiction, we investigated legislations, practice directives as well as the content of current sample cadastral plans that were used for subdividing and registering ownership in vertical developments. The plans included different types of floor plans, cross-sections, and isometric diagrams created in each jurisdiction.

3.5 Fusing survey results with information extracted from sample plans

The answers provided from participants of the online survey were investigated further by considering the information provided in the studied sample plans to provide more accurate understanding and interpretation of 3D cadastral data elements in each jurisdiction. This helped us to perform a more concrete comparison of jurisdictions.

3.6 Similarities and differences between jurisdictions

The comparison results were used to identify the similarities and differences between eight Australian jurisdictions as well as New Zealand. The comparison outcomes are presented in Section 4.

3.7 Developing a nationwide framework for 3D cadastre in Australia and New Zealand

Based on comparison outcomes, we proposed a general nationwide framework comprising differences and similarities in current practices pertaining to subdividing legal ownership of vertically stratified properties to support 3D cadastre in all jurisdictions of Australia and New Zealand. The components of this framework is detailed in Section 5.

4. SURVEY OUTCOMES AND JURISDICTIONAL COMPARISON

In this section, we will first present the survey outcomes with some tangible examples to showcase the current status of 3D cadastre practices in each jurisdiction.

4.1 Australian Capital Territory (ACT)

In ACT, the common types of primary parcels for 3D cadastre are (ACT Parliamentary Counsel, 2020):

- **Unit:** A unit represents individually owned part of a parcel which is subdivided under Unit Titles Act. There are two classes of units: Class A and Class B. Class A units are depicted as part of a whole building, with their limits established by reference to walls as well as floors and ceilings (see Figure 3). Class B units have boundaries unlimited in height except to the extent of any encroachment at, above or below ground level by another part of the parcel.
- **Unit Subsidiary:** A unit subsidiary annexed to a unit, which means it is appurtenant' to its corresponding unit. For instance, a balcony area is defined as a unit subsidiary (see Figure 3).
- **Common Property:** A common property represents a collective ownership of all parts of the parcel that are not shown as units or unit subsidiaries.

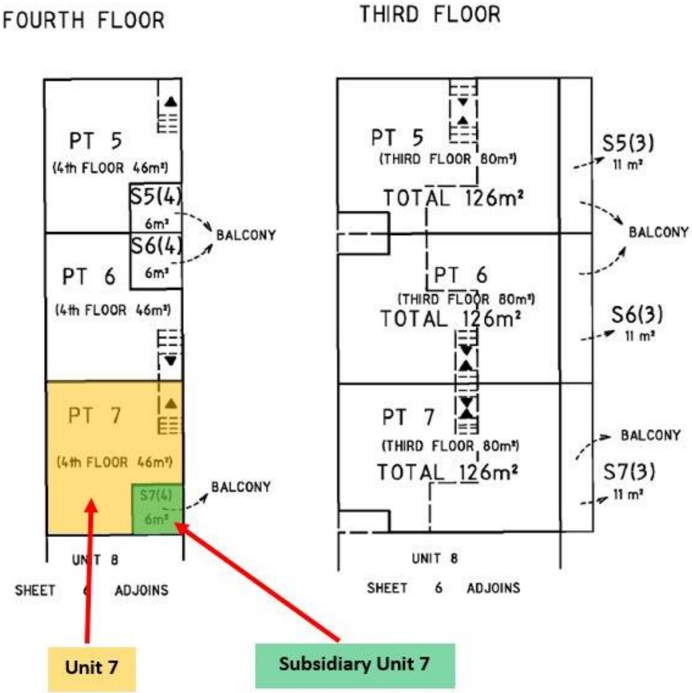

Figure 3. Examples of units and unit subsidiaries in ACT

The well-known 3D secondary parcels identified in the ACT jurisdiction are:

- Easement: Easement is defined as an interest the owner of a benefited estate (i.e., unit or common property in context of the ACT jurisdiction) may have against the owner of a burdened estate.
- Restriction: Restriction imposes a limitation or condition on the land parcel. It must clearly indicate the land which benefits from the restriction and the land which is burdened by the restriction.

The secondary interests typically overlap with the entire or part of primary parcels in the ACT jurisdiction. In the context of 3D cadastre, the legal boundaries defined in this jurisdiction include the following types (ACT Parliamentary Counsel, 2020, 2021):

- Party wall: It means a wall or structure designed for the common use of 2 or more buildings and erected, or to be erected, on a common boundary, or part of such a boundary, between 2 parcels of land, and extending laterally into each of those parcels of land

- Common boundary: There two types of common boundaries: internal and external. The internal common boundary is typically located at the centre of a floor, wall or ceiling, when the floor, wall or ceiling separates a class A unit or a unit subsidiary from common property or another unit or unit subsidiary. It is also possible to define the internal boundary in any other location inside the floor, wall or ceiling as specified in the relevant unit title application or units plan. The external common boundary is defined by an external wall of the building containing the units. There two scenarios for external common boundaries: 1- The external boundary of the unit or unit subsidiary lies along the centre of the wall 2- The part of the wall outside the external boundary is common property.
- Measured boundary: This type of boundary is delineated using survey measurements and it is typically defined by bearing and distance values for the boundary line.

4.2 New South Wales (NSW)

Among the most prevalent types of parcels used for 3D cadastre in NSW are (NSW Parliamentary Counsel, 2016):

- Lot and part lot: It refers to one or more cubic spaces that make up part of the parcel that the strata scheme relates to, with each cubic space's base being designated as a single lot, or part of one lot (see Figure 4).
- Common property: Common property is the portion of a land that is not included in any individual lot or part lot (see Figure 4).
- Development lot: It refers to a lot in a strata plan that is identified by a strata development contract as a lot that is to be the subject of a strata plan of subdivision under the development scheme.

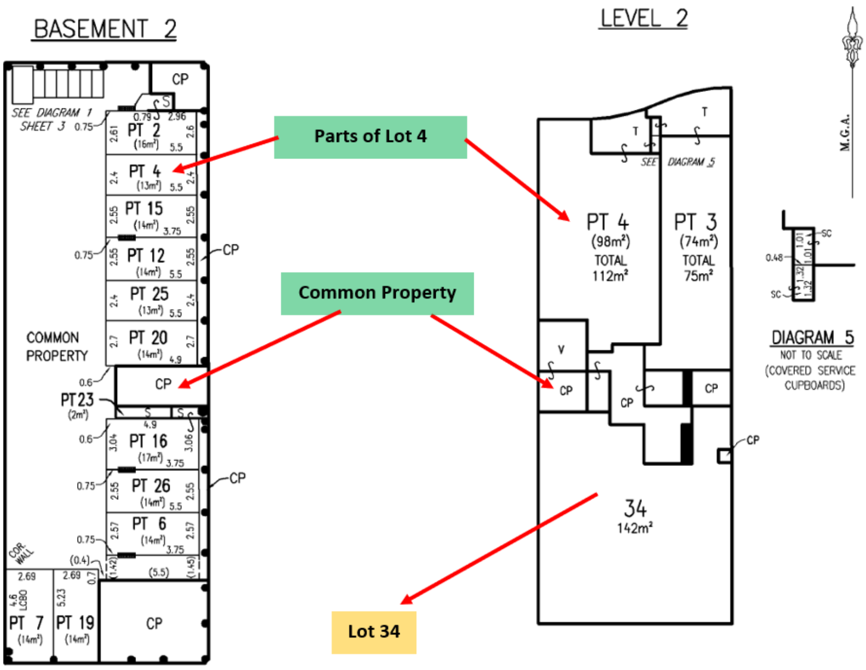

Figure 4. Examples of part lot, lot and common property in the NSW jurisdiction

The secondary interests that are important for 3D cadastre in NSW are (NSW Land Registry Services, 2020):

- Easement: It is defined as being a portion of primary parcel which gives someone (usually a third party) the right to use the parcel for a specific non-exclusive purpose.
- Restriction: It is an agreement between two or more parties that something will not be done with the land. The benefit of the restriction may be adjoining land, nearby land or the council. It is negative (restrictive) in nature and may be created to:
    1. protect a residential amenity e.g. a view.
    2. preserve the environment, e.g. preventing the lopping of trees or restricting where buildings can be erected.
    3. restrict undesirable development and preserve the character of the neighbourhood, e.g. limiting the height of buildings and/or the material of construction and/or fencing type.
- Stratum statement: Stratum statements are required if a lot is not limited in height and or depth by a structure. Lots which are within a building are generally accepted to extend from the upper surface of the floor to the lower surface of the ceiling. A stratum statement will be required for all lots outside a building which are not fully covered by a structure or do not have a structural base for their entire area.

The relationship between primary parcels and secondary interests are determined by notations on plan and Section 88B within the Conveyancing Act 1919 (NSW Parliamentary Counsel, 2021). The notations and Section 88B typically require the surveyor to provide the primary parcels that benefit from and burdened by the easements and restrictions.

Legal boundaries are defined by continuous (i.e., unbroken) lines and there are two common types: building and line boundaries. Building boundaries which are defined by a structure must be shown by thick lines. There are three categories of building boundaries: interior, median, and exterior. Boundaries which are not defined by a structure are referred to as line boundaries. Line boundaries must be dimensioned by distance only and be defined by right angled offsets and/or connections from specified points on a structural feature shown on the floor plan.

4.3 New Zealand (NZ)

In NZ jurisdiction, the following types of primary parcels are considered for 3D cadastre (Land Information New Zealand, 2021):

- Principal unit: A principal unit is a unit that is designed for use (whether in conjunction with an accessory unit or not) as a place of residence, business or otherwise (see Figure 5).
- Accessory unit: An accessory unit is a unit that is designed for use with any principal unit, such as a garden, garage, car parking space, storage space, swimming pool, laundry, stairway, or passage (see Figure 5).
- Future development unit: A future development unit is a type of unit that is shown on a stage unit plan; and is intended to be developed or subdivided into one or more units (with or without accessory units or common property) in a future stage.
- Common Property: Common property is all the land shown on a unit plan that is not: a principal unit; or an accessory unit; or a future development unit (see Figure 5).

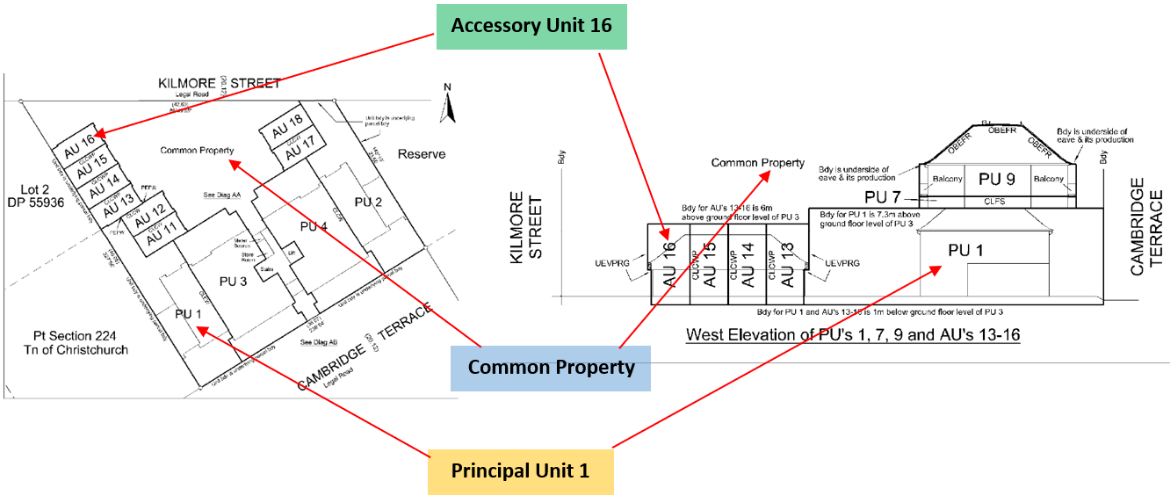

Figure 5. Examples of 3D primary parcels in the NZ jurisdiction (adopted from (Gulliver et al., 2017)

In addition, the following primary parcels are also considered in NZ jurisdiction but may be less common for 3D cadastre purposes:

- owned by the Crown, with the exception of a movable marginal strip parcel
- held in fee simple (mainly private ownership)
- Māori freehold land or Māori customary land
- part of the common marine and coastal area
- the bed of a lake or river
- road or railway,
- vested in a local authority (includes some types of reserves).

The secondary parcels that are identified in this study for 3D cadastre in NZ jurisdiction are:

- Easement: An easement is a right to use another person's land in a particular way. It cannot include any right to have possession of the land or to take any part of the soil or produce of other land.
- Covenant: A land covenant is an agreement whereby the covenantor undertakes to do (or not do) something in relation to their land that would benefit the owner or occupier of the covenantee's land.
- Movable marginal strip: A marginal strip is a strip of Crown land created along the banks of rivers and lakes, or along the foreshore. There are fixed and movable marginal strips.
- Esplanade strip: An esplanade strip is a right over a strip of land that adjoins a river, lake, or the sea.
- Lease: A lease is an instrument under which a lessor confers upon a lessee the right to the exclusive possession of the land being leased, for particular length of time.
- License: A licence to occupy is similar to a lease in that it gives the owner of the licence a right to use a flat or office; and it will have terms and conditions; however unlike a lease, a licence to occupy does not normally have a term/expiry date.

All secondary interests must be represented as a polygon or polyhedron, with the exception of:

- existing centreline easements that meet certain criteria which are allowed to be depicted as a centreline. A centreline easement is defined as an easement which is spatially represented by one or more lines along its centre.
- existing easements that have not been spatially defined previously.

The relationships between primary parcels and secondary interests are depicted spatially. Where the boundaries are defined using right-line, arc and stratum boundaries, sufficient information to enable the relationships to be determined mathematically is also required. There are six legal boundary types that may be used in NZ's 3D cadastre practices. Four are solely for use in defining the horizontal extent:

- Right-line boundary: A boundary that follows the shortest distance between two boundary points
- Water boundary: A boundary set at the landward margin of:
    1. a river bed or a stream bed,
    2. a lake bed, or
    3. the common marine and coastal area or other tidal area,
    4. and includes a natural boundary where this term is used in enactments to refer to a boundary at a water margin
- Irregular boundary: A boundary that is depicted as an irregular line but is not a water boundary
- Arc boundary: A boundary that follows part of the circumference of a circle

The fifth boundary type is solely for use in defining the vertical extent is called stratum boundary. It is a boundary, not being a permanent structure boundary, that defines the upper or lower extent of a parcel. The final boundary type can be used for both the horizontal and vertical extent, which is called permanent structure boundary. It is a boundary related to a permanent structure. Note that a permanent structure is defined as - a building or recognisable physical structure that is likely to remain undisturbed for 50 years or more.

4.4 Northern Territory (NT)

The primary parcels that are identified in this study for 3D cadastre in NT jurisdiction are (Department of the Attorney-General and Justice, 2021):

- Unit: A unit is a lot that is created on the registration of a plan of subdivision or plan of consolidation and specified as a unit in the scheme statement by reference to a cubic space, a parcel of land unlimited in its vertical dimensions, or both (see Figure 6).
- Common Property: It refers to so much of a parcel that is not within a unit. Therefore, a unit or part of a unit, or a body corporate asset, cannot be common property (see Figure 6).
- Road: It is a primary parcel that is used for the benefit of the public.
- Reserve: Similar to roads, reserves are for the benefit and use of public community. Reserves include those land parcels owned by city councils.

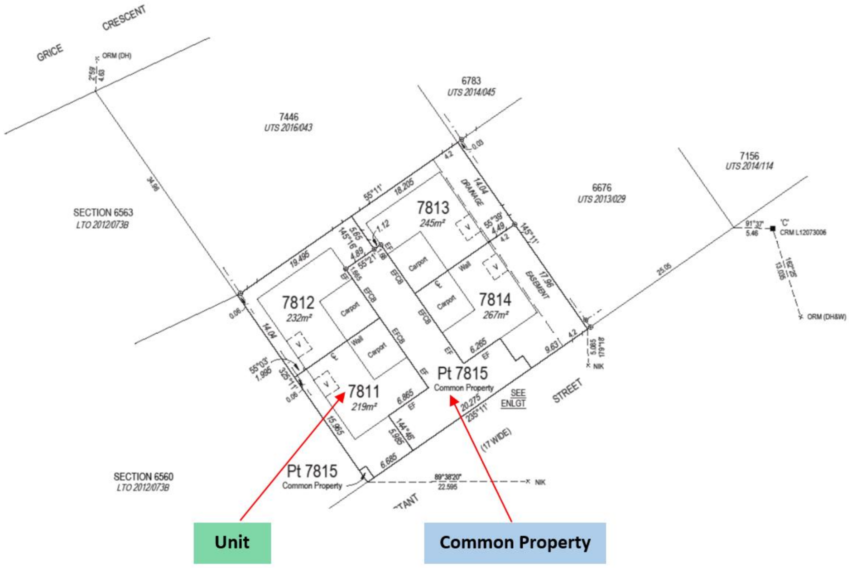

Figure 6. A unit titles subidivison in the NT jurisdiction

There are two main types of secondary interests in the NT jurisdiction for 3D Cadastre:

- Easement: It refers to a right annexed to land (the dominant land) to use other land (the servient land) in a particular manner or to prevent that other land from being used in a particular manner but does not include a right to take the soil or produce of other land. There are two easement types: general and statutory (Department of the Attorney-General and Justice, 2021).
- Covenant: It is an obligation (whether positive or negative) in respect of the use, ownership or maintenance of particular land (servient land) that is created for the benefit of other land (dominant land).

In the NT jurisdiction, the relationship between primary parcels and secondary interests is through overlay as well as annexing the secondary interests to the primary parcels. The legal boundary types in this jurisdiction include measured boundary, a physical boundary referring to a cubic space and a boundary referencing a parcel of land unlimited in its vertical dimensions.

4.5 Queensland (QLD)

In the QLD jurisdiction, the common primary parcels which are important for 3D cadastre include (Registrar of Titles Department of Resources, 2018):

- Base lots: These primary parcels are either Building Format or Community Title Scheme (CTS) standard lots or access/height limited parcels and they are defined for either building subdivision or land subdivision.
- Common property: All strata subdivision needs at least one common property which is managed by body corporate (see Figure 7).
- Road (2D as well as 3D Volumetric parcels): If road is created then land is usually surrendered to the council, however if common properties are used as access then managed by body corporate, easements can also be used for access.

- Building format lots (Units): In buildings, units/apartments are created, and can be multi-part (e.g., one lot can have ownership in multiple levels, a garage and external patio) (see Figure 7).
- Volumetric format lots: These primary parcels often created to reserve an initial envelope (see Figure 8) and further subdivided into building format lots and they also used for structural/infrastructure/utilities features, or roads.
- Private courtyard: Some apartments have private courtyards in the title shown on a plan with dimensions, which is obviously limited to the owners of the ground floor, and other floors have no access to these courtyards (see Figure 7).

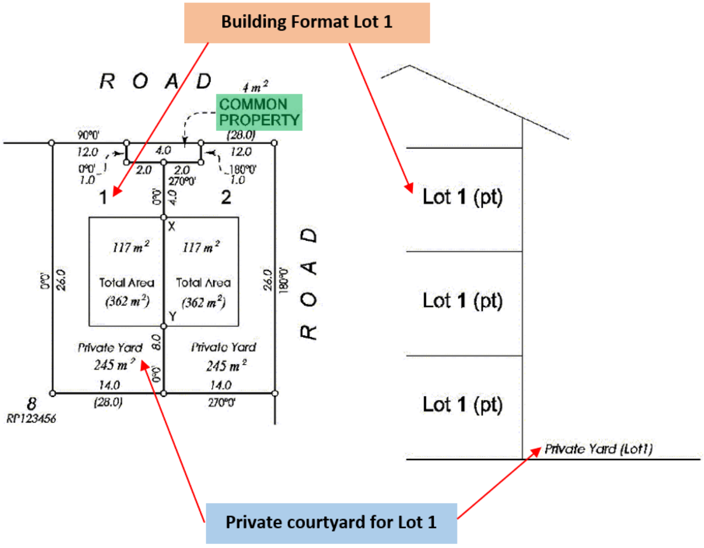

Figure 7, Examples for building format plans (adopted from Registrar of Titles Department of Resources, 2018)

The main secondary interests in QLD jurisdiction for 3D Cadastre are:

- Permits: This includes permits over trust, road, creek, river, reserve, USL with a lot-on-plan title reference, land beyond tidal boundary (river), land beyond tidal boundary (ocean)
- Lease: In a lease, the lessor, as the registered owner, provides the lessee an estate or interest in land for a specified time in exchange for the lessee paying rent. As long as the lease is in effect, lessees maintain title to leasehold property, while lessors hold the reversion, which is the lessor's ownership interest in the land subject to lease. An asset of the lessee, the leasehold estate may be transferred during the lessee's lifetime or at his/her death.
- Easement: An easement is a right annexed to land to utilise other land in a particular manner. It does not involve the taking of any part of natural produce of the land or any part of its soil. It may, however, prevent the owner of the other land from utilising his/her land in a particular manner.
- Covenant: It is a voluntary agreement that creates an obligation by a deed entered into by the parties. Covenants may be of a positive nature in that they require the performance of an action. They may also be negative or restrictive, that is one of the parties is forbidden from undertaking or performing a specified action. Examples of using covenants include:

1. a building on the lot/land must be used for educational or residential or commercial purposes,
2. the covenant area must be used for noise attenuation purposes
3. the lot/land is to be used only for the purpose of construction of buildings used for the development of technology
4. the lot/land is to be used only for the purpose of construction of water-sensitive residential housing.

- Profit a prendre: It is an interest that arises by an agreement between two parties and relates to the right of one party to enter on the land of the other and extract or remove part of the land's substance. In simple terms, it is the right to take soil (e.g. sand, gravel) or produce (e.g. wood, turf, fish, etc.) from another's land or to graze animals on it.

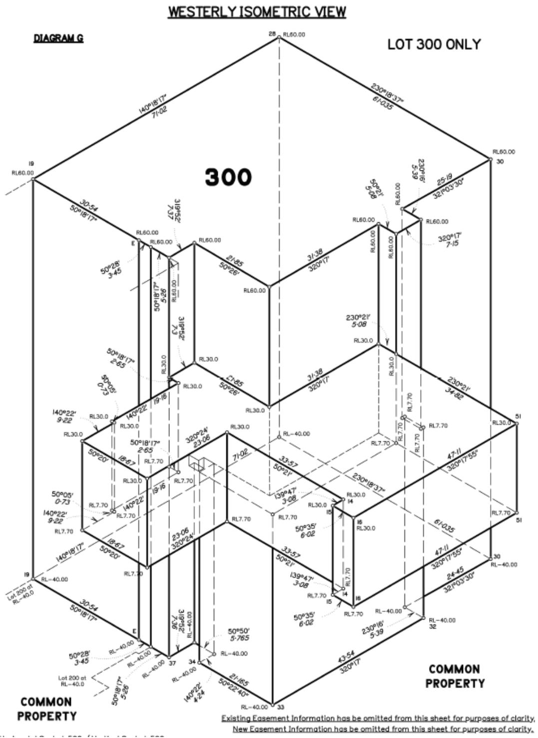

Figure 8. An example of volumetric lot in the QLD jurisdiction

In terms of the relationships between the primary parcels and secondary interests, a secondary interest is typically constrained within primary parcels. The legal boundaries of parcels are typically delineated using by using bearing and distance values alongside the boundary lines. Another common type of legal boundaries is a physical feature boundary. It is a boundary of the land whose location follows a physical feature, which can be either natural or artificial. The physical feature exists now or used to exist, and no longer exists. There are two scenarios for physical feature boundaries: ambulatory and fixed. If a dramatic change has not caused them to become permanent, the limits of water and other natural features are continually moving about, while artificial features are always fixed. It is important to note that physical feature boundaries come in many forms:

- Tidal and non-tidal water boundaries
- Other natural feature boundaries, e.g. cliffs and watersheds

- Artificial feature boundaries. For example, a constructed rock wall can be adopted as a boundary.

4.6 South Australia (SA)

In the SA jurisdiction, the common primary parcels which are important for 3D cadastre include:

- Allotment: It refers the whole of the land comprised in a certificate of title. An example of allotment is provided in Figure 9.
- Unit: The boundaries of the units are defined by reference to parts of the building, not by reference to the land. The units are defined under Strata Titles Act 1988 (South Australia Government, 2021b) (see Figure 10).
- Unit Subsidiary: The units may also include unit subsidiaries set aside for the exclusive use of a particular unit, for example carport or yard (see Figure 10).
- Community lot: It refers to an individually owned land parcel or ownership space that is created under Community Titles Act 1996 (South Australia Government, 2021a).
- Development lot: It refers to the land comprised in a development lot that will be divided during a subsequent stage or stages in accordance with a development contract.
- Lot: It refers to a community lot or a development lot
- Lot Subsidiary: It refers to an area within the building or comprising land outside the building to be used for a purpose that is ancillary to the purpose for which the rest of the lot is to be used
- Strata Lot: It refers to a community lot created by a strata plan. Strata lots are defined upper and lower boundaries as well as lateral boundaries (see Figure 9).
- Common Property: Common property is the part of the land and building in the strata plan which does not form part of any unit and is for common use by all owners, e.g. stairways, paths and driveways.
- Road: A road parcel is vested in a council or prescribed authority
- Reserve: A reserve parcel is vested in a council or prescribed authority.

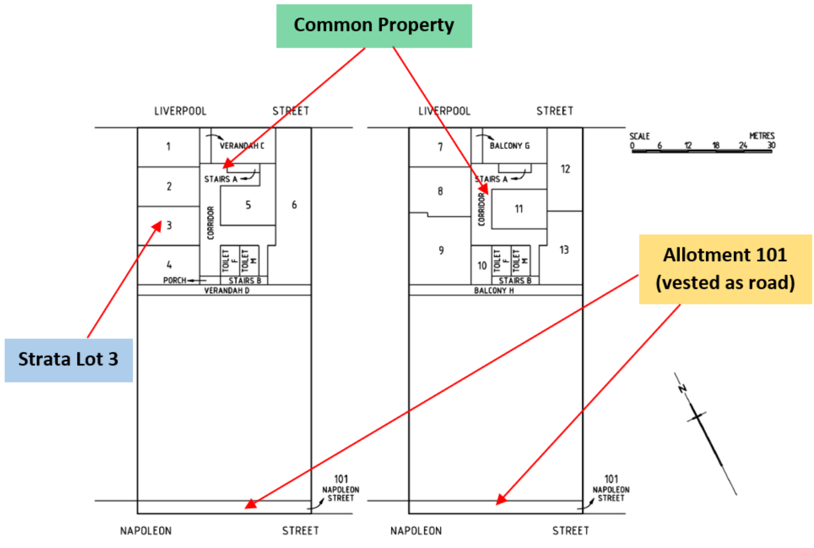

Figure 9. Floor plan diagram examples for Community Strata Plan with an allotment to vest as public road

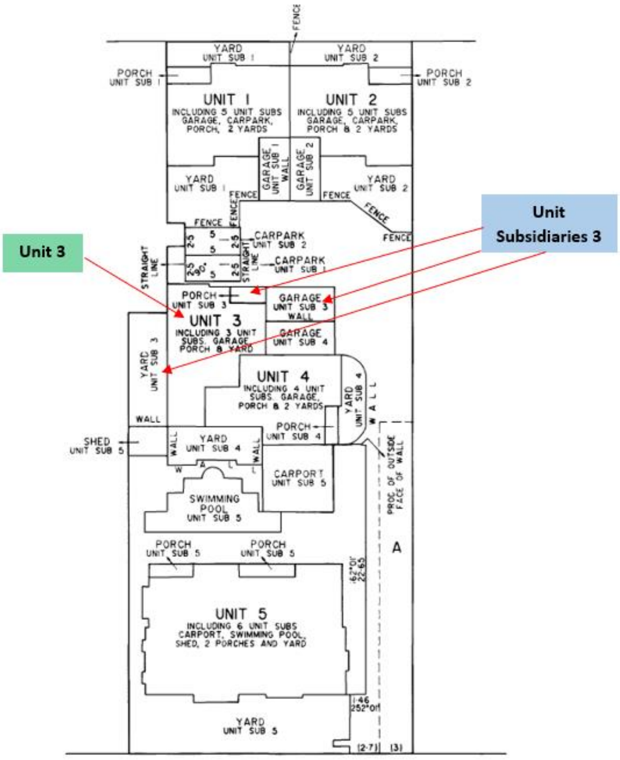

Figure 10. Floor plan diagram for a Strata Plan

The secondary interests include easements and restrictions. In strata subdivisions, the easements are used for support and shelter and allow for the establishment and maintenance of pipes, ducts, cables and other equipment. Restrictions typically apply to the appearance of community lots or buildings or other enhancements placed on community lots. In addition, as much as possible SA jurisdiction tries to apply the restriction to the common property so that it is more manageable in the future.

In regard to the relationship between primary parcels and secondary interests, any secondary interest can be defined over any primary parcel or portion of it. The legal boundaries are typically defined through the following types:

- Wall or fence boundary: When a wall or fence is used to define a boundary, the boundary is the inside surface of the wall or fence.
- Floor boundary: When a floor is used to define a boundary, the upper surface of a floor is used to define the boundary.
- Ceiling or roof boundary: When a ceiling or roof is used to define a boundary, the under surface of a ceiling or floor is used to define the boundary.
- Surveyed boundary: Boundary is defined by measuring bearing and distance of the boundary line.

4.7 Tasmania (TAS)

In TAS jurisdiction, the following primary parcels are generally defined:

- Private Parcel: Land privately owned by an individual(s), organisation, or company

- Water Area: An “arbitrary” parcel over part or whole of a lake, river, estuary for the purpose of completing a “base” layer for TAS jurisdiction.
- Authority Land: It refers to primary parcels owned or managed by a Commonwealth, State or Local Government Agency, Government Business Enterprise (GBE) or a legislated Authority.
- Casement: This primary parcel forms part of the Road, Railway or Footway network

In the context of 3D cadastre, the following two primary parcels are prevalent in strata plans:
- Lot: It refers to an area or space allocated for separate occupation by the owner of the lot or a person deriving rights of occupation from the owner.
- Common Property: It means all land within the scheme that is not within the boundaries of a lot and all other property administered by the body corporate

The secondary interests relevant for 3D cadastre are:
- Easement: It is defined as a set of legal rights and restrictions over land favouring a person or party registered on the property title.
- Covenant: It is similar to the definition provided in QLD and NSW jurisdictions
- Profit a prendre: It is similar to the definition provided in QLD and NSW jurisdictions

In terms of the relationships between primary parcels and secondary interest, a secondary interest exists over the primary parcel. For example, easements exist over the lots and common property in favour of the body corporate and the owners of lots to the extent reasonably necessary for the installation, maintenance, operation, repair, and replacement of service infrastructure.

4.8 Victoria (VIC)

The primary parcels in Victoria include (State Government of Victoria, 1988):
- Lot: A lot typically refers to a piece of land, building, airspace or any combination of these, which is assigned to an individual or a private owner (see Figure 11).
- Common property: A common property refers to parts of land and buildings that are not considered as lots, reserves, or roads. All lot owners collectively own the common property.
- Road: A road is a type of primary parcel which is for the benefit and use of public community. There are various types of road parcels such as carriageway, pavement, verge, and kerb.
- Reserve: Similar to roads, reserves are for the benefit and use of public community. Reserves include those land parcels owned by city councils. City council usually uses these parcels to establish parks or similar amenities. Reserves are typically assigned to pieces of land.
- Crown parcels: This refers to those primary parcels owned by the government. Crown land constitutes almost one-third of Victoria, and these parcels are allocated for public use, which typically includes national parks and state forest, freeways, recreation areas, hospitals and sporting facilities (DELWP 2016). There are two types of crown parcels: crown portion and crown allotment.

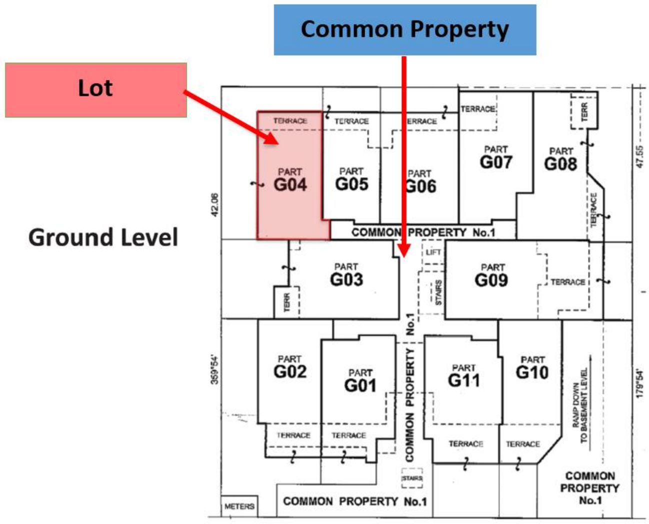

Figure 11. Lot and common property in a building subdivision plan

The secondary legal interests in Victoria include:

- Easements: Easement is part of the land or building owned by one interest holder that can be used by another interest holder or public authority.
- Restrictions: Restrictions are a type of covenant which defines the area or space on one or more lots where limitations on the use of the land apply.
- Depth limitations: Depth limitation is a form of restriction that originates from the original crown grant in Australia.

There are two common types of legal boundaries: general and fixed. General boundaries are specified and observed based on real world, tangible spatial objects. Fixed boundaries are specified based on surveying measurements such as distance, angle, and azimuth. There are three main types of general boundaries:

- Building: Building boundaries are defined and measured by considering the building structure or a part of it.
- Ambulatory: Ambulatory boundaries are defined based on observing the movement of dynamic natural features such as coastlines and river borders
- Projected: Projected boundaries are defined in balconies and terraced areas of buildings. It is mainly delineated by extending structural boundaries in both and vertical directions.

4.9 Western Australia (WA)

The primary parcels that can be considered for 3D cadastre in the WA jurisdiction are:

- Lot on Strata Plan: One or more cubic spaces forming part of the parcel to which a strata scheme and are defined by a combination of statements and dimensions depicted on the floor plan(s)(see Figure 12). Each lot is limited in height and depth.
- Common Property on Strata Plan: Any part of the scheme not labelled with a lot or part lot number is common property. This includes the airspace and land above and below the height and depth of each lot/part lot.

- Lot on Survey-Strata Plan: The lot boundaries are shown as dimensions and survey detail similar to deposited plans which depict green title lot boundaries (see Figure 13). They are usually unlimited in height and depth unless noted on the survey-strata plan.
- Common Property on Survey-Strata Plan: The areas that are common property are shown on the plan prefixed by the letters CP, e.g. CP3. (see Figure 13)
- Dedicated Road: A road or street dedicated to public use. This land is crown land under the control and management of the local government.
- Reserve: Areas of Crown Land set apart for various public purposes, such as parks, recreation, drainage or church sites.

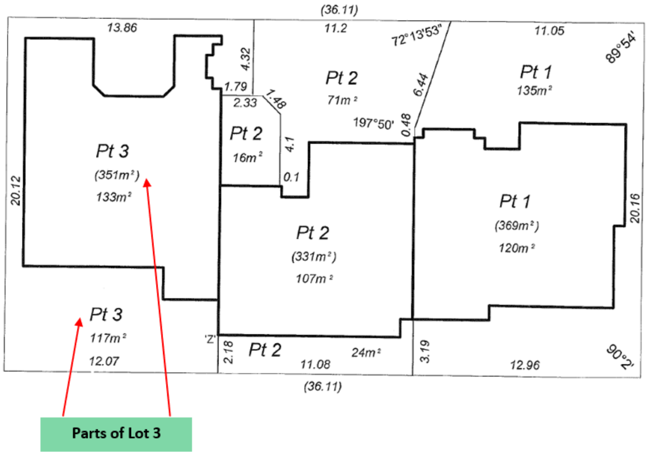

Figure 12. Example of lot on strata plan in the WA jurisdiction (adopted from Western Australia's land information authority, 2021)

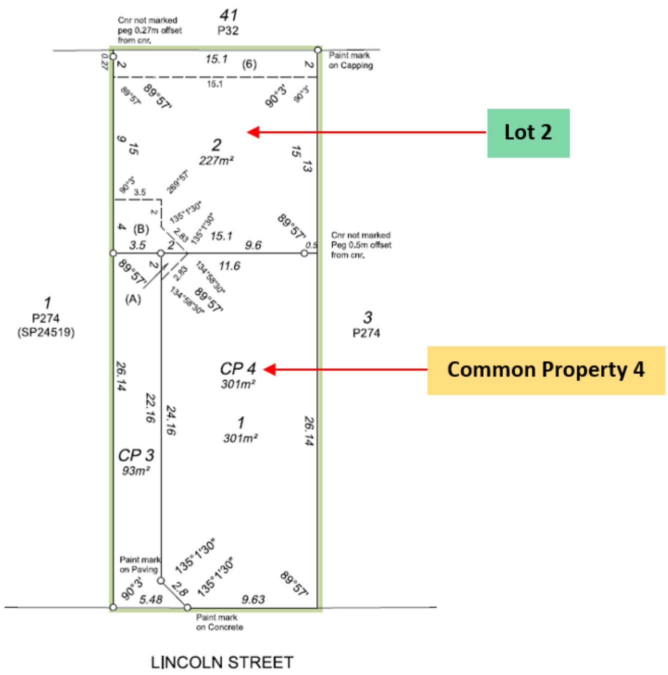

Figure 13. Example of lot and common property on survey-strata plan in the WA jurisdiction (adopted from Western Australia's land information authority, 2021)

The secondary interests identified in WA jurisdiction are similar to those in VIC jurisdiction. The relationship between these interests and primary parcels are typically identified by dimensions and comments on strata and survey-strata plans. The legal boundaries are defined through one of the following methods:

- Building boundaries
- By dimensions: This boundary type is used to define part lots external to the building and survey strata boundaries
- Stratum definitions for height and depth
- Imaging mixture of dimensions and statements, e.g. prolongation of external face of wall.

4.10 Similarities and differences between jurisdictions

The findings show that Australian and New Zealand jurisdictions have some similarity in terms of managing 3D cadastral data while there some differences between them. One main similarity is that 3D legal boundaries are typically delineated by either referencing physical structures or fixed survey measurements. Common property as a primary parcel and easement as a secondary interest have similar purposes in all Australia and New Zealand jurisdictions.

The differences mainly refer to the different types and terminologies used for primary land parcels and secondary interests in each jurisdiction. In addition, similar ownership concepts are named differently in each jurisdiction. For instance, the "Lot" primary parcel, which defines the ownership space of a private property, in Victoria is the same as "Unit" parcel in Northern Territory. All jurisdictions, except VIC, have specific legislations for 3D cadastre. For example, VIC jurisdiction considers a unified legislation, under Subdivision Act 1988, for dealing with any type of land and property ownership. Table 2 shows the summary of different 3D cadastral data elements in Australian and New Zealand jurisdictions.

Table 2. Important 3D cadastral data elements in Australian and New Zealand jurisdictions

Jurisdiction	Primary parcels	Secondary interests	Spatial relationships	Legal boundaries
ACT	Unit, Unit Subsidiary, Common Property	Easement, Restriction	Secondary interests overlap with the entire or part of primary parcels	Party wall, common boundary (internal and external), measured boundary
NSW	Lot, Part lot, Common Property, Development Lot	Easement, Restriction, Stratum Statement	Notations on plan, Section 88B instrument of the Conveyancing Act 1919	Building boundary (interior, exterior, median), ambulatory boundary, line boundary
NZ	Principal Unit, Accessory Unit, Future Development Unit, Common Property	Easement, Covenant, Movable marginal strip, Esplanade strip, Lease, License,	The relationships are depicted spatially. Where the boundaries are defined using right-line, arc and stratum boundaries, sufficient information to enable the relationships to	Right-line boundary, water boundary, irregular boundary, arc boundary, stratum boundary, permanent structure boundary

			be determined mathematically is also required.	
NT	Unit, Common Property, Road, Reserve	Easement (general, statutory), Covenant	Secondary interests overlay on the base primary parcels.	Measured boundary, Boundary referring to a cubic space, Boundary referencing a parcel of land unlimited in its vertical dimensions
QLD	Base Lots, Common Property, Road, Building format Lots (Units), Volumetric format lots, Private Courtyard	Permits over: Trust, Road, Creek, River, Reserve, Land beyond tidal boundary (river), Land beyond tidal boundary (ocean), Lease, Easement, Covenant, Profit a prendre	Strata development constrained within primary parcel	Bearing and distance, physical feature boundary (Tidal and non-tidal water boundaries, Other natural feature boundaries, Artificial feature boundaries)
SA	Allotment, Unit, Unit Subsidiary, Lot (Community or Development Lot), Lot Subsidiary, Strata Lot, Common Property, Road, Reserve	Easements, Restrictions	An interest can be defined over any primary parcel or portion of it.	Wall or fence boundary, Floor boundary, Ceiling or roof boundary, Surveyed boundary
TAS	Lot, Common Property, Private Parcel, Water Area, Authority Land, Casement	Easement, Covenant, Profit a prendre	Secondary interests exist over the primary parcels	boundary structure (Centre of the structure or other specified location), Measured bearing and distance
VIC	Lot, Common Property, Road, Reserve, Crown Portion, Crown	Easement, Restriction, Depth Limitation, Crown Land Service	Secondary interests are spatially related to the primary parcels	Building boundary (interior, exterior, median, other), ambulatory boundary, projection, fixed boundary

	Allotment,			
WA	Lot on Strata Plan, Common Property on Strata Plan, Lot on Survey-Strata Plan, Common Property on Survey-Strata Plan, Dedicated Road, Reserve	Easement, Restriction, Depth Limitation	Dimensions and comments on strata and survey Strata plans	Building boundaries, By dimensions for part lots external to the building and survey strata boundaries, Stratum definitions for height and depth, Imaging mixture of dimensions and statements (e.g. prolongation of external face of wall)

5. PROPOSED FRAMEWORK

By considering the differences and similarities outlined in Section 4, we proposed a new framework to support 3D cadastral data elements in all of the studied jurisdictions. As shown in Figure 14, there are four tiers for the proposed framework:

- **Definition tier:** This tier includes the definition elements that are fundamental to the developed framework for 3D cadastre in Australia and New Zealand. These elements provide a set of basic and generic entities related to geometric and topologic representations as well as various semantic definitions. Modelling 3D cadastral elements' geometric or spatial shape is described using a number of different geometric representation techniques such as solid models (e.g., Boundary representation, Constructive Solid Geometry), multi-surface and tessellated models. Topological elements can include vertex, edge, and face. In addition to geometry and topology concepts, a range of semantic definitions of basic concepts related to 3D cadastre are considered in this part of the framework. For instance, an agreed definition of 3D land parcel can be included. These definition and concepts provided here can be used in core, interoperability, and jurisdictional elements.
- **Core abstract tier:** This tier includes abstract and general data elements. Primary parcel, secondary interest, legal boundary, survey element, and physical element are the most common types of items in this category. All subsequent specialisations in interoperability and jurisdiction elements are defined based on data elements considered in this section of the framework. The abstract elements considered are not instantiated in the real-world cases. However, the fundamental structures, essential relationships, and broad concepts established by these elements can then be reused and refined by classes in the interoperability and jurisdictional tiers.
- **Interoperability tier:** In this tier, data elements that are shared across all jurisdictions based on their similarities are defined. This tier is significantly important for supporting data exchange and semantic interoperability between Australian and New Zealand jurisdictions. Among primary parcels, lot and common property are similar data elements among all jurisdictions while easement is considered as a secondary interest in all

jurisdictions. More specialised concepts of physical elements include wall, floor, ceiling, and roof which are mainly used for defining building boundaries in the studied jurisdictions. In addition, these physical elements can be used as part of the entire spatial structure of common property parcels. In terms of survey elements, all jurisdictions generally consider survey marks and observations to define survey network and measure legal boundaries. In general, interoperability data elements can be used to communicate and share 3D cadastral information between jurisdictions.

- **Jurisdictional tier:** The most specific data elements for each jurisdiction are defined within this tier. The jurisdictional data elements are self-contained, and there is no possibility to further specialize or reference them in other tiers. This tier includes a set of specific data elements for nine jurisdictions, namely ACT, NSW, NZ, NT, QLD, SA, TAS, VIC, and WA. These data elements may include specific elements, attributes, relationships, and code lists that are used in a particular jurisdiction. For instance, in VIC jurisdiction, the median boundary can be defined as a specific type of physical boundary.

6. DICUSSION AND CONCLUSIONS

In this research, we studied the current practice of 3D cadastre in all Australian states and territories as well as New Zealand jurisdictions. By using a questionnaire, we have used the land administration experts' input to identify different types of primary parcels, secondary interest, legal boundaries as well as the relationships between the primary parcels and secondary interests. Out investigation of sample cadastral plans, the relevant land and property legislations as well as guidelines and survey practice directives helped us to better consolidate our findings and obtain a more concrete understanding of 3D cadastral data elements in the studied jurisdictions. Our study helped us to identify the similarities and differences between these elements across the jurisdictions. In addition, we developed a new generic nationwide framework to describe how specific jurisdictional practices can be harmonised. Theoretically, our proposed framework would provide a starting point for developing a nationally connected digital data ecosystem for 3D cadastre in Australia and New Zealand.

Moving towards 3D digital cadastre can be considered through three common lenses: technical, legal, and institutional. From a technical point of view, developing a new 3D data model for is fundamentally important for implementing 3D digital cadastre. The data model provides the basis for the lifecycle of 3D digital data including data capturing, validation, visualisation, storage, query and analysis. Currently, the 3D Cadastral Survey Data Model and Exchange (3D CSDM) is being developed to provide a standard for transferring digital cadastral survey information between the survey industry and government land administration agencies in Australia and New Zealand. This data model should be able to support 3D cadastral data elements in various jurisdictions that we studied in this investigation.

The implementation of the conceptual data model for 3D cadastre is done through developing appropriate technical encodings. In our view, building information modelling (BIM) and its IFC standard can be considered as an appropriate encoding for exchanging 3D digital cadastral data during subdivision processes including planning permit, certification, and registration. This is due the fact that BIM models provide rich 3D digital data sharing space during the building lifecycle. It would also facilitate 3D data re-use, share and exchange with other stakeholders such as architects and engineers. However, BIM cannot be a good solution for upgrading the current 2D property map base into 3D digital environment. In this case, a technical encoding based on CityGML or InfraGML standards would provide a suitable approach for storing all 3D cadastral and survey information within a 3D digital cadastral database (3D DCDB).

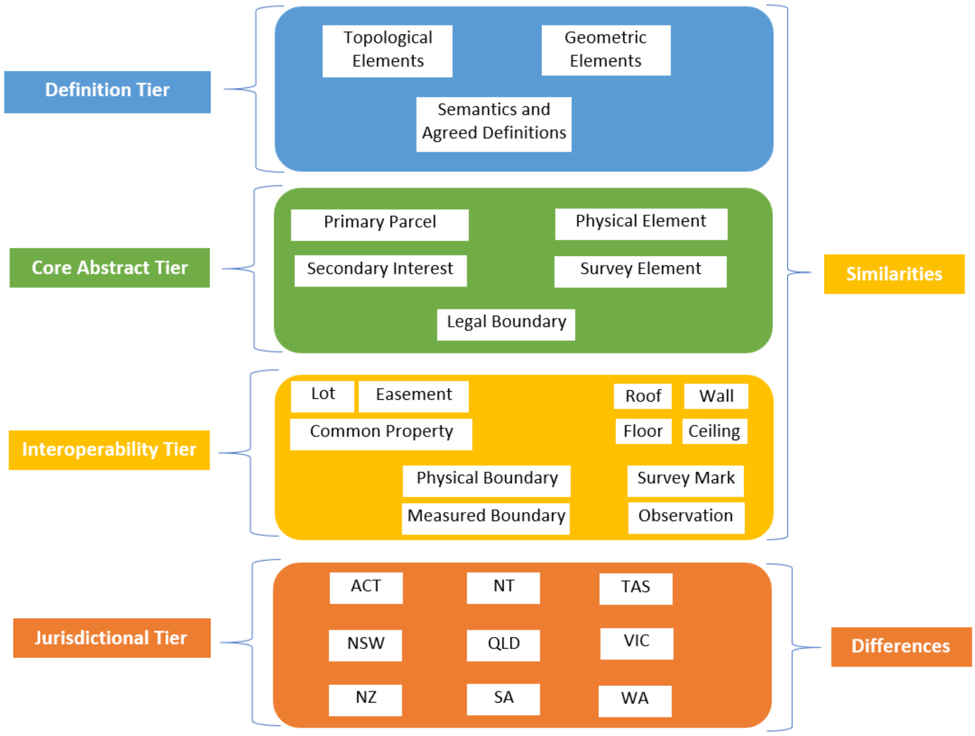

Figure 14. Proposed framework for 3D cadastre in Australian and New Zealand jurisdictions

In terms of legal aspects, the required changes in legislation relevant to supporting 3D digital cadastre implementation should identified. Rules and regulations need to fully support lodging 3D models for cadastral registration. This includes looking closely at the existing Acts and regulations and proposes the required changes for facilitating the change process for 3D digital cadastre implementation. To address the legal challenges, the following key questions are expected to be answered:

- Does the current legislation allow for the registration of vertically stratified ownership rights using 3D digital models?
- What are the required changes to the existing legislation to enable the use of 3D digital data?
- What would be the potential format of 3D digital models as the legal instrument?

Finally, some institutional changes are also expected. This includes changes to the processes and activities at land registries, surveying industry as well as other key land administration stakeholders including councils and referral authorities. This includes looking closely at the existing land administration processes and stakeholders' interaction and proposing the required modifications for facilitating the change process for 3D digital cadastre implementation. The following questions are important for institutional changes:

- What is the appropriate solution for incorporating 3D digital models into the land approval processes undertaken by councils and referral authorities and the government land authorities' registration processes?
- How will plan information be incorporated into the contract of sale for transferring legal ownership, and supplementing real estate marketing?
- How will the surveying and property industries align their systems to read, interpret and make administrative decisions to cadastral information represented in a 3D digital environment?
- Will 3D digital models replace or supplement 2D cadastral plans/ images or data files?

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BIOGRAPHICAL NOTES

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Practical verification of Polish 3D cadastral model

Jarosław BYDŁOSZ, Artur WARCHOŁ, Monika BALAWEJDER and Agnieszka BIEDA, Poland

Key words: 3D cadastre, 3D land administration, Polish cadastral model, Terrestrial Laser Scanning – TLS, UML

SUMMARY

The 3D cadastre model in Poland has been developed for several years. The summation of these works is the proposal of the model of the Polish cadastre developed using the UML language on the basis of the existing legal regulations, presented in detail in the work (Bydłosz and Bieda, 2020). The aim of the current research was practical verification of this model. This work was performed on the example of a semi-detached building located near Cracow in a housing estate of family houses.

The modelling of relationships between already existing elements (parcel, building) and proposed 3D cadastre objects was performed in UML language. Problems encountered in proposing 3D cadastre objects resulted mainly from a complicated legal situation. The twin building is located on a parcel of land that is jointly owned by the building owners. The paper proposes to solve such a problem by dividing the cadastral parcel so that the building owners have separate properties. The corresponding UML diagrams are presented here.

The second part of the research concerned the application of laser scanning for practical verification of the 3D cadastre model. For this purpose, the building was measured using laser scanning. This measurement was made outside and partly inside the building. During this research, however, it was not possible to fully apply scanning for the verification of this model. According to the authors, this topic requires further research.

STRESZCZENIE

Model katastru 3D w Polsce był rozwijany od kilku lat. Podsumowaniem tych prac jest propozycja modelu polskiego katastru opracowana z wykorzystaniem języka UML na bazie istniejących przepisów prawnych, szczegółowo przedstawiona w pracy (Bydłosz i Bieda, 2020). Celem obecnych badań była praktyczna weryfikacja tego modelu. Prace te wykonano na przykładzie budynku bliźniaczego położonego niedaleko Krakowa w osiedlu domków jednorodzinnych.

W języku UML wykonano modelowanie zależności między istniejącymi już elementami (działka, budynek) i proponowanymi obiektami katastru 3D. Problemy jakie napotkano przy propozycji obiektów katastru 3D wynikały głównie ze skomplikowanej sytuacji prawnej. Bliźniaczy budynek jest położony na działce będącej wspólną własnością posiadaczy budynków. W pracy zaproponowano rozwiązanie takiego problemu poprzez podział działki ewidencyjnej tak, aby właściciele budynków mieli osobne nieruchomości. Przedstawiono tu odpowiednie schematy UML.

Druga część badań dotyczyła zastosowania skaningu laserowego dla praktycznej weryfikacji modelu katastru 3D. W tym celu wykonano pomiar budynku za pomocą skaningu laserowego. Pomiar ten wykonano na zewnątrz oraz po części wewnątrz budynku. W trakcie tych badań nie udało się jednak do końca zastosować skaningu do weryfikacji tego modelu. Temat ten wymaga dalszych badań.

Practical verification of Polish 3D cadastral model

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1. INTRODUCTION

Information on real estate in Poland is recorded in two independent systems, which are the land and building cadastre and land and mortgage register. The legal basis of the former is the Law on Geodesy and Cartography (Act, 1989) and the regulation concerning the Land and Building Cadastre (Regulation, 2021). Land and building cadastre objects are land parcels, buildings or separate premises (apartments). The information collected in the land and building cadastre primarily concerns their location in the orthogonal coordinate system, but the database also contains a number of attributes describing the physical and legal status of the cadastral objects (Puniach et al., 2018). The only reference to the three-dimensional space can be considered descriptive information on the number of underground and aboveground floors.

The most numerous objects of the land and building cadastre are the cadastral parcels. In the real world, a parcel is a three-dimensional surface that is part of the earth's surface. A parcel of land can be used "vertically" both upwards and downwards, subject to compliance with the law and possibly obtaining the relevant permits. It follows that, in fact, a registered parcel of land is a solid with boundaries that are not fully defined the vertically.

In the conceptual model of land and building cadastral data, a parcel of land is defined as a polygon with enclaves, and for its description the geometry type GM_Surface is used. The representation of the parcel both in the cadastral database and on the map is a simple two-dimensional polygon (possibly enclaves), and the height component (z) is generally not collected and reported.

Another cadastral object is a building. Geometrically, in the real world this object is a solid or a group of solids, parts of which may be located both above and below the ground surface. Edges of such a building are more and more often not straight lines, but curves of various types, and boundary walls are not only parts of a plane, but surfaces of other types. In the land and building cadastral data model, a building is defined as a set of polygons with enclaves and for its description the geometry type GM_MultiSurface is used. The building attributes are among others the information related to the height dimension such as the number of floors above or below ground.

The last in the order of the cadastre object is the premises, which are independent residential premises or premises for other purposes (Act, 1994). In geometric sense a premises is one or more solids, located in the outline of a building. The features related to the spatial reference of the premises are characterized by attributes such as the area of the premises, the area of the appurtenant rooms or the number of the storey on which the premises are located. In addition, a share in the common parts of the building and in the land parcel on which the building is built are generally associated with premises.

Detailed considerations of the actual land and building cadastral objects in terms of their mathematical notation and the recording of their geometry in the cadastral database are presented in (Bydłosz, 2017).

The land and mortgage register operates on the basis of the Act on Land Register and Mortgage (Act, 1982). Land and mortgage register objects are real estates. Real estate can consist of land parcels, buildings or separate premises (apartments). Buildings and premises may be separate properties or may be part of another object. The building may make the same real estate as land parcel and the premises may be part of a building.

Ideas about a 3D cadastre have gained widespread popularity in Poland. In 2010, a questionnaire on a 3D cadastre for Poland was completed within the activities of the FIG Joint Commission 3 and 7 Working Group on 3D Cadastres (Questionnaire, 2010). Such questionnaires were subsequently completed in the years 2014 (Questionnaire, 2014) and 2018 (Questionnaire, 2018).

Since then, much research concerning 3D cadastre has been conducted in Poland. Their scope encompasses theory, practice or very often are the combination of both. The more detailed description of these studies performed till 2020 is presented in (Bieda et al., 2020). In 2020 two papers on 3D cadastre concerning Poland were published. In (Bieda et al., 2020) made a trial of implementing 3D cadastral objects on the example of historical objects. In (Bydłosz and Bieda, 2020) the existing UML cadastral model in Poland is extended, resulting in creating UML model for 3D cadastre. This model is strictly theoretical, without practical verification. The main idea of this research is to verified UML model for 3D cadastre on the example of building surveyed with the application of laser scanning.

2. LASER SCANNING

Much research has been carried out on the registration of ground-based structures. In particular, they relate to general 3D cadastre issues. In the literature, we can meet such issues as visualization (Cemellini et al., 2018) or registration (Dimopoulou et al., 2018). General issues in the field of 3D Cadastre are dealt with, among others, by scientists such as: Adi et. al (2018), Gursoy Surmeneli et al. (2018), Jaljolie et al. (2018) Larsson et al. (2018) and Radulović et al. (2017). There are many limitations when registering 3D objects. The 3D limitations of registration for cultural heritage features are described by Kitsakis and Dimopoulou (2017). On the other hand, 3D restrictions resulting from registration in connection with underground facilities are described by Bieda et al. (2020).

Nowadays, registration of 3D objects is performed with the use of modern geodetic technologies. Primarily, these methods include laser scanning (Warchoł et al., 2019; Warchoł, 2013; Warchoł et al., 2011). Depending on the platform, scanning can be divided into: terrestrial (Terrestrial Laser Scanning – TLS), mobile (Mobile Laser Scanning – MLS), airborne (Airborne Laser Scanning – ALS), or satellite (Satellite Laser Scanning – SLS). The primary task of all laser scanners is to measure the distance of an object from the device. In the case of time-of-flight (TOF) instruments, this distance is a function of the time it takes the beam to travel all the way to the object and back. A special optical system, with a given frequency, sends light beams (most often in infrared) of a specific wavelength and a specific direction. Each reflection from an obstacle is recorded as the location of a point in space, with three coordinates. In the first step in Scanner Own Coordinates System (X,Y,Z) (triad with Sp on Fig. 1), after registration all scans into the project in Project Coordinates System (triad with pr in Fig. 1) and finaly after fitting into National Coordinate System as geodetic coordinates (X, Y, h) (triad with gl in Fig. 1).

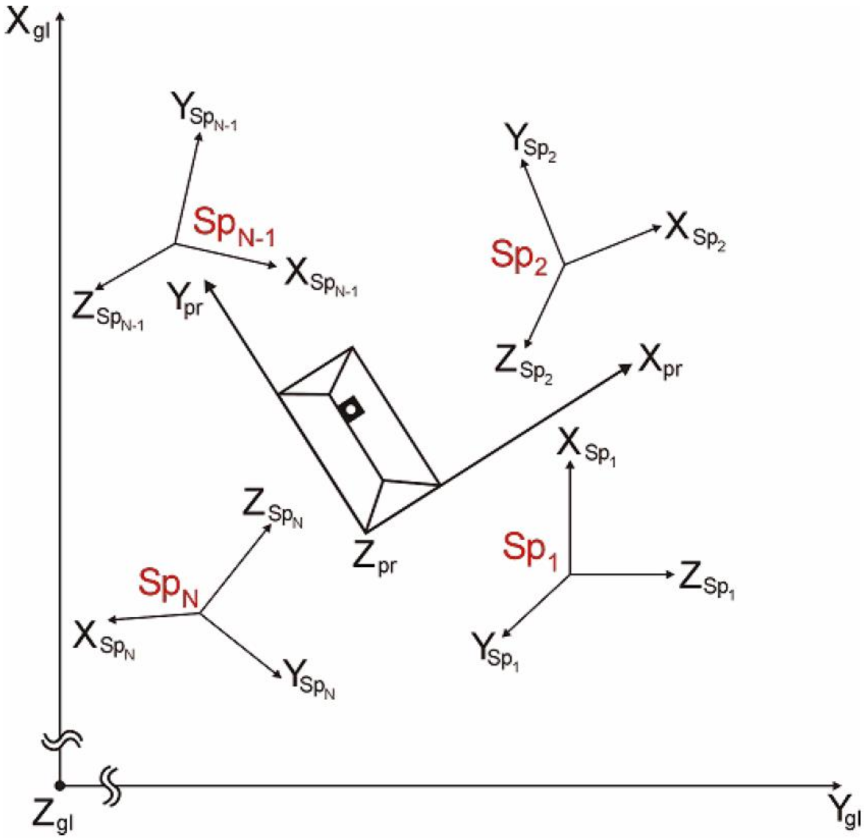

Figure 1. Scheme of changing coordinates from scanner to global coordinates (Riegl et al., 2003)

The advantages of TLS devices over even the most advanced geodetic instruments include on the enormous efficiency of data acquisition (the fastest devices can record up to 2 million points/s), independence of measurements from lighting conditions and high automation of field work, which significantly reduces the interpretive subjectivity of the researcher.

It is worth noting that laser scanning made in LiDAR (Light Detection and Ranging) technology is one of the modern and fast methods of obtaining information about the geometry of objects (Warchoł, 2015; Warchoł and Szwed, 2019; Warchoł, 2019). Therefore, TLS or MLS instruments can be used to acquire 3D spatial data for cadastral purposes. But MLS is difficult to use in dense cities and cannot be reached everywhere with a mobile measurement platform. Therefore, in order to carry out this research for the inventory measurement of the object in question, was performed using terrestrial laser scanning (TLS).

The point clouds were acquired with the Faro Focus 3D X130 terrestrial laser scanner. The entire project consisted of 26 scanner positions, of which scans 1st to 8th covered the facades of two buildings (64A/1 and 64A/2), while scans 9th to 26th covered the interior of one of the twins (64A/2). All point clouds were acquired together with RGB photos. Nominal cloud densities were set at 6.1mm by 10m for the facade and 7.6mm by 10m for the interior of the building. The individual scans were registered into one coherent project in Trimble Real Works 11.3 using the c2c method with an overall Cloud-to-Cloud Error at 1.69 mm. The entirety of the acquired data is almost 680 million points in 26 files with a total volume of 16.3 GB in LAS 1.2 file format.

Then the entire cloud was trimmed to the boundaries of the parcels on which the buildings were located. Then manual cleaning – getting rid of the "noises points" was done. Finally, about 612 million points remained, which were next used to create a 3D BIM model.

3. PRACTICAL EXAMPLE

3.1. General description

In order to carry out a practical verification of the Polish 3D cadastre model, an example was chosen, which is one building situated on one cadastral parcel. This object is located in a housing estate of single-family houses in one of the communes near Cracow (Cracow County, Małopolskie voivodship). The location of the Cracow County is presented in Figure 2.

Figure 2. The location of the Krakow county

The top view of this settlement is shown in Figure 3. The objects for which the 3D cadastral model will be built are marked in red. In addition, their photograph is included in Figure 4.

Figure 3. Top view of the estate, based on data obtained from developer

Figure 4. Photo of the object

As can be seen, the building which is the subject of the study consists of two identical parts with a floor area of approximately 111 square metres each. Both of them could constitute a separate building. As mentioned before, the analysed building is located on one cadastral parcel (1134/10). This parcel is shown in Figure 5. The area belonging to the buildings, identical to Figure 2, is marked in red on it. It consists of two registered parcels (1133/10 and

1134/10). The total area of these two parcels is 408 square metres (including parcel 1133/10 – 50 square metres and parcel 1134/10 - 358 square metres).

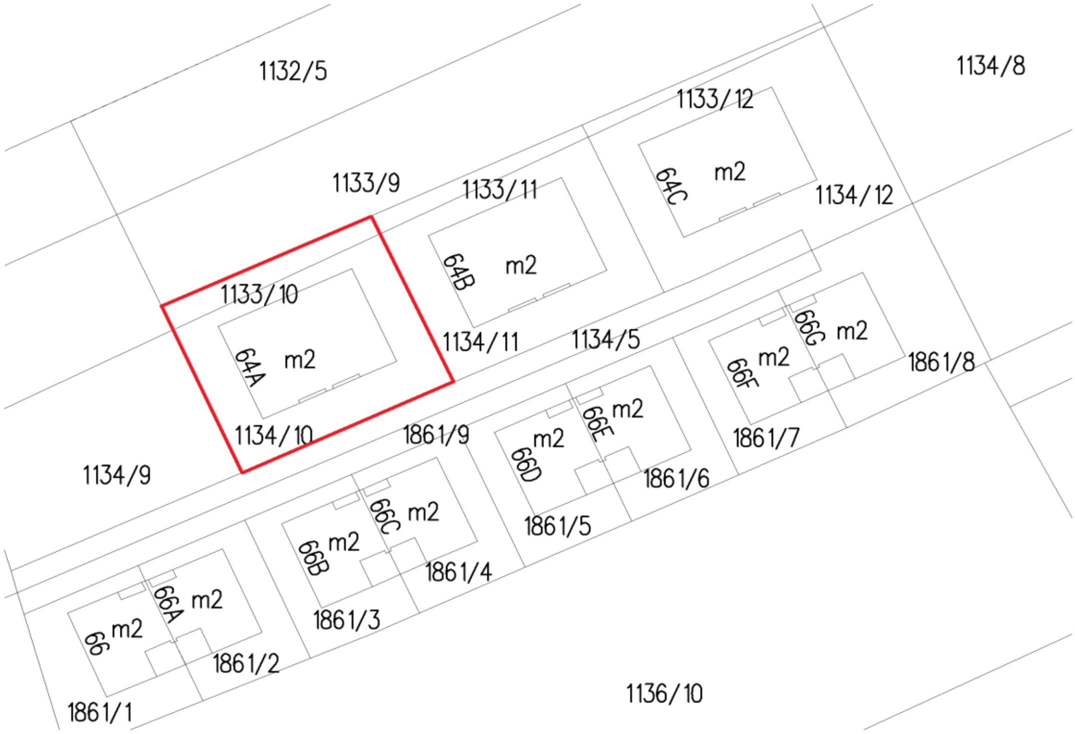

Figure 5. Cadastral map, based on data from the state geodetic and cartographic centre

According to the Polish law, a building (even one consisting of two identical and separable parts), as a component of the land, always belongs to the entity (or entities), which has the ownership perpetual usufruct right to the land on which it stands (Fig. 6a). The existing configuration of the cadastral boundaries makes it impossible to sell part of the building to different entities. In the presented situation, it would only be possible to sell the whole to two entities in fractional parts. In this way, each of these entities would have a share in the parcel, but also in the whole building and its individual parts. Each entity would thus be able, and sometimes even required, to decide on the part of the building that it does not use. Such a situation is clearly unacceptable from the point of view of potential buyers.

In order to be in a position to sell the rights to these buildings to different entities, the simplest thing would be to divide parcels 1133/10 and 1134/10. The surveying division would lead to a pair of identical cadastral objects (the building and the two parcels under it). The boundary between them would be drawn along the wall separating the two parts of the analysed building.

However, for reasons unknown to the authors, the developer did not opt for such a subdivision. We can only presume that it was most likely impossible due to the regulations on divisions of real estate (Act, 1997) in force in Poland. Pursuant to these regulations, a subdivision must comply with the conditions set forth in the local spatial development plan. The parcels in question are designated for single-family residential development with services (Resolution, 2007). In this area, the area of the parcel after division may not be less than 800 square metres. The area comprising plots 1133/10 and 1134/10 is already significantly smaller than this value.

Subdivision may also be carried out regardless of the plan's provisions, but only for the purposes specified in the Real Estate Management Act (Act, 1997). In this situation, two cases could apply:

1) abolition of co-ownership of real estate developed with at least two buildings, erected on the basis of a building permit, if the division is to consist in separation for individual co-owners, indicated in a joint application, of buildings together with parcels of land necessary for proper use of those buildings;
2) to separate a building parcel necessary for the use of a residential building.

In the first case, the entire building and parcels 1133/10 and 1134/10 would first have to be sold to the new owners in fractional parts and only then would they be able to order a partition to cancel the joint ownership. In the second case, the authority approving the division (the head of the municipality) would have to consider the two parts of the merged building as separate buildings that require the separation of parcels necessary for their use.

In order to make the division of parcels 1133/10 and 1134/10 unnecessary, the developer decided to establish, in clearly separate parts of the building, independent residential premises (Fig. 6b), which meet the conditions of the Apartment Ownership Act (Act, 1994). That is, each of them is formed by a room or a set of rooms separated by permanent walls within the building and intended for permanent residence of people, which together with auxiliary rooms serve to satisfy their housing needs.

The right to any premises may be transferred to another entity. Such premises include the right to the common parts of the building and the right to the land on which the building in which the premises are situated is located. In this particular case, there are no common parts in the building. However, the owners of the premises must have a share in the right to the parcel of land located under the building (Fig. 6c). This share depends on the useful area of the premises. Since it is identical in both buildings (exactly 111.33 sq. m), the share in the right to the parcel for those who have the right to each premises is the same, i.e. 1/2. After acquiring the right to the premises with the fractional right to plots 1133/10 and 1134/10, the new owners will be able to independently order a division in order to dissolve the joint ownership (Fig. 6d). After the division, however, only the parcels of land with the buildings as their components will belong to them. Premises will cease to exist because for them to have a right to exist there must be some other parts in the building. Furthermore, they can carry out a merger of parcels 1133/10 and 1134/10 as part of the subdivision procedure (Fig. 6e). The new parcels that will arise from such a merger will be given completely new numbers. These numbers will, of course, depend on what numbers have already been used previously in that cadastral area. They will be the next available natural numbers.

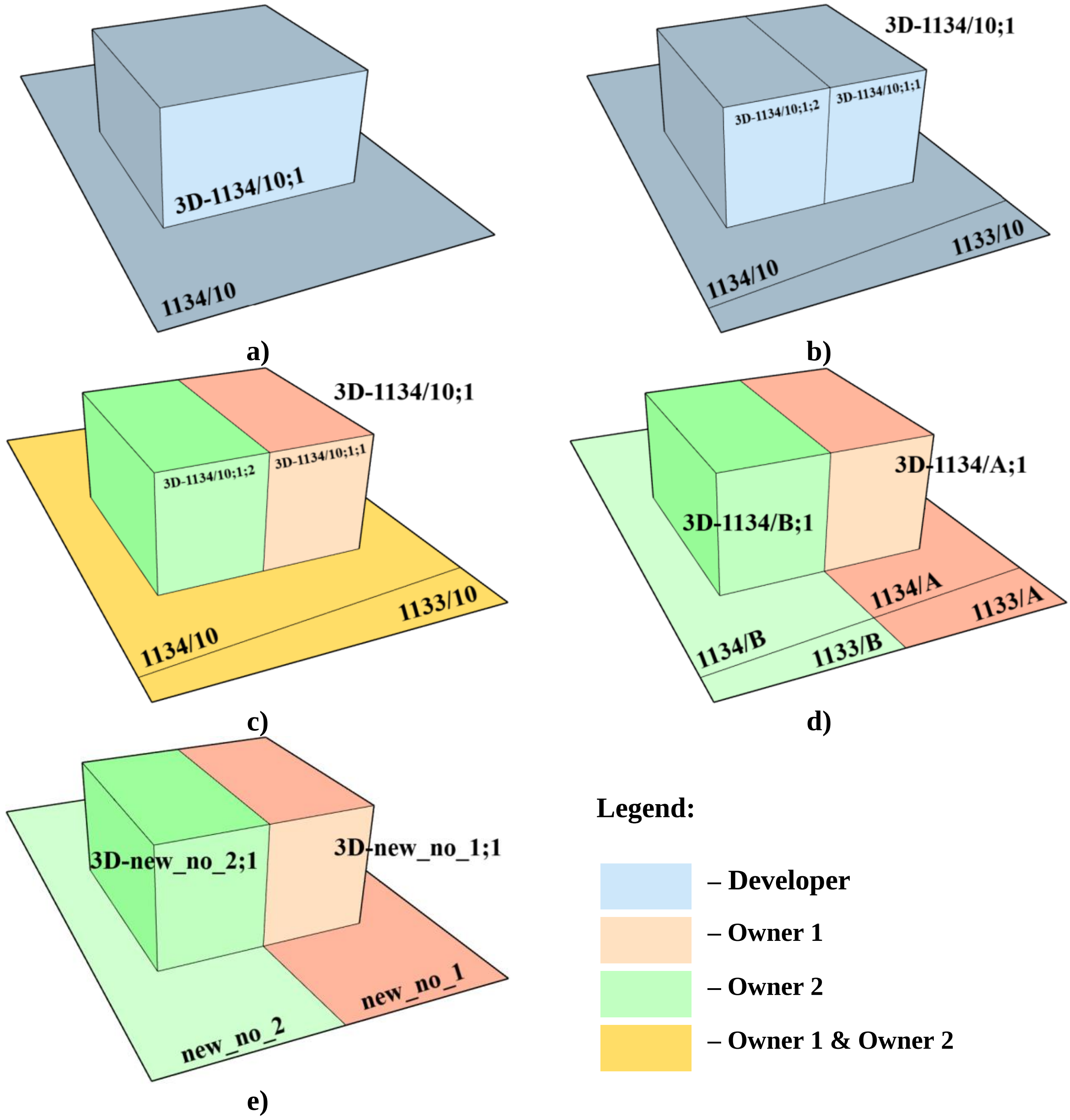

Figure 6. Diagram of the situation: (a) anticipated – one building and one parcel of land belonging to the Developer; (b) actual before the sale – one building with two units and two parcels of land belonging to the Developer, (c) actual after the sale – one building with two units belonging to new entities and two parcels of land co-owned by the owners of the units; (d) obtainable through subdivision – two buildings which are components of parcels resulting from the subdivision of parcel 1134/10 belonging to different entities and "belonging" to them according to the development plan of the estate parcels resulting from the subdivision of parcel 1133/10; (e) obtainable through merger and subdivision – two buildings which are components of parcels belonging to different entities

3.2. Laser scanning

The point clouds were acquired with the Faro Focus 3D X130 terrestrial laser scanner (Fig. 7). The entire project consisted of 26 scanner positions, of which scans 1st to 8th covered the facades of two buildings (64A/1 and 64A/2), while scans 9th to 26th covered the interior of one of the twins (64A/2). All point clouds were acquired together with RGB photos. Nominal cloud densities were set at 6.1mm by 10m for the facade and 7.6mm by 10m for the interior of the building.

Figure 7. TLS instrument Faro Focus X310 during point cloud acquisition

The individual scans were registered into one coherent project in Trimble Real Works 11.3 using the c2c method with an overall Cloud-to-Cloud Error at 1.69 mm. The entirety of the acquired data is almost 680 million points in 26 files with a total volume of 16.3 GB in LAS 1.2 file format (Fig. 8).

Figure 8. Point cloud of the research object coloured by RGB values

Then the entire cloud was trimmed to the boundaries of the parcel on which the buildings were located. Then manual cleaning – getting rid of the "noises points" was done. Finally, about 612 million points remained, which were next used to create a 3D BIM model.

3.3. Models

There are different ways to get a 3D model. The most correct model will be obtained when the designer / architect, translating his idea into an object, performs the project immediately in BIM technology. Other methods are: creating a model based on 2D documentation (vector or paper), or making inventory measurements that will then be used to create a 3D BIM model. In the context of modelling and BIM technology, it is worth remembering that the BIM model is not only geometry but also an information layer in the form of attributes / parameters of individual objects. As a rule, the design documentation and the actual state of the building differ after the building is constructed. Therefore, in order for the developed model to reflect the actual state of affairs as much as possible, it was decided to perform a laser scanning which will be the basis of 3D model.

3.3.1. Models from scanning

Based on the previously prepared point cloud, a 3D BIM model was made. Modelling consists in recreating the real state in digital form, using the elements available in the program and libraries. Bearing in mind the purpose of creating the model and the actual state of the object, the LOD was setting up at level 100. The main structural and architectural elements were modelled – walls, ceilings, beams, roof, doors and windows. However, the inventory did not cover any elements of technical equipment – pipes, conduits nor ducts etc. The final model is shown on Fig. 9.

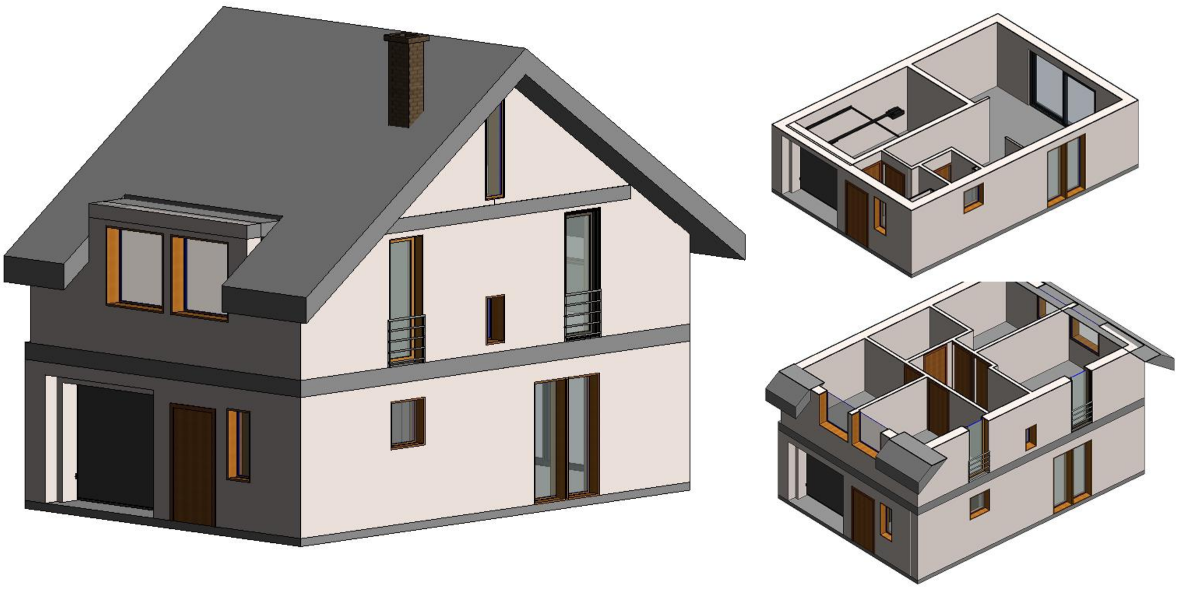

Figure 9. 3D BIM model of the research object (whole on the left) and parts of model divided by levels (right)

The modelling accuracy was estimated at the level of 2 cm on the basis of randomly selected places where the position of the point cloud and the model were compared manually.

3.3.2. Schemas, UML models

General diagram defining the relationships between 'Cadastral Parcel', 'Cadastral Parcel 3D' and both 2D and 3D building objects was defined in (Bydłosz and Bieda, 2020) and is presented in Fig. 10.

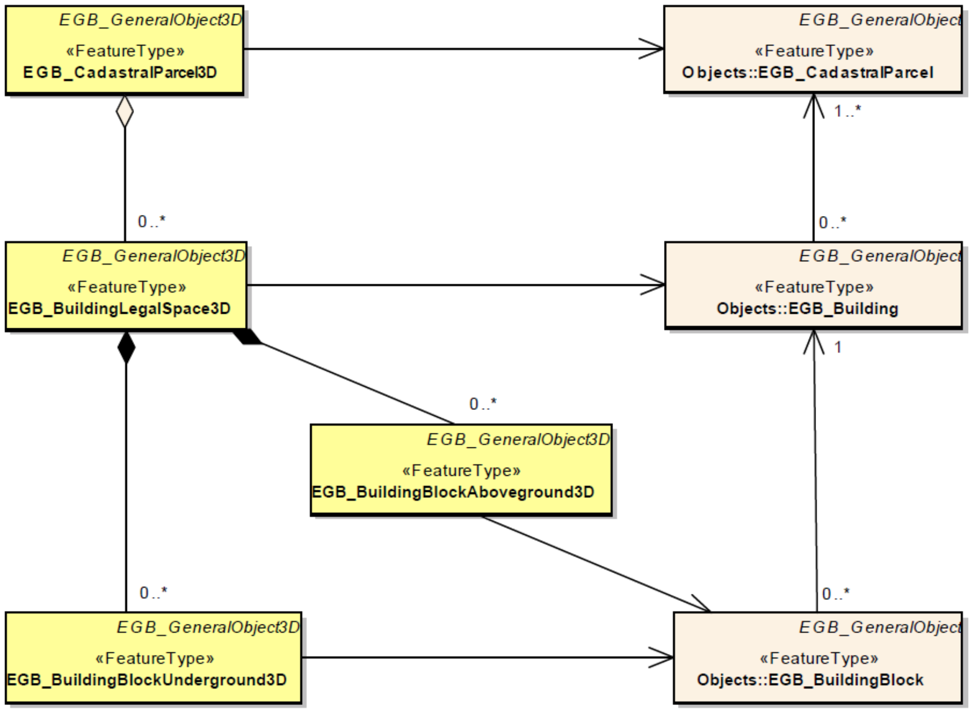

Figure 10. Diagram of defining the relationships between 'Cadastral Parcel,', 'Cadastral Parcel 3D' and both 2D and 3D building objects, based on (Bydłosz and Bieda, 2020)

As already stated above the subject site consists of two registered parcels 1133/10 and 1134/10 which are built up with two semi-detached houses. The buildings are only located on the parcel 1334/10. In this case there are neither premises and nor building blocks. The parcel is co-owned by the owners of both buildings. In this case it is possible to create 'Building Legal Spaces 3D', being part of 'Cadastral Parcel 3D' for both buildings. The schema of such situation is presented in Fig. 6b and the UML diagram for this case is presented in Fig. 11.

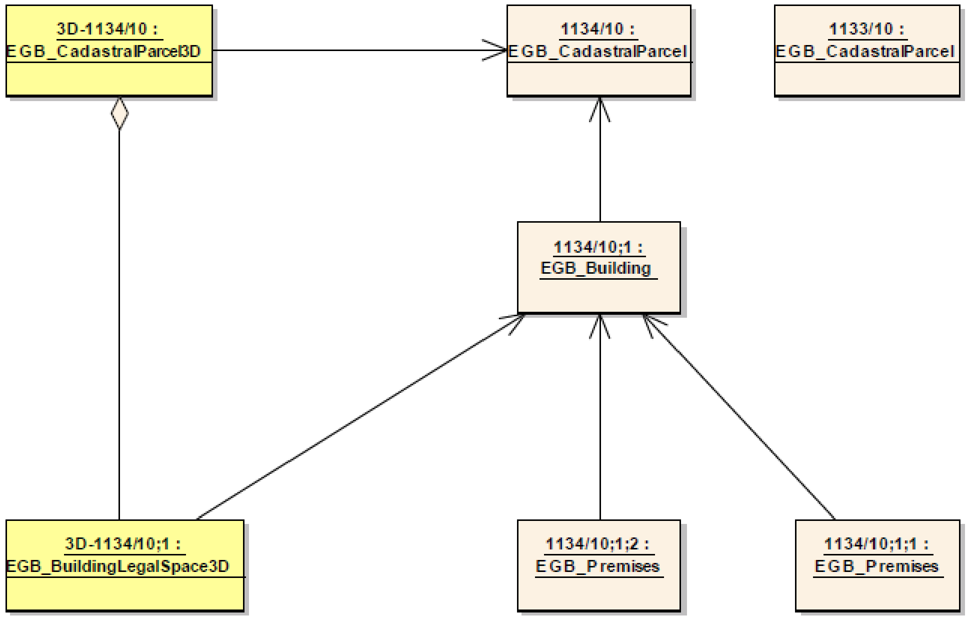

Figure 11. UML Diagram defining the relationships between 2D and 3D cadastral parcels, buildings and its legal spaces for parcels 1134/10, 1133/10 and buildings – corresponds to Figure 6b

The case like this with semi-detached houses and co-ownership of cadastral parcel may be source of problems as theoretically both owners have the right for the whole space above the cadastral parcel (represented by Cadastral Parcel 3D – 3D-1134/10:), except for buildings (represented by corresponding 'Building Legal Spaces 3D').

The possible solution of this problems is creating two separate real estates. It can be done by dividing the parcel in a such a way that every building is situated on the different parcel. A UML schema of subdivision is presented in Fig. 12.

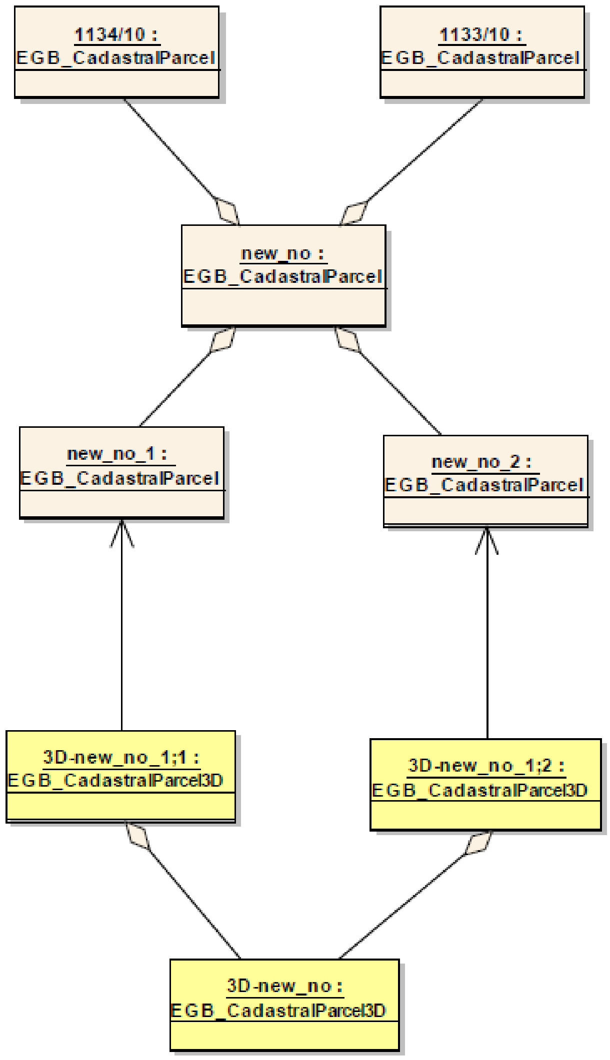

Figure 12. Schema of subdivision and merging of 2D parcels 1134/10, 1133/10 and new 3D cadastral parcels

UML model for such situation (after subdivision of parcel 1134/10 into two parcels) is presented in Fig. 13. The result are two separate real estates. I means that there are different objects like 'Cadastral Parcel', 'Cadastral Parcel 3D', 'Building', 'Building Legal Space 3D' for both new parcels.

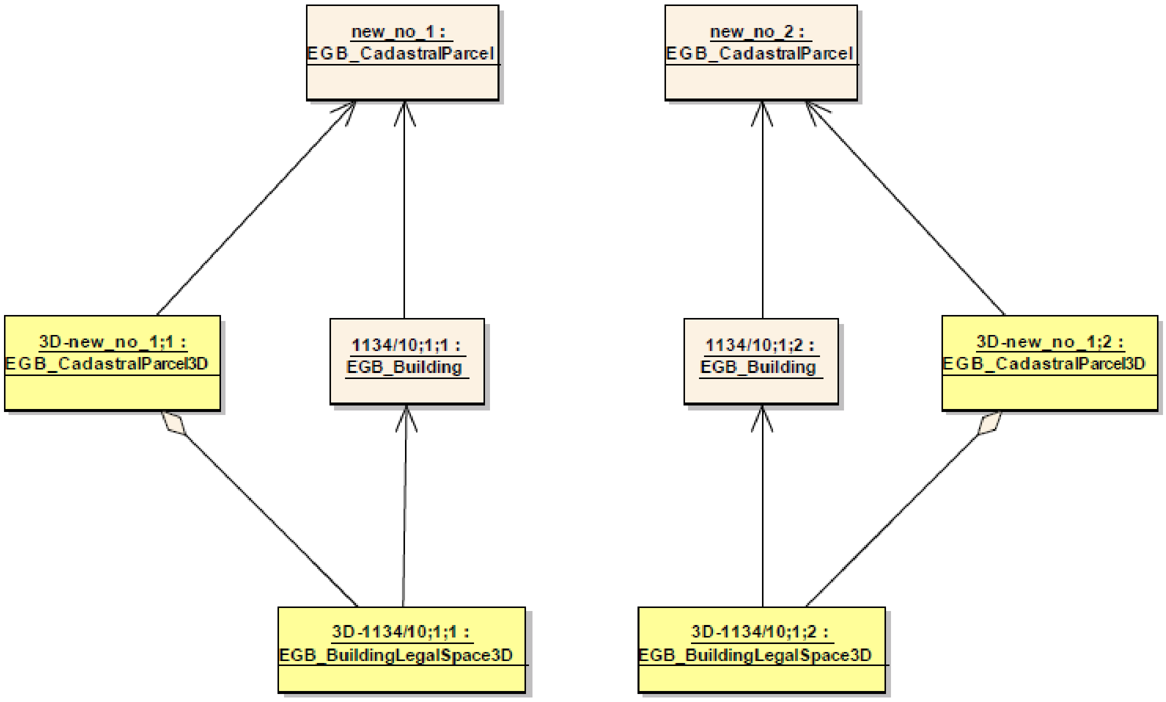

Figure 13. The situation after subdivisions and creating new parcels – corresponds to figure 6e

4. DISCUSSION AND CONCLUSIONS

Some possible problems independent from applied surveying method but resulting from the analysed case appeared. The proposed solution is the division of parcel to create two independent real estates and correspondingly all 2D and 3D cadastral objects.

Preparing a 3D BIM model of an object based on a point cloud from terrestrial laser scanning is more expensive and requires more time than preparing a model based on the design documentation. However, it allows to significantly reduce the risk of improper reproduction of reality, because it is a measurement in nature. During construction works, changes to the design are possible that do not require the consent of the Department of Architecture of the competent authority. There are also changes made by the owners on their own, without the consent of the designer. For this reason, the constructed object may differ from the designed one. Therefore, it is safer to make a model based on direct measurements, among which the fastest and most accurate technology is Terrestrial Laser Scanning (TLS).

However, in the course of this research, the authors did not fully succeed in applying scanning to verify the 3D cadastre model. This topic requires further research.

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Temporal Perspective Towards the Design of Cadastral Database in Taiwan

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Key words: land administration, ISO 19152, 3D Cadastre, time perspective, LADM

SUMMARY

Regardless of whether explicitly recorded, every geographic data has various aspects about time. Especially for integrated applications, the temporal aspects of geographic data from different stakeholders play an extremely critical role. Ignorance of the temporal difference or valid time of the datasets may easily lead to unexpected and even unpredictable mistakes. It is hence the responsibility for data designers to cautiously consider the demanded temporal information during schema design and correctly convey unambiguous meanings of the temporal information to users. It is also the responsibility of users to correctly interpret the temporal information before making any decision. Cadastre is governments' system developed to facilitate the management of lands and buildings, so as to protect citizens' property and drive the growth of economy. The massive volume of real estate transactions makes the management of cadaster systems a big challenge that involves both spatial and temporal aspects. From the interoperable application perspective, the ultimate goal of the cadastre system is to ensure every piece of information is based on the precise and coherent spatio-temporal modeling results, such that every decision can be made without ambiguity. It is therefore necessary to have a thorough examination on the spatio-temporal characteristics of the various types of cadastral data, as well as their relationships with the cadastre operations.

This research mainly focuses on the temporal modelling issue, especially in the valid time and semantics of temporal information. The Land Administration Domain Model (LADM) from ISO/TC211 (International Organization for Standardization/ Technical Committee 211) is chosen as the reference model in this study because it offers a whole package of standardized classes specifically designed for land administration purpose. As LADM is endorsed by international organizations like FIG and already adopted by many countries for developing national profiles for their cadastre systems, we believe the research results are not only beneficial to the digital cadastre systems of Taiwan, but also contribute to the guidelines for designing temporal information for domain data. Thie preliminary result shows the feasibility of introducing LADM to model the various temporal characteristics for the current cadastral data in Taiwan, but additional guidelines for designing temporal information with semantics to fulfill the needs required by related laws are also necessary. It would be even advantageous such standardized vocabularies can be unambiguously defined and extensively used in cross-domain integrated applications to improve the interoperability of temporal information.

Temporal Perspective Towards the Design of Cadastral Database in Taiwan

Sin-Yi Ho and Jung-Hong Hong, Taiwan

1. INTRODUCTION

The successful operation of Geographic Information System (GIS) heavily relies on the integration of various themes of data to "model" the reality. From the perspective of "modelling", every data represents the status of earth phenomena at a specific time, therefore all geographic data naturally has a temporal aspect and such information serve as an extremely important role while integrating data independently collected by different domains. Failure to recognize and address the temporal issues may cause serious problems, while users may never notice, e.g., overlaying two datasets referring to two different time together and use it as a map for decision. Unfortunately, the importance of temporal information is often overlooked by both domain data designers and users such that we are often dealing with data only with spatial consideration. This may become a even more risky issue when the data sharing becomes easier with the fast growing volume of worldwide open data.

Cadastral data is one of the core datasets of the National Geographic Information System (NGIS) in Taiwan even since it was launched in 1989. The operation of cadastre system in Taiwan can be dated back to the early 1900s, while both cadastral maps and registration data were recorded on papers. The development of digital land database began 1991 and continuously evolved over last 30 years (Ministry of the Interior, 2007). The current registration data includes six types of data, namely, related rights of land and building, identification of land and building, registration information, information of subjects, transaction index, and historical data. The map data includes cadastral maps, building survey map, etc. All cadastral data is updated and maintained according to the real estate transactions or government land reform projects. Since the cadastral data is specifically handled by cadastre agencies, the temporal status of any type of cadastral data should be able to be unambiguously determined. The challenges are to determine the best way for modelling each type of data according to their distinguished spatio-temporal characteristics and develop effective mechanism to correctly integrate different data for intended applications.

The temporal description framework developed in this research intends to address the modelling of various aspects of time information from a semantic and standardized perspective. The Land Administration Domain Model (LADM) is an international standard (ISO19152) designed to serve as the common conceptual model of land-related administration requirements, such that related parties can communicate data based on a set of a shared vocabulary with unambiguous semantics. Since the design of the LADM is based on the "common" characteristics of land administration models, it is neither intended to be a complete package, nor a specific model for an individual country system (Hong, 2016). Each country can design profile specifically according to the distinguished needs of their cadastral systems following the common conceptual schema from LADM. Countries that have developed LADM profile widely cover different continents, e.g., South Korea, Croatia, the

Netherlands, Malaysia, Singapore, etc (Polat, Z. A., & Alkan, 2018), which indicates the standardization of cadastre system is clearly a common challenge to all he countires.

The first version of the LADM framework was published in 2002 (Van Oosterom et. al, 2013), Lemmen and van Oosterom (2006) later argued the attributes of this model should considerthe time aspect and proposed to start a 4D cadastral study (Döner, F. et. al, 2010). We would particularly pay special attention to the temporality issue of Taiwan Cadaste. The proposed model intends to ensure the consistency of time information in cadastral management and cross-domain applications. The correct spatial-temporal record can be introduced as the constraints all data must rigorously follow. Furthermore, the standardized processing of data can improve the efficiency of data use, remove errors and conflicts and enable the correct interpretation to enhance the quality of decision-making.

2. TEMPORAL ISSUES IN LAND MANAGEMENT

2.1. Temporal Characteristics of Cadastral Data

Since our living world is not static, every recorded data should by default have a time information to indicate the status is valid at the specified time. Being used in various legal scenarios, this is also true for the cadastral data. One of the important issues of cadastral data is its timeliness. As the content of the cadastral data may change for various reasons, the design of any type of data should take the time factor into consideration. In order to establish the correct and dynamic relationship between different thematic data from the temporal and spatial perspective, Van Oosterom et.al. (2006) proposed three types of time in the cadastral database, namely, database time, legal event time, and variation of the right with time.

The database time is the time when the data was input to the system or database; the legal event time is the time for the events with legally valid status in law, e.g., the transaction dates and times related to ownership and other rights, the time for land division and consolidation; finally, the time period of various types of rights, such as leases, rights that will be effective in the future, and those that take effect on regular basis rights (grazing rights). Polat and Alkan (2021) argued that many users in Turkey (such as legal institutions, local governments, banks, and owners) not only need current cadastral data, but also historical data from the past. Therefore, land models must effectively address the management of data at different stages.

Moreover, environmental protection may also require consideration of cadastral time. For example, Unger et al. (2019) proposed the LA-DRM model (Land Administration-Disaster Risk Management) for integrating land administration and DRM activities to prepare, prevent, mitigate and respond to natural disasters more adequately, in which the validity period of land use rights needs to be traced. The above discussion shows that the temporal issue is an essential element in cadastre, and while countries begin to develop cadastral profiles to manage more complex land use, time will play an indispensable role in the schema design and related operations (Babalola et.al, 2015).

2.2. Standardization of Cadastral Data

The Land Administration Domain Model (LADM) is an international standard (ISO19152) designed to serve as the common conceptual model of land related administration issues, such that related stakeholders can communicate with each other based on the same model and a set of shared vocabulary. The purpose of LADM is to provide a more comprehensive conceptual schema and offer a standardized description to remove the heterogeneity and enable the development of interoperable applications. As for the temporal issue, the class of VersionedObject is a class specifically designed to manage the modelling of time in the LADM standard.

The major three packages and one subpackage in LADM are designed to inherit from the class of VersionedObject, shown as Figure 1 (except the class of AdministrativeSource and SpatialSource), such that the time information for each class by default include the time it starts and ends, respectively defined by the name of beginlifespanversion and endlifespanversion. Becasue the start time is a mandatory attribute, it implies the start time of every described phenomenon is always available, while whether the value of the end time is recorded depends on the data itself. For example, when an instance of data is replaced by a new version of the same instance, the value of the attribue of endlifespanversion for the current version must be specified to indicate the time this instance is outdated and the new version of data must be given a DateTime value as the beginlifespanversion, which is the same value as the "end" stamp of the old version. (Inan, 2010). In addition, these classes also "automatically" inherit attribute information such as time, quality, and source. Since the management of start time and end time of the state described in the cadastral data is the responsibility of the land administration agency, in principle, all the changes to the database can be fully controlled, including all the historical versions (Hong et al., 2016).

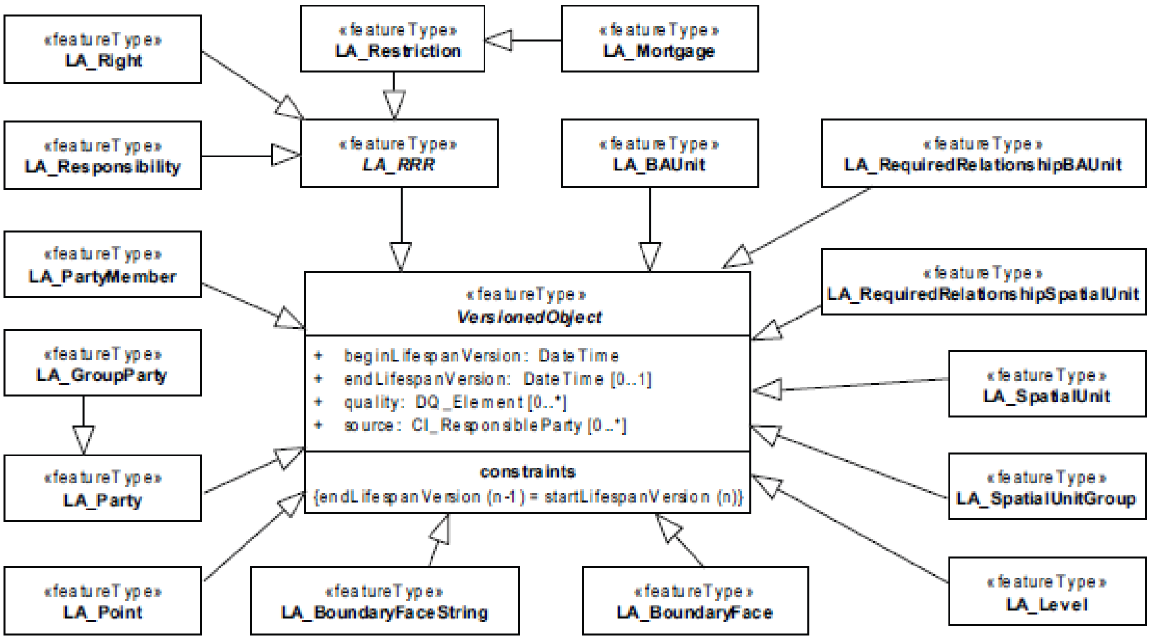

Figure 1. Inheritance diagram of VersionedObject class

Two issues require further consideration. One is the interpretation of time stamp or time period can only be inferred depending on if the end time is recorded. If only the start time is recorded, the time of the phenomena is interpreted as a time stamp; while if the time of the phenomena has an end time, it will be interpreted as a time period. The challenge is to determine the status for described phenomena that has yet to have a end time. The other issue is while the class of VersionedObject uses the same design, the start and end time, to record time information, the semantics of such concept for different classes are different. For example, the start time of a person shall be his or her birthday, while the same attribute for the ownership shall be interpreted as the time of transaction or the time of registration. It is therefore necessary to consider how the time issues are appropriately modelled in the cadastre systems and provide the data to the users in a meaningful way without semantic ambiguity.

3. CADASTRE DEVELOPMENT IN TAIWAN

3.1. Land/ Building Registration in Taiwan

The current land registration system in Taiwan adopts the characteristics of both the German right registration system and the Torrens registration system, that is, when accepting the case from the citizen, it should be reviewed immediately, and the liability for damages should be attached (Land registration system after Restoration, 2020). Major properties of the cadastre systems include:

- For the change of land rights, registration is necessary. The so-called compulsory registration requires the registration for each land. All the registration information is managed by databases.
- The registration adopts the substantive examination doctrine. The concept is to carry out a detailed review from the substantive law. If it is found to be defective, it will be rejected or corrected within a time limit, and registration will not be granted.
- Registration has absolute effect. The so-called absolute effect means that entrust the registered items with absolute truthfulness and credibility, and the registered rights are consistent with actual rights.
- The register is in order of parcel number or building number.
- Anyone can apply for a transcript of the register to understand the contents of the register.
- After the ownership or other rights are registered, a certificate of ownership or a certificate of other rights shall be issued as a certificate of the right to facilitate the exercise of the right.
- If the real right holder suffers damage due to registration errors, omissions or hypocrisy, the land administration agency shall be liable for damages, but when the land administration agency proves that the cause is attributable to the victim, the victim shall be responsible for it.

3.2. Temporal issues in Taiwan Cadastral Database

Since Taiwan’s cadastral system has two major characteristics: compulsory registration and absolute validity of registration, the people’s property is based on the right to the possession of the right certificates issued by the government. The content of the land or building rights certificate consists of three major sections: the land/building description, the land/building ownership, and the other rights of land/building. Land/building description records the identification and basic information of the land/building, such as the parcel number, address, and area. Land/building ownership records the information of the owners and their ownership. The other rights of the Land/building records the other types of rights related to the land/building, such as the superficies, easement, mortgage, etc. Moreover, the digital cadastral map records the identification and geometry information of parcels and their associated boundary points.

In Taiwan, cadastral data is maintained by the government, therefore, it must include a description of the start time. This is rather different from the situation of natural phenomena because we can seldom determine when a phenomena starts. From the point of view of valid status, the time record of cadastral data include three types of choices (Figure 2): (1) Time stamp: the state of the event is only guaranteed at the moment specified, for example, the construction complete date, the registration date. (2) Time period: this usually used for modelling a historical status continued for a period of time. For example, the validation of ownership or other rights. (3) Should be record both begin time and end time, and the phenomenon is not changed for a long time, so the end time will not record usually.

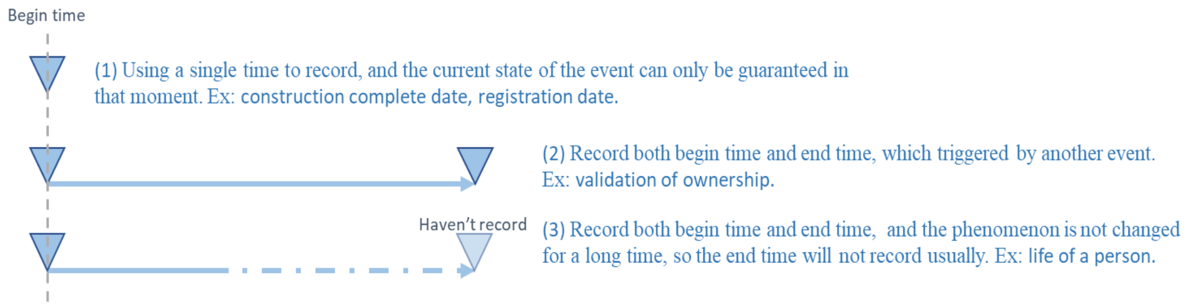

Figure 2. Three kinds of time recording types

In addition to above the standardized temporal information offered by the LADM, sometimes temporal information with specific semantics is required to supply additional explanation. For example, the data set metadata standard specifications formulated by the National Development Council of Taiwan requires to provide metadata about the start collection date, end collection date, launch date, metadata update time and data resource update time of the distributed open data (National Development Council, 2018). This type of information helps users to establish an understanding about the acquired data. These "standardized" temporal metadata elements are designed to provide distinguished time information for the data from the semantic perspective. Users can hence interpret the data and determine their fitness for use in a consistent way. Even if the importance of time information is well recognized, the ”standardized design” of temporal information to address different application needs is rather limited, such that different vocabularies are used for similar scenarios.

A pilot study for introducing LADM to model the Taiwan cadastre data was conducted in 2016. By choosing the building registraton as the target, Figure 3 shows the preliminary research results. The design basically follows the classes designed by LADM. The core classes are Party, RRR, BAUnit and SpatialUnit. The TW_Party, TW_Right, TW_BAUnit and TW_SpatialUnit classes are designed in consideration of the characteristics of the cadastre systems through inheritance from LADM classes and expansion of attributes. The related description classes of the surveying and representation sub package are mainly represented by the LA_BoundaryFace, LA_BoundaryFaceString, and LA_Point classes are designed by LADM. Related reference documents such as the building plan are represented by the class ofTW_SpatialSource, and the building ownership certificates are represented by the LA_AdministrativeSource class.

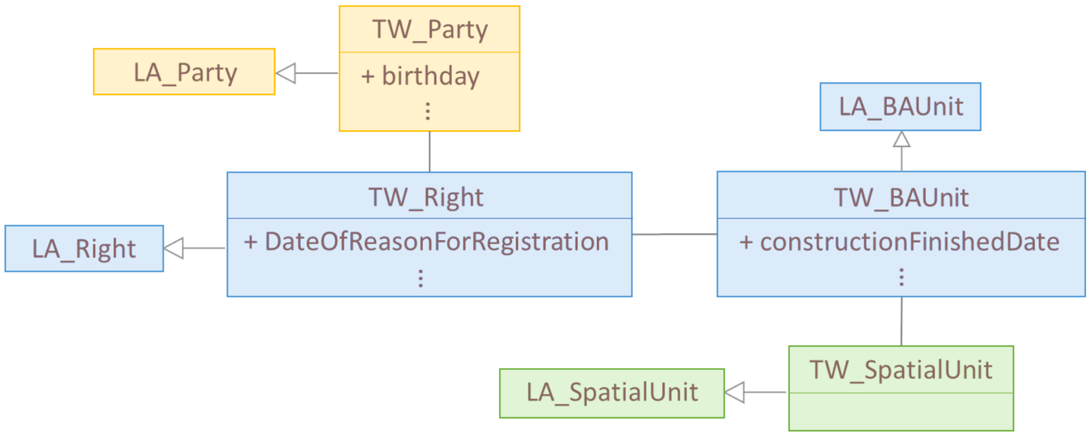

Figure 3. Taiwan LADM profile preliminary plan (core part of the temporal attributes)

TW_Party added birthday attribute to record the owner's date of birth, TW_BAUnit class added constructionFinishedDate attribute to record the completion date of the building, and TW_Right added DateOfReasonForRegistration attribute to separate the date of occurrence and registration of the cause date, because the effective time of rights is the registration time, this time is not equal to the time that the event that caused the change of rights occurred. For example, the transfer of land ownership is caused by the act of buying and selling, but the actual effective time of the transfer of ownership is not the time of buying and selling, so the land transcript will record the date of registration and the date of the cause (the date of signing the sale and purchase agreement).

The land or building rights certificate combines multiple information from various classes in LADM Taiwan Project into one document containing all the information most needed in Taiwan.

Table 1. Land/ building rights certificate combines various classes in LADM Taiwan Project

Time record	Directions	Taiwan Project Class
Land Description Part		
Registration time	The date of the latest registration of the land or building.	TW_SpatialUnit/ TW_BAUnit
Land Ownership Part		
Registration time	The date of registration after the change in ownership of the land or building.	TW_SpatialUnit/ TW_BAUnit
Reason happening time	The date of the cause of the change in the ownership of the land or building.	TW_Right
Current Declaration of the Land Value time	The declaration land price at the time of registration.	TW_BAUnit
Last transaction value or Assessment of land value time	The land value at the time of the previous land ownership transfer or when the land was first transferred, the original prescribed land value.	TW_BAUnit
Date of birth	Date of birth of the owner of the land or building	TW_Party

Land of Other Rights Part		
Submission time	The date of the submission of the application for the other right.	TW_RRR/ TW_Right
Registration time	The date of the other right register.	TW_RRR/ TW_Right
Duration	Duration of other rights.	TW_RRR/ TW_Right

4. TEMPORAL CONSIDERATION OF CADASTRAL DATABASE IN TAIWAN

4.1. Conceptual Design

There are two main strategies for the design of time attributes. One is to follow the versionedObject architecture, and the other is to expand the attributes with specific semantics. Three major requirements include the connection with international standards, the time semantics that effectively represents the specific meaning of Taiwan, and the clear display of the effective status of the phenomena for users to make correct judgments.

Based on LADM standard, the classes and attributes are expanded and modified to meet the application of Taiwan cadastral database. Continuing the four major packages designed by LADM, describing the relationship between people, parcels, and rights, and connecting them to the measurement. Use the VersionedObject class to record part of cadastral time such as the period of ownership, birth time of natural person, etc. However, when two types of data are overlapped, we must determine the effective time period to explain the state of the phenomenon. A common problem is only recording the event at the start time, we don't know how long its status lasts, so that we can't compare it with other data. Another problem stems from not understanding the meaning behind the concept of time. In order to deal with the different data recorded by each temporal model, we should develop the temporal semantic issue. The land ownership certificate contains various dates, which I mentioned in section 3.2. Because the lack of background, we do not know the meaning of each date, and we can't realize when the state recorded on the certificate begins and when it finishes. Regarding the registration time, it is found in the identification part, the ownership part and other rights part. They all use the same word: "registration time" but it is obvious that they represent different meanings (See Table 1).

To enrich the semantics of the distributed data, the expanded design of temporal attributes adopts the concept of the CI_DateTypeCode of ISO 19115-1 (Table 2). ISO 19115:2003 standard defines the schema required for describing geographical information and services. It provides information related to the identification, extent, quality, spatial and temporal schema, spatial reference, and distribution of digital geographical data. Although we have our own metadata profile called TWSMP (Taiwan Spatial Metadata Profile), there is a lack of time regulations, focusing on other quality assessments. In our study, we add the temporal semantic such as: release time, confirmation time, validity time, termination time, production time, update time, transaction time, etc., among which validityBegins and validityExpires are specifically designated according to Taiwan cadastral requirements, which have legal meanings. Each semantic meaning has its own characteristics. Although data from different sources may choose to use different attribute names, their concepts can be attributed to one of the semantics listed in Table 2. Finally, the valid status of the event can hence be determined through the description of the temporal semantics. For example, the code of ”examined” is used to indicate that the data status has been determined and will not change after that time point, therefore, the status is valid from the time of recording. The code of ”lastUpdate” indicates the last time the data is updated. As the database can only be maintained by the governments, for some types of data, this information can be interpreted as the status remain valid from the time of recording till now.

Table 2. Temporal semantic vocabularies

Name	Definition	Example
creation	Data creation time.	Boundary points determine date, GPS station deploy date
publication	Date publication or announced time.	Upload time, announcement time
examined	Data verification or deadline.	Data approval time, verification date, modification time.
update	The time of re-recording the state, data may not change its value.	Update time
lastUpdate	The time when the information was last updated, and value may be different from the current status.	Update time
validityBegins	The time at which the phenomena began to be in a valid state.	Contract establishment time
validityExpires	The time when the phenomena is no longer activated.	Registration of deletion time
transaction	The status of the data changes, and the record of this time is triggered for some reason, which is different from the previous version.	land division、land consolidation, Date of occurrence of cause registration
representative	Use a certain point in time to represent the ongoing phenomenon.	Demographic time in May、satellite image photography time
begin	The time when the phenomenon occurred.	Date of birth, date of announcement
end	The end time when the phenomenon occurred.	Construction completion date, closing date, announcement expiry date, overdue date/time
execute	The time of occurrence of events related to various specialized domains that are not beginning and ending.	Correction time, retest time, survey time, application time, receipt time, request time

4.2. Logical Design

The logical design of the correct temporal record method at least includes name, time, and semantic. It can be further subdivided into sub-elements necessary for each element record, such as time must specify its reference system. Therefore, the design of the database is subdivided into three main categories (Figure 4), namely, time identification, time description and time scope. Time identification is the basic information describing the event, and the validity of the version must be explained; the time description category is the main time record, such as the clock, how long it lasts, the update frequency, etc. In this part, the time attribute specified by VersionedObject is mainly retained, and other attributes are additionally extended to determine which type of the data belongs to; the time scope category describes for applications where time is applicable, users must pay attention to the description of the scope of time when comparing two types of data to avoid making wrong decisions.

- **Identification:** The attributes in this part include versionID, lastVersionID, nextVersionID, validityState, and timeName. The purpose is to link the previous and next version with the identifiers. We also record the validity state of the event to understand the effectiveness of the duration such as contract establishment time and registration time, so that we can clearly know when the situation of the data starts and end.
- **Description:** This part is designed to record time information.In addition to the beginlifespanversion and endlifespanversion included in the VresionedObject from ISO19152, four attributes, periodlifespan, updateSituation, updateFrequency, and approximateTime are added. Recording format follows ISO 8601- date and time format. ISO 8601 standardizes the universal time recording format throughout the world. Because it is an international standard, the content is planned and designed in the way of international time recording standards: A.D. and UTC. The format is based on year, month and day (YYYMMDD) plus hour, minute and second (hhmmss).
- **Scope:** This part explains the scope of applications, including the basic descripitive elements such as reference system, resolution, primitive, quality, and semantics. Except for quality information, all attributes are recorded by respective code lists, such as reference system（TW_ calendarReference Type, TW_ timeReference Type）, resolution（TW_ resolutionType）, primitive（TW_ primitiveType）, semantic（TW_ semanticType）. The above code lists are all formulated according to our country’s needs. For example, TW_calendarReference Type includes the Republic of China commonly used in Taiwan, and the lunar calendar (Chinese calendar) is added to accommodate the unique 24 solar terms in our country.

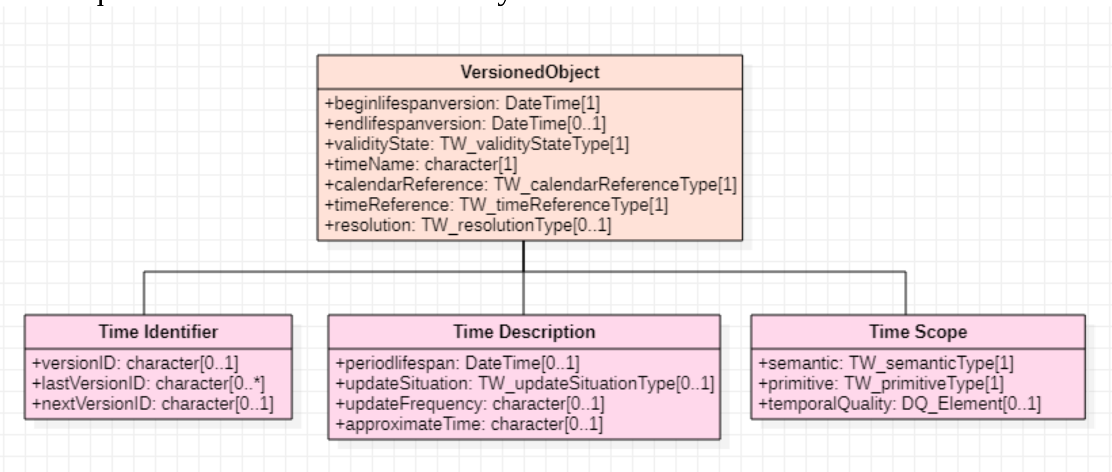

Figure 4. Standardized temporal schema

Respond to the Chapter 3.2, we can distinguish three kinds of situations from the standardized temporal schema we proposed, summarized as Figure 3. In addition to record the begin and end time, we also rely on the primitive to explain if the end time of the phenomena should be record or not. If the primitive is time period and the end time haven’t been recorded, it implies the described status remains the current status. On the other hand, if primitive is time stamp, meaning that the phenomena is a moment situation.

Table 3. Land/ building rights certificate combines various classes in LADM Taiwan Project

Time record	Belong group	How to record
Land Description Part		
Registration time	(3). Should record both begin and end time, but the end time will not record usually.	Primitive= period；beginlifespanversion
Land Ownership Part		
Registration time	(2) or (3). The start and end time should be recorded, unless the phenomenon has ended, the end time will not be recorded.	Primitive= period；beginlifespanversion；(endlifespanversion)
Reason happening time	(1). Using a single time to record, indicates the completion of the action.	Primitive= time stamp
Current Declaration of the Land Value time	(3). Should record both begin and end time, and the phenomenon but the end time will not record usually.	Primitive= period；beginlifespanversion
Last transaction value or Assessment of land value time	(2). Record both begin time and end time.	Primitive= period；beginlifespanversion；(endlifespanversion)
Date of birth	(3) Should record both begin and end time, and the phenomenon but the end time will not record usually.	Primitive= period
Land of Other Rights Part		
Submission time	(1). Using a single time to record, indicates the completion of the action.	Primitive= time stamp
Registration time	(2) or (3). The start and end time should be recorded, unless the phenomenon has ended, the end time will not be recorded.	Primitive= period；beginlifespanversion；(endlifespanversion)
Duration	(2) or (3). The start and end time should be recorded, unless the phenomenon has ended, the end time will not be recorded.	Primitive= period；beginlifespanversion；(endlifespanversion)

5. TEST ANALYSIS

Take the land register in Taiwan as an example, shown as Figure 5, and we can summarize it into Table 4. In the land register includes various time information which may cause the user to confuse to read and make it difficult to use. However, through the temporal semantic proposed in this paper, the required registration information can be record by one of semantic vocabularies, which consequently clear to understand the meaning of each recording name.

What's more, combine the primitive and time recording, we can solve the problem that LADM does not know whether the event is over or not.

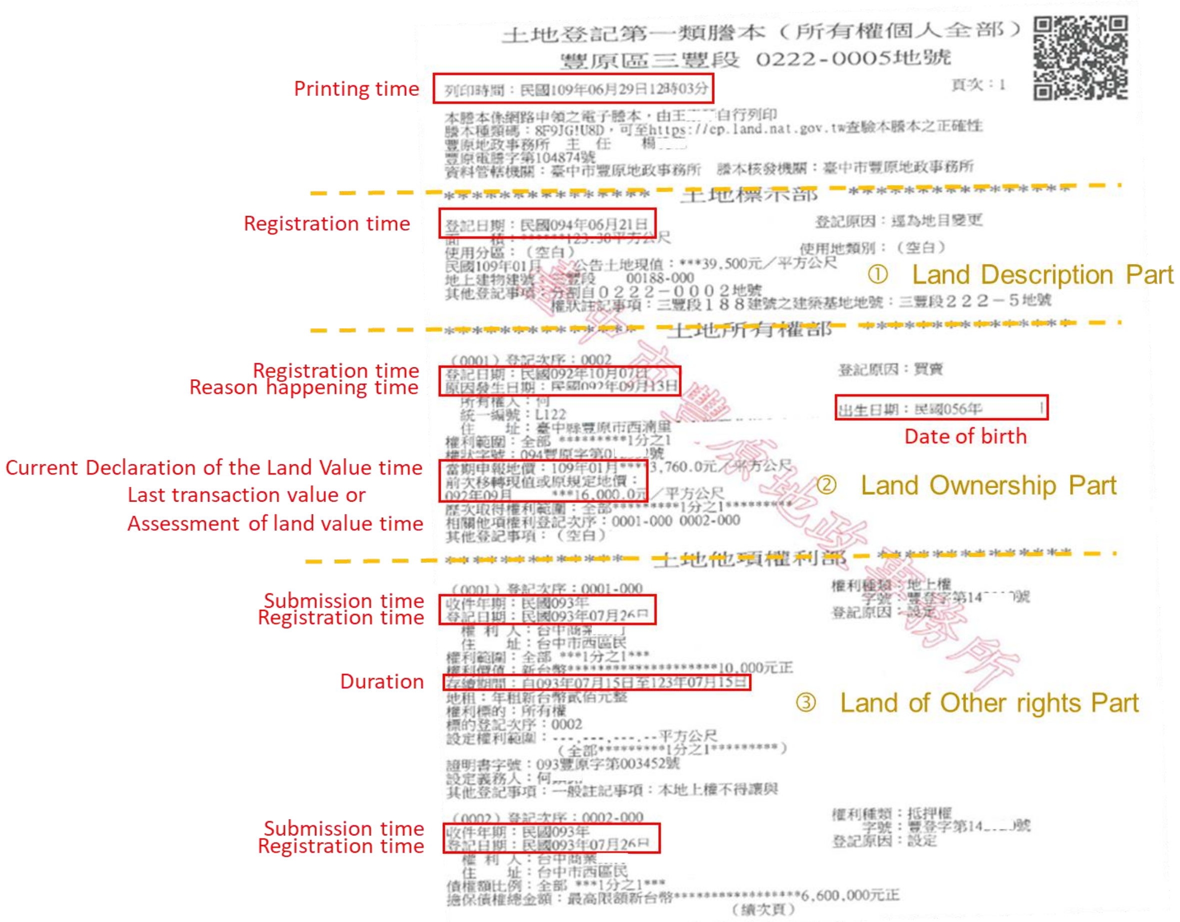

Figure 5. Land Register

Table 4. Recording terminology

#	Name	primitive	beginlifespanspan	Endlifespan version	Semantic vocabulary
1	Printing time	Time stamp	2020.06.29 12:03		creation
			Land Description Part		
2	Registration time	Time period	2005.06.21		validityBegins
			Land Ownership Part		
3	Registration time	Time period	2003.10.07		validityBegins
4	Reason happening time	Time stamp	2003.09.13		transaction
5	Current Declaration of the Land Value time	Time period	2010.01		publication
6	Last transaction value or Assessment of land value time	Time period	2003.09		lastUpdate

7	Date of birth	Time period	1967.08.06		begin
Land of Other rights Part					
8	Submission time	Time stamp	2004		execute
9	Registration time	Time period	2004.07.26		validityBegins
10	Duration	Time period	2004.07.15	2034.07.15	validityBegins / validityExpires

When we want to retrieve the history of all events in the life cycle of the land:
First, we can check whether each event is finished or not. Number 1, 4, 8 events are time stamp recording types, so they don't need to record the end time any longer. Except for them, the rest are time period recording types, and those who didn't record the end time means haven't been finished.

From the recommend semantic vocabularies in Table 2, we can know which time points are of legal characteristics, showing validBegins and validExpires. According to the meaning of the recorded data, users can easily understand the time when the ownership is transferred and legally takes effect, which should be based on the registration time. And in the setting of other rights, it is obvious to rely on Registration time. In addition, the concept of last update displayed in Last transaction value or Assessment of land value time indicates that the status of this phenomenon has version information, and the information is the current latest version. This concept can remind users to find the latest version when checking the information.

6. CONCLUSIONS

To evaluate the feasibility of the proposed temporal model, digital cadastre based on LADM (ISO19152) is chosen as the research target. The analysis respectively examines the temporal aspects of every LADM package and proposes appropriate time attributes according to the regulations of Taiwan cadastral database. The result intends to serve as the basis for future development of LADM Taiwan profile. The following lists the major findings in the research:

- The class of VersionredObject in LADM can be used to present the valid temporal status of the described phenomena. However, additional temporal attributes are still required in developing Taiwan profile. Through the proposed temporal semantic code list, the temporal aspect of all the analysed cadastral data can be represented by one of the twelve scenarios, and each scenario has a specific meaning of valid situation for modelling its distinguished temporal characteristics.
- Following the standardized temporal LADM profile, the correct management of historical cadastral data can be tremendously improved, especially the temporal consistency among the multiple versions of cadastral data. The proposed model can be used to unambiguously describe the temporal relationship between events and status.
- As the geographical data sharing between the platforms can be described in a standardized way, effective data exchange can be carried out between various domains. When web services are provided, users can correctly interpret the time information and determine its

use and limitation. Temporal information of data from the different domains can be explicitly recorded by the standardized rule to enhance the cross-domain applications and improve the interoperability between heterogeneous geodata.

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BIOGRAPHICAL NOTES

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Implementation of the 3D Cadastre in Israel - Stage 1

Ksenia KHASANSHINA, Shimon BARAZANI and Yoav TAL, Israel

Key words: Israel, 3D Cadaster, 3D Registration

SUMMARY

Israel is a small territory country. It causes a lack of land for residance in areas of demand. Therefore, the issue of utilizing land effectivley include underground and above, registration of rights in the land in a three-dimensional form is particularly relevant. The main problem was the definition of ownership in Israeli legislation.

At the end of 2018, an amendment to the Real Estate Law was approved, which allows for vertical splitting to different spatial levels and defines a new term in legislation as a three-dimensional parcel. A cadastral system includes a variety of components; legislation and administrative components that were reflected in the land registry, and the spatial element revealed in the cadastral mapping. The process begins with town plan (planning map), which describes «Re Design» that defines new lots and land use. Therefore, the whole process that ends with the registration of rights in three dimensions requires the development of a new method begins with a three-dimensional Town Plan stage, to the 3D mapping and division plan stage to the 3d registration stage.

As a result of tremendous active partnership among various government ministries, at the end of 2020, the first three-dimensional plan for registration purposes (vertical mutation plan) was approved in Israel, and at the beginning of 2021, the first three-dimensional parcel was registered in Israel. Currently, the three-dimensional registration process in Israel is implemented and operates.

This article describe the processes of preparation and implementation of a three-dimensional cadaster and registration, to date. It will include a description of legal proceedings, which were implemented in order to allow for three-dimensional registration. It will also include a description of administrative and technical processes, which are in place, with the aim of implementing registration of property rights in three dimensions.

Implementation of the 3D Cadastre in Israel - Stage 1

Ksenia KHASANSHINA, Shimon BARAZANI and Yoav TAL, Israel

1. THE DEVELOPMENT OF CADASTER IN ISRAEL

1.1 The Cadaster from the beginning to the current pre-3D cadaster period

Land registration in Israel began in 1858 with the publication of the Land Law and other civil laws in the statute book by the Ottoman government. Registration under these laws was named a "state note registration". It was not accompanied by land measurements and maps, so the parcel areas recorded were usually determined by a general assessment of the area. Therefore, the reference of registration in the state note register constitutes only "apparent evidence" of our contents.

After the occupation of Palestine by British forces in WW1 in 1917, the Ottoman registration system continued to exist, but at the same time, a new registration method was applied based on a geodetic control network that established in Palestine. According to the "Land Ordinance (Property Rights Arrangement) – 1928", the Mandate Rule began to carry out on its behalf, and from the initiative of a land settlement in Palestine, and recorded the rights of land owners in a method developed by Australian Customs Minister Torrance, and given the name the "Torrance Method" or the "Property Rights Registration" method. The registration according to the Torrance method divided the territory of the country to blocks. Each block contains one or more parcels. The land is described through official measurement and mapping related to the national coordinate network. Each registration block has a special rights book that include all the details of the parcels in the block according their order. The reference to the content of the listing in the land listed in the rights registers is the value of "conclusive evidence".

The State of Israel continued the land settelment activitey that the British began in 1928 and so far, about 97% of the land in the territory of the country has been settled. A change in the division of land that has been settled is carried out based on mutation plans – plans for registration purposes. A mutation plan is a plan that defines real estate operations following planning processes such as: a town plan in the manner in which the proprietary unit (parcel) will be compatible with the planning unit (lot). A plan for registration purposes presents actions of merging and dividing of plots of land, within the area of one registration block, and/or transfer of plots from block to block, in such a manner that the new parcels will be matched with the lots that are defined in the town plan.

In the end of the 1980s, with the development of land survey equipment and computing devices, a new era begins, i.e. the transition from paper maps to cadaster data files and Using digital equipment, it was possible to establish a national geographic information system (national GIS) that includes, Cadastral layers of blocks and parcels of the entire country.

The development of measurement technologies (the development of satellite measurement methods - GPS) and the development of land information systems enabled the establishment of a new and accurate national control network based on a Transvers Mercator Projection. The transition to the new Israel network was carried out in the 1990s, and later in 2007. This network was improved through the establishment of satellite permanent stations and has since been called the Israel formal Network. During this period, the Survey of Israel (SOI) initiated an activity called a coordinate-based cadaster (CBC), aimed at determining parcels boundary points, positioned based on coordinates in the formal Israel network. This was done by measuring and calculating original details in the initial grid and the target grid, transformation and coordination. To date, about 60% of the country has been defined as CBC.

1.2 Land ownership definition

By 2018, the cadaster in Israel was two-dimensional. Parcel boundries defined by horizontal coordinates, with which one can obtain and calculate parcel area and geometry but cannot get ground coverage data as point heights, and topographic data. This is the result of definition of ownership in the legislation. According to the Land Law (1969), the right of ownership in a parcel includes the space above and belowit, include what is built and planted on the parcel. In addition, the legislation prohibits to transfer apart of parcel to other use and ownership. This means that ownership transactions can only be executed on the whole parcel.

Due to this limitation in the legislation, the Cadaster in Israel could not handle situations of more than one land designations in parcel, while splitting ownership. Therefore, does not allow registration of rights of infrastructure (mainly transportation) located below or above ground (e.g. subway), registration of condominiums together with underground private parking lots under public areas, or registration of mixed land use complexes in the same area unit (e.g. residential complex above a covered road). Such a situation prevents the efficient utilization of the above and underground space.

The State of Israel has a particular interest to use optimality land due to the relatively rapid population growth and because it is a small country with a shortage of land, mainly in the areas of demands of the country and in the centers of major cities. Therefore, starting in 1999, the Israeli government has made a number of decisions regarding streamlining land use, which are a catalyst for the implementation of a 3D cadaster. One of the decisions was the establishment of an inter-ministerial committee headed by the Ministry of Justice. Additional members are the Ministry of Finance, the Ministry of Construction and Housing, the Israel Lands Authority and the SOI. The Committee was tasked with formulating recommendations and determining principles for the execution of transactions in the subsurface and in the space above it. In addition, examining the legal issues involved in the aforementioned matters and determining the actions necessary for the assessments of the parties dealing with the issue in order to create a three-dimensional cadaster, including the necessary legislative and regulatory amendments.

1.3 Amendment 33 of the Land Law – A 3D Cadaster

In December 2018, Amendment 33 of the Land Law was approved, which allows the registration of property rights in 3D. The Amendment to the Land Law defined a 3D parcel as a volumetric unit with the boundaries listed and displayed in a 3D manner (X, Y, H). Secondary, legislation defined that a 3D parcel can only be created in reg land that was setteled (Property Rights Arrangement) – 1928". The purpose of this definition is the creation of a catalytic for the performance of a land asettelment and secondally is the legal status of unsettled land (alleged evidence only).

It is important to note that the amendment to the law does not change the two-dimensional cadaster system in Israel, but only adds another possibility of defining rights in the region. A 3D parcel whose boundaries were defined in a three-dimensional manner in the space, using coordinates, will not affect the residual ownership of the land parcel owners. This means that the property rights of a land parcel will continue to extend to any infinite depth and height except for the same area belonging to the 3D parcel. On the other hand, the property right domain of a 3D parcel will be limited only to the 3D area only. The legislation did not limit the amount of 3D parcels spanning the above and underground space of a parcel of land, provided that one 3D parcel was not overlapped into another 3D parcel.

It is also important to note that the Land Law does not allow the registration of a 3D parcel as a substitute for registering an apartment in a condominium. Registration of a condominium is a registration method that regulates the status and rights of several property owners in the same parcel and its use is for cases of listing buildings that have more than one housing unit. The listing defines the rights of the apartment owners each and their share of the common area. In addition, there are regulations that define how the condominium is managed. This registration method has been implemented in Israel since 1951 and provides a legal solution of separate ownership for each apartment for registration of rights and transactions.

3D registration does not replace the condominium registration system, 3D parcel registration will be done in cases where there is no dependencies on the management of the properties (residential structure above a road) and in situations where there are various uses of land independently. Registration of condominiums will be implemented in cases where there is a dependence between the various real estate uses such as residential buildings or residential buildings above commercial floors.

The Amendment to the Land Law is intended to address a number of issues related to the development of the State of Israel in the context of planning and registration of rights in real estate. One of them is a reduction of discrepancies between the planning layer (lots) and the proprietary layer (parcels). Currently, in Israel, there are situations in which there is a mix of uses in the space, but without 3D registration it is not possible to register the right and correct property rights. For example, apartment owners in a residential complex built above trafic tunell.

In addition, the lack of possibility of making a correct registration limits planning vision and development. Due to difficulty or the failure to register that reflects the required planning conception, it happens that planning projects are supported in standard and accepted solutions in accordance with traditions, instead of creative planning thinking. The amendment to the law enables advanced planning solutions and ensures the registration of rights in an appropriate manner to all stakeholders in the same land and in the same space. A major issue that an amendment to the Land Law is intended to solve, is the optimal utilization of urban areas. Objects that do not require daylight for their functioning occupy about 40% of urban areas; hence, they are not required to be above ground. Examples of these are transportation infrastructure (roads, railways), parking lots, some entertainment centers, commerce and more. The amendment to the law enables the creation of parcels out of nowhere in large city centers and high-density areas by roofing roads and tracks and building residential complexes or parks above them, as well as by moving parking lots and entertainment centers underground. This can free up areas of the city for residential construction and parks. For example, one of the barriers to building a metro in central Israel (Tel Aviv and the surrounding area) was the problem of expropriations and the registration of land rights due to the large volume of expropriations that were supposed to be carried out in the traditional manner. With an amendment to the Land Law, disproportionate expropriations can be carried out in accordance with the engineering needs and act in order to reduce the scope of expropriations. In addition, the transfer of underground transportation infrastructure in intercity areas is a significant step in maintaining open and parks and creating quality land uses for the public benefit.

2. PRACTICAL 3D CADASTER

2.1 Principles and stages of 3D Cadaster Application

The Cadaster system includes a variety of components: legal components (legislation), process management and information expressed in the Land Registry, as well as the geographical component expressed in the cadaster map (Van Oosterom, 2004). Registration is only the last stage of the land registration process, although it is the most important in terms of assigning property rights on real estate.

The process begins with a town plan, which describes a new usage and division by lots, designated and rights and building restrictions in real estate. Town plans apply changes in rights and ownership, and therefore it is necessary to create new cadaster parcels in accordance with the new lots (planning) through a plan for registration purposes (mutation plan) and finally register it in the Land Registry. Every part of the process from planning to registration is in the responsibility of another government agency. It is carried out in accordance with laws and procedures: town plans approved by planning and construction committees in the Planning Administration of the Ministry of the Interior, mutation plans are examined and approved by the SOI and the registration is examined and approved by the Land Rights Registration and Settlement Authority in the Ministry of Justice.

Preparation for the implementation of a 3D cadaster in Israel required joint work of all the parties mentioned above. In order to manage and promote the new process, a "3D team" was established in accordance with the decision of an inter-ministerial committee headed by the Deputy Attorney General of the Ministry of Justice. The team's mission was to lead and promote the necessary activities to enable an applied 3D cadaster system. The team began operating in 2017 and included representatives of all relevant parties to the process. The team's goal was to formulate the principles of 3D registration and the work processes that accompany it, including legislation, sample maps, submission specifications, management system and accessibility of information.

The guideline in the team's work was performining minimal changes to the existing cadaster concept and adding an option for 3D registration alongside the existing method and process and as part of it. Principles of 3D Cadaster in Israel:

- The area of ownership of land parcels remains in accordance with the law prior the amendment – also extends in the space above and below the ground,
- A 3D parcel has finite boundaries and is defined in space in a single-valued way. Each 3D parcel boundary point will have horizontal coordinates and height,
- Only a 3D parcel changes ownership after registration, all the residual space in the 2D parcel remains within the ownership of the rights owners,
- A 3D parcel can be spread underground, and above the ground at the same time,
- A shape of a 3D parcel can be any form, there are no restrictions to a simple geometric shape (box, cylinder, etc.),
- 3D parcel is not bound to vertical boundaries of the terrestrial parcels. This means that a 3D parcel projection on a horizontal plane can differ from the projection of land parcel boundaries on a horizontal plane,
- A 3D parcel is bounded to vertical borders of a cadaster block and will therefore extend to a maximum of one block. For example, a tunnel that passes through several blocks it is divided into several parcels depending on the amount of blocks it passes through,
- 3D parcels can only be created in regulated land and coordinate-based Cadaster areas,
- A 3D parcel can be created only in accordance with a town planthat defines at least one lot in 3D, or in accordance with the 3D expropriations by the state and its institutions.

In order to accelerate the entire process of implementing a 3D cadaster in Israel, it was decided to divide the process into several stages. The considerations are to provide a quick response to a 3D cadaster needs, while at the same time, moving forward and plan a wide-ranging governmental system, in which the geographic information systems will support 3D and form the basis of a "smart city" approach.

A 3D Cadaster application has been divided into the following steps:

Stage 1 included addressing a change in legislation, based on existing tools and without a large investment in development and using minimal changes in existing systems. Defining the submission format by expanding the national mapping specification and defining the final product for a 3D program for registration purposes (hereinafter referred to as TAMAR – acronyms of 3d mutation plan in hebrew). Using sample maps for the various cases, managing a process that enables registration, training and implementation, experimenting with the process through pilots, generating lessons and assessments for Stage 2, building an educational program and holding trainings (seminars and courses), preparing a guide and defining tasks.

Stage 2 will include migrating to a new modern cadaster database that will support multidimensional data as well as quality assurance/control and display tools.

Stage 3 will include consolidating systems and creating a uniformed environment for the entire town plan preparation process, the 3D plan for registration and registration purposes through Israel's 3D web portal. The goal is to create a uniformed environment for all their activities, government ministries relevant to the process from planning to registration and will form the basis of a smart government/city.

2.2 Preparing for a 3D cadaster

2.2.1 Preparation of the Israeli Planning Administration

The Planning Administration (the agency responsible for the planning) has defined three possibilities for 3D planning on which 3D registration can be performed:

- A "New Division" town plan that guides the creation of a 3D lot and includes its coordinated definition. This type of program will include a graphic appendix that will include a description of a 3D lot in a coordinated manner and with the addition of typical perspectives. The plan will include a description of the projection of a 3D lot with the background of a usage change in 2D land zoning. Such a plan is considered a 3D town plan and forms the basis for preparing a program for the purposes of 3D registration. Attached in Appendix A a "new division" town plan that guides the creation of a 3D lot and 3D plan appendix.
- A "New Division" town plan that guides the creation of a 3D lot and does not include its coordinated definition. This plan is intended for cases in which at the statutory planning stage it is not possible to definitively define exact heights of 3D lots or their location except in principle. In these cases, a 3D lot will be determined at a ground usage level and not coordinated. In this case, for the purpose of 3D registration, another plan of the type "Land Distribution" plan must be prepared in advanced stages of planning that will show discrete boundaries values of the 3D lots.
- A "Land Distribution" plan that accurately defines the boundaries of a 3D lot created in a previous plan that did not accurately define the 3D lot. This type of plan will include a description of a 3D lot in a coordinated manner, and the plan will include a projection of a 3D lot on the background of 2D real estate zoning. Such a program forms the basis for 3D registration.

In parallel with the change in the Land Law, a change was also made in the Planning and Construction Law, which forms the basis for the activity of the Planning Administration. In accordance with changes in primary legislation, regulations were written, which define how a 3D lot was defined. The regulations mainly refer to how the boundaries of a 3D lot are described in town plan and documents. In addition, the Planning Administration has added additional definitions to the specifications of submitting plans (MAVAT) relating to how they will be drawn and presented a 3D lot in the town plan design.

2.2.2 Preparation of the Survey of Israel

In accordance with the change in the main legislation, an amendment was written and approved for the measurement regulations that regulate the survey profession include cadaster. The regulations introduced new definitions, changes in existing settings, and requirements for vertical accuracy of the Cadaster borders. Emphasis was given for measuring and editing a 3D mutation plan for registration purposes, and for auditing and approval of the 3D mutation plan, and the conditions for approval.
In accordance with the regulations, guidelines were written for measuring and preparing a 3D program that detail the process of preparing a plan, permitted actions in the plan content, presentation and manner of submission.

The "National Mapping Specification" which is a CAD specification for submitting computerized map files for various purposes was expanded accordingly and added entities, blocks and layers. The importance of a national mapping specification that produces a common language throughout the process: planning – construction – cadaster – registration, and allows quality control and approval for databases.

A final product submitted for the SOI audit is a CAD file that includes 3 sheets: main sheet, perspectives sheet, and position sheet. A main sheet includes a 3D model of 3D parcel, a 3D model of the surface above or below a 3D parcel, general information on the 3D mutation plan, calculation tables that describe actions carried out in the plan (e.g., the creation of a new 3D parcel). Main data displayed in tables are the number and volume of a 3D parcel, the upper and bottom height of a 3D parcel, and a 3D parcel projection area. In addition, the plan presents the same data for each detriment generated in the plan (parts of the area of ownership of a terrestrial parcel that were transferred to a 3D parcel). A perspectives sheet that includes vertical perspectives of a 3D parcel and its subtractions in length and width. Position sheet includes a polygon of a 3D parcel projection against the background of 2D Cadaster borders. An example of the 3D plan for registration purposes can be found in Appendix D. The stages of preparing 3D plan were described in detail in the article "Implementation of the 3D Cadaster in Israel" (Adi, Shnaidman, Barazani, 2018).

A "technical appendix" that constitutes a document containing technical information about the details accompanies the 3D plan, including how to measure, how to build the 3D model, and more. The final product includes a 3D PDF file signed digitally by a certified surveyor and by SOI as the regulator. As stated above, phase one of the 3D Cadaster application is a stage that does not include technological transition to a 3D database. Currently, the presentation of 3D plan is carried out based on existing two-dimensional systems. In the Cadaster database, a layer of "3D parcels" added that shows the position of a 3D parcel over the background of 2D cadaster borders and added a layer of "3D cadaster areas", in which a polygon of 2D parcels that have a 3D parcel appeared to be detracted due to a 3D parcel, (Figure 1).

Cadaster 3D require training and assimilation. Training activities carried out aimed at creating a cognitive impact and professional training for the professionals engaged in planning, measurements and registration. A national "3D planning and registration" conference was held with the participation of about 600 participants, in which the activities and their products were presented, as well as common cases and operational information. In addition, many seminars, training and meetings held with professionals from various fields in order to present new options in planning and registration in the framework of optimal and informed planning.

2.2.3 Preparation of the Ministry of Justice

Regulations have been written and approved in accordance with an amendment to the Land Law that define provisions regarding the creation and registration of a 3D parcel, including provisions regarding the definition of a 3D parcel; the area of ownership there and conditions for its registration. These regulations defined the conditions for registering a 3D parcel.

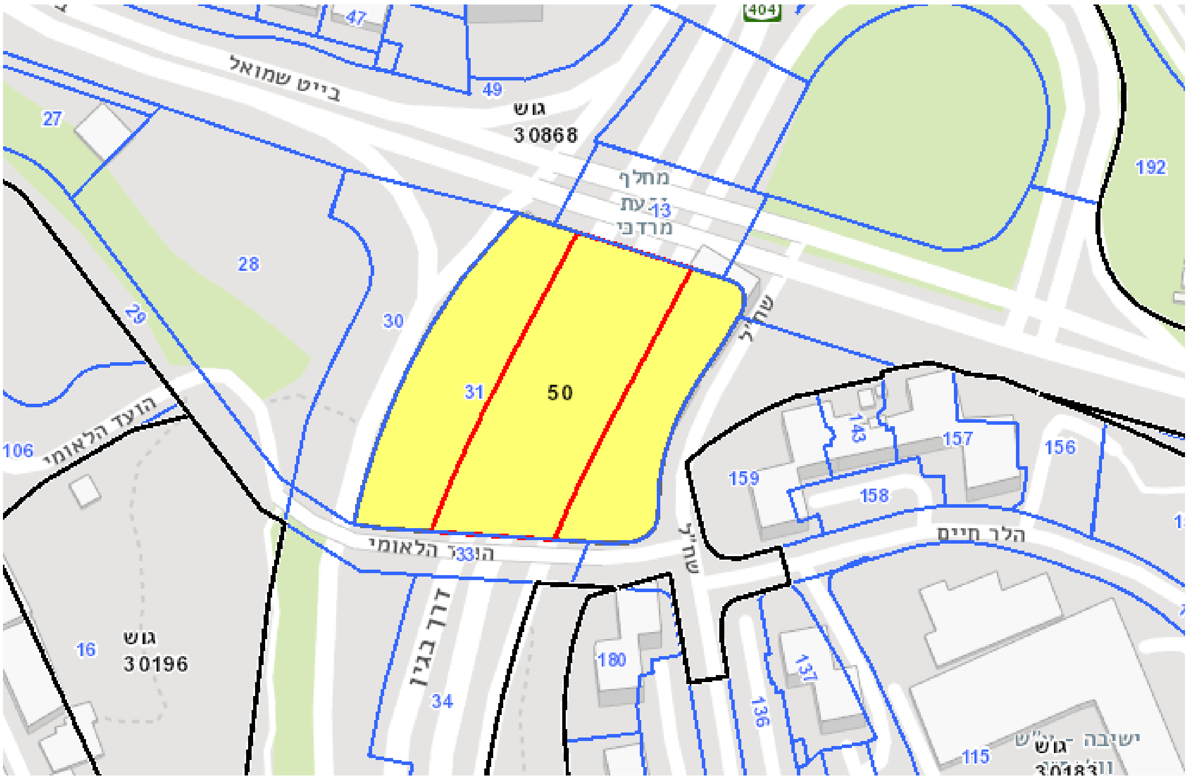

Figure 1. Display a 3D parcels projection (red line) and a 3D cadaster area (yellow color) against the background of blocks (black line) and parcels (blue line)

The 3D registration process required adapting an existing database to collect, display, and manage new type of data, such as type of parcel (terrestrial - 2D or 3D), 3D volume, 3D parcel projection area, top and bottom height of 3D parcel. Later, structural and logical tests were developed.

One of the Missions of the Ministry of Justice was to define a registration deed for a 3D parcel, and to introduce changes to the deed of the 2D parcel that has a 3D parcel underneath or above. In the deed of a terrestrial parcel, information about detractions was also recorded (parts of the area of ownership of a terrestrial parcel that were transferred to a 3D parcel). The deed of a terrestrial parcel is attached to the article as Appendix B. A deed of a 3D parcel in part, including the same data, some data was described differently accordingly and new data. It is attached to the article as Appendix C.

It is difficult to describe parcel boundaries in 2D, let alone in 3D. Therefore, in the deed of a 3D parcel, a hyperlink was inserted to the 3D final PDF map so that anyone who looks at the deed's wording can also review the 3d mutation plan and view the 3D parcel from every possible direction.

2.2.4 Data interface

For registering, one of the things that the registration bureau should receive is a 3D plan for registration purposes. After Amendment No. 3 of the Electronic Signature Law (2001) that introduced conditions for full transfer to a digital world, SOI was one of the first government agencies to make a transition to electronic signature of maps. This transition enables to create a digital interface between SOI and the Ministry of Justice registration bureau, in order to transfer information between offices in a faster and higher quality manner and reduce bureaucracy. The "Rimon Interface" is a "bi-directional" and intended for the transfer of information from SOI to the registration office for the purpose of registering and returning the final information to SOI after registration.

The data required to complete the registration of a 3D parcel (digital data and maps) transmitted through the interface system. In conclusion, at the end of 2019, preparations in government ministries have ended and a work process established, that allows the registration of property rights in 3D.

2.3 3D Cadaster application

After completing all the main processes of preparation, the promotion of projects with the potential for 3D registration began. In order to experiment with the process and gain experience, SOI and its main partner, the Israel Land Authority (which manages the state land), carried out a number of 3D plans preparation and registration projects, which are currently in various stages of preparation, auditing or registration.

Each project has unique characteristics, listing, planning, or engineering. From the execution of the work, it was found that the main difficulty in preparing a 3D plan is in defining the 3D parcel limits. When the parcel limits are not predetermined in a planning plan, its boundaries must be determined in the process of land distribution design map given the exclusion range and planning data. The following is a description of several 3D cadaster projects, which are in different stages.

2.3.1 Mordechai hill interchange

The Mordechai hill interchange is a crossing of two arterial roads in Jerusalem that are on different levels. Above the interchange, a residential complex was planned and built, including commercial complex and an underground parking lot above Menachem Begin Road, which is on the lower level below the residential and commercial lot (Figure 2).

Since it is not possible to register the property rights of the condominium and the road, because the road that passes under a residential complex is owned by the Jerusalem Municipality, and the buildings are privately owned land division, the conclusion was to register a tunnel as a 3D parcel.

A "Land Distribution" plan was prepared in accordance with a town plan 4761, approved in 2004. As part of this plan, a lot was created for a residential and commercial complex above the Menachem Begin Road. Figure 3 display the planning situation before and after the approval of the plan. The town plan created a residential lot including a private and public parking lot and the trading floor.

Figure 2. "Mordechai hill" interchange

A town plan 4761 is considered a "new division" planning plan that creates a 3D lot and does not include its coordinated definition. In addition to the plan, there is an approved building permit in the Planning and Construction Committee, which includes a detailed engineering description of the tunnel structure and residential complex.

The purpose of the project is to define the tunnel that passes under the residential and commercial complex as part of a 3D parcel and to register it as the ownership of the Jerusalem Municipality. The model of the 3D plan created based on the road field survey. In the implementation of the 3D model, we used "as-made Maps" from 2007, in which the state of the area is described before the construction of the residential and commercial complex. The upper boundary of the 3D plot defined in the middle of the ceiling. The side borders defined by the tunnel walls. The lower boundary is determined by the level of the actual driving path, subtracted 3 meters. This exclusion range is required for the purpose of the driving path structure and the infrastructure that passes along the way.The 3D parcel shape consists and repeats the actual tunnel shape. The 3D parcel shape is inclined and angled.

Each boundary point has horizontal coordinates and height defined. A 3D model of the parcel can be viewed in the figure 4.

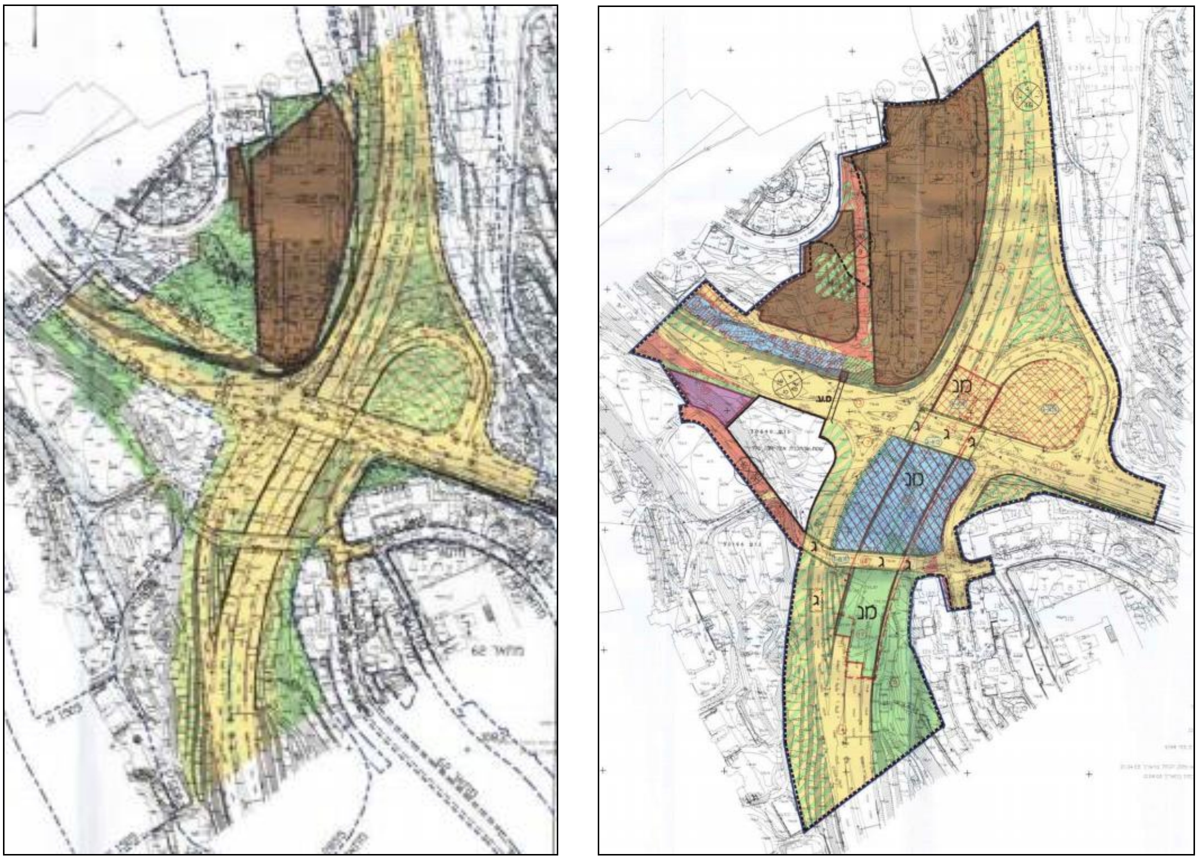

Figure 3. The town paln 4761 that determines a 3D lot

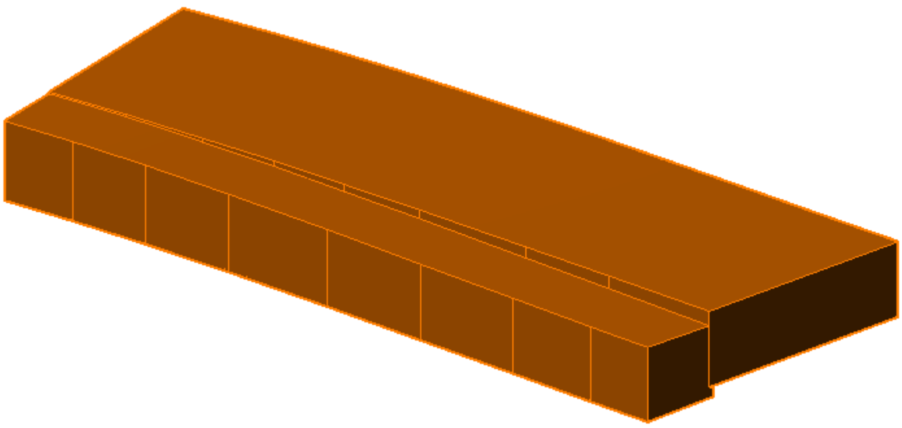

Figure 4. 3D model of the first 3D parcel

In the 3D plan, operations were carried out to create a new 3D parcel and calculate detriments. The plan includes volume calculations, projection areas, upper and bottom heights of the 3D plan and the depreciation. The 3D cadaster mutation plan includes 3 sheets: main sheet, position sheet and perspectives sheet. The main sheet includes a 3D parcel model, a 3D model of the surface above the 3D parcel, calculation tables and written information. The 3D plan sheets in Appendix D.

After the completion of the preparation of the 3D cadaster plan, it was approved by the Planning and Construction Committee as a 3D land distribution on 09/12/2020 and as 3D cadaster plan on 28/12/2020. This 3D cadaster plan is the first one approved and registered in the State of Israel on 28/02/2021.

2.3.2 The Carmel Tunnels

The Carmel Tunnels are underground tunnels connecting two interchanges that constitute an entrance and exit to the city of Haifa. The overall length of the Carmel Tunnels system is about six kilometers, in which one-way routes constructed, in two driving lanes, with a separate tunnel system in each direction. The tunnels cross the city of Haifa from from west to east, also extend beneath neighborhoods. The specialty of the project in terms of a 3D cadaster, expresses that the basis for registration is not a town plan but an expropriation in favor of an underground road for the benefit of the public. In this case, the process of setting the border of the 3D parcel was adjusted to the information specified in the expropriation documents. Therefore, the result of the project's registration will be several 3D parcels as the amount of blocks through which the tunnels pass. Registration will be carried out based on a 3D parcelization program prepared in accordance with the expropriation documents.

Figure 5. Photograph of the Carmel Tunnel Entrance Portal (right) and Orthophoto of the route of road number 23 – the Carmel Tunnel (left).

2.3.3 Underground passage in "Sarona complex" in Tel Aviv

The "Sarona complex" is a complex that combines residential, offices, commerce, private and public parking lots and a public road with its infrastructure located in central Tel Aviv. From a proprietary point of view, the complex constitutes a complexed system combined of private owners (residential, commercial, private parking lot), the Tel Aviv Municipality (commerce, road and public parking lot). The whole complex was designed as one complex. In the "Sarona complex", property rights can only be regulated correctly in 3D registration, because it is not possible to register rights on a public road using the method of registering a condominium. The essence of the project that is currently in the 3D plan preparation stage is to define the field of the road and carry out its registration in 3D cadaster plan in the municipality's ownership.

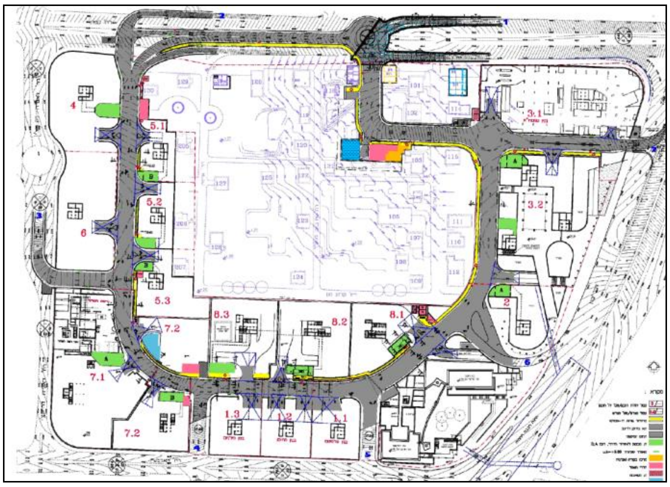


Figure 6. Appendix of a town paln of the "Sarona complex", portrays an underground road and connection to existing roads against the background of a new division of the complex (left). Simulation of the "Sarona complex", most of which is already built, and partially under construction (right)


Figure 7. Infrastructure pass divided into two levels (left). Public Underground Road of the "Sarona Complex" (right)

This action will allow the process of registering the rights of all other rights holders using the method of condominium registration in the terrestrial plot. The complexity of setting the 3D parcel limit is greater, due to the way public infrastructures that serve the road are deployed. For example, on the route there is an infrastructure crossing, divided into two levels, one of which belongs to the infrastructure of the road and the other to the infrastructure of an electric company that serves the residential buildings. In addition, there is another difficulty in defining infrastructures such as shafts, air ducts and eemergency roads, due to the complex route and geometry that access is partially or inaccessible.

2.3.4 Conclusion

Currently, in Israel there is an applied 3D cadaster. The solution implemented is an easy and quick solution for an application that does not require vast development. Currently, there are several projects in various stages of preparing 3D cadaster plan, some of which described in this article, some of them infrastructure projects at a national level, such as:

- Registration of a public transportation system in Tel Aviv and nearby cities – "Metro" in Gush Dan,

- Roofing of the arterial road "Ayalon Highway" - a main road in Tel Aviv that is several kilometers long and about 100 meters wide that crosses Tel Aviv from north to south ,
- Roofing of the "Menachem Begin" road - main road in Jerusalem, part of which constitutes a pilot project described in the article.
- Registration of a high-speed train line to Jerusalem,
- Registration of tunnels Highway 6 – a highway that crosses the entire country from north to south.

In addition to large projects, work is carried out in the registration of small projects that streamline the utilization of land, such as private parking under an open public area (parks, green areas).

It is clear that the proposed solution does not make it possible to deal with large volumes of projects. The desired solution is to move from the world of the 2D map to the world of the 3D model and for this purpose, we are preparing for the second stage of the 3D Cadaster that will be based on 3D databases and will form the basis for smart cities.

3. FUTURE VISION

Stage 2 of the 3D Cadaster application is of technological transition. Within this stage, the relevant government ministries, such as: SOI and the Planning Administration, intend to implement a 3D database that will enable cadaster data management and 2D and 3D planning simultaneously. The new database will enable the reception, management, maintenance and display of 3D information and will support all new processes related to a 3D and multidimensional cadaster. Due to the large volumes of execution of the works at this stage, it is necessary to develop tools for processing 3D information and automating the process of submission, absorption, auditing, maintenance and management of 3D planning and cadaster data in order to provide a more efficient and fast service that meets the requirements of evolving reality.

Technological transition of all government ministries to the cloud environment will enable to reach phase three of the 3D Cadaster application through a 3D web-portal. The portal will serve as a uniformed system that will allow all relevant government ministries in the planning and registration chain to operate in a uniformed environment and according to common standards. The system will concentrate and manage all operations in the field of planning, measurements and registration of all parties. The system will be up-to-date source of information based on location for all types of information. A 3D view display, utilizing Digital twin technological principles will be implemented. The permissions to each government office will be assigned as necessary and according to functioning. The system will allow expediting, simplifying and streamlining the entire work process, and reducing delays and errors.

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Uri Shoshani, Moshe Benhamu, Eri Goshen, Shaul Denekamp and Roy Bar (2004). Registration of Cadastral Spatial Rights in Israel – A Research and Development Project. In proceedings FIG Working Week 2004, Athens, Greece, May 22-27, 2004.

Uri Shoshani, Moshe Benhamu, Eri Goshen, Shaul Denekamp and Roy Bar (2005). A Multi Layers 3D Cadastre in Israel: A Research and Development Project Recommendation. In proceedings FIG Working Week 2005 and GSDI-8.

Uri Shoshani, Moshe Benhamu, Eri Goshen, Shaul Denekamp and Roy Bar (2004). Registration of Cadastral Spatial Rights in Israel – A Research and Development Project. In proceedings FIG Working Week 2004, Athens, Greece, May 22-27, 2004.

Uri Shoshani, Moshe Benhamu, Eri Goshen, Shaul Denekamp and Roy Bar (2005). A Multi Layers 3D Cadastre in Israel: A Research and Development Project Recommendation. In proceedings FIG Working Week 2005 and GSDI-8.

APENDIX A: THE "NEW DIVISION" TOWN PLAN THAT GUIDES THE CREATION OF A 3D LOT

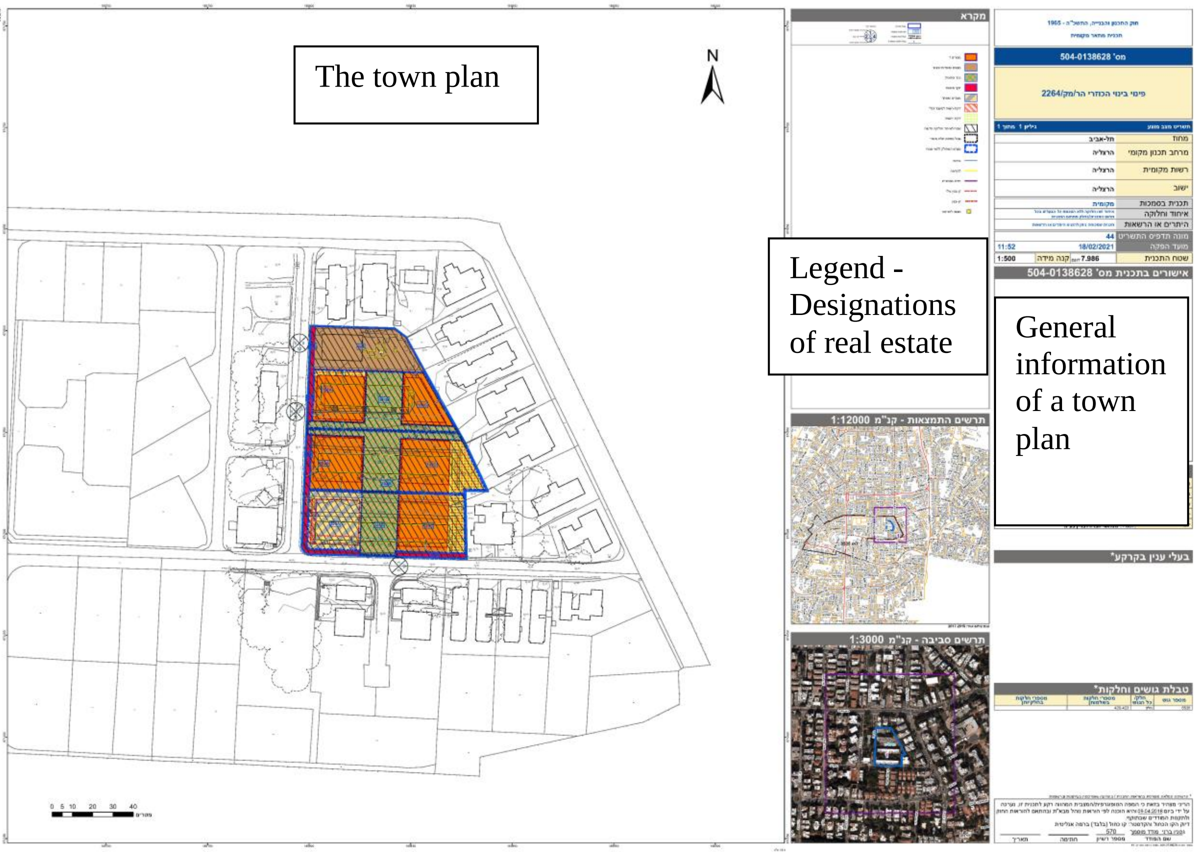


Figure 8. The "New Division" town plan that guides the creation of a 3D lot

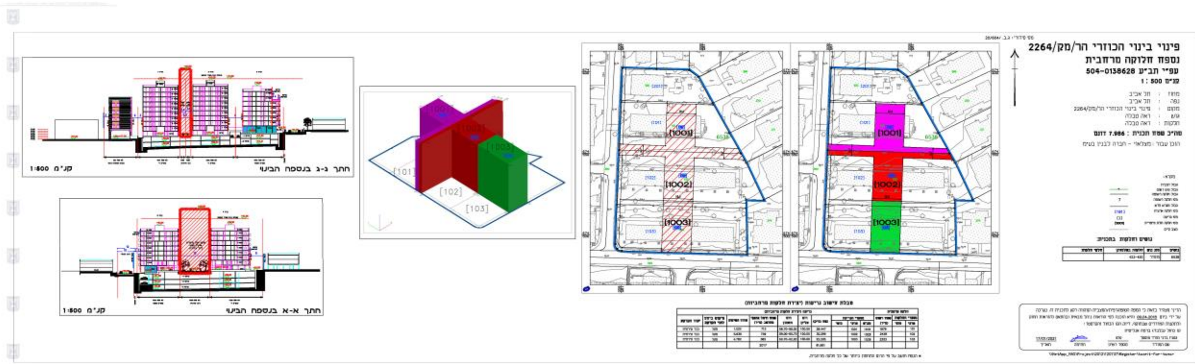
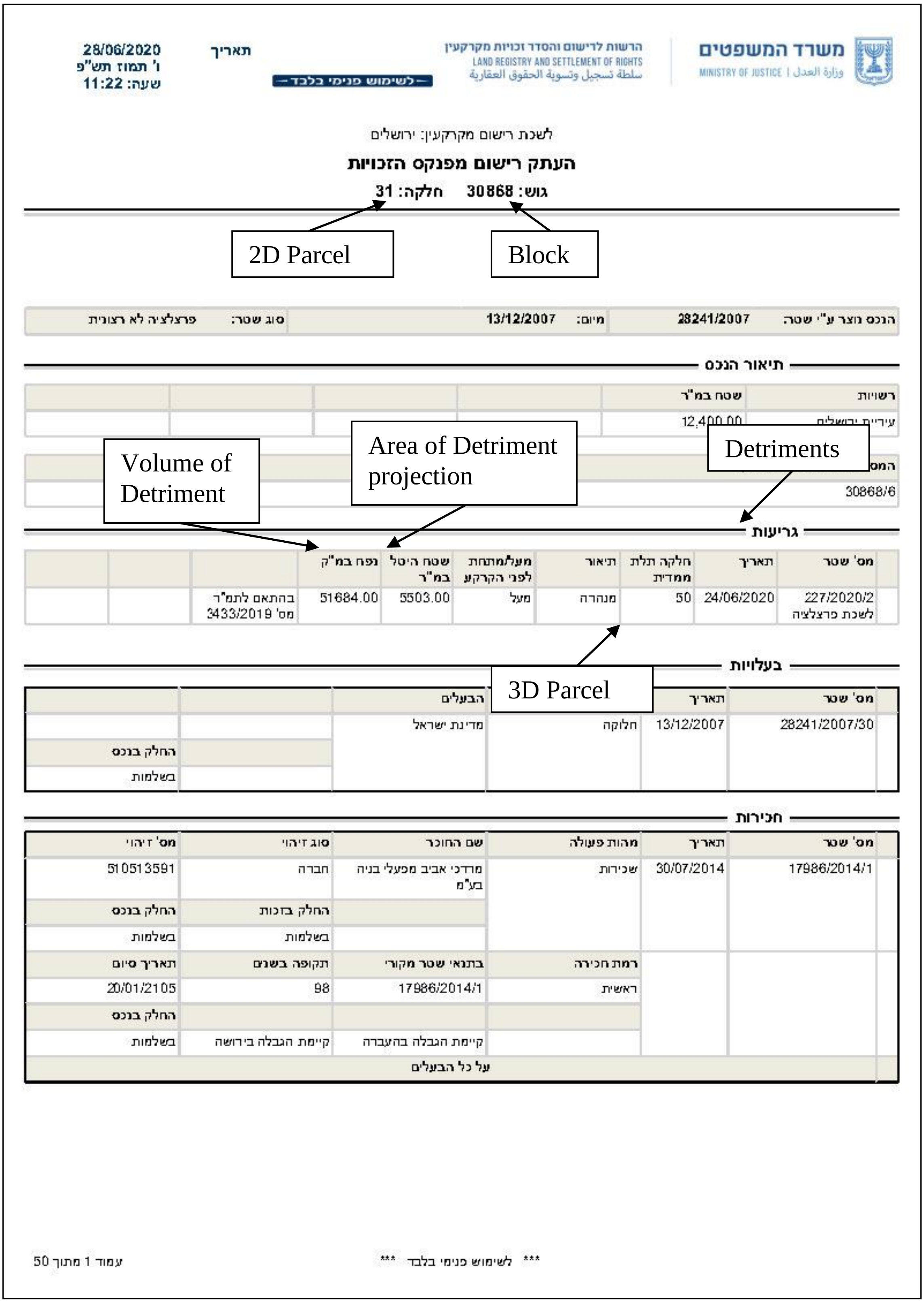


Figure 9. 3D Plan Appendix Of the "New Division" town plan

APENDIX B: 2D REGISTRATION DEED



משרד המשפטים
MINISTRY OF JUSTICE | وزارة العدل

הרשות לרישום והסדר זכויות מקרקעין
LAND REGISTRY AND SETTLEMENT OF RIGHTS
سلطة تسجيل وتسوية الحقوق العقارية

—לשימוש פנימי בלבד—

תאריך 28/06/2020
ו' תמוז תש"פ
שעה: 11:22

לשכת רישום מקרקעין: ירושלים

העתק רישום מפנקס הזכויות

גוש: 30868 חלקה: 31

הנכס נוצר ע"י שטר:	28241/2007	מיום:	13/12/2007	סוג שטר:	פרצלציה לא רצונית

תיאור הנכס

רשויות	שטח במ"ר				
עיריית ירושלים	12,400.00				

המס...
30868/6

גריעות

מס' שטר	תאריך	חלקה תלת ממדית	תיאור	מעל/מתחת לפני הקרקע	שטח היטל במ"ר	נפח במ"ק			
227/2020/2 לשכת פרצלציה	24/06/2020	50	מנהרה	מעל	5503.00	51684.00	בהתאם לתמ"ר מס' 3433/2019		

בעלויות

מס' שטר	תאריך		הבעלים		
28241/2007/30	13/12/2007	חלוקה	מדינת ישראל		
					החלק בנכס
					בשלמות

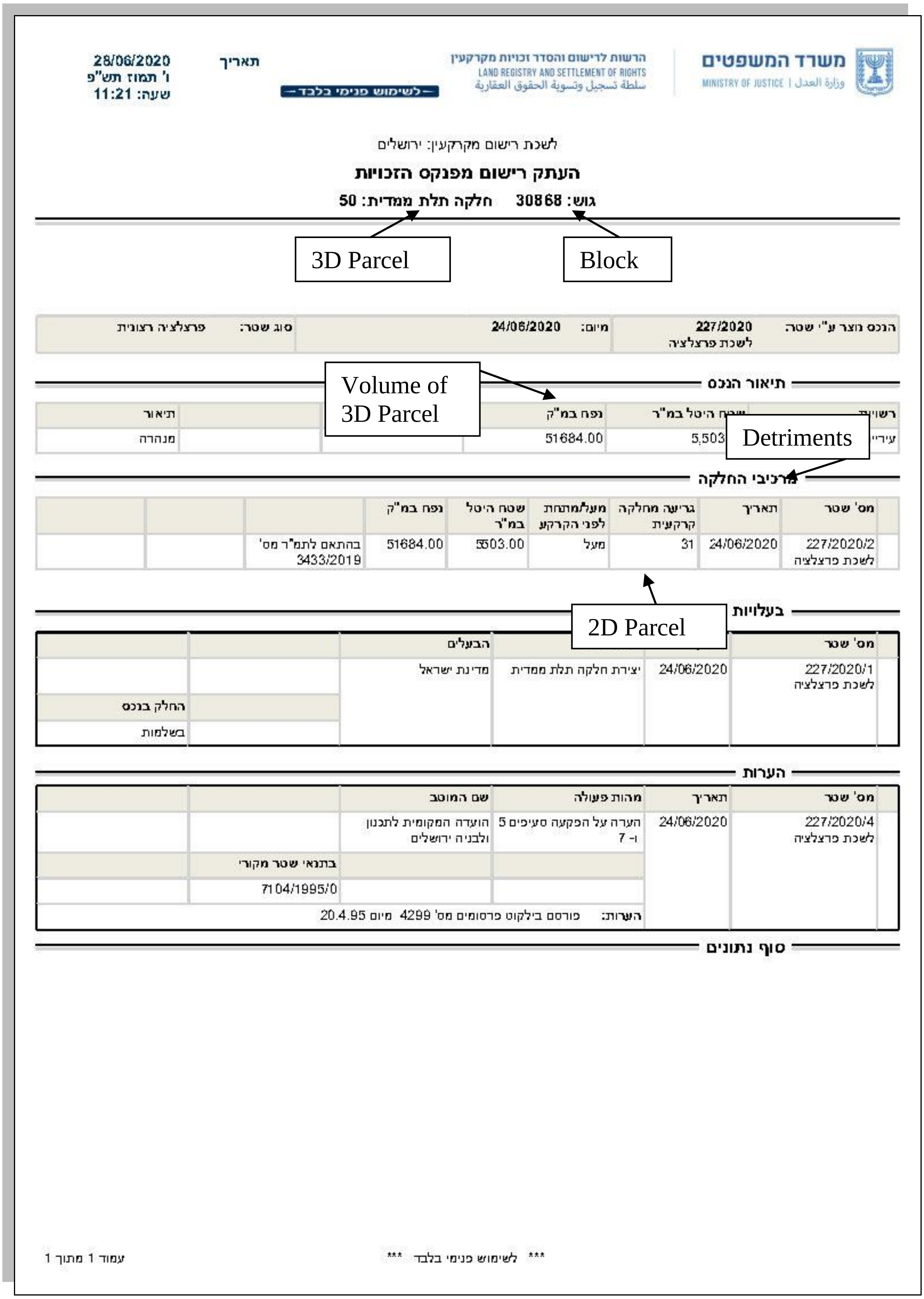
חכירות

מס' שטר	תאריך	מהות פעולה	שם החוכר	סוג זיהוי	מס' זיהוי
17986/2014/1	30/07/2014	שכירות	מרדכי אביב מפעלי בניה בע"מ	חברה	510513591
				החלק בזכות	החלק בנכס
				בשלמות	בשלמות
		רמת חכירה	בתנאי שטר מקורי	תקופה בשנים	תאריך סיום
		ראשית	17986/2014/1	98	20/01/2105
					החלק בנכס
			קיימת הגבלה בהעברה	קיימת הגבלה בירושה	בשלמות
			על כל הבעלים		

*** לשימוש פנימי בלבד ***

עמוד 1 מתוך 50

APENDIX C: 3D REGISTRATION DEED



משרד המשפטים
MINISTRY OF JUSTICE | وزارة العدل

הרשות לרישום והסדר זכויות מקרקעין
LAND REGISTRY AND SETTLEMENT OF RIGHTS
سلطة تسجيل وتسوية الحقوق العقارية

—לשימוש פנימי בלבד—

תאריך 28/06/2020
ו' תמוז תש"פ
שעה: 11:21

לשכת רישום מקרקעין: ירושלים

העתק רישום מפנקס הזכויות

גוש: 30868 חלקה תלת ממדית: 50

הנכס נוצר ע"י שטר	227/2020 לשכת פרצלציה	מיום:	24/06/2020	סוג שטר:	פרצלציה רצונית

תיאור הנכס

רשויות	שטח היטל במ"ר	נפח במ"ק			תיאור
עיריי	5,503	51684.00			מנהרה

מרכיבי החלקה

מס' שטר	תאריך	גריעה מחלקה קרקעית	מעל/מתחת לפני הקרקע	שטח היטל במ"ר	נפח במ"ק			
227/2020/2 לשכת פרצלציה	24/06/2020	31	מעל	5503.00	51684.00	בהתאם לתמ"ר מס' 3433/2019		

בעלויות

מס' שטר	תאריך		הבעלים		החלק בנכס
227/2020/1 לשכת פרצלציה	24/06/2020	יצירת חלקה תלת ממדית	מדינת ישראל		בשלמות

הערות

מס' שטר	תאריך	מהות פעולה	שם המוטב		בתנאי שטר מקורי
227/2020/4 לשכת פרצלציה	24/06/2020	הערה על הפקעה סעיפים 5 ו- 7	הועדה המקומית לתכנון ולבניה ירושלים		7104/1995/0

הערות: פורסם בילקוט פרסומים מס' 4299 מיום 20.4.95

סוף נתונים

עמוד 1 מתוך 1 *** לשימוש פנימי בלבד ***

APENDIX D: 3D PROGRAM FOR REGISTRATION PURPOSES (TAMAR)

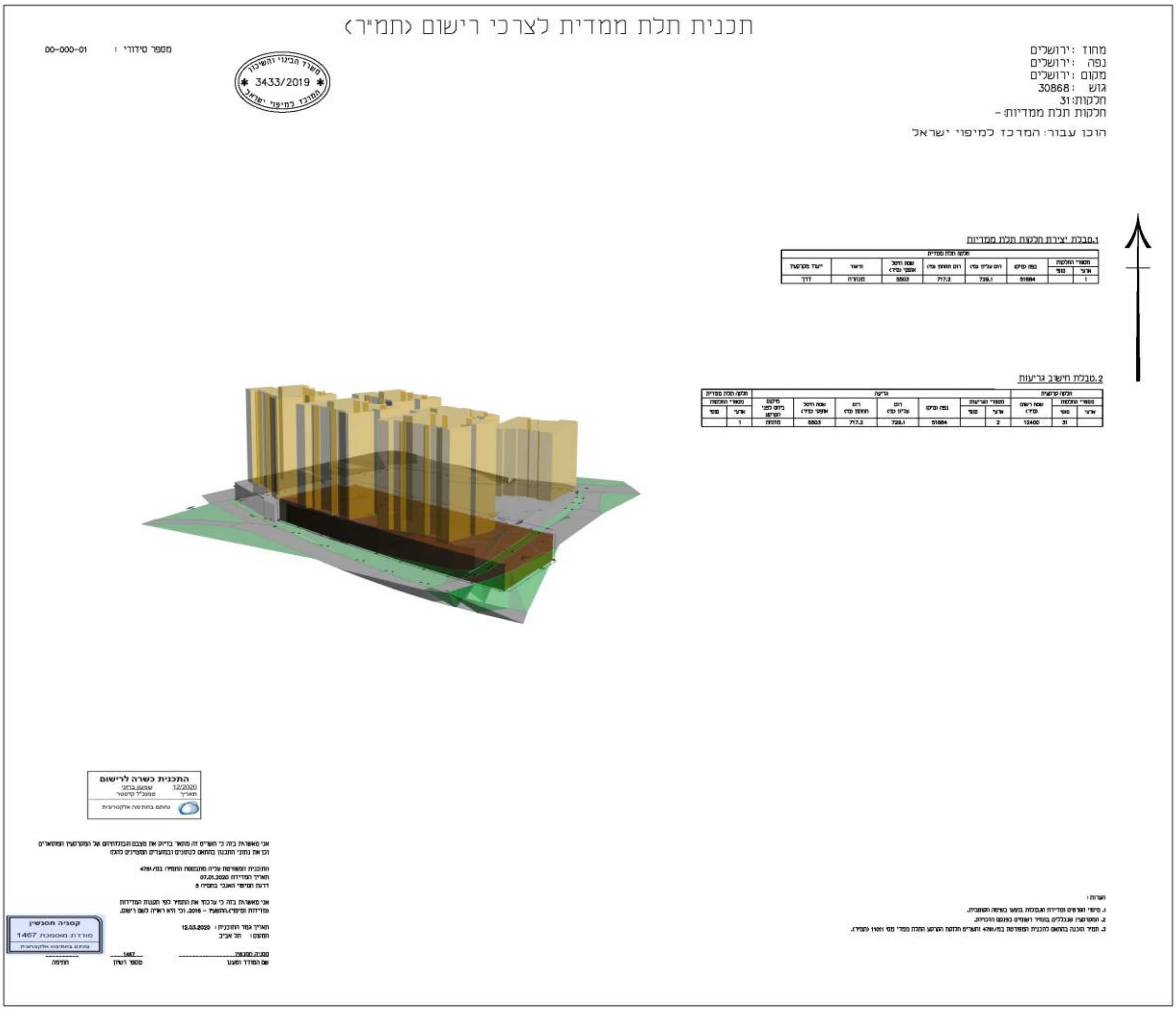


Figure 10. Main sheet of 3D Cadaster Mutation Plan

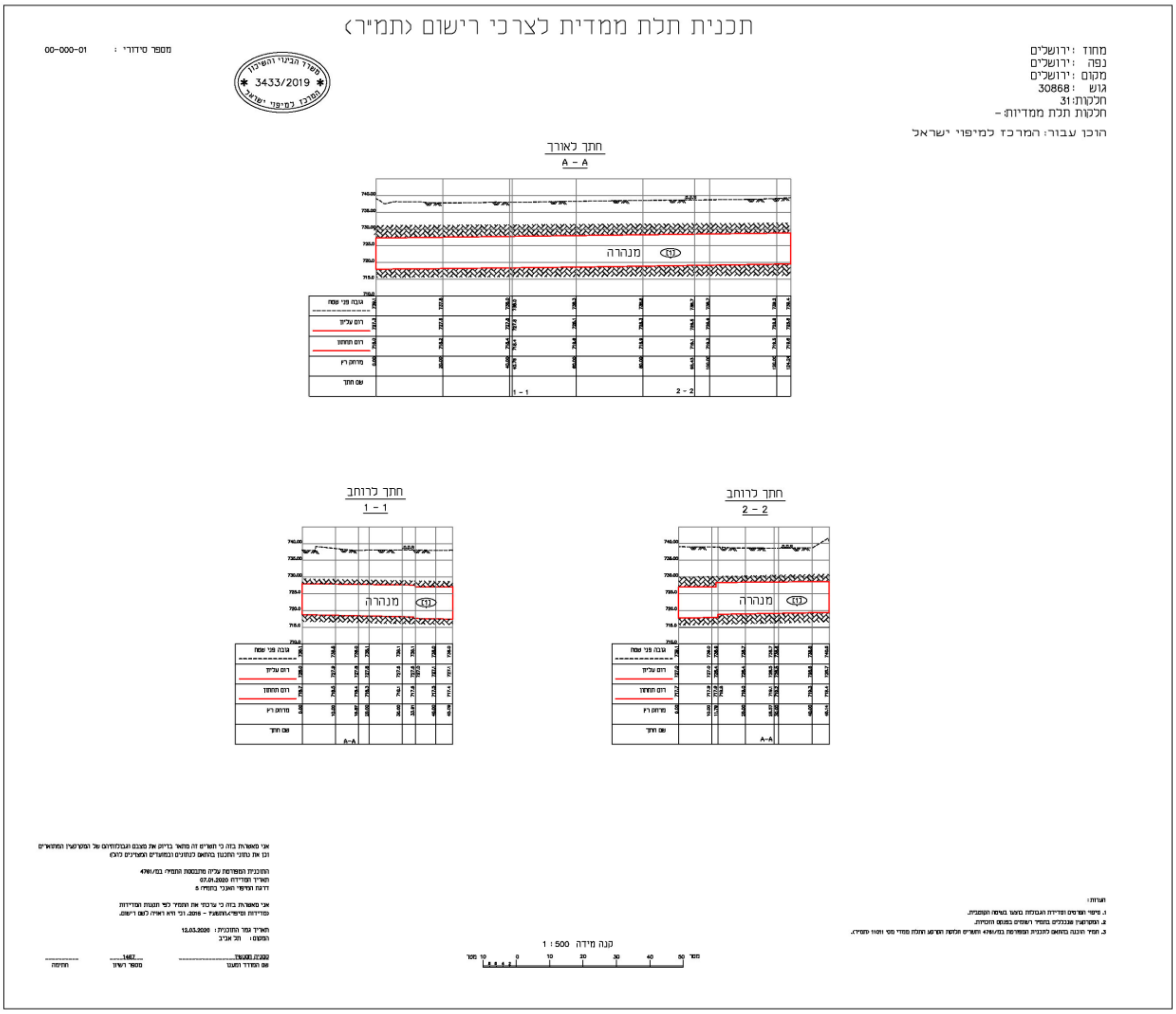


Figure 11. Perspectives sheet of 3D Cadaster Mutation Plan

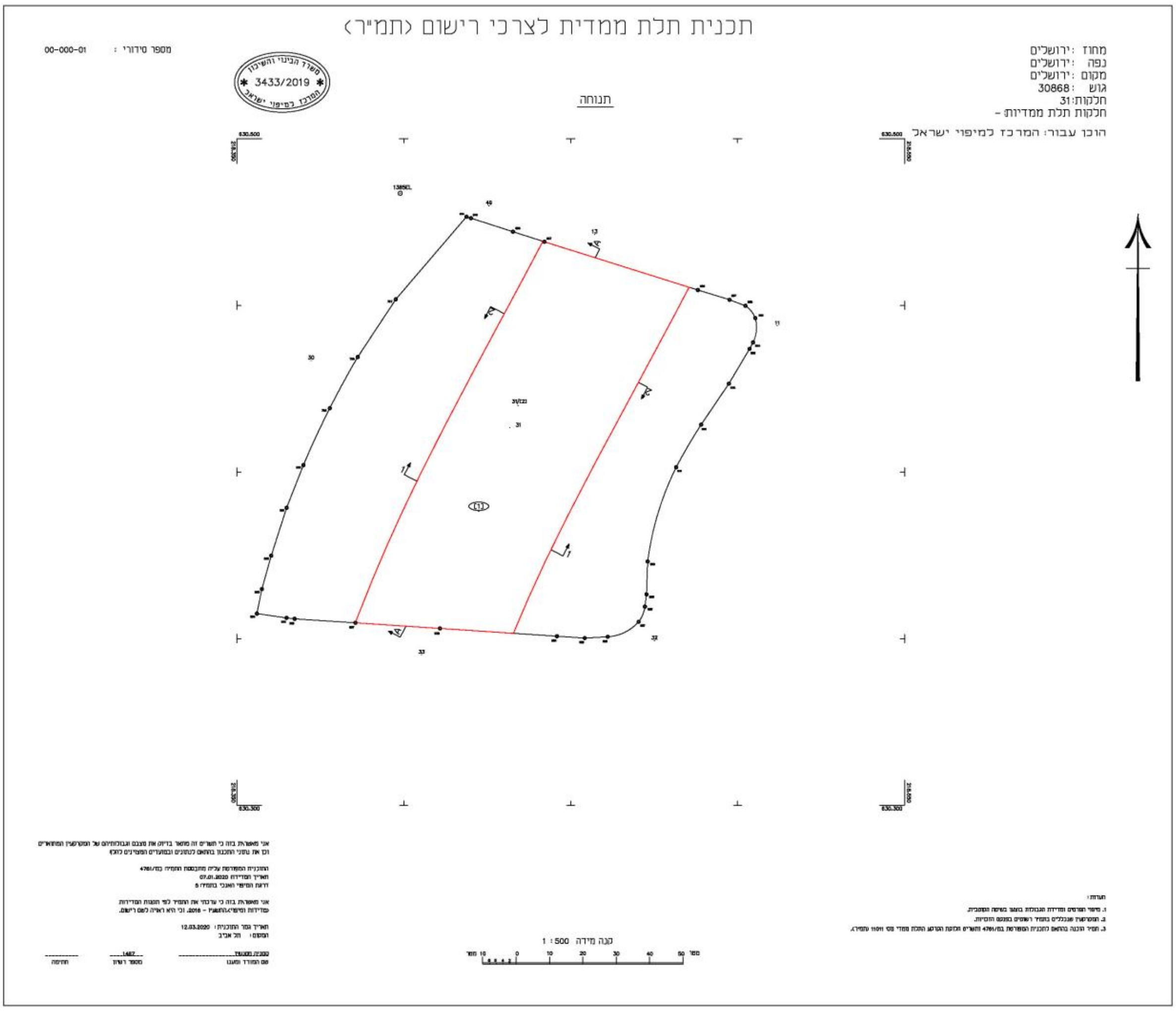


Figure 12. Position sheet of 3D Cadaster Mutation Plan

BIOGRAPHICAL NOTES

Eng. Ksenia Khasanshina graduated from the Kuban State Agrarian University, Russia with MSc in Cadastre and Geodesy (2013). She is a Licensed Surveyor in Israel Since 2017. Currently in the final stages of MUE (Master Urban Engineering) at the Technion. At this time, she is a Head Section of 3D Cadastre at the Survey of Israel.

Eng. Shimon Barazani graduated from the Technion Haifa, Israel with a BSc. in Geodesy (1995), and Civil Engineering (1994). He is a Licensed Surveyor in Israel Since 1997. He was a Department Head in D.E.L, a private surveying and engineering company. A Section Head of Surveying in the Ministry of Construction & Housing of Israel, a Director of Mapping Technologies in The Survey of Israel and currently he is the Deputy Director General for Cadaster in the Survey of Israel.

Yoav Tal is acting as the CTO at the Survey of Israel. Mr. Tal has 35 years of experience in the mapping, GIS, cadaster and geoinformation technology. Among his various responsibilities he is leading the technological transition operations for a new modern cadastral multidimensional database and applications.

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3D Modelling, Validation and Visualization of 3D Parcels in First Registration for 3D Cadastre - Indonesia Case

Trias ADITYA, Dany P. LAKSONO, Dedi ATUNGGAL, Febrian F. SUSANTA, Nurrohmat WIDJAJANTI, Mohammad B. SETIAWAN, Nurhidayat AGAM and Tri WIBISONO, Indonesia

Key words: 3D modelling, field validation, 3D visualization, first registration

SUMMARY

Developments of legal, institutional and technical aspects in realizing property registration of 3D parcels situated above and below 2D parcels are still evolving in many countries. 3D cadastres have to deal with various institutional/legal gaps and challenging information integration regarding the Rights-Restrictions-Responsibilities (3R) of 2D parcels. This paper aims to present a proof of concept implementing 3D cadastre of a new regulation of land registration in Indonesia (Government Regulation Number 18/2021 on Rights to Manage, Land Rights, Strata Title and Land Registration). This study presents the modelling and validation of 3D cadastral objects for realizing the first registration using the new regulation on 3D cadastre. The study encompasses 2D & 3D data integration, 3D modelling, field validation and visualization of 3D units. The 2D parcels were extracted from the land registration map, collected from the Central Jakarta and the South Jakarta land offices. The 3D constructions to be registered were obtained from PT. MRT in the form of as-built drawings of floor plans and selected cross-sections. The 3D models were created by reconstructing 2D floor plans and cross-sections using Autodesk Revit to create an IFC file of 3D units from geometries of floors, walls and ceilings. Surveyors validated 3D representations of 3D units of two MRT terminals. Field validation includes determining the legal spaces against the 3D constructions and validating floor areas and volumes of 3D units. After field validation is done and agreed upon by stakeholders, 3D models were converted into CityGML to create representations of legal spaces of 3D units. The tools used to convert IFC into CityGML 2.0 are Sketchup City Editor and eveBIM. Data conversion results must be cleaned and edited to include the semantic of 3D units and registration attributes. The results of the integration of 2D and 3D parcels are presented in Terria Map, which shows the constructions, legal spaces of 3D units and 2D parcels with rights.

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1. INTRODUCTION

In Indonesia, land administration is considered one of sectors requiring substantial improvement, especially regarding its time, cost and procedures. The country score for property registration in Ease of Doing Business (EODB) measures has been below 70 for years (The World Bank 2021). The government of Indonesia recently unleashed Jobs Creation Law, commonly referred to as the "Omnibus Law". Indonesian parliament passed the Omnibus bill on 5 October 2020 and was signed by the President on 2 November 2020. This law covers many clusters, including business licensing, investment ecosystem, workforce, forestry, environment, taxation and land administration. Regarding land administration, the government acclaimed the omnibus law to provide new legal frameworks that support EODB reforms on land banks, rights to manage, strata titles and land registration for 3D parcels below and above ground.

Article 146 from the omnibus law specifies that 3D parcels located below or above ground can be used for certain activities by parties. A 3D parcel is entitled to one of the following ownership types: rights to manage (known as *Hak Pengelolaan*/HPL), rights to build (*Hak Guna Bangunan*/HGB) and rights to use (*Hak Pakai*/HP). The government launched a new regulation number 18/2021 (Government Regulation Number 18/2021 on Rights to Manage, Land Rights, Strata Title and Land Registration) to empower legal and intuitional aspects of land registration which includes registration to 3D parcels either above or below ground. The articles regulating 3D cadastral objects, types of rights (including their required permits and approval), parties and administrative arrangements are specified from Article 74 to Article 83 in this government regulation.

As 3D cadastres have to deal with various institutional/legal gaps and challenging information integration regarding the Rights-Restrictions-Responsibilities (3R) of 2D parcels, appropriate guidelines and standards for implementing this new regulation is necessary. At the moment, land administration in Indonesia is focusing only on 2D representations. This paper presents the results of a pilot study involving the government Ministry of Agrarian Affairs and Spatial Planning/National Land Agency (MoASP/BPN), the university (Universitas Gadjah Mada/UGM) and the user (PT Mass Rapid Transit Jakarta/MRT). The study took place from July to August 2020 in two newly built Mass Rapid Transportation (MRT) terminals in Jakarta City. This paper is a part of studies related to implementing 3D cadastre in Indonesia, collaborating with the National Land Registry Agency of Indonesia (BPN). The focus of this paper is to set the stage for 3D cadastre initial registration to understand an ideal pipeline for the MoASP/BPN officers in implementing the newly issued regulation on-field surveying for

3D cadastre. The study encompasses 2D & 3D data compilation, 3D modelling, field validation and visualization of 3D units.

Section 2 will give a short literature review regarding data modelling and visualization. Section 3 will first describe the procedures and methods in creating and visualizing 3D models for the first registration mission. Section 4 will present the results of the pilot study. Section 5 will highlight essential elements in creating the national guideline for 3D cadastre implementation and some issues to be resolved in the future.

2. LITERATURE REVIEW

Developments of legal, institutional and technical aspects in realizing property registration of 3D parcels situated above and below 2D parcels are still evolving in many countries. Despite many examples of partial implementation of first registration, no country has a fully functional 3D cadastre (Dimopoulou et al. 2018). That is also true for the case of Indonesia land administration. The strata title registration mandated by the Law number 20/2011, can be regarded as an early implementation of 3D registration in Indonesia land administration. The law (created first in 1985 as the Law number 16/1985 and then revised into number 20/2011) allows the government to give parties their ownership rights of individual units in addition to common rights within the building. For this purpose, a field survey to validate the boundary units (spatial data) and underlying documents (legal/administrative and party data) should be done by the land office where the application is submitted. In order to improve the certainty regarding the validity and representation of spatial and legal data of individual 3D cadastral objects, a relevant 3D survey and mapping procedure for the country has been tested for some 3D objects (Aditya et al. 2020). In the proposed procedure, land surveyors can create 3D models for the 3D cadastre registration from field survey or digital reconstruction generated from the file submitted by the users.

Over the past two decades, various 3D data models for 3D cadastre have been implemented without or with semantic enrichment to the geometry. eXtensible Markup Language (XML)-based data models such as Keyhole Markup Language (KML) and COLLADA with limited or no semantic information have been used as data exchange formats to display simple 3D representations of parcel units for web 3D cadastre (Aditya et al. 2011). The approaches for semantic enrichment for 3D cadastre can be realized using two data formats, i.e., Building Information Model(BIM) /Industry Foundation Classes (IFC) (e.g., in Atazadeh et al. 2019; Olfat et al. 2021) and 3D CityModel using the OGC's City Geography markup Language(CityGML)(e.g. in (Biljecki et al. 2021; Eriksson et al. 2021). Both options, i.e., BIM/IFC oriented and 3D CityModel approach, are required to be able to represent two types of boundary representations: physical and legal boundaries or spaces of Rights-Restrictions-Responsibilities (3Rs) in 3D cadastres.

In order to represent both physical and legal boundaries, researchers have investigated the integration of legal and physical models. Atazadeh et al. (2018) explored the matching between IFC data format as the physical model and Land Administration Domain Model (LADM) as the legal reference model. Li et al. (2016) realized the integration between

CityGML and LADM by adding an Application Domain Extension (ADE) for CityGML to precisely reveal legal objects' ownership structure regarding their physical objects in a condominium unit.

Both options of IFC-cadastral extension to LADM and CityGML-LADM ADE (currently) do not have built-in support for 3D cadastre and needs to rely on ADE for storing 3D cadastre data. However, for this pilot study, CityGML ADE is better and more matured for supporting 3D legal spaces and building objects (e.g., Rönsdorf et al. 2014; Donkers et al. 2016) compared to IFC’s ADE support for property and built environment such as road network (Lee and Kim 2011; Atazadeh et al. 2021).

Although we realized that the options for a comprehensive legal and physical boundary representation would be: CityGML-LADM ADE or Cadastral Extension of IFC, we did not explore those two options equally from the data modelling into data visualization as two separate cases (for further comparison). Instead, we considered IFC-based data modelling as the standard approach for data modelling and processing for 3D constructions, while CityGML as the data format for 3D cadastre visualization. This pilot study creates 3D models from the building as-built (ABD) drawing, submitted by the user to MoASP/BPN. This CAD file has been considered as the standard format provided by the existing 3D building and infrastructure users who apply for existing regulated construction permits in big cities in Indonesia. Thus, in this pilot study, the data modelling and validation were managed using IFC and data visualization was done using CityGML. This approach was also undertaken for some practical reasons:

- This study will be used by the MoASP/BPN to develop a national technical guideline for land surveyors to conduct survey and validation activities for unregistered 3D parcels below or above ground. Hence the focus is on the 3d modelling and validation using Computer Aided Drawing (CAD) applications that support IFC/BIM as it was applied for surveying and mapping 2D parcels in using CAD and geopackage as data input format (see, e.g., (Aditya et al. 2021);
- The MRT case study is an ideal situation for CAD/BIM formats suggested by earlier regulations for 3D Building development in Indonesia. Government regulations have favoured BIM standards (e.g., The regulation of Ministry of Public Works number 22/2018 and the Government regulation No. 21/2021 on level-5 BIM and level-8 BIM implementations for national projects).
- a new data model reengineering study in MoASP/BPN is still in progress, including recommendations for physical and legal boundary representations for 2D and 3D cadastre integration.

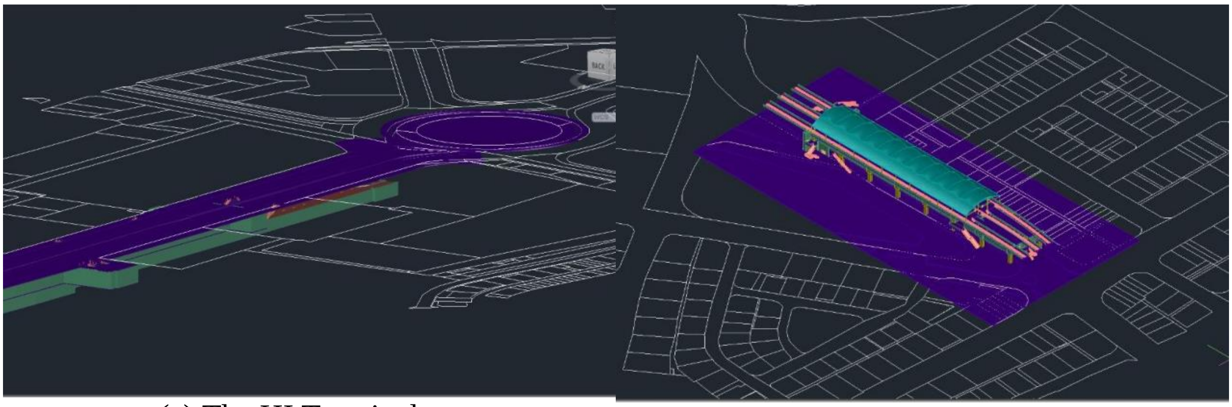
3. IMPLEMENTATION OF THE PILOT STUDY

3.1. Study Areas

The study took place in two newly built Mass Rapid Transportation (MRT) terminals at Hotel Indonesia Roundabout (HI) and Blok M Square (Blok M) in Jakarta, managed by PT. MRT, a municipally-owned corporation. These two MRT terminals are among The Phase-1 MRT

Jakarta development (MRT 2020) and was fully operational when the study was undertaken. The field validation was done in close cooperation with the PT. MRT as the operator and the MoASP/BPN. Figure 1 shows the 2D parcels surrounding both terminals. The 2D parcels where the terminals are built are land assets managed by the Special Capital Region of Jakarta Province.

In this pilot study, party identity and the underlying documents that applicants typically submit in the first place in case of 2D first registration are assumed to be clear and clean. The registration system from the MoASP/BPN will forward the user application to the surveying and mapping section to validate spatial objects. Here, the land surveyors from MoASP/BPN typically require a working map showing the situation of existing 2D parcels to ensure the location is correct and valid and the status of 3D parcels. The 2D parcels were extracted from the land registration map, collected from the Central Jakarta and the South Jakarta land offices. Meanwhile, the 3D constructions to be registered were obtained from PT. MRT in the form of ABD of floor plans and selected cross-sections.



(a) The HI Terminal (b) The Blok M terminal

Figure 1. the study areas for the pilot study of two MRT terminals in Jakarta (Atunggal et al. 2020)

3.2. Data Modelling

The 3D models of spaces to be registered were created based on the digital version of the as-built drawing (ABD) plan produced by PT. MRT in CAD format. The digitization was done from floor to floor to all physical rooms according to the ABD plan and the ABD vertical sections using Autodesk Revit 2019 (Figure 2). The 3D geometry of walls for each floor was created by digitizing corner points of walls seen from the ABD vertical sections. The 3D geometry of the floor and ceiling for each floor was created by digitizing the top view of the ABD plan. The height between top points (ceiling) and low points (floor) for each room was determined by extruding the 2D geometry of the floor based on the height derived from the cross-section view. The digitization and extrusion were done to all physical spaces in the building using the ”Wall”, ”Ceiling” and ”Floor” tools in Revit. After the building reconstruction by manual digitization was finished, the data conversion was done to export 3D models originally stored as Autodesk Revit 2019 data format (*.RVT) into 3D models of

IFC 2x3 format (Figure 3). The resulted component and attributes from this conversion follow the IFC format schema (buildingSMART International 2021) .

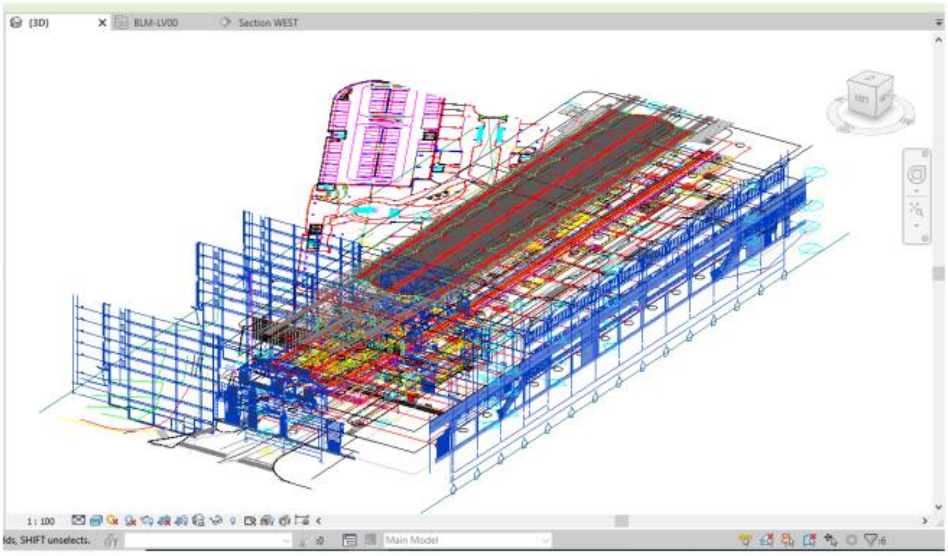


Figure 2. The ABD plans and sections of the building loaded into Revit and overlaid with the map of surrouding 2D parcels (top left) (Atunggal et al. 2020)

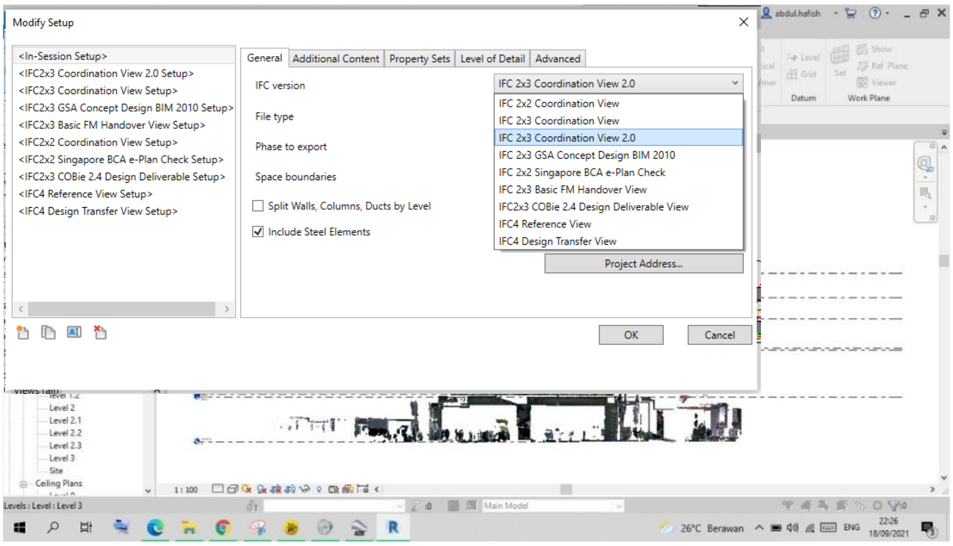


Figure 3. Options to convert the models into the IFC 2x3 format

It is worth mentioning that the IFC model of MRT terminals was not generated from 3D as-built survey as often found on BIM models. Instead, the IFC was developed from the buildings’ floor plan, which limited the modelling to some extent. Figure 4 depicts the results of BIM modelling in the IFC/BIM format.

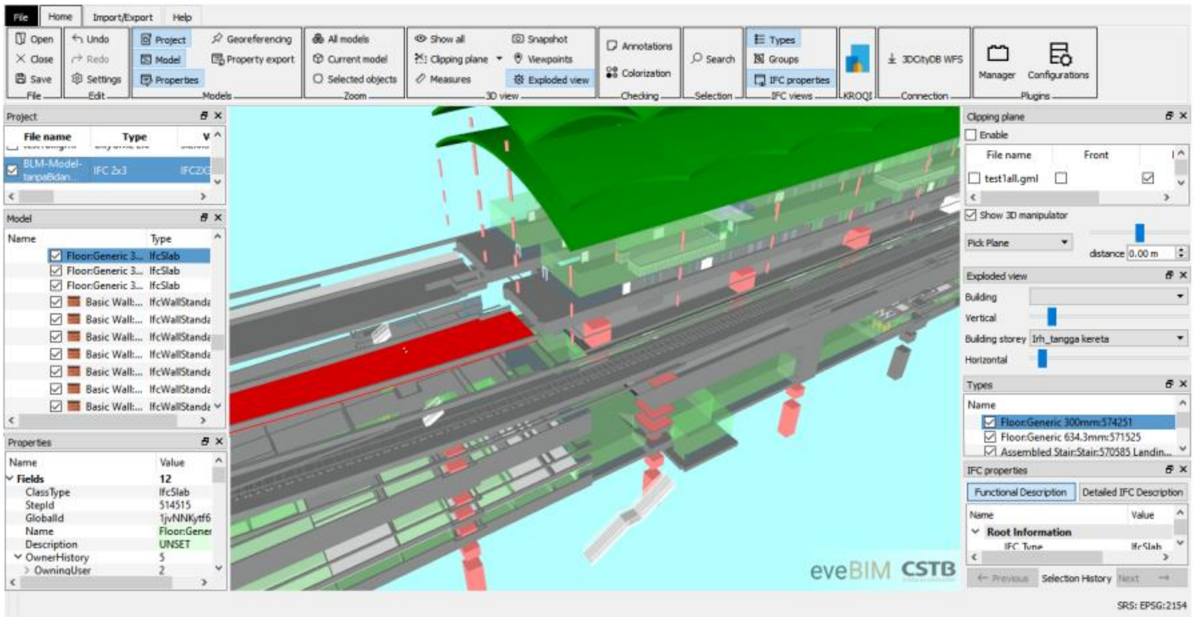


Figure 4. The resulted IFC/BIM of Blok M terminal in eveBIM (Atunggal et al. 2020)

3.3. 3D Validation

By 3D field validation, a surveyor performs the field validation survey to selected 3D units on the field. For this purpose, as also required for 2D parcel measurements, a surveyor must prepare the working map. The working map can be in the form of a 2D plan or 3D views of spatial units to be checked. In our pilot study, in addition to the parcel map, research members (acted as surveyors) used the digital version of the planimetric and cross-sections view of 3D models for conducting the field measurements. During the field validation, surveyors check the points and boundaries of 3D spaces to be registered (seen as 3D legal spaces). Using a distance meter, surveyors measure side distances and diagonal distances to gain areas and volumes (Figure 5).

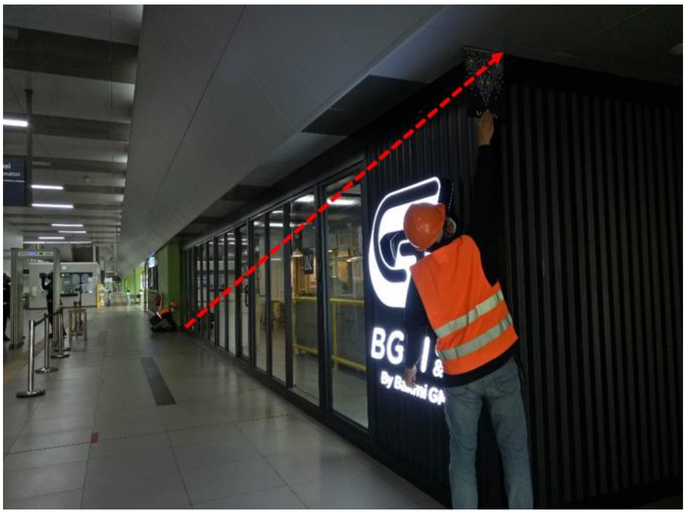


Figure 5. Measuring a diagonal distance of the wall of a unit (Atunggal et al. 2020)

After surveyors completed the survey, they assessed differences between survey and computation results. The factual areas and volumes will be compared against the areas and volumes computed from the 3D model. During field validation activities, any errors in the generated 3D model were documented to be edited straightaway on the field or later in the office. As it is required for first titling in 2D Cadastre, the results of the field validation should be documented into a measurement plan (known to surveyors as *Gambar Ukur*/GU). The digital measurement plan for 3D cadastre can be presented either in section by section or room by room, depending on the complexity of the building units (see e.g., Figure 6).

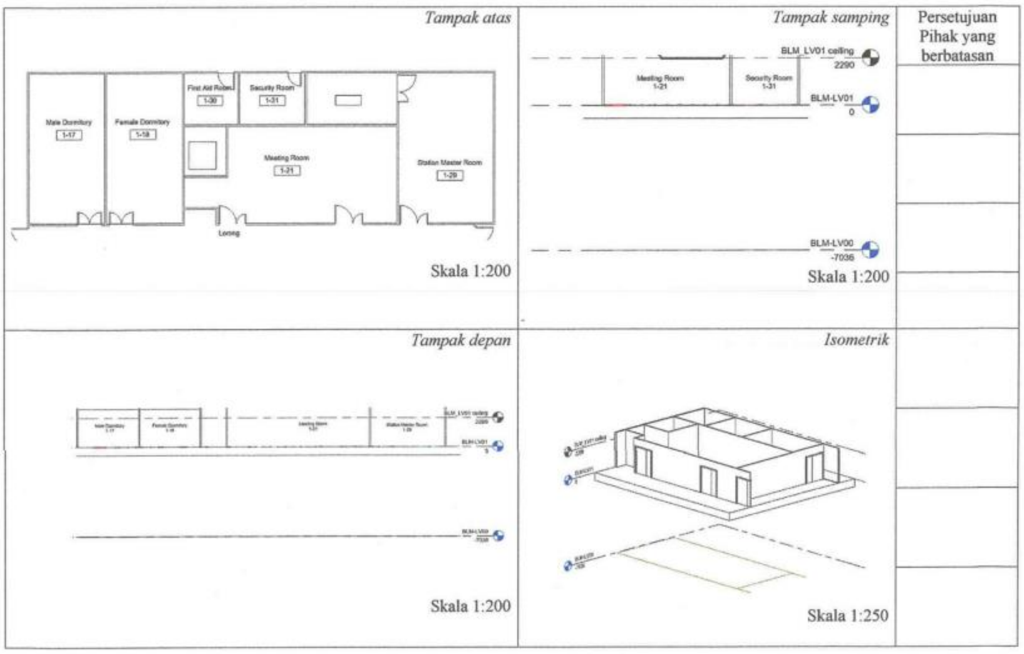


Figure 6. An example of field measurement plan (top-side-isometric-front view) and contradictory delimitation agreements, prepared for a field validation of 3D units.

In addition to representations of 3D units, the field measurement plan contains the identifiers of parties involved in 3D boundaries' delimitation. As implemented for the 2D boundary survey, person identifiers or fingerprints of boundary survey participants can be collected on the field using the surveyor mobile app like Survey Tanahku (Aditya et al. 2021).

3.4. 3D Visualization

To present the data into web visualizations, we converted 3D models of both Blok M and HI MRT terminals from IFC 2x3 format into CityGML using eveBIM. The conversion was done by selecting IfcSpace of the resulted IFC data model. The version that we used in this pilot study was CityGML version 2.0. At the time we finished the study, the available version for CityGML was CityGML 2.0. In addition to the eveBIM, some alternative software can convert IFC into CityGML format data, including QGIS, ArcGIS, Safe software FME, Autodesk Infraworks and so forth (Noardo et al. 2021). To visualize the 3D legal spaces, this study used eveBIM and Sketchup City Editor to produce CityGML building type with multisurface representations by selecting each wall as data input for data conversion from IFC to CityGML. Sketchup City Editor can be used to determine specific surfaces in the model for data conversion (e.g., selecting IFC surfaces to be converted as room classes of CityGML).

After the data was converted, the CityGML 2.0 format validation was executed to ensure the validity of the system coordinates, the geometry content and the semantic information of the converted geometry. For this study, the authors utilize open-source software (i.e., CityGML Tools and val3dity) to validate the files resulted from the conversion (Figure 7). We found more than 600 errors after the conversion. Common errors were on the coordinate system definition, ID and semantic mismatch of the MRT 3D models. To exemplify, in our case, the CityGML converter did not recognize TM-3o, the coordinate system being used for the Indonesian cadastral mapping system (i.e. the study area is at 48.2 zone of TM-3º).

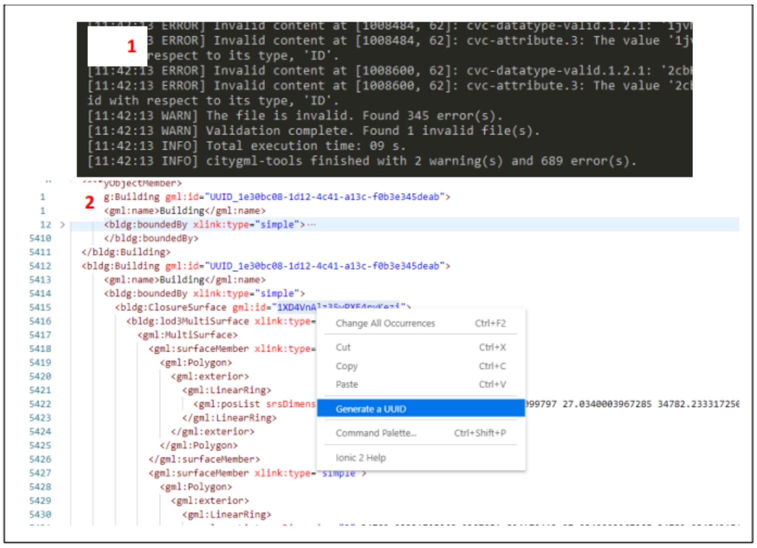


Figure 7. The CityGML format validation with CityGML Tools (1) errors found (2) the editing process to fix errors (Atunggal et al. 2020)

In fact, it is also possible to develop a web-based visualization for the IFC model (e.g., using (Viegas 2021)). However, the authors are currently investigating the pipelines for 3D Tiles as format for visualization, which provides many benefits when dealing with large datasets. 3D Tiles could be obtained by converting a 3D data format such as CityGML, for example, through platforms such as Cesium Ion (Cesium 2021) as per the previous study conducted by the authors (Aditya et al. 2020). The authors are aware that similar options are also available for the IFC format, but this investigation is out of the scope of this pilot study. The results of data modelling and field validation were visualized as a tileset on the Teria Map. For this option, the 3D tiles from CityGML were prepared as binary GLTF (.glb) using Cesium Ion.

4. RESULTS

The reconstruction of 3D models of two MRT terminals and the preparation of the working map for field validation could be finished in a month. If the team received ABD plans and sections in the CAD files that were directly generated from 3D as-built survey, the development of IFC 3D models would have been faster. Additional field photos and videos were undertaken to help accelerate the reconstruction of floors, walls, ceilings and room interiors using ABD plans and sections (Figure 7). The results of 3D models were integrated with existing 2D parcels, which were then exported and taken to the field to validate distances, areas and volumes of individual units.

The field check were done to 35 units of rooms in the HI station and 48 units of rooms in the Blok M station. These units have different types of uses, e.g. storage and auxillary rooms, service rooms, commercial rooms, office rooms and pubic spaces. The room areas were ranging from 4 m^2 to 160 m^2 with the volumes from 14 m^3 to 999 m^3. Many of these rooms are typical rooms with possible 3D variations, from simple to complicated 3D variations. During the field check, we sampled both simple and complicated units. For example, typical commercial rooms had floor areas of 23 m^2 and 33 m^2.Both total stations and distance meter were used to verify the 3D models (thus to verify the actual spaces typically applied for 3D rights as well). From the field check to the total of 83 units in two terminal stations, it was found that the distortion of 3D model areas and volumes in average was no more than 2% from the field check. There were eight (4) rooms exceeded 1 m^2 difference in floorareas, 5 in HI terminal and 3 in Blok M terminal. In general, the generated 3D models from ABD plans and sections were accurate, however some 3D units were not correctly represented as the height determination from the floor to ceiling in some rooms were wrong. This can be the result either the ABD section is incomplete or the were some changes after the ABD creation.

All the changes and distortions on the field were marked and documented in the field measuremnet plan for further processing. This can be important notes for further processing of 3D spaces to be registered. After the field validation was completed, the physical data, the ownership boundary and the attrbutes of owneship can be entered into the registration system.

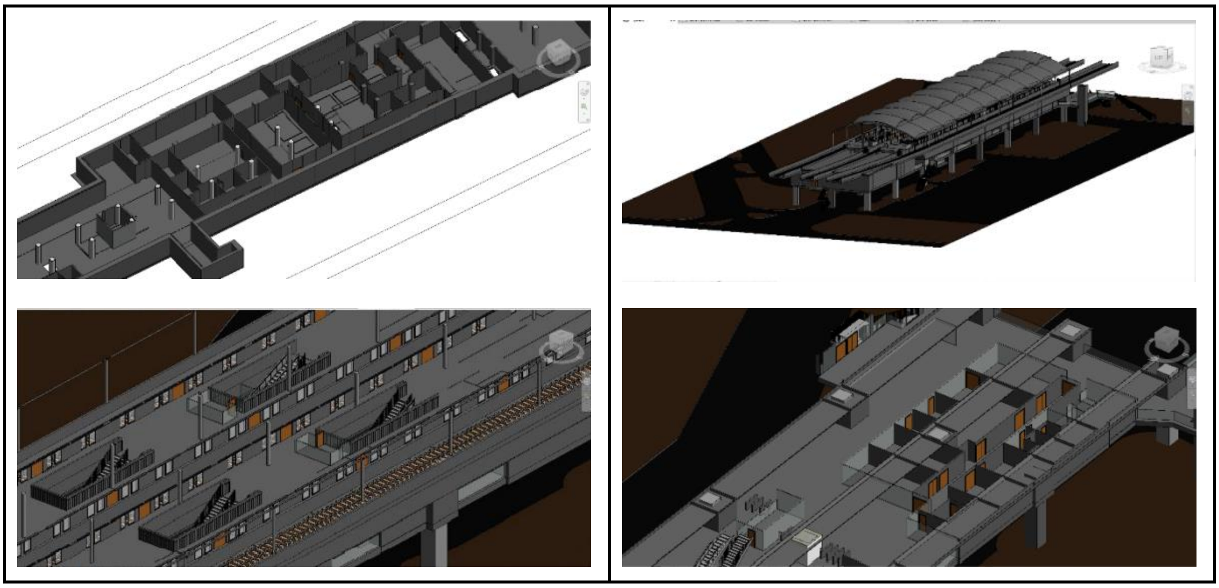


Figure 8. Reconstruction of 3D Models from As-Built Drawing (ABD) data of the MRT Stations of HI Station (left) and Blok M Station (right) (Atunggal et al. 2020).

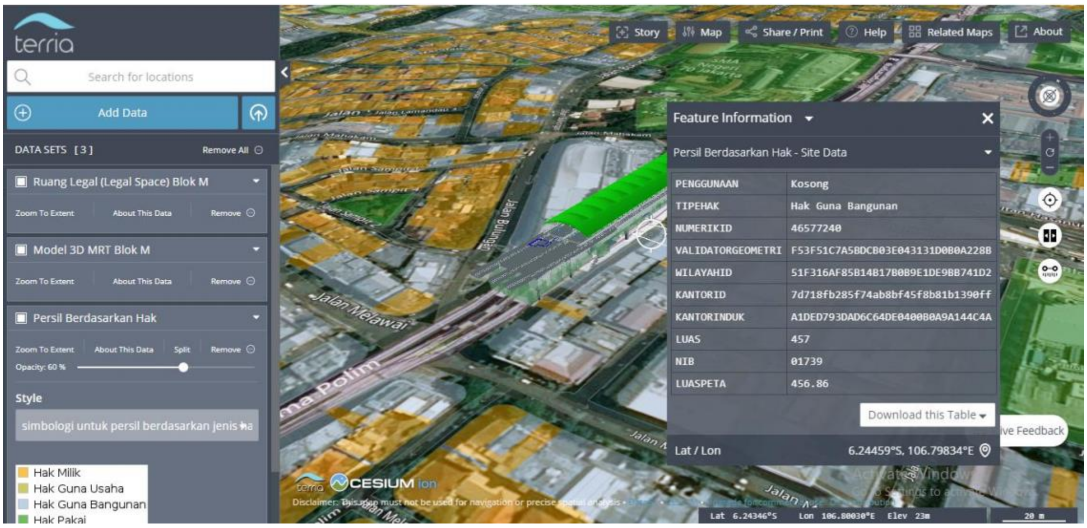


Figure 9. A visualization platform for displaying field validation; three layers can be activated (left panel from top to below): physical 3D model of Blok M station, legal spaces of Blok M and 2D parcels with rights

In this pilot study, we only focused to present the spatial data of physical and legal of 3D units. The visualization of the Blok M terminal station was done using TeriaJS as the visualization platform and Cesium to provide 3D Tiles to Teria map. There are three layers to display in Teria map: the physical 3D model, the legal space (3D parcel) and the 2D parcel (Figure 9). As discussed earlier in Section 2, the legal spaces were gained by previous editing which comprises of selecting walls, floors and ceilings for each unit as IFCSpace, which subsequently converted to CityGML BuildingRoom using EveBIM. The legal spaces can be activated to support the visual check of 3D units (Figure 10). In the pilot study, the HI terminal was not presented into Teria map.

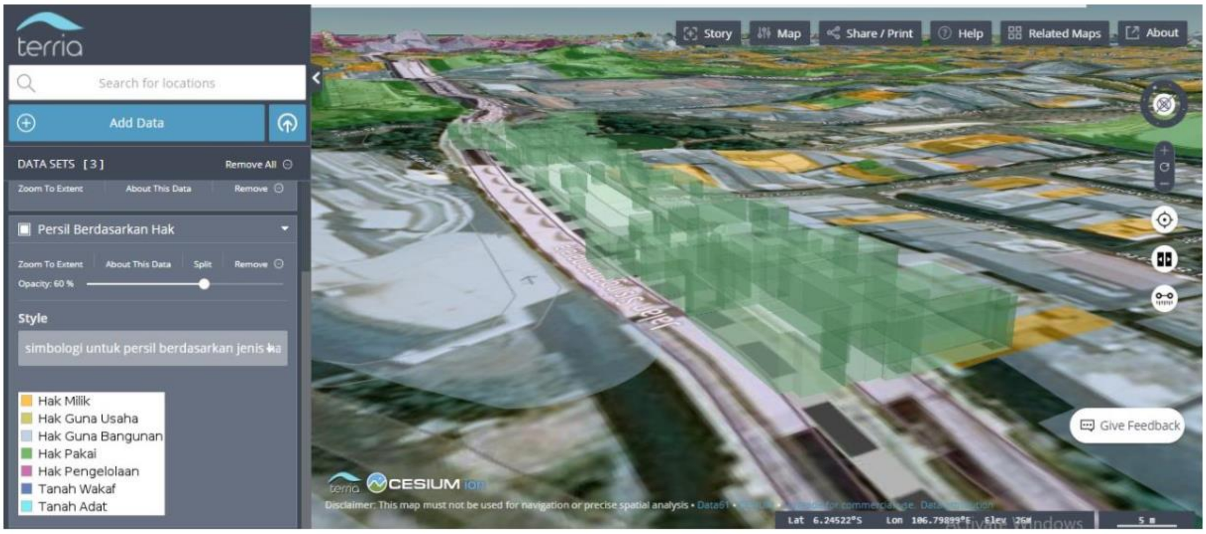


Figure 10. Legal spaces of MRT terminal at Blok M and its surrounding 2D parcels with rights (Atunggal et al. 2020)

5. DISCUSSION

According to the new regulation, once the 3D boundary verification (including height conformance to the spatial plan) is finished, the registration of 3D rights can be processed. Prerequisites for the registration include construction permits and spatial plan approval (in case the units are above or below specific heights regulated by the spatial plans), which the developer operator should provide. The authors realized that more investigations are needed on some issues (e.g., conformance to 3D spatial plans) regarding the technical and legal implementation of 3D cadastre in Indonesia.

The ownership of 3D units of terminals will be either with a right to build (HGB) or a right to use (HP), depending on the proposed use activities by the operator and the tenants. During the pilot study, the conceptual workflow and the systems (e.g., handling the typical operator or developr construction data for efficient processing in 3D registration, the field measurement plan and documentation) were developed. The study results have been used as one of core materials to develop guidelines for implementing survey and mapping activities for the 3D cadastre initial registration by the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency (MoASP/BPN) to be published at the end of 2021.

The choice to use the IFC format for 3D modelling seems appropriate considering the popularity of the format for developers/operators and the mandate by the ministry that regulates buildings and infrastructures (i.e., Ministry of Public Works). The new building models are directed to support the level 5 to level of BIM implementations as mandated by the Government regulation number 16/2021. Previously, in 2018, this ministry has required that developers of government or state buildings utilize BIM technology in its planning, construction and management. This study presented the 3D physical and legal spaces using 3D Tiles created from CityGML. This approach was chosen to follow a similar workflow implemented for registering 2D parcels in land offices, i.e. surveying and mapping in CAD while boundaries and their corresponding rights in geometries of simple features. The study has not delved into the comparison between 3D Tiles from CityGML and 3D Tiles from IFC format in terms of efficiency and effectiveness, accustomed to existing cadastral databases of the country. An alternative for creating 3D tiles from the IFC format has also been proposed and tested (Chen et al. 2018; Olfat et al. 2021). For this reason, the following research should address this issue to find the answer on the compatibility of both options to be integrated with the national cadastral databases system, which currently is only focusing on 2D parcels.

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Towards 3D-Real Property Cadastre in Slovenia

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Key words: Slovenia, Land cadastre, Building cadastre, Real property cadastre, floorplan, 3D building models

SUMMARY

The article presents the Slovenian land administration system focusing on the cadastral registration of buildings. We present the current structure of the land administration system and the latest upgrades introduced in 2018. In addition, we outline the main changes in the near future as a result of the new legislation adopted in April 2021 that will come into force in April 2022. The ongoing research and development activities led by the Slovenian SMA (GURS) are further presented. In light of recent research, we study the possibilities for long-term developments of the Slovenian cadastral system towards a fully functional 3D cadastral system. We present two case studies related to the registration of buildings. The buildings were recently registered according to the official registration procedures currently in force. We performed additional measurements and 3D modelling required to obtain a 3D representation of the registered real property units. Once we had the 3D real property units available, we investigated the possibilities of storing the data in a spatial database. The current official registration procedure is compared with the presented procedure for obtaining 3D real property units. We conclude that the proposed approach still needs to be optimised in terms of data processing efficiency for operational introduction in the Slovenian land administration system, where each new building needs to be registered. However, it represents a viable option to enrich the registration documentation for complex RRR situations, where clear 3D spatial delineation of RRRs is needed.

Towards 3D-Real Property Cadastre in Slovenia

Jernej TEKAVEC, Ema POGORELČNIK, Anja KRŽAN and Anka LISEC, Slovenia

1. INTRODUCTION

Nowadays, many 2D land administration systems face the challenge of limited ability to capture and register complex spatial situations in terms of rights, restrictions and responsibilities (RRR). 3D land administration attempts to address these issues by introducing 3D real property units. The term 3D land administration is very broad. From a technical point of view, there are numerous technical solutions and implementation options, which in general have already been pointed out by Stoter (2004). There is also no single organisational and legal solution, as each system and legislation have its own particularities.

Despite the above-mentioned differences, it is very important to develop solutions for 3D land administration that are as universal as possible. Standards play an important role in this regard, especially the ISO standard in the field of land administration LADM (ISO, 2012), which is currently being revised and will extend its support for 3D land administration. However, LADM is a conceptual standard that does not provide exact technical implementation (van Oosterom and Lemmen, 2015). Countries, therefore, need to find solutions that fit their systems and enable a seamless transition to the newly developed solutions. Many countries are already considering the development of 3D land administration (van Oosterom 2018, van Oosterom et al., 2020). While many countries have some form of condominium or strata title in their legislation, independent 3D real property units are only introduced in some land administration systems (e.g. Sweden, Australia) (Paulsson, 2007; Shojaei, 2018). The Dutch Cadaster, for example, has already implemented 3D technical solutions into its system (Stoter et al., 2017). In Slovenia, the legal system allows for the registration of strata titles, but not as independent 3D real property units. The latest update of the system in 2018 introduced additional height attributes and digital floor plans, but there is neither a legal nor a technical solution for the registration of 3D real property geometries.

At this point, it is important to highlight that Slovenia operates two parallel but linked cadastral databases, namely Land cadastre and Building cadastre. In 2000, when the *Building Cadastre* was introduced by law, Pogorelčnik and Korošec (2001) investigated the potential for using 3D geospatial data. Interesting research was provided by Drobež et al. (2017), who investigated the possibilities of developing the Slovenian land administration system towards the 3D-enabled system, focusing on additional 3D modelling of the external geometry of buildings using UAV photogrammetry. The recent research on 3D cadastre, also related to the Slovenian legal framework, was done by Tekavec et al. (2020).

In the following chapters, the Slovenian land administration system is presented together with the recent upgrades, the upcoming reform and ongoing research. This is followed by the two case studies, in which we use real-world examples to investigate the possibilities for future upgrades of the system towards 3D land administration. In this study, we follow the concept of detailed modelling of indoor building structure that was proposed by Tekavec et al. (2020).

2. SLOVENIAN LAND ADMINISTRATION

The Slovenian land administration system is based on a dual registration system consisting of a cadastral and a land registry part. The cadastral subsystem, operated by the Surveying and Mapping Authority (SMA), consists of the *Land cadastre* and *Building cadastre*. While the *Land cadastre* dates back to the *Franciscan cadastre* of the former Austrian Empire in the beginning of the 19th century, the *Building cadastre* is a relatively new system introduced after 2000 and aims at providing detailed data on buildings and parts of buildings needed for the registration of ownership and other rights on parts of buildings in Land registry. The Land registry, which is linked to the cadastral system, is operated by the Court and also has its roots in the 19th century. The cadastral system with the Land cadastre and Building cadastre, provides data on the spatial extent and physical characteristics of real property units, while the Land registry manages the data on RRR (Figure 1). As for the compliancy of the Slovenian land administration system with the LADM standard, no study has yet focused solely on this. The system complies with the core concept LADM to link RRRs, parties and spatial units.

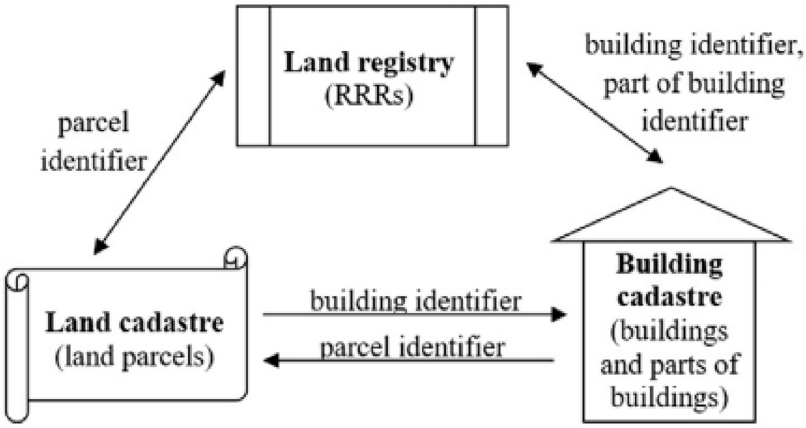

Figure 1: Structure of Slovenian land administration system (Drobež et al., 2017)

2.1 Building cadastre

The Slovenian *Building cadastre*, introduced in 2000, is special compared to other cadastral solutions in the countries in the region. It provides a technical basis for the registration of stratified rights (strata titles) to buildings in the Land registry. Before the introduction of the *Building cadastre*, strata title was registered in the Land registry, where spatial data (sketches of dwellings) was part of the registration documents. A building can be registered in the *Building cadastre* if it can be entered by a person can, if it is designed for housing (permanent or temporary), business activities or any other activities, and it cannot be moved without damaging its substance. A part of a building, i.e. a real property unit, may represent an apartment, office or other parts of a building that can be considered an independent subject on the real estate market.

In the first period of its implementation (2000–2006), photogrammetric acquisition of all buildings was performed, and various attribute data were collected. During this period, the first detailed building entries were made in the *Building cadastre* as part of the creation of the strata titles. Nowadays, the *Building cadastre* contains detailed data on the buildings built after 2006 or on older buildings for which strata titles have been created. All other buildings are registered using basic attributes and geometries, acquired during the first implementation period (2000–2006), and attributes from the mass inventory of real properties. In Slovenia, the strata title is a type of 3D real property where real property units are divided horizontally and vertically. Therefore, the Building cadastre should provide their unambiguous definition with the help of unified documentation containing a georeferenced footprint, maximum building outline, floor plans, and detailed data about the physical characteristics of the building and its parts (Drobež, 2017). Unfortunately, only the georeferenced footprint and the outline of the maximum building extent were recorded in digital vector format at the SMA, while the other data was saved in the form of a scanned document.

2.1.1 Recent changes

Based on the experience of more than 10 years of operational use, the *Building cadastre* was partly modified in 2018. The changes concerned the classification of the use of building parts, digital data submission and geometric data requirements. Regarding the latter, floor plans are now georeferenced and submitted in digital format (GeoJSON). The floor plans contain the outlines of the real property units for each floor. Additionally, the height attributes for each floor must also be submitted to SMA and are stored in the cadastral database. The main reasons for the introduction of vector floor plans were:

- improved quality control of the submitted data,
- enabling 3D visualisation (Figure 2), which, which, as discussed in Tekavec and Lisec (2020), provides a clearer representation of real property units (2020),
- facilitating changes in the delineation of real property units.

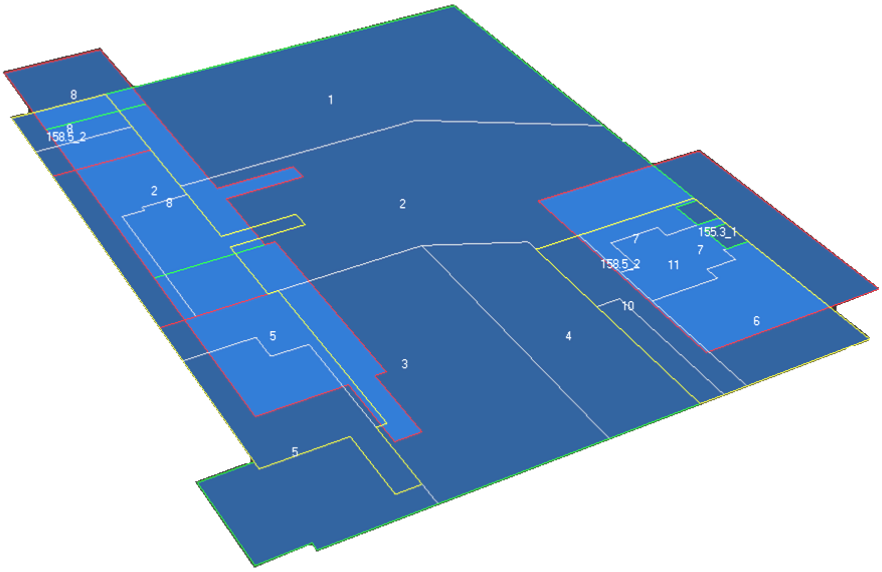

Figure 2: 3D view of GeoJSON floorplans

The changes also affected the authoritative status of the collected data. Many attributes relating to a building or part of a building that were provided by an owner (who also guaranteed for the correctness of the data) prior to 2018 are now verified and provided by the licensed surveyor.

2.1.2 Building registration process and documentation

Under current legislation, the building must be registered in the *Building cadastre* using the detailed documentation (i) if the building is newly constructed or (ii) if the strata title is to be created for an older building. The detailed documentation is prepared by a licenced land surveyor, who is employed in private practice at the request of the owner. The licenced surveyor shall perform the required on-site surveys of the building:

- outline of the maximum extent of the building,
- outline of the intersection of the building with the ground surface,
- minimum and maximum height of the building,
- elevation of the entrance,
- heights of all floors,
- areas of all spaces inside the building,
- outlines of all parts of the building on each floor.

All measurements are performed in the official Slovenian (vertical and horizontal) coordinate system. The documentation for registration consists of several structured forms, an XML file with attributes for database import, georeferenced photos of the building, and floor plans in a GeoJSON file. All documentation prepared by the licenced surveyor is submitted to the Slovenian SMA, where the official administrative registration procedure is initiated. The documentation is then checked and verified. If there are no errors and the legal appeal period has expired (15 days) after the final decision, the new data is transferred to the official database and can be viewed in the public data viewer.

2.2 The upcoming reform of land administration system

In April 2021, the Slovenian government adopted the new legislation (Real Property cadastre Act), which provides the legal basis for the establishment of a new holistic *Real property cadastre*. The act will come into force in April 2022. It is planned to establish a unified cadastral information system that will combine data from the *Land cadastre* and the *Building cadastre*, so that data on parcels, buildings and parts of buildings will be stored and maintained together in one information system. This will enable more efficient management of cadastral data.

As well as bringing together the now separate information systems, the new legislation will also bring improvements to registration processes and documentation. All documentation will be digital, with an emphasis on structured digital data (fewer scanned documents). This will allow more checks and validation procedures to be carried out automatically when the licenced surveyor uploads the registration documentation to the cadastral information system. This will reduce both the need for manual validation of documents and the possibility of errors passing through the registration processes.

In addition, the new legislation allows for the registration of easement and building rights geometries in the cadastral information system. Currently, sketches of the spatial extent of these rights could only be added as appendices to the documents in the Land registry. However, the new legislation will not change the legal definition of 3D real property or the legal definition of easements and building rights. This means that strata title will remain the only option to delineate real property vertically. The same applies to easements and building rights. Here, the new legislation in the cadastral domain, together with the new IT solutions will make it possible to model and include the geometric and attribute data on easements and building rights in the cadastral information system.

For buildings, new geometric properties of buildings will be added to further improve their spatial representation. Outlines of the maximum above-ground extent and maximum underground extent will be added in addition to the currently required outlines of maximum extent and intersection of the building with the ground.

2.3 Research and development activities

The introduction of digital floor plans and additional height attributes in 2018 enables 3D visualisation of the registered real property units. Slovenian SMA has developed a 3D viewer for both floor plans and the external geometry of buildings. Both viewers are already operationally implemented in the internal information system. The main advantage of the 3D viewer for floor plans is the link to the attribute data, which enables combined identification and clear representation of building parts for each owner (Figure 3). The 3D viewer of the external geometry provides a better spatial representation of the data and also helps to identify errors, among others, in height attributes (Figure 4).

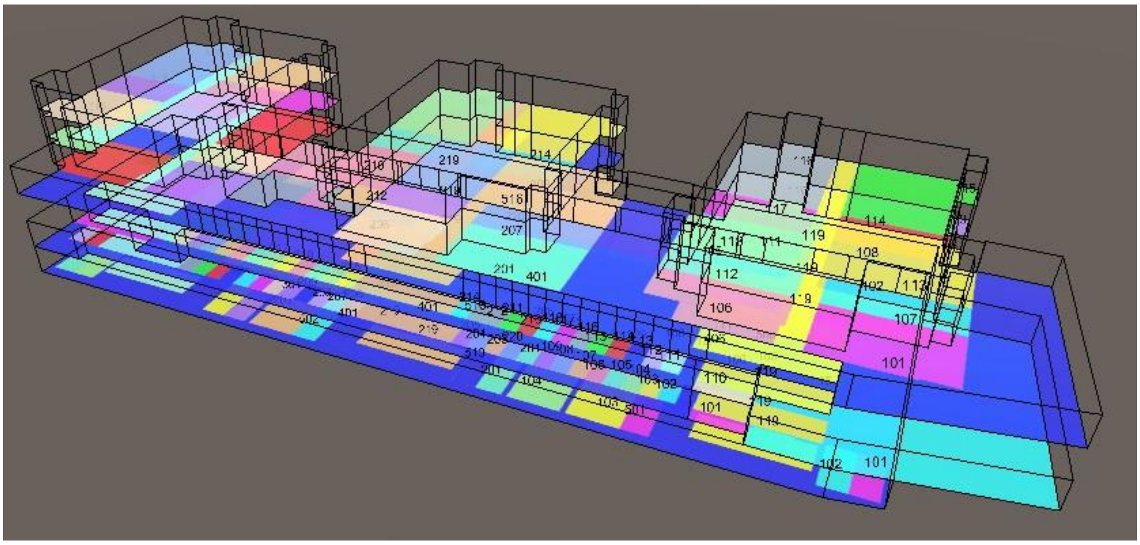

Figure 3: 3D view of GeoJSON floorplans

Prior to 2018, floor plans were submitted to SMA in the raster format, with no height attribute for each floor. The Slovenian SMA launched the pilot project to investigate the possibilities of vectorising these raster floor plans, obtained from cadastral documents. Altogether, 574 buildings were selected for the pilot project.

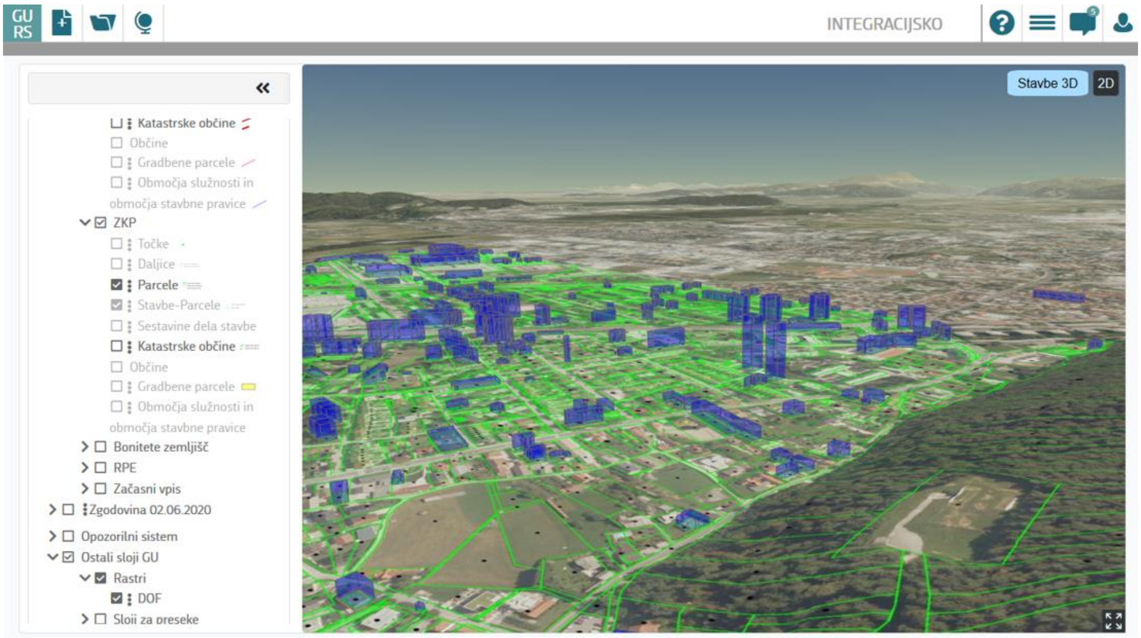

Figure 4: 3D viewer for external building geometry in the Slovenian cadastre

The criteria for the selection aimed to cover all possible variants of the stored data and assure the spatial distribution of the selected buildings over the entire Slovenian territory. As a result of the pilot project, the vector floor plans and height attributes for all buildings were acquired. Several problems were identified during the project:

- misplacement (swapped positions) of building part numbers in the floor plans,
- the shape of the floor plan not matching the shape of the external building outline,
- inconsistency between the attribute data and the graphical representation of the building part (mainly inconsistency between the calculated area from the geometry and the attribute for the building part area)
- missing building part numbers,
- unclear subsequent changes to the building parts,
- missing floor plans,
- illegible floor plans.

All these problems were considered and solved to the best of our abilities. That is, the outcome of the project was also comprehensive quality control and processing, e.g. editing, of the registered data. In the following EU funding scheme (2021-2027), it is planned to extend the pilot project to all buildings registered in the *Building cadastre* before 2018, with the exception of buildings that have only one building part. There are still 155,282 buildings with floor plans, which are not yet vectorised.

In 2021 the Slovenian SMA has published an open call for a 2-year application-oriented research project entitled *GeoBIM and national surveying data*. The project aims to promote research on the adaptation of information systems, legislation, data structures and processes to support BIM data at the SMA. The focus of the project is on the utilisation of BIM data for the registration of buildings and public infrastructure. As the project is relatively short and has a small budget, its results are expected to provide a basis for future projects, which are already planned as the continuation of this project.

3. POSSIBILITIES FOR UPGRADE TO 3D CADASTRE

Our aim was to investigate the potential for upgrading the Slovenian cadastre to a 3D cadastral system for the buildings that were recently registered in the *Building cadastre* (and *Land registry*) using the current official procedure. The concept for the 3D cadastre (Tekavec et al., 2020) essentially uses the 3D modelled indoor spaces, each of which is associated with a corresponding real property unit. In addition, we performed in-situ measurements and incorporated the data into the 3D modelling process to obtain a detailed 3D model of the building. We also evaluated the current capabilities of 3D technology to store the case study data in a database.

3.1 Case study data

The first selected building is a typical Slovenian single-family house (Figure 5), while the second is a more complex commercial and shopping centre that is divided into several real property units (Figure 6). In both buildings, we additionally acquired data on the thickness of the walls and ceilings, the locations and dimensions of the passages. In the more complex spaces (sub-roof spaces, stairs), we measured additional heights to allow for proper 3D modelling of the spaces.

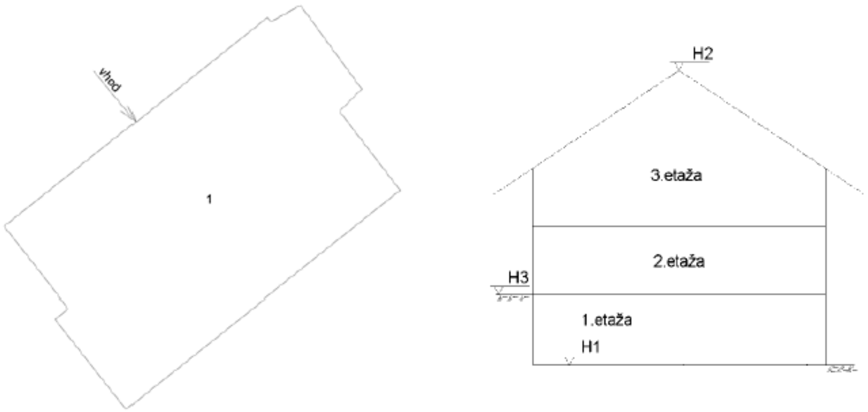

Figure 5: Floor plan and cross-section from the official documentation of the first building

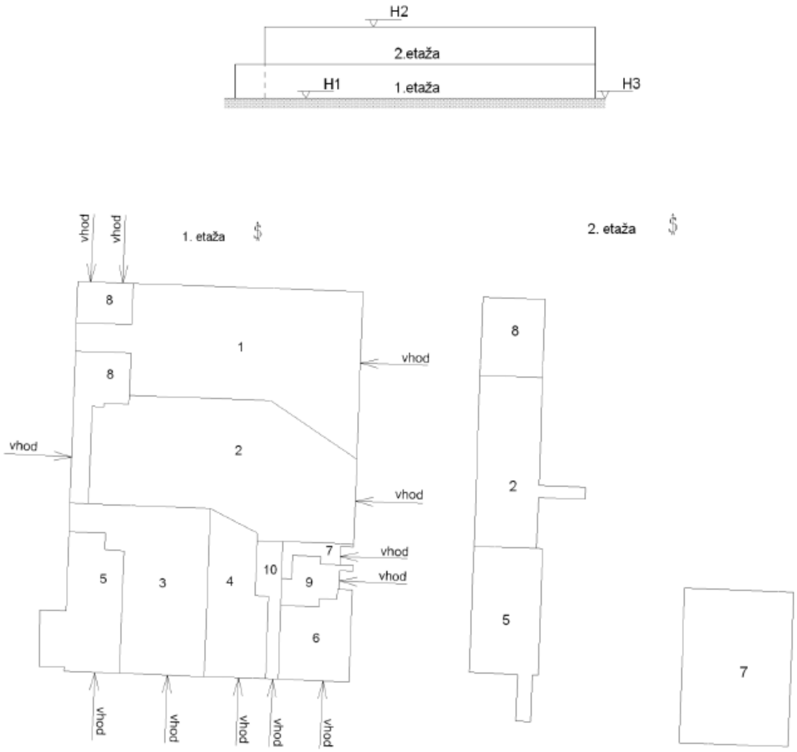

Figure 6: Floor plan and cross-section from the official documentation of the second building

3.2 3D modelling

We used Trimble SketchUp software for 3D modelling of indoor spaces. Each space was modelled as a solid component (Figure 7). The passages between spaces were modelled with a touch relationship. During modelling, we can also assign attributes to each indoor space. The most important is the real property unit to which the space corresponds. SketchUp does not allow adding multiple attributes to the component, so additional attributes can be added using the delimiter character. An attribute can be later parsed into multiple attributes in the FME.

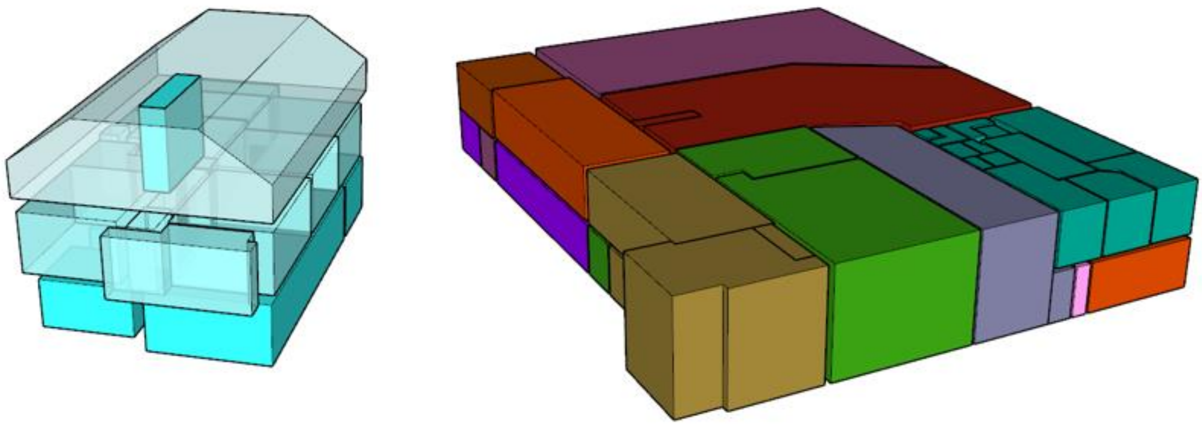

Figure 7: 3D models of indoor spaces for the first (left) and the second building (right)

3.3 DBMS storage

The 3D model has to be pre-processed to be suitable for DBMS storage. We used Safe Software FME to transform the geometries and prepare the attributes, and a PostgreSQL database for data storage. The geometries are imported as one feature, so we first needed to remove the aggregation with the *Deaggregator* transformer. The attributes were extracted using the *GeometryPropertyExtractor* transformer. Then the individual attributes contained in that attribute and separated by delimiter were extracted using the *AttributeSplitter* and *AttributeManager* transformers. The geometries were transformed into solids using the *SolidBuilder* transformer. If errors were made in modelling solid geometries in SketchUp, the *SolidBuilder* transformer identifies these geometries and rejects them. The geometries and attributes are inserted into the PostgreSQL database using the PostGIS writer. Such data can be linked with current data in the official Building cadastre database.

4. DISCUSSION AND CONCLUSIONS

The current ongoing modernisation of the Slovenian land administration system will be completed in April 2022. There are still some difficulties in the implementation of the information system, as the system is to be integrated into the common digital environment of the Ministry Public Administration. Difficulties are also expected in the timely training of both private sector surveyors and SMA staff to properly use the new system. As far as the introduction of 3D geometry into the Slovenian cadastral system is concerned, some steps have already been taken and are presented in this paper. For georeferenced 3D building models, the vector floor plans introduced in 2018 have to be georeferenced to represent the actual position of a real property unit in the national reference geodetic system. For a building model, as suggested in this research, e.g., indoor spaces as the core elements representing 3D real property units, measurements inside the building have to be performed in the official Slovenian coordinate system. Since a line is delineating two real property units, there is also a well-known dilemma regarding the position of the line in relation to the walls.

We have found in the case studies that the amount of additional data and work required to obtain correctly modelled 3D real property units cannot currently be introduced for all buildings. The biggest problem is the acquisition and combination of additional data and 3D modelling. Usually the missing measurements/data in the current building registration process are found when performing 3D modelling. Also, 3D modelling is much more complex than creating a 2D floor plan and takes more time. However, the proposed approach could be used to solve complex RRR situation, where 2D floor plans a cannot clearly represent the situation clearly. Last but not least, new technologies (e.g. SLAM scanners) will become more widespread and will allow more efficient 3D spatial data acquisition and modelling for indoor environment. This will reduce the additional costs of the processes, and consequentially make the operational implementation of 3D technologies, as presented in our case studies, more feasible.

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BIOGRAPHICAL NOTES

Jernej Tekavec graduated from the University of Ljubljana, Faculty of Civil and Geodetic Engineering (UL FGG) in the field of Geodesy. Currently, he is employed as assistant researcher at the Chair of Geo-informatics and Real Estate Cadastres, UL FGG, and is a PhD candidate at the same faculty. His research is focused on real estate cadastres, 3D city modelling, and 3D spatial analyses. He is actively involved in current national and international projects and activities of the chair.

Ema Pogorelčnik Graduated from the University of Ljubljana, Faculty of Civil and Geodetic Engineering. She continued the postgraduate studies at the Faculty of Law in Ljubljana. Employed at the Surveying and Mapping Authority of the Republic of Slovenia (GURS), currently as the head of the sector for the building cadastre. She managed all projects in the field of building cadastre in the Republic of Slovenia. She is currently leading a project of information modernisation of real estate registers.

Anja Kržan Studied and recently received a Master's degree from the University of Ljubljana, Faculty of Civil and Geodetic Engineering. Her work was related to 3D modelling of cadastral data with the focus on buildings.

Anka Lisec Since completing her PhD in 2007 Anka Lisec has been employed at the University of Ljubljana, Faculty of Civil and Geodetic Engineering (UL FGG), currently as Associate Professor and researcher. She has been the head of the Chair of Geoinformation and Real Estate Cadastres since 2016. Beside her research work within national and international projects in the fields of geoinformatics and land administration, she is currently actively involved in the preparation of new cadastral legislation as well as in developing strategic guidelines for the national mapping and surveying service.

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LADM based taxation model in Montenegro:
Using BIM in taxation process

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Key words: taxation, LADM, BIM

SUMMARY

Real properties plays an integral role in the economy of every country. Considering this, property valuation and taxation processes are of great importance. Revenues from property taxes can be allocated to other areas thus improving the quality of life for all citizens. Since the valuation and taxation are related to properties themselves, the good cooperation between real estate cadastre and tax administration is necessary. Real estate cadastre submits current data on real properties and rights to them to the tax administration. These data and additional data on properties and their locations are then used to form a tax for citizens to pay.

In the paper, an analysis of the legal regulations and laws, as well as the way of functioning of the current information system for the tax administration in Montenegro is performed in order to develop LADM based tax administration model. Developed model is an extension of previously developed LADM country profile for Montenegro. Based on the new model, an information system for tax administration is developed and all relevant procedures prescribed by the 'Law on property tax' (2019) and 'Regulation on detailed criteria and methodology for determination of real property market values' (2011), are implemented. The most important procedures are how to define the value of the property or how to calculate appropriate taxes. The basic criteria for determining the value of real properties are average market price per m^2 of real property, purpose of the real property, size of real property, the place where the real property is located, quality of real property and other elements that may have an impact on the market value of real property. Every municipality defines the coefficients that correct the main formula for tax calculation.

The new buildings have a BIM model created in a design phase which is a part of the documentation for issuing a building permit. Such BIM model can be used for at least two other purposes in addition to basic use. The first one is to serve as an input for 3D cadastre. Another reason is the use of BIM to calculate taxes. Data such as the area of the building and the quality of the building (building construction, building facade, windows, number of rooms, installations, number of bathrooms, etc.) can be directly loaded into database from the appropriate BIM model. Such solution can be resolved by expanding the regulative and the law to allow the use of this data. In the paper, the authors presented the mapping of entities from the BIM model to the appropriate code lists of the building quality and other attributes defined by the national regulation which are used to calculate tax. In this way, the tax calculation process would be accelerated and automated because the data from the project documentation would not be entered manually but would be taken over from BIM.

LADM based taxation model in Montenegro: Using BIM in taxation process

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Key words: taxation, LADM, BIM

1. INTRODUCTION

Real properties play an integral role in the economy of every country. Considering the factors like size and location of the property, year of construction, quality of the property, purpose of the property, valuation and taxation processes are of great importance. Revenues from property taxes can be allocated to health care, environmental protection, energy efficiency, agriculture, water management, reforestation, paving, construction of kindergartens and preschools, education, sport and recreation and thus improving the quality of life for all citizens. Since the valuation and taxation are related to properties themselves, the good cooperation between real estate cadastre and tax administration is necessary. Real estate cadastre submits current data on real properties and rights to them to the tax administration. These data and additional data on properties and their locations are then used to form a tax for citizens to pay.

In this paper, an analysis of the legal regulations and laws, as well as the way of functioning of the tax administration procedure in Montenegro is performed in order to develop LADM based tax administration model. Based on the previously developed LADM country profile for Montenegro (Radulović et al., 2015), the LADM Valuation Information Model for Montenegro is developed and presented.

In the paper, the authors also presented the potential mapping of entities from the BIM model to the appropriate code lists of the building quality and other attributes defined by the national regulation which are used to calculate tax. In this way, the tax calculation process would be accelerated and automated because the data from the project documentation would not be entered manually, but would be taken over from BIM. Since the amount of data for the building quality is quite large, it is often not entered in practice (in order to speed up the procedure or if the data does not exist in documentation), but a predefined building quality coefficient is entered for each building. The source of such data is usually not the result of standardized procedures and is often left to the discretion of the citizen to report quality elements without the need for proof. Often these data are of questionable quality. This leads to a miscalculated tax, i.e. the same tax is paid for buildings of the same size that are luxuriously or moderately decorated. Automating this process by using BIM, which is mostly made for new buildings, would solve this problem, because the quality coefficient of the building would be determined according to the correct parameters, the municipality would receive more money than usual, and owners of moderate real properties would be satisfied not to pay

the same amount as the owners of exclusive properties. This would make the tax collection system more equitable.
An initial design of LADM based valuation and taxation data model was introduced by Çağdaş et al., (2016). Kara et al., (2021) describe the development of a prototype for the implementation of the LADM Valuation Information Model and assesses its operability through a case study for Turkey. Property valuation system using the LADM valuation information model in Croatia is presented by Tomić et al. (2021). Impacts of property taxation on residential real estate development was analysed by England et al. (2013).

Kara et al. (2020) analyze how three-dimensional (3D) information can be used in order to better estimate and explain values of property units. Property valuation domain does not widely use 3D models and 3D datasets to derive external characteristics of property unit except for visibility analysis. Therefore, the authors presented how 3D datasets and spatial analyses could be used to support property valuation activities and to investigate to what extent it is possible and meaningful to include derived 3D characteristics of property units in valuation registries. The research is based on 3D GIS solutions. Çağdaş (2013) proposed an Application Domain Extension (ADE) to CityGML for immovable property taxation. Use of 3D cadastral data for real estate mass valuation in the urban areas was proposed by Tomić et al. (2012). A BIM and machine learning integration framework for automated property valuation was proposed by Su and Li (2021). They propose an automatic information exchange between AEC projects and property valuation and develop IFC extension for property valuation and an IFC-based information extraction algorithm.

The paper is structured as follows. First Section contains introduction in which the motivation for this research and related work are described. Second Section describes the property taxation in Montenegro based on the actual laws and common practice. Third Section presents the new data model for property valuation and taxation in Montenegro based on LADM. Fourth Section presents possibilities to use BIM data as input for faster determination of building quality in process of property valuation and taxation. Conclusions and future work are given afterward.

2. PROPERTY TAXATION IN MONTENEGRO

Tax administration procedure in Montenegro is prescribed by the 'Law on property tax' (2019). The law defines how the real estate tax is calculated. The basis of real estate tax is the market value of the real property. The market value represents the value of that real property on the 1st of January of the year for which the tax is determined. The law provides basic criteria for its determination. The basic criteria for determining the market value of real property are:

- average market price per m^2,
- purpose of the real property,
- size of the real property,
- the place where the real property is located,
- quality of the real property and
- other elements that may have an impact on the market value of the real property.

Detailed criteria and methodology for determining the market value of real property are prescribed by the Government of Montenegro within the ‘Regulation’ (2011). Mass valuation of real property is still not conducted but is planned in the future changes of the law.
Every municipality defines the coefficients that correct the main formula for tax calculation. As pilot municipality, the Municipality of Bar is chosen. The Municipality of Bar is a coastal municipality in Montenegro, accompanied by rapid urbanization and construction of both residential and tourist buildings. The basis for the real property tax is being determined by multiplying the real property area by the average market price per m2 of real property in the Municipality of Bar and correcting it by coefficients of location, quality and purpose and property age. Price is determined on the municipality level for each type of building (residential, business, auxiliary, etc.), part of building (flat, business, garage, etc.) or purpose of the land (building and construction land, agricultural land, forest, etc.).

Next several formulas will present the procedure of determining tax value for one building and one building owner. Similar procedure is used to calculate the tax value for land or part of the building. Value of the building is determined as a product of building area and price of one m2 of the building with a certain purpose:

$$buildValue = price * area$$

The building area is a value that is obtained from the real estate cadastre together with other information like property purpose and right holders. This information is obtained on the 1st of January and according to this information a tax value is calculated. The price depends on a type of the building, and it is defined by the Municipality of Bar. The building value is then corrected with the age of the building (multiplied with the maximum age coefficient) and location of the building. The area of the Municipality of Bar is divided into seven zones and a special coefficient has been determined for each zone:

$$zoneVal = \left(buildValue - buildValue * \left(\frac{coefOld * (year - constYear)}{100}\right)\right) * coefZone$$

According to the quality criteria of the construction object, the market value is corrected by the quality coefficient of the building, by dividing the total number of points for all quality elements that building has, by the number of points for the highest quality of the building in the Municipality of Bar, which is 550 points.

Elements for determining the quality of the building are:
- type of building construction (barracks, prefabricated buildings, buildings made of prefabricated and mixed materials, classic construction),
- building exterior (classic facade, demit facade, artificial stone, natural stone and marble),
- building equipment (PVC joinery, wooden joinery, aluminum blinds, shutters),
- sanitary equipment (completely or partially arranged bathroom),
- water supply system (plumbing installation connected to the water supply network or to the well),
- sewerage system (sewage connected to the sewer network or to the septic tank),

- electrical and telephone installation,
- heating system (central, other),
- additional elements that increase value of the building like pools or exit to the asphalt road.

Quality of the building is calculated as follows:

$$qualVal = \left(\frac{\sum_{n=1}^{n}(qualBuild_n)}{coefQualTotal}\right)$$

The value of the tax is determined for each right holder individually, so it is necessary to obtain information on the right share from the real estate cadastre in order to adjust the amount that one party has to pay with that value. Tax rate is proportional value and amounts to 0.25% to 1.00% of the market value of the real property and this value depends on the type of the building. In the following formula, a tax value is calculated as a product of tax rate with building value corrected with location and quality, as well as with right share displayed as fraction (shareNum is numerator and shareDen is denominator in right share):

$$rateVal = \frac{\left(\frac{shareNum}{shareDen} * qualVal * zoneVal * taxRate\right)}{100}$$

Additionally, tax value is decreased if the right holder lives in that building. This is achieved with coefficient of inhabitance:

$$inhabVal = rateVal - rateVal * \frac{coefInhab}{100}$$

Tax value is corrected based on number of members in the household and for this, a special coefficient is defined for each number of members:

$$taxVal = inhabVal - inhabVal * \frac{coefMemb}{100}$$

Tax value is calculated for every year based on updated data from municipality, tax administration and real estate cadastre.

3. LADM BASED DATA MODEL FOR PROPERTY TAXATION IN MONTENEGRO

The data model is the basis of every information system, so it is necessary to harmonize the data model used for taxation with the land administration model. The Land Administration Domain Model - LADM defined by ISO 19152 is an international standard for the land administration domain. LADM focuses on the legal, geometric and administrative aspects of land management, but does not deal with real property valuation and taxation. However, LADM provides external classes that connect land administration systems to other related land administration databases. In this way, the model provides a good and flexible basis for property valuation and taxation. Since, many countries already developed their LADM country profiles and newly proposed LADM Valuation Information Model is on the agenda of the development of the second edition of LADM (Kara et al., 2021), it is natural to think about developing a country profile for valuation and taxation.

Figure 1 shows LADM based model for property taxation in Montenegro and its connections to LADM basic classes. Montenegrin LADM country profile is previously developed and presented by Radulović et. al (2015). In Figure 2 the basic classes of this model are displayed. Full list of classes are presented in Govedarica et. al (2021). Class MNE_RealestateFolio represent the real estate document that is used in Montenegro to connect together data about rights (MNE_Ownership) on one or several parcels (MNE_Parcel) in a way that the total sum of shares that each party (MNE_Owner) has is equal one. Additionally, the real estate document contains data on buildings (MNE_Building) and special parts of buildings (MNE_PartOfBuilding) that are located on parcels recorded within the same real estate document together with rights on them. Finally, the real estate document contains the data about existing restrictions (MNE_Restriction) on all properties recorded within the real estate document.

Classes that represent property taxation in Montenegro are displayed on Figure 3. MNE_ValuationUnit is a unit of valuation and taxation. In Montenegro, this unit can be parcel (MNE_VM_Parcel), building (MNE_VM_Building) and part of building (MNE_VM_PartOfBuilding). These classes are introduced in order to add additional attributes that represent location and quality information which are not recorded in basic LADM profile classes. In the model, connections between classes from LADM profile and valuation model are represented with associations between two appropriate classes, but in practice, information about spatial unit attributes are obtained via web services owned by geodetic authority. That way, all necessary information from both geodetic authority and tax administration can be used in valuation and taxation process. Two attributes that are important for valuation and taxation are location and quality of property. By its location, every property is categorized into one of seven zones and a coefficeint is added to each zone (MNE_ZoneElements). Zone is determined by property address. Second important attribute is a list of quality elements for each property. Quality elements and corresponding coefficients are defined within MNE_QualityElementsParcel code list for parcels and MNE_QualityElementBuilding code list for buildings and part of buildings. Important parameters that are obtained from real estate cadastre are area of the property, purpose/way of use of the property, year of construction for buildings, right holders and rights.

In the process of valuation and tax calculation, a predefined set of coefficeints is used. Most of the coefficients are defined within the valuation model (MNE_VM_ValuationModel) for a fiscal year. These coefficients are defined on the municipality and country level. Values displayed on the diagram are defined for the municipality of Bar. For different municipalities, coefficients can differ. Within this code list, a coefficients for each type/purpose of the property are defined, tax rate and price per m2. Also, a correction on the tax if possible if tax payer lives in property or if there are greater number of household members. For such situations, a set of coefficients are introduced and classes MNE_VM_Ownership and MNE_VM_TaxPayer with additional attributes in regard to classes MNE_Ownership and MNE_Owner.

Based on the formulas presented in previous section, a tax value is calculated for each property and a tax is assigned to a tax payers according to their share in right.

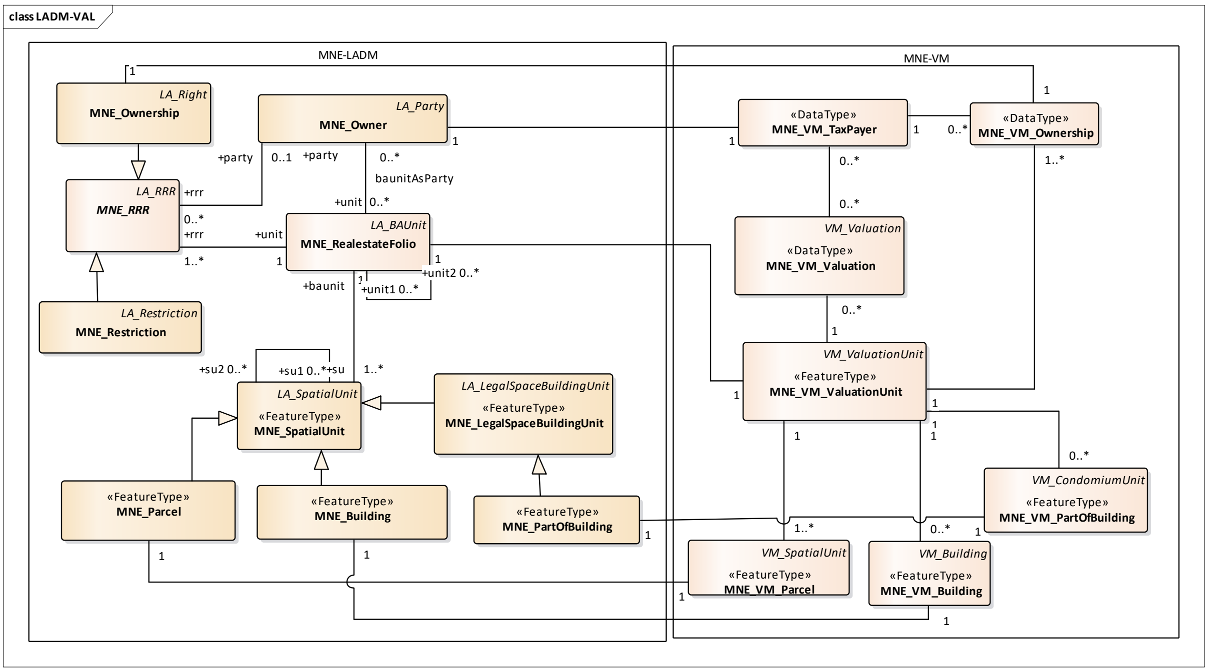

Figure 1. LADM based model for property taxation in Montenegro

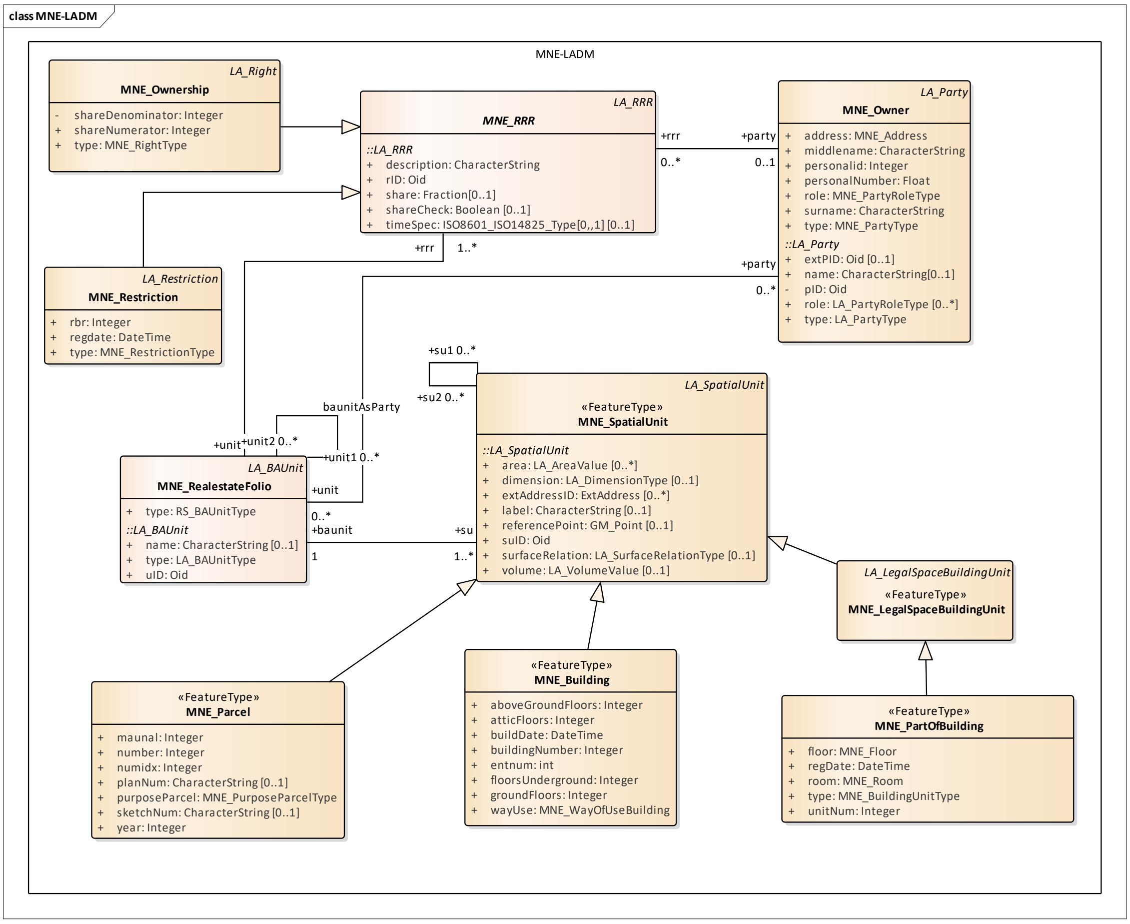

Figure 2. Montenegrin LADM country profile classes

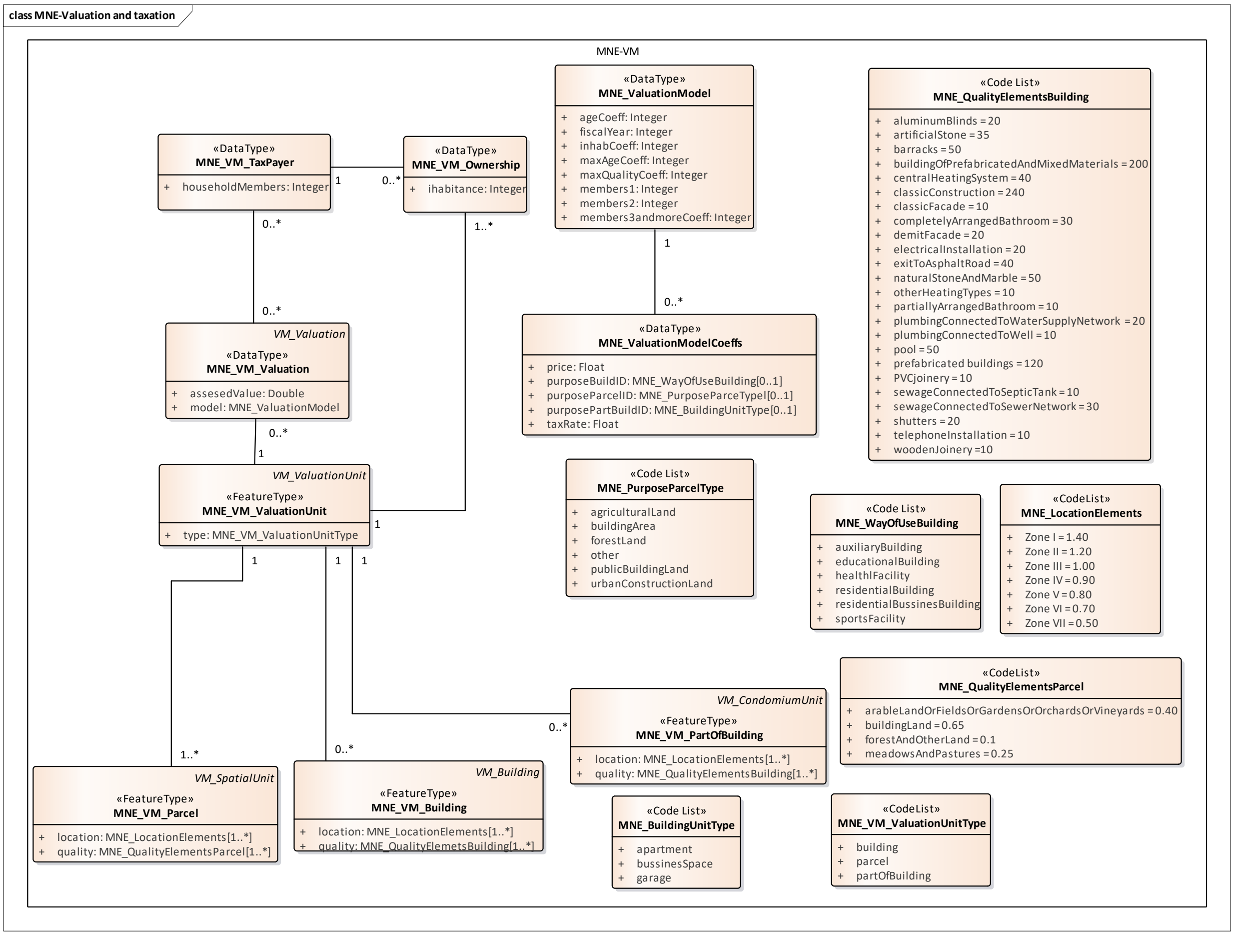

Figure 3. Valuation and taxation model for Montenegro

4. USING BIM FOR BUILDING QUALITY ASSESMENT

As pilot Municipality in this research, the Municipality of Bar is chosen. The Municipality of Bar is a coastal municipality in Montenegro, accompanied by rapid urbanization and construction of both residential and tourist buildings. The new buildings have a BIM model created in a design phase which is a part of the documentation for issuing a building permit. Such BIM model can be used for at least two other purposes in addition to basic use. The first one is to serve as an input for 3D cadastre. It can be linked to the cadastral database via unique property identification number (UPIN) as described by Sladić et al. (2020). The second one is the use of BIM to extract information relevant for calculation of taxes, such as quality of the building, building age, etc. In Montenegro, the tax is calculated based on several factors. Data such as the area of the building and the quality of the building (building construction, building facade, windows, number of rooms, installations, number of bathrooms, etc.) can be directly loaded into database from the appropriate BIM model. Such solution can be resolved by expanding the regulative and the law to allow the use of this data.

Figure 2 shows IFC entities and relations that could be used to extract information about the quality of the property. The central entity is ifcBuilding, a subtype of ifcProduct, which is defined by the property set (named PsetBuildingCommon) such as a year of construction, year of last refurbishment, net planned area, or a construction method. Single value property (ifcPropertySingleValue) of an ifcBuilding named ConstructionMethod is of type ifcLabel and can be used to enter free text about construction method of the building according to the building construction code list. Building construction can also be extracted from the enumeration IfcConstructionMaterialResourceTypeEnum. However, this enumeration does not contain all the values from the code list, so it is necessary to expand it with user defined types. IfcConstructionMaterialResourceTypeEnum can also be used to extract information about building exterior (facade), but it is also necessary to expand it with user defined types. The Figure 2 also shows entities related to windows and window style (ifcWindow, ifcWindowStyle) such as PVC windows, which are also used to calculate the quality. Sanitary equipment can be determined using IfcSpaceType in the form of free text or using IfcSanitaryTerminalTypeEnum enumeration with the chosen values (bath, shower, sink, toiletpan, washhandbasin, wcseat, etc.).

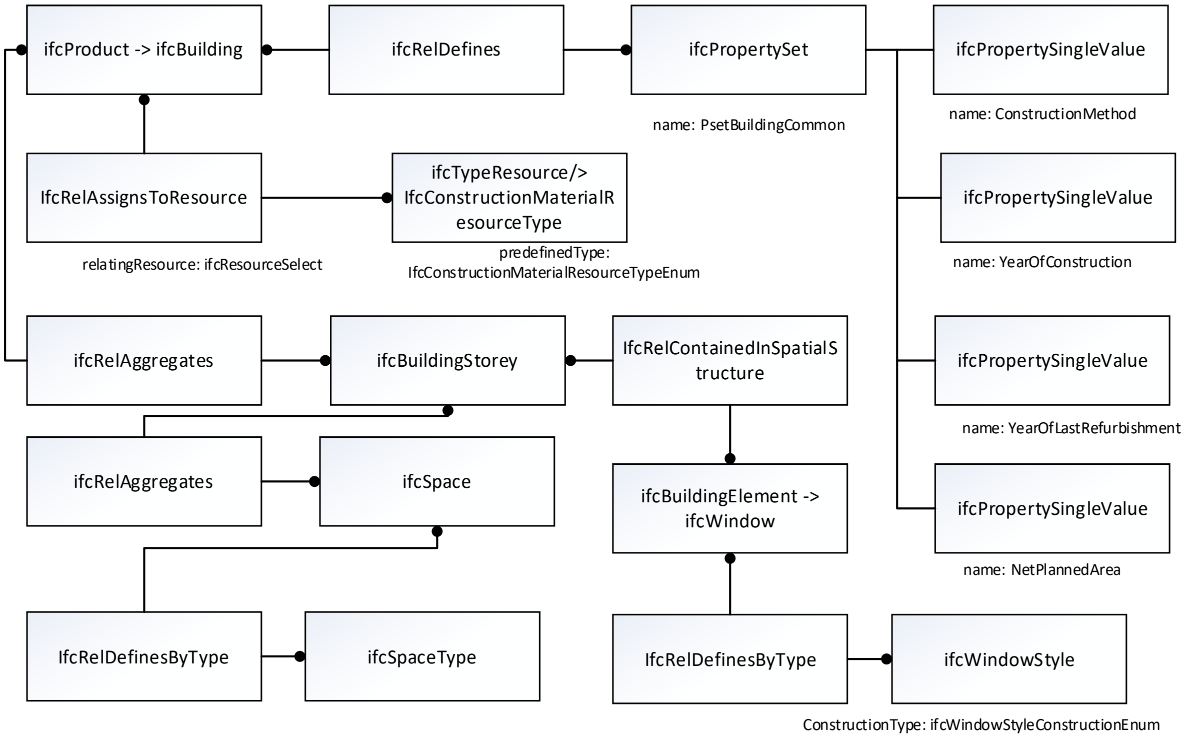

Figure 4. IFC entities related to property quality assessment

Table 1 shows the mapping of the IFC elements to the quality parameters defined in the quality code list. In addition to the entities showed on Figure 4 the mapping also contains parameters such as water supply, sewage, electrical installation, heating and elements that increase the value of an object. In some cases, the quality parameter can be extracted if the appropriate IFC entity exists, such as cable segments or electrical distribution board in the case of electrical installations. If enumerations are used, they usually should be expanded with user defined types, since they do not contain all the necessary values. Other option is to use free text in the name or label attributes.

Table 1. The mapping of the IFC elements to the quality parameters

Quality parameter	Quality description	IFC mapping
1. Building construction	1.1. Buildings made of unfired brick or barracks 50 points; 1.2. Prefabricated buildings (wooden, sheet metal, iron) 120 points; 1.3. Buildings made of prefabricated elements and mixed materials 200 points; 1.4. Classic construction (hard material) 240 points;	ifcBuilding - Pset_BuildingCommon - ConstructionMethod (ifcLabel) IfcConstructionMaterialResourceTypeEnum (AGGREGATES – Construction aggregate including sand, gravel, and crushed stone. CONCRETE – Cast-in-place concrete. DRYWALL – Wall board, including gypsum board. FUEL – Fuel for running equipment. GYPSUM – Any gypsum material. MASONRY – Masonry including brick, stone, concrete block, glass block, and tile. METAL – Any metallic material. PLASTIC - Any plastic material. WOOD – Any wood material. NOTDEFINED – Undefined resource. USERDEFINED – User-defined type
2. Building treatment (exterior)	2.1. Classic facade 10 points; 2.2. Demit facade and brick-clad facade 20 points; 2.3. Artificial stone 35 points; 2.4. Facade lined with natural stone or marble 50 points;	IfcConstructionMaterialResourceTypeEnum (AGGREGATES – Construction aggregate including sand, gravel, and crushed stone USERDEFINED – User-defined type)
3. Equipment of construction facilities	3.1. Window 3.1.1 PVC 10 points; 3.1.2 Wooden joinery 10 points; 3.1.3 Aluminum blinds 20 points; 3.1.4 Shutters - shutters 20 points;	ifcWindow, ifcWindowStyle, IfcWindowStyleConstructionEnum (ALUMINIUM, HIGH_GRADE_STEEL, STEEL,WOOD, ALUMINIUM_WOOD, PLASTIC, OTHER_CONSTRUCTION, NOTDEFINED)
4. Sanitary equipment	4.1. Completely decorated bathroom (bath - shower, toilet, sink) 30 points; 4.2. Partially decorated bathroom, 10 points per apartment;	IfcSpaceType/LongName , IfcSanitaryTerminalTypeEnum (BATH, SHOWER, SINK, TOILETPAN, WASHHANDBASIN, WCSEAT)
5. Water supply	5.1. Plumbing connected to the water supply network, 20 points per apartment; 5.2. Plumbing connected to the well - hydrophore 10 points;	IfcPipeSegment/ IfcPipeSegmentType / IfcPipeSegmentTypeEnum
6. Sewage	6.1. Sewerage connected to the sewerage network, per apartment 30 points; 6.2. Sewage connected to the septic tank, per apartment 10 points;	IfcWasteTerminalTypeEnum (FLOORWASTE – Pipe fitting, set into the floor, that collects waste water and discharges it to a separate trap, USERDEFINED - User-defined type.)
7. Electrical Installation	7.1. Electrical installation 20 points; 7.2. Telephone installation 10	IfcCableSegment / IfcCableSegmentType /IfcCableSegmentTypeEnum,

	points;	IfcElectricDistributionBoard / IfcElectricDistributionBoardType /IfcElectricDistributionBoardTypeEnum
8. Heating	8.1. Central heating 40 points; 8.2. Other heating (solid fuel, liquid and electric) 10 points;	IfcSpaceHeater / IfcSpaceHeaterType, IfcSpaceHeaterTypeEnum (CONVECTOR / RADIATOR / USERDEFINED)
9. Elements that increase the value of an object	9.1. Swimming pool 50 points; 9.2. Exit to the asphalt road 40 points	IfcConstructionEquipmentResourceTypeEnum (PAVING - Roads or walkways such as asphalt or concrete)

5. CONCLUSION

In this paper we developed LADM based conceptual model for property valuation and taxation in Montenegro. Basic classes form LADM country profile for Montenegro are presented and described in the paper. Based on this conceptual model, a database and a web-based software solution were developed in Municipality of Bar. Furthermore, we introduced the idea of using BIM to extract quality parameters of building that are used for valuation and taxation to provide automation, which are otherwise entered manually and are very often incorrect in practice. The proposed model covers all three types of properties in Montenegro, land (parcels), buildings and part of buildings like apartments, business offices, etc. BIM models that are already created for new buildings are introduced as a mean for automation of collection information about quality, while for the old buildings the data is already entered manually or will be entered manually as before.

Since the amount of data of building quality for the purpose of valuation and taxation is quite large in Montenegro and that the valuation model could operate with less and more generic data related to the building quality, there are two reasons for this kind of valuation. The first reason is that such procedure is defined by the law. Another reason is that there are large differences in the price of buildings at the same location. Without appropriate quality information the similar amount of tax would be assigned to moderate real properties and exclusive properties. The income of taxes is important for local self-governments, especially since Bar is a touristic place and there are a lot of luxury real properties for which a larger tax should be paid. Furthermore, there are a lot of luxury real properties that are built in recent years and are planned to be built, so using BIM for automation will decrease considerably time for entering quality information and increase accuracy of recorded data, since in past it was not unusual not to record the quality data but to enter some predefined value.

The property tax for real properties is determined and gathered on the local level by local Government, while other revenues from properties during transactions are gathered on the national level. Because of that, it is very important that property taxes are righteous, not to overload those who own low quality buildings, and also for luxury buildings a tax to be calculated as prescribed by the law. This income is very important for the municipality because these resources can be allocated to health care, environmental protection, energy efficiency, agriculture, water management, reforestation, paving, construction of

kindergartens and preschools, education, sport, and recreation and thus improving the quality of life for all citizens.
Future work will include development of IFC extension for property valuation. Since Montenegro has numerous summer resorts on its coast, the collection of tourist taxes can bring significant funds to the municipality. Future work will involve expanding the developed model to include tourist tax and procedure to calculate it.

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BIOGRAPHICAL NOTES

Aleksandra Radulović (Ph.D) is an Associate Professor at Faculty of Technicial Sciences, University of Novi Sad, Serbia. She has published several papers in ISI journals and conferences. She has also participated in several research projects including GIS (geoportal) for the Ministry of Environmental Protection and Ecology of Serbia, Information system of the real estate cadastre for Republic Geodetic Authority of Republika Srpska, Information system of the real estate cadastre in Montenegro, Information system for user requests submission in the cadastral system in Republic of Serbia, Information system for valuation in Bar, Montenegro and GIS for the city of Novi Pazar. Her domains of interest are Geographic Information Systems, Spatial Data Infrastructures, Service Oriented Architecture, Cadastral Systems, etc.

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Dušan Raičević is the Mayor of the Municipality of Bar. His specialty is management in economy. During his career, he was the secretary in the Secretariat for Economy and Finance of Bar and in 2018, he was elected on mayor position. His work is focused on the development and progress of the municipality of Bar, which includes following the trends in the development of information technology, appropriate standards and cooperation with the academy as a relevant institution for such metter.

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The Role of Positioning Infrastructure and Mapping Surveys in 3D Cadastre Implementation for Mass Rapid Transport Infrastructures – Indonesia Case

Dedi ATUNGGAL, Nurrohmat WIDJAJANTI, Trias ADITYA and Agus WAHYUDI, Indonesia

Key words: Cadastre, Positioning Infrastructure, Reference System, Validation Survey, First Registration

SUMMARY

In response to recent increases in the utilization of 3D spaces situated below and above land surfaces, both users and registrar increasingly demanding a reliable positioning infrastructure for a cadastre. This paper discusses some challenges and requirements for establishing a reliable positioning infrastructure to support 3D cadastre implementation in Indonesia. Since three decades ago, ground survey marks (TDT) have been conventionally used for parcel mapping and only have 2D coordinates. TDT can be used for 3D cadastre implementation by assigning the TDT height to the national height datum. Surveyors can define the TDT height by referring to the orthometric height pillars (TTG) or the Indonesian national geoid (InaGeoid). These two references are sub-elements of the 2013 Indonesia Geospatial Reference System (SRGI 2013), which since 2013 has been used as a reference for various geospatial data nationally. 2D parcel mapping practices in Indonesia are still referring to the previous reference system used by Indonesia, namely the 1995 National Geodetic Datum (DGN95). This condition makes an integrated 3D survey to support first registration and right transfers for 3D Cadastre is challenging. At the same time, a 3D validation survey for 3D cadastre aiming to validate X, Y and Z coordinates of 3D parcels to be registered needs to be done efficiently and accurately. This paper discusses challenges regarding coordinates shift, inconsistencies between 2D and 3D parcels, missing height references and lack of coordinate redefinition of GPS coordinate services. This paper will examine the 3D cadastral validation survey results done in the Mass Rapid Transit (MRT) stations in Jakarta City and evaluate the positioning infrastructure in Jogjakarta City where an MRT connecting the new airport to the city center will soon be built.

The Role of Positioning Infrastructure and Mapping Surveys in 3D Cadastre Implementation for Mass Rapid Transport Infrastructures – Indonesia Case

Dedi ATUNGGAL, Nurrohmat WIDJAJANTI, Trias ADITYA and Agus WAHYUDI, Indonesia

1. INTRODUCTION

The use of 3D space above and below land surfaces in Indonesia is increasing. The Indonesian government regulates the use of 3D space through Law no. 14/2020. Details of regulations are stipulated through Government Regulation no. 18/2021 which is then detailed through the Regulation of the Minister of Agrarian Spatial Planning/National Land Agency No. 16/2021. To implement the regulation, support from a reliable positioning infrastructure is needed.

Since three decades ago, ground survey marks (TDT) have been conventionally used for parcel mapping and only have 2D coordinates. TDT can be used for 3D cadastre implementation by assigning the TDT height to the national height datum. Surveyors can define the TDT height by referring to the orthometric height pillars (TTG) or the Indonesian national geoid (InaGeoid). These two references are sub-elements of the 2013 Indonesia Geospatial Reference System (SRGI 2013), which since 2013 has been used as a reference for various geospatial data nationally. 2D parcel mapping practices in Indonesia are still referring to the previous reference system used by Indonesia, namely the 1995 National Geodetic Datum (DGN95). This condition makes an integrated 3D survey to support first registration and right transfers for 3D Cadastre is challenging. At the same time, a 3D validation survey for 3D cadastre aiming to validate X, Y and Z coordinates of 3D parcels to be registered needs to be done efficiently and accurately.

This paper discusses challenges regarding coordinates shift, inconsistencies between 2D and 3D parcels, missing height references and lack of coordinate redefinition of GPS coordinate services. MRT was chosen as a case study because this infrastructure was developed as a solution to overcome transportation problems faced by big cities in Indonesia. Implementation of 3D cadastre in different cases at different countries as described and explained in Best Practices 3D Cadastres (van Oosterom, 2018) used as a basis for analyzing the implementation of 3D cadastral in this case study

2. EXISTING POSITIONING INFRASTRUCTURES IN INDONESIA

The existing positioning infrastructure in Indonesia consists of horizontal ground survey marks, vertical ground survey marks, national geoid model and Continuously Operating Reference Stations (CORS).

2.1 Horizontal Ground Survey Marks

The horizontal ground survey marks in Indonesia consist of zero order to 4th order control points. The zero order and 1st order control points were established in the early 1990s by the National Mapping Coordination Agency (Bakosurtanal) which in 2011 became the Geospatial Information Agency (BIG). The 2nd order, 3rd order and 4th order control points were established by the Ministry of Agrarian Affairs & Spatial Planning/National Land Agency (MoASP/BPN, formerly known as BPN) from 1994 to 2007. The distribution of the horizontal ground survey marks is shown in Figure 1. Interdistance of each order is presented in Table 1.

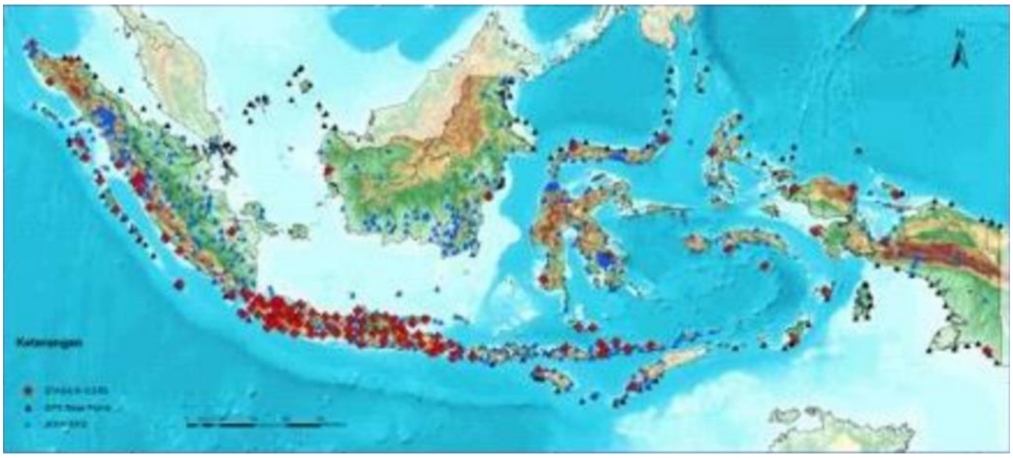


Fig. 1. Distribution of the horizontal ground survey marks (https://srgi.big.go.id)

Table 1: Interdistance of horizontal ground survey marks

Order	Interdistance (km)	Control Points
0	500	National geodetic control points
1	100	Regional geodetic control points
2	10	Local geodetic control points
3	2	Densification control points
4	0.1	Mapping control points

The total number of zero order and 1st order is 1,266 points of which 363 points also have height coordinates and serve as vertical control points. These horizontal ground marks were initially defined to the first geocentric datum used by Indonesia, the DGN95. The realization of DGN95 was done using the zero order control points and referred to International Terrestrial Reference Frame 1991 (ITRF91) 1992.0. In 2013, along with the establishment of the new datum – SRGI 2013, coordinates of these ground survey marks were updated and referred to ITRF08 2012.0 (Abidin et al., 2015). After the establishment of the SRGI 2013, various geospatial data have been referred to this new reference system.

The 2nd, 3rd and 4th order control points are approximately 10,000 points and have only horizontal coordinates. These horizontal ground survey marks were defined by referring to the zero order or the 1st order control points and the previous datum (DGN95). These control points are used for 2D cadastral mapping, e.g. to produce the cadastral base map and land parcel map.

2.2 Vertical Ground Survey Marks

Indonesia's vertical ground survey marks consist of zero order to 4th order control points established by Bakosurtanal. The control points are distributed along the main connecting roads between provinces, as shown in Figure 2. The spacing of the control points is determined based on each segment's slope value, as presented in Table 2.

Fig. 2. Distribution of the vertical ground survey marks (source: https://srgi.big.go.id)

Table 2: Interdistance of vertical ground survey marks

Criteria	Slope (%)	Interdistance (km)
I	0-5	4-5
II	>5	2-4

These control points were defined by precise leveling and terrestrial gravity survey. The total number of vertical survey marks is 5747 points, of which 4860 points have both vertical coordinate and gravity value, and 524 points only have vertical coordinate.

2.3 National Geoid Model

The Indonesian Geoid Model is generated using gravity data, global geoid models, and digital elevation models (DEM). Gravity data were obtained from both terrestrial and airborne gravity surveys. The global geoid model and DEM used for the modeling are the Earth Gravity Model 2008 (EGM 2008) 360 degrees and the Shuttle Radar Topographic Mission (SRTM) with a resolution of 30 meters. The geoid modeling method is carried out using the Remove - Restore Technique and the Fast Fourier Transformation (FFT) approach. Figure 3 shows geoid undulation from InaGeoid.

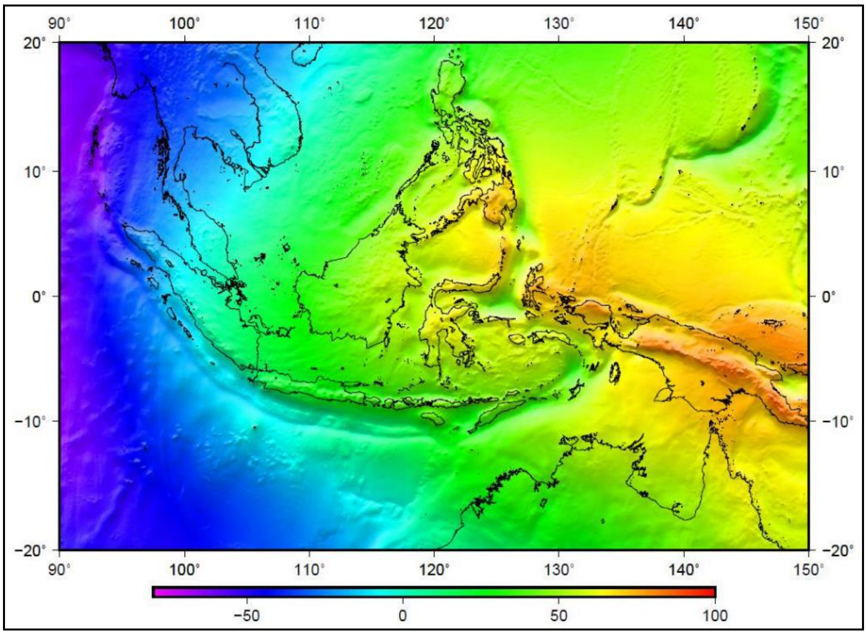


Fig. 3. Geoid undulation model from InaGeoid (Source: Pahlevi, Sofian, Pangastuti, & Wijanarto, 2019)

BIG has carried out verification of the accuracy of InaGeoid. It was conducted by comparing the value of the geometric undulation of the vertical control point used as a sample with the gravimetric undulation of InaGeoid. Geometric undulations are obtained by differentiating the geometrical height or ellipsoid height resulting from GNSS observations with orthometric height values resulting from precise leveling measurements that have been corrected with gravity data. The gravimetric undulation is obtained by interpolating the undulation values from the InaGeoid geoid model. The accuracy of the Indonesian geoid model is calculated per island. The accuracy of geoids is only available for five major islands in Indonesia due to the limited number of vertical control points that can be used for verification. The accuracy of the Indonesian geoid model can be seen in Table 3.

Table 3: The accuracy of InaGeoid (https://srgi.big.go.id)

Island	Number of Verification Points	Min (cm)	Mean (cm)	Max (cm)	Deviation Standard (cm)
Jawa	186	-12.8	0.03	30.4	5.1
Bali	184	-38.3	-0.3	31.1	10.3
Sumatera	26	-8.38	21.4	51.3	17.3
Sulawesi	53	-60.1	-10.5	41.3	22.4
Kalimantan	35	-35.7	23.3	69.5	24.7

2.4 Continuously Operating Reference Stations (CORS)

CORS in Indonesia was developed by BIG and MoASP/BPN starting in 2010. The CORS managed by BIG is known as InaCORS. The number of InaCORS stations until 2019 consisted of 295 stations whose distribution can be seen in Figure 4. InaCORS was developed to support establishing the Indonesian Geospatial Reference System (SRGI), monitoring tectonic activity and making Indonesian deformation models. BIG in 2018 has carried out densification of 30 stations in Sumatra (Mundakir & Chabibi, 2019) and will add another 50 stations in Kalimantan in 2021. As part of the SRGI 2013, the coordinates of InaCORS has been referred to the ITRF 2008 2012.0

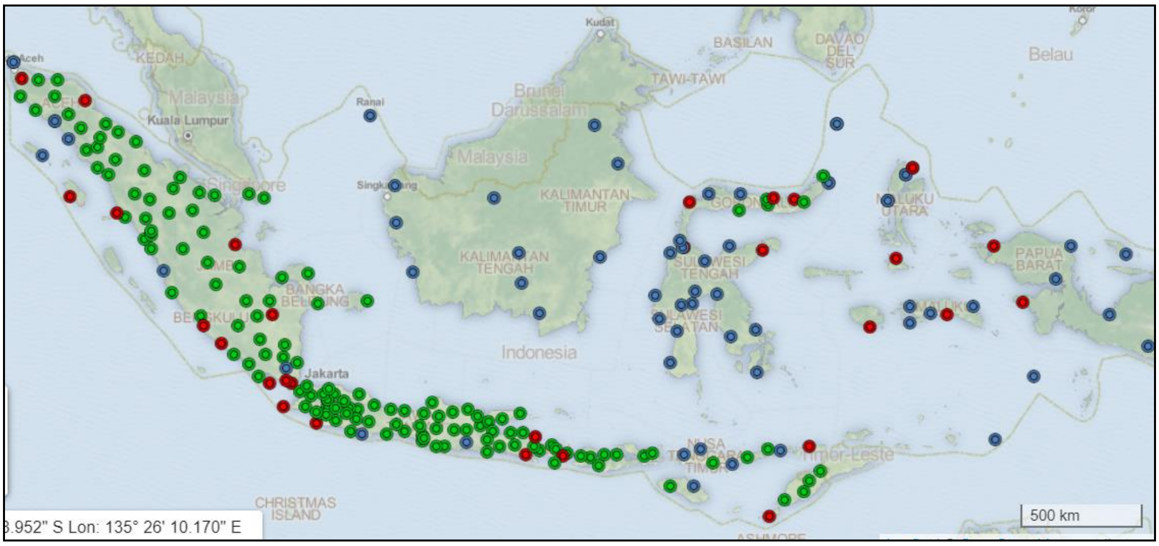


Fig. 4. Distribution of InaCORS (https://nrtk.big.go.id)

CORS managed by the MoASP/BPN is known as the Land Satellite Reference Network (JRSP). The number of reference stations managed by the MoASP/BPN is about 120 stations as shown in Figure 5. JRSP was developed to support cadastral mapping for land registration. Hence, the development was prioritized for Land Offices with high volumes of land transactions and with complex land issues. The coordinate of JRSP still referred to DGN95. Currently, JRSP is being unified and integrated with InaCORS and will be managed by BIG.

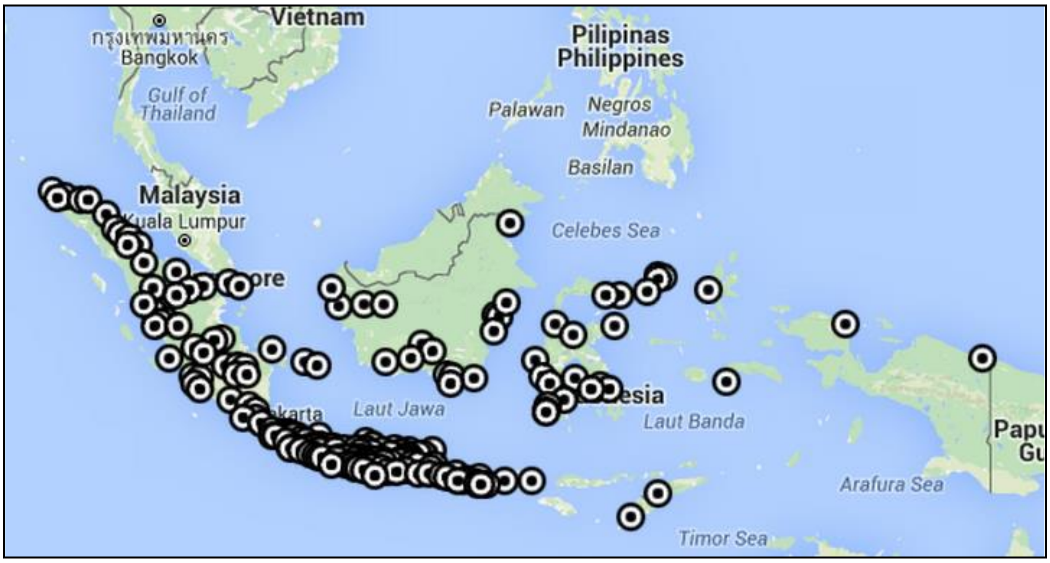


Fig. 5. Distribution of JRSP

3. 2D AND 3D CADASTRAL MAPPING SURVEYS IN INDONESIA

3.1 2D Cadastral Mapping Surveys

In the past, 2D cadastral mapping in Indonesia was mostly done without referring to control points. This resulted in many maps of land parcels that could not be georeferenced. In the last decade, the Indonesian government has made serious efforts to solve this problem. Two of them are implementing complete systematic land registration (PTSL) activities and improving the quality of land parcel maps. These two activities can be carried out quite well in recent years because awareness of the use of control points is increasing.

3.2 3D Cadastral Mapping Surveys

3.2.1 3D Cadastral Mapping Surveys for Strata Titles

3D cadastral mapping surveys began to be implemented in Indonesia following the implementation of the strata titles (Law no. 20/2011). According to this law, the physical buildings referring to mixed-use apartments and condominiums can be divided into three legal spaces: shared properties or shared objects (e.g., parking lots, stairs, corridors, and elevators), shared structures (e.g., columns and partition walls), and strata titles/apartment ownership rights.

Ownership rights or strata titles of mixed-use apartments can be granted as soon as three mandatory requirements for the first can be fulfilled, i.e., the underlying land rights, description of the parcel and space division, and the site plan (Aditya et al., 2020). A field survey or field validation is required to determine the geometry of strata titles at the time of property registration. Many survey methods can do this, but measurements using a laser distance meter or measuring tape are sufficient to validate the distance and area based on the data on the separation deed submitted by the applicant.

With the enactment of Law no. 14/2020 and Regulation no. 18/2021, rights to 3D space are regulated in one cluster with Land Rights and different from Strata Titles.

3.2.2 3D Cadastral Mapping Surveys for Legal Spaces Above and Below Land Surface

According to Law no. 14/2020 and Government Regulation no. 18/2021, a 3D cadastral mapping survey is required to verify the geometry of legal spaces and the 3D position of each 3D cadastral object. This can be performed using either terrestrial survey methods (e.g., Global Navigation Satellite System (GNSS) Survey, Total Station, Terrestrial Laser Scanner and Distometer/laser distance measurers, or a combination) or photogrammetry methods.

3D cadastral objects may be easily validated in the field using local heights. Still, for 3D cadastral objects to be visualized and integrated into a 3D cadastral information system, the use of a national height system is essential (Drobež et al., 2017, Atazadeh et al., 2021).

Given that cadastral control points in Indonesia so far only have 2D coordinates, then assigning heights to TDT may be one of the challenges that need to be solved. The alternative of 3D cadastral mapping using CORS as regulated in Regulation of the Minister of Agrarian Spatial Planning/National Land Agency No. 16/2021 may offer a practical solution to this.

Validation of 3D cadastral objects using CORS will be efficiently carried out when combined with the Indonesian National Geoid model. Research needs to be done to define best practices in the use of such systems in Indonesia. Hybrid local geoid can also be used as an alternative in areas that have not been covered by the national geoid or in cases where the geoid accuracy is not sufficient (Putraningtyas, Heliani, Widjajanti, & Aditya, 2021).

Referring to Government Regulation No. 18/2021 article 74, the use and utilization of land parcels owned by the holder of Land Rights are limited by:

- height limit which is specified according to the building coefficient and the floor coefficient which are set in the local spatial plan; and
- depth limit which is specified in the local spatial plan or determined to 30 meters below the ground in case the limit has not been regulated by the local spatial plan.

3D parcels with separate structures or functions of rights with their land's surface are classified as land/space managed by the government. For that reason, it is crucial to validate the position of the 3D cadastral objects during the validation survey. This validation should be carried out by referring to the validation survey control point on the ground surface.

4. CASE STUDIES

This paper discusses the 3D cadastral validation survey results done in the Mass Rapid Transit (MRT) stations in the Capital City Jakarta. In addition, this paper evaluates the positioning infrastructure in Special Region Yogyakarta Province, where an MRT connecting the new airport to the city center will soon be built. The study area is shown in Figure 6.

Fig. 6. Locations of case study in Indonesia

4.1 Validation Survey of MRT in Jakarta

The 3D cadastral object validation survey at MRT Jakarta was carried out through several stages:

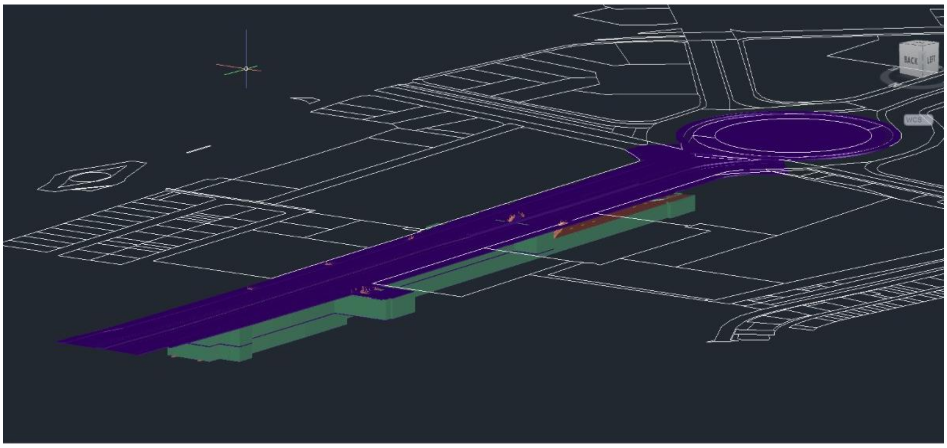
- Creating a work plan map;
- Measuring control points at ground level;
- Conducting a validation survey of 3D cadastral objects above and below ground surface;
- Making validation results document.

The validation survey was conducted based on 3D models of two MRT stations (Bundaran HI Station and Blok M Station) converted from each as-built drawings. The use of 3D models converted from as-built drawings is expected to stimulate and facilitate the implementation of 3D cadastral because it is cost effective. The 3D model is used as a requirement for submitting rights to the 3D cadastre and the cost to create the 3D model is borne by the applicant.

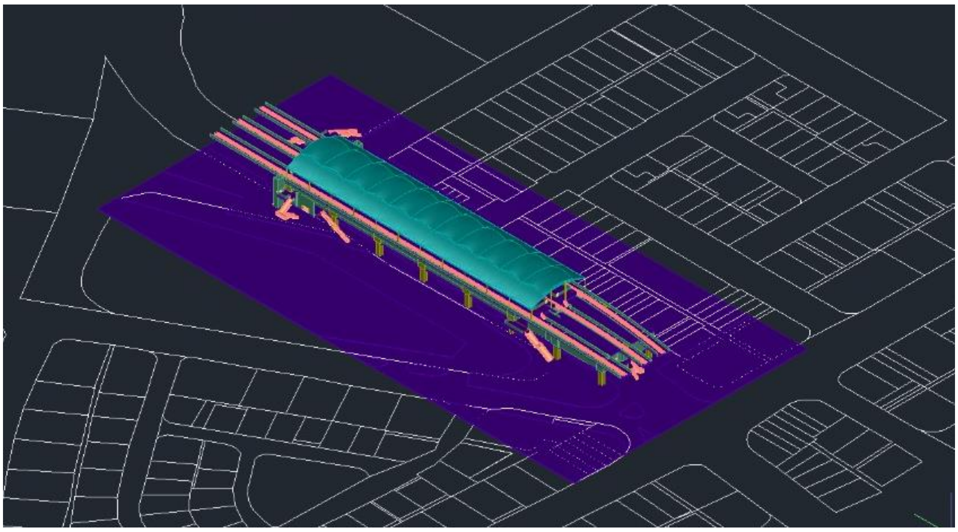
4.1.1 Work Plan Map for Validation Survey

Before the validation survey was carried out, work plan maps for the validation survey at the two MRT stations were prepared. Each 3D model was overlaid with land parcel maps where the two facilities are located (Figure 7). In this initial process, it is identified that there are coordinate shifts and inconsistencies between the 3D models and the land parcel maps at the two stations. It was recognized that the land parcel map uses the Transverse Mercator 3° projection system (or often known as TM3) and refers to the DGN95 datum, while the as-built drawing uses the Universal Transverse Mercator (UTM) projection system and no information about the datum used in the document.

The absence of metadata related to the datum used in the as-built drawing causes difficulties in creating the work plan map. This information is important and becomes the basis for performing datum transformations (in casaes that different datums are used). This problem was overcome by switching the projection to TM 3 using DGN95 and SRGI2013 alternately as the reference system of the as-built drawing. This process was then followed by checking several features (common points) that can be recognized on the land parcel map and on the as-built drawings. Further verification was done by field measurement on several common points. From these processes, it can be concluded that the as-built drawings tend to refer to SRGI 2013. Hence the coordinate shifts and inconsistencies probably are due to the different reference systems and projections used by the two data.



(a)



(b)

Fig. 7. 3D Model of MRT stations combined with 2D land parcels: (a) Bundaran HI Station, (b) Blok M Station (source: Atunggal et al., 2020)

4.1.2 Measurement of Control Points for Validation Survey

The validation survey begins with determining the 3D position of control points at each station. Measurements were carried out using geodetic GNSS receiver referring to horizontal ground survey marks (TDT0902022) and vertical ground survey marks (TTG0267) located approximately 5 kilometers from the two stations shown in Figure 8. The same procedure was applied to define the second control point at each station. The height of the control points was defined by two methods, namely GNSS heighting by referring to the orthometric size of the vertical control point (TTG0267) and online processing by using InaGeoid service. Example of InaGeoid service processing result is shown in Figure 9.

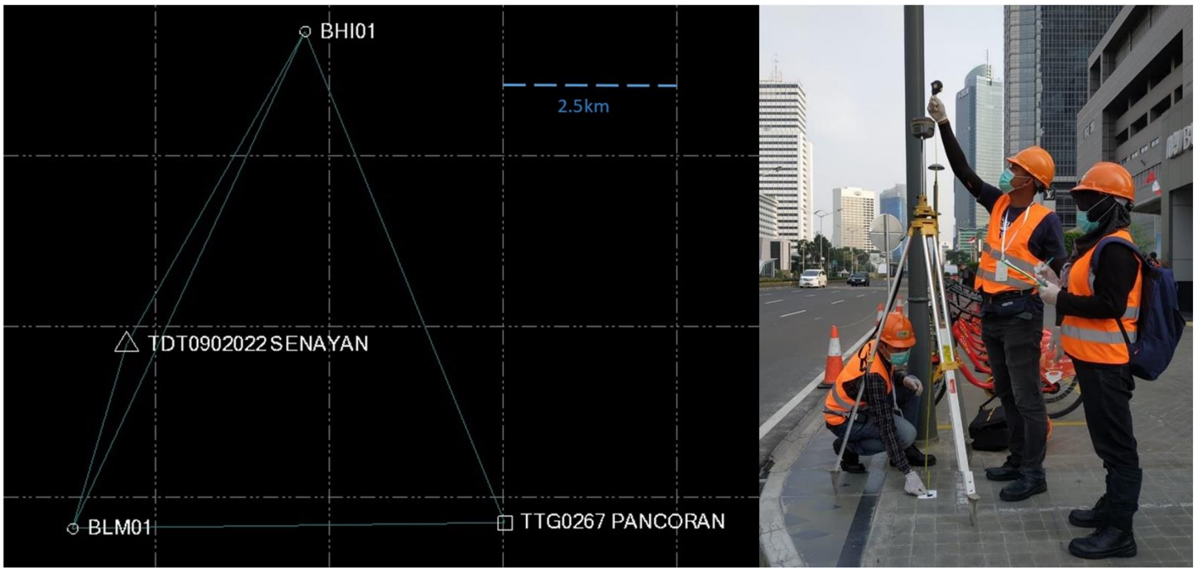


Fig. 8. GNSS observation of validation survey control points

As shown in Table 4, the height difference in each control point is approximately 10cm between GNSS heighting and InaGeoid. In this case, both methods show results with a fairly good level of conformity. As claimed by the InaGeoid online service, the accuracy of the height defined by the service is 5 centimeters. These results look promising but further research on different cases in Indonesia needs to be conducted to see the applicability of such a system on a national scale. An important factor regarding height referencing, as highlighted by Navratil & Unger (2013) and Gulliver & Haanen (2014) needs to be considered for evaluating the application of the system on a national scale.

Table 4: Coordinates of control points for validation survey

Control Point	TM3 Easting (m)	TM3 Northing (m)	GNSS Heighting (m)	InaGeoid Height (m)
BHI01 (Bundaran HI)	235720.086	815452.031	2.139	2.027
BHI02 (Bundaran HI)	235715.697	815436.155	2.341	2.229
BLM01 (Blok M)	233048.109	809638.426	20.509	19.940
BLM02 (Blok M)	233063.734	809623.166	20.110	20.008

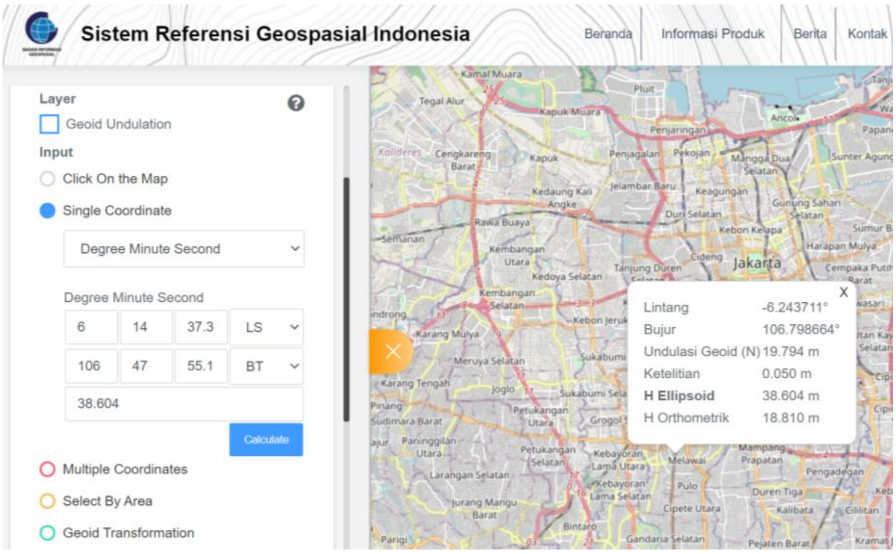


Fig. 9. Example of InaGeoid service processing result

4.1.3 Validation Survey of 3D cadastral objects

Validation survey at each station includes validation of position, length, area and volume of 3D cadastral objects. Of the four validations, the one directly related to the positioning infrastructure is position validation. While the validation of distance, area and volume is related to the quality of the 3D model used.

Position validation at the Bundaran HI station is carried out by using Total Station. Measurements are carried out to determine the height value and the maximum depth of the underground facility at the Bundaran HI station. This is done by measuring trigonometric leveling referring to control points BHI01 and BHI02, which are located near the station entrance at ground level. Validation of 3D cadastral objects in Bundaran HI station was then followed by measuring distances, areas and volumes of several 3D cadastral objects. This measurement is carried out using Total Station combined with a laser distance meter (Figure 10).

Fig. 10. Validation survey by using Total Station and distometer (Atunggal et al., 2020)

Results of the measurements show that the underground facility at the Bundaran HI station is located from 0-17 meters below the land surface. The height of the lowest infrastructure is at 14.973 meters below MSL. Because the Bundaran HI station is located under a public road, the station which is located from ground level to a depth of 17 meters is in accordance with existing legal provisions, see the illustration (Figure 11). In cases MRT infrastructure is located below land rights which are owned by individuals/companies, it is necessary to ensure that the infrastructure is located below 30 meters or in accordance with the depth limits determined by the site.

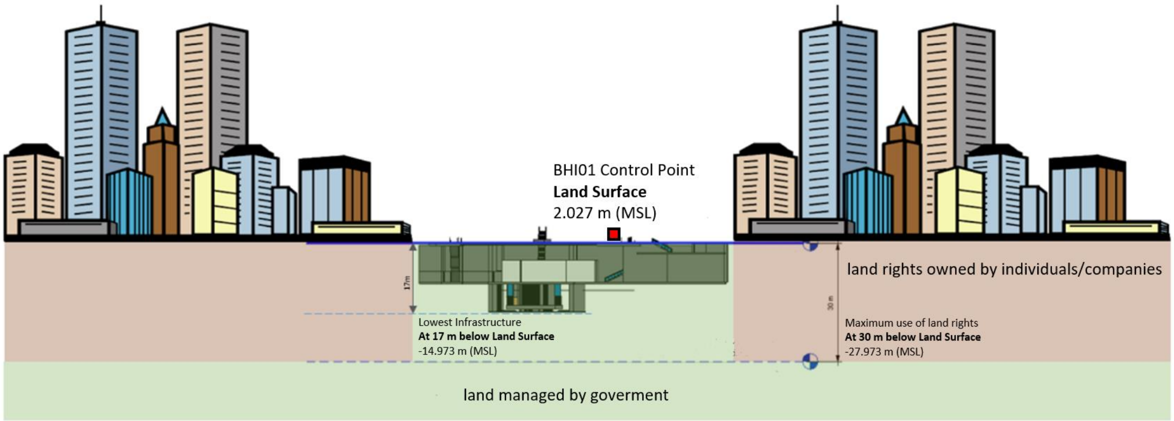


Fig. 11. Illustration of Bundaran HI Station position (Atunggal et al., 2020)

Position validation at Blok M Station is simpler because this 3D cadastral object is located above a public road. From the Total Station measurements, it is known that the maximum height of the building is in accordance with the provisions.

The results of the validation of distance, area and volume at both stations showed promising results. The results from measuring length with the Total Station and diameter with data from the 3D model differ only in millimeters to 1 -2 centimeters. The difference in areas and volumes of validation results with 3D models is mostly less than 2%.

4.2 Evaluation of Positioning Infrastructure in Yogyakarta

In order to illustrate the geospatial infrastructure for 3D cadastre, this paper will also describe relevant findings based on surveys and evaluation of positioning infrastructure in the Special Region of Yogyakarta Province. The total number of horizontal ground survey marks in Yogyakarta is 290 points consisting 15 2nd order control points and 275 3rd order points. BPN produced these ground survey marks from 1994 to 2007. It is necessary to evaluate the number of cadastral ground survey marks that are still reliable to be used as reference points, considering that these ground survey marks are almost 3 decades old. It is necessary to ensure that the control point monument is still in good physical condition and that the surrounding environment has minimum obstructions so that it is conducive to using GNSS observations. Considering the 30 years and the tectonic velocity in Yogyakarta is approximately 2cm/year, the coordinates of the control point and its actual position in the field may differ by up to 54cm. Hence, it is crucial to redefine the coordinates of those control points to SRGI 2013. This would benefit land offices since land parcel mapping will represent its actual position, making it easier to integrate with other geospatial data. The existing vertical ground survey marks and the InaGeoid model in Yogyakarta are also described to picture the current height reference in Yogyakarta.

4.2.1 Horizontal ground survey marks in Yogyakarta

A preliminary survey of 109 ground survey marks sample was carried out. From the results of the preliminary survey, it is identified that 65 control points are still in good condition, 8 control points are physically damaged, and 36 points are missing or cannot be found (see Figure 12). This means that about 60% of the existing ground survey marks can still be used as a control point for cadastral mapping surveys. However, it should be underlined that those 65 control points have varying environmental conditions and obstructions. The number of horizontal ground survey marks that has a minimum obstruction is 45 points.

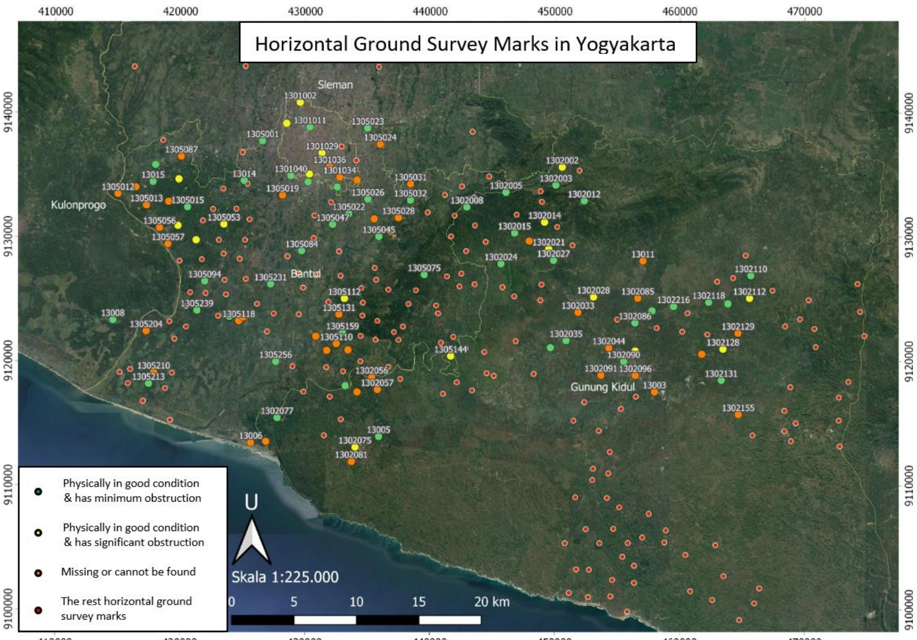


Fig. 12. Horizontal ground survey marks in Yogyakarta

For the purpose of updating the coordinates of cadastral control points in Yogyakarta, static GNSS survey were conducted on those 45 cadastral ground survey marks. The processing of the static GNSS network was done by sciencetific GNSS processing software by referring to zero order control point and CORS in Yogyakarta. Results of the processing produces coordinates of the control points which refer to the SRGI 2013. The accuracy of the results is in the range 1-6cm. This coordinate was then compared with the coordinate values listed on the site log (known as Buku Tugu) when the control points were established. The coordinate shift between the latest processing result (SRGI 2013) and its initial coordinate from the site log (DGN95) range from 0.8-1.5 meters with a systematic shift direction as shown in Figure 13.

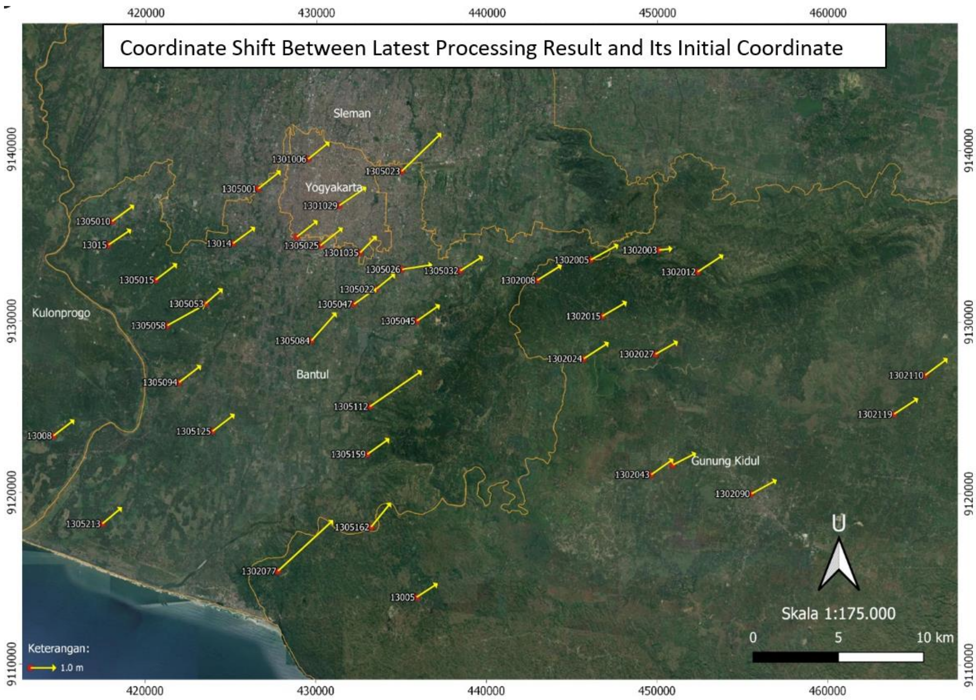


Fig. 13. The coordinate shift between the latest processing result (SRGI 2013) and its initial coordinate from the site log (DGN95)

4.2.2 <u>Height reference in Yogyakarta</u>

A preliminary survey was also conducted to check the availability of vertical survey marks in Yogyakarta. Result of the survey shows that from 22 vertical ground survey marks sample, 16 points are physically still in good condition and the rest of the control points are missing or cannot be found (Figure 14). It means that about 70% of the existing vertical ground survey marks can still be used as height reference for validation survey of 3D cadastral object in Yogyakarta.

As claimed by the InaGeoid online service, the accuracy of the height referencing by using InaGeoid in Yogyakarta is about 5 centimeters. Further investigation needs to be done to verify the consistency of height referencing between vertical ground survey marks and InaGeoid in Indonesia.

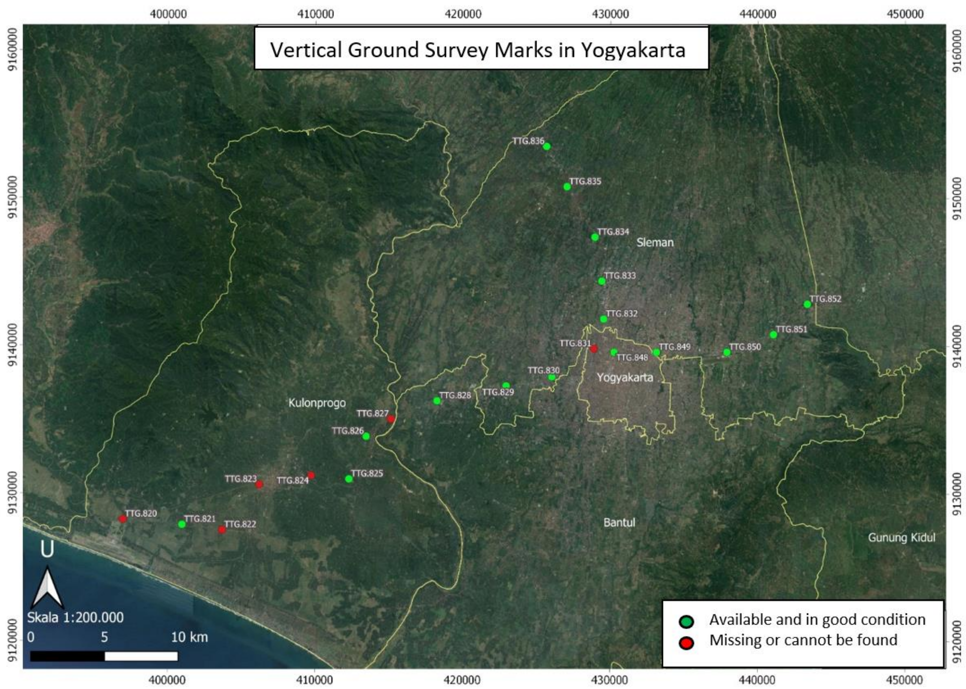


Fig. 14. Distribution of vertical ground survey marks in Yogyakarta

5. CONCLUSIONS AND RECOMMENDATIONS

From this case study, we can conclude that positioning infrastructure plays a vital role in validating the position of 3D cadastral objects below and above ground level. Positioning infrastructure in Jakarta can be used to validate the position, distances, areas, and volumes of 3D units with good results. The use of GNSS heighting refers to ground survey marks, and the determination of height using the InaGeoid online service is different at the decimeter level. However, the availability and reliability of positioning infrastructure in other regions or cities in Indonesia need to be further investigated.

From the evaluation of positioning infrastructure in Yogyakarta, it is identified that the availability of the horizontal ground survey marks is at 60% of its total number and 70% for vertical ground survey marks. Meanwhile, about 30-40% of the ground survey marks are missing or cannot be found on the field. The reduced number of ground survey marks in the field may hinder the implementation of 3D cadastral. Therefore, the Indonesian government needs to increase the number of ground survey marks or increase the number of CORS stations.

The result of the latest processing of horizontal ground survey marks shows that the coordinate shift between the latest processing result (SRGI 2013) and its initial coordinate from the site log (DGN95) range from 0.8-1.5 meters with a systematic shift direction. As claimed by the online service, the accuracy of InaGeoid online height referencing in Yogyakarta is about 5 centimeters. Further investigation needs to be done to verify the consistency of height referencing between vertical ground survey marks and InaGeoid.

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Integration of LADM and CityGML for 3D Cadastre of Turkey

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Key words: LADM, CityGML, 3D Cadastre, 3D City Database, SQL Query

SUMMARY

Representation of Right, Restriction, and Responsibility (RRR) in the 2D cadastral system falls short due to rapid urbanization causing complex infrastructures. Turkish cadastre, as in many other countries, faces difficulties in the daily recording of property transactions such as sales, donations among others. Therefore, it is highly recommended to represent the RRR in 3D Cadastre. The study elaborates on the current RRR in the cadastral system (2D) in Turkey and is proposing a new integrated data model using international standards as Land Administration Domain Model (LADM) and CityGML v2.0 (City Geography Markup Language). We propose an Application Domain Extension (ADE) that extends the LADM and CityGML data model's integration with the legal and administrative concepts defined in Turkish law for cadastral objects. To show the developed model operability, the data was managed in an open-source PostgreSQL database. This paper provides a detailed overview of the Turkish legal cadastral system with the newly developed integrated LADM and CityGML model providing both visualization and standardization within the scope of 3D cadastre and a proposal for its physical realization based on international standards.

Integration of LADM and CityGML for 3D Cadastre of Turkey

Hicret GÜRSOY SÜRMENELİ, Turkey, Mila KOEVA, The Netherlands and Mehmet ALKAN, Turkey

1. INTRODUCTION

Information regarding rights, restrictions, and responsibilities (RRR) on the cadastral parcel should be visualized on the cadastral maps (Kaufmann and Steudler, 1998; Stoter and Oosterom, 2007). However, although most legal systems enable the creation of property rights with 3D boundaries, they create cadastral maps that still mainly rely on 2D-based cadastral systems for current Land Administration Systems (LASs) (Ho et al., 2015; Atazadeh et al., 2016; Kalogianni et al., 2017; Rajabifard et al., 2018). Thus, RRR on the land cannot be adequately represented by LAS. For this reason, very detailed studies of 3D cadastres in a wide range of countries worldwide can be found in the International Federation of Surveyors (FIG) 3D cadastres' best practices book (Oosterom, 2018). In addition, the cadastre 2034 vision, published by ICSM in 2015, suggests that the basic services expected from the cadastre, such as knowing all RRRs, regarding real estate and the creation of the future cadastre in 3D with the policies, models, and standards should be developed (Aien, 2013; Alkan et al., 2020).

3D cadastre is defined as a system where RRRs (legal models) of buildings and properties correspond to their physical models (provision of registered rights above and below the 3D terrain surface) with advanced policies, standards, and models. (Aien, 2013; Alkan et al., 2020; Sürmeneli H.G. et al., 2020). The most efficient standardized model that represents RRR in the land administration system (LAS) field is the Land Administration Domain Model (LADM). It is an ISO standard in 2012; ISO19152:2012 (ISO, 2012), aims to establish a common ontology for RRR affecting land administration and its geometric components. Although LADMs current version provides an international framework for LAS, it is limited to support 3D cadastre since it lacks geometric or topologic representations (Kalogianni et al., 2020). The second edition of the LADM (LADM II) aims is to extend the initial scope of the conceptual model such as valuation information, spatial planning/zoning, linkage of legal objects with physical ones, and support of other legal spaces: mining, archaeology, utilities, etc. Furthermore, the current conceptual model is being improved, including formal semantics/ontology for the LADM Code Lists, more explicit 3D+time profiles, an extended survey, and legal models. (Kalogianni et al., 2020). The 3D cadastre should include 3D spatial objects with their legal and physical 3D representation (Atazadeh et al., 2016; Sürmeneli H.G. et al., 2020). While a legal model is a real or virtual spatial unit with homogeneous RRRs that can be represented in different forms such as text, sketch, point, lines, surface, or 3D volume, a physical model is the structure of the permanent construction such as walls, ceilings, columns, windows, doors and similar architectural elements (Lemmen et al., 2010; Atazadeh et al., 2016; Kalogianni et al., 2020).

Thanks to the advance in technology in geographic information science, 3D cadastral developments have matured in terms of 3D visualization and analytical capabilities. (Kitsakis et al., 2016; Dimopoulou et al., 2018; Su et al., 2019; Kalogianni et al., 2020). Within the scope of these developments, Turkey has made improvements in its cadastral systems in comparison to 2014

(Stuedler, 2014) and 2034 (ICSM, 2015) visions such as in most countries. Turkish cadastre consists of two parts: land registry that represents the legal relationship between people and real properties, and cadastral maps based on 2D geometries with annotations for the concrete land use (Sürmeneli H.G. and Alkan 2018). However, this information is stored independently from the geometry as a separate attribute. There are three basic cadastral objects in the cadastral system: the parcel, the building, and the independent section of buildings (condominium). Registration of the individual units is subject to the Condominium Law, and the rights on the individual units are recorded in a condominium book (Sürmeneli H.G. and Alkan, 2020). Usually, every individual unit owner has full property rights for a part of the building (the condominium unit). Simultaneously, the shared areas (such as staircases and elevators) are held as co-property.

The legal interests currently registered in Turkey's 2D cadastral system are Parcel, Shared property, Right, Easement, Restriction, Registration object, Building, Condominium, Boundary, Survey, and Documents. Especially in the current cadastral system, RRRs are used for 3D representation. RRR represents all kinds of relationships on real estate to which real or legal persons are related. At the same time, there may be some restrictions on real estate. Therefore, the responsibility of the person against real estate is represented in law. So, the representation of RRRs in the 3D cadastre is very important. 3D cadastral work under various institutional projects has been carried out in Turkey. These studies and projects are the Turkish Land Register and Cadastre Information System (TAKBIS in Turkish), and Turkey's National Geographic Information System Project (TUCBS in Turkish). They contribute to the TUCBS project in the context of National Spatial Data Infrastructure (UKVA in Turkish). TUCBS results from technological developments at the national level and involves the creation of a web portal by public institutions and organizations for providing geographic information (Sürmeneli H.G. and Alkan, 2020).

The aim of the current research is to develop a database model that supports the regulation and analysis of 3D land rights, restrictions, and responsibilities for the Turkish Cadastral System. We use the ISO 19152 (ISO, 2012), Land Administration Domain Model (LADM) that represents RRR on the real estate, and the CityGML that represents the physical side of this object for the conceptual model. In addition, the PostgreSQL database development platform is used for the 3D database. The remaining of this paper covers the methodology of the study followed by results, discussion, and conclusion.

2. METHODOLOGY

The methods used in this research combine the two open standards LADM for cadastral information and the CityGML v2.0 for physical models. PostgreSQL is used to develop the 3D databases. Thus, the scope is dedicated to RRRs applications and includes temporal queries for real estate. The methodology that is used for the current research is shown in Figure1.

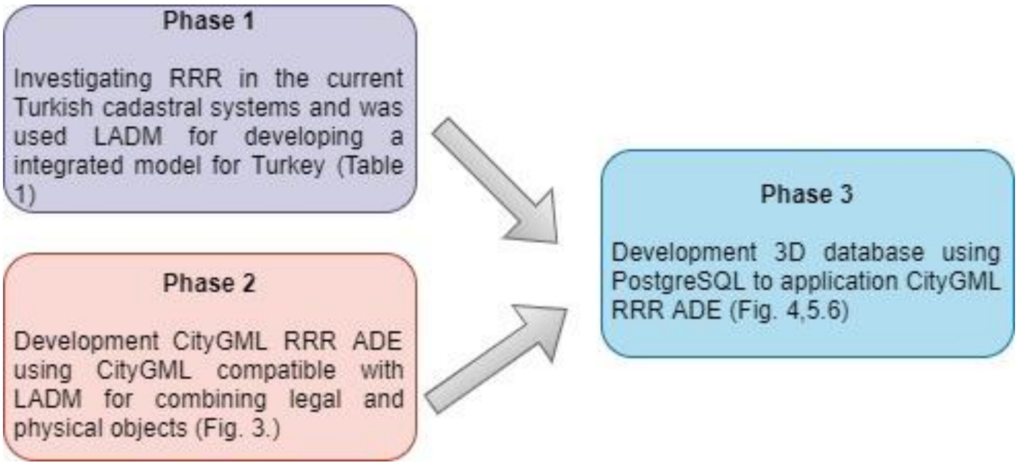

Figure 1. The process steps in the study

2.1 Land Administration Domain Model (LADM, ISO 19152)

LADM that aims to establish a common ontology for rights, restrictions, and responsibilities (RRR) is developed to contribute to Land Administration Systems (LAS). ISO/TC211 has established the LADM intending to standardize geographical information and geo-characteristics (van Oosterom et al., 2006; Sürmeneli H.G. and Alkan, 2020). Thanks to the common ontology of LADM, it enables the communication between related parties within a country or between different countries (Atazadeh, 2017). LADM has three main packages and one sub-package: LA_Party (Party package), LA_AdministrativePackage (Management package), and LA_SpatialUnitPackage (Spatial Unit package), and LA_SurveyingAndRepresentation (Lemmen et al. 2015) (Figure 2).

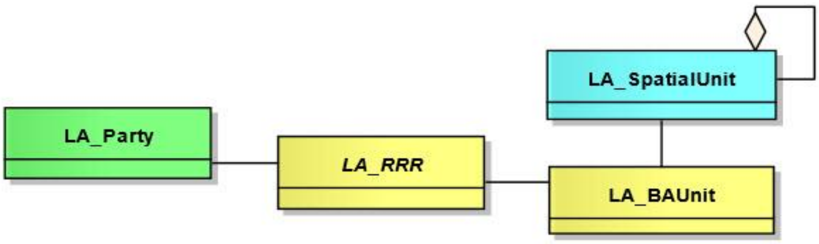

Figure 2. Basic packages of LADM (ISO19152)

It also supports the time component of the Land Administration Basic Model. The most important feature of the model is that it is a flexible model and can be expanded within specified standards. It is possible to associate with external classes such as Valuation, Address, and the Landcover as required by the model feature.

2.2 A General Overview of CityGML

The City Geography Markup Language (CityGML) is an XML-based format, and an open data model for data storage, sharing and maintenance of the virtual 3D city models. It has enabled the exchange of different hierarchies of geographical, topological, and semantic information for 3D representations, and issued by Open Geospatial Consortium (OGC). (Agugiaro et al., 2018). 3D city models in terms of their geometry, topology, semantics, and appearance are represented with basic entities, attributes, and relations by CityGML (Sürmeneli H.G. et al., 2020). CityGML v2.0 provides substantial coverage at the urban scale of buildings, utility networks, energy, and hydrology. Also, it has 10 thematic modules such as Bridge, Tunnel, CityObjects, etc. In addition, CityGML can be extended by the user community for more specialist domains through the Application Domain Extension (ADE) mechanism.

2.3 3D Database Management System (DBMS)

3D DBMS (database management system) offers spatial data types and spatial functions are used to store the 3D data, which is important and necessary for 3D models with large data volume and various data sources. Storing spatial data and performing spatial can be completed with SQL queries. DBMS use widely Oracle Spatial and PostGIS for 3D geometric. The 3D objects can be stored in three forms such as 3D polygon, 3D multi-polygon, and 3D solid (Ying et al., 2020).

The 3D City Database (3DCityDB) has been developed as an Open Source to 3D geo-database solution for CityGML based 3D city models. It has been developed as a platform-independent software suite to facilitate the development and deployment of 3D city model applications. It uses relational database management systems (ORACLE Spatial or PostgreSQL/PostGIS) to import, manage, analyze, visualize, and export virtual 3D city models according to the CityGML standard (Yao et al., 2018).

3. RESULT

3.1 RRRs Profile based on LADM in Turkish Cadastral System

Turkish cadastral system consists of two basic units, including land registration and cadastral mapping (Sürmeneli H.G. and Alkan 2018). Although the use of parcels is volumetric, land parcels and cadastral objects like a building are represented as 2D. The use of volume parcels is provided by the real rights determined in the Turkish Civil Code (TMK, 2001). Also, although the horizontal boundaries of the cadastral parcel are clearly expressed in the law, the definition of the vertical boundary is not sufficient. However, there are several rights set out in the Turkish constitution concerning the third dimension (e.g., easement right) such as RRRs are used to determine the boundary. In Turkey, there are some rights under the constitution relating to the implementation of the third dimension. These rights are classified as easement rights, real servitude rights, and private easement. Types of real servitude, right is right of passage, the right of superficies, right of the source and another easement. Types of private easement rights are the right of usufruct, superficies (residence), the right of construction (construction), a right of resource and other rights. These rights defined in laws are classified in accordance with LADM (Table 1). The rights defined by laws have been classified and adapted to LADM standards. These rights correspond to the RRR package in LADM.

The TR_RRR package is based on the LADM. TR_RRR is an abstract class in which the rights, restrictions, and responsibilities set out in the Civil Code are represented to represent the 3rd dimension. The TR_RRR package has three sub-classes TR_Right, TR_Restriction, and TR_Responsibility (Fig. 3).

The right to property is the right of the owner or legal person to make all kinds of operations, such as the use of property, purchase, sale, rent, etc. The TR_Right class is divided into two sub_classes as mortgage and easement. The easement right is a type of right that gives the right holder the right to use and benefit from that real estate. The type of easement right can be one of the rights types specified in the RightType code list. The mortgage is both a type of right and restriction. Some rights and restrictions may overlap, such as the mortgage.

These restrictions are subdivided into representations (Beyanlar in Turkish), rights and liability (Hak ve yükümlülükler in Turkish), annotations (Şerhler in Turkish), and mortgages in the land register. The representations are recorded in the land register with the topic, which is a transaction, the page number of the land register, and the document number. The mortgage class is the class of information required for the collateral of real estate for a possible debt. The annotation class is part of the disclosure of rights on real estate. It is the class in the declaration class that contains information about any situation related to real estate. The Rights and Liabilities class is the part where the rights such as easement, usufruct, right of access, timeshare property rights are registered to the land register.

The "representation" class contains the attributes necessary for the fulfillment of responsibilities such as tax and maintenance on real estate. There may be at least one or more types of responsibility on real estate.

Table 1 Definitions of the RRRs in the Turkish cadastral system according to LADM

RRR	Definition
Rights	It is the state of being able to make all kinds of transactions on real estate. The person has the Property right and Limited Real Rights on the real estate. The limited real rights are divided into two as Mortgage and Easement.
Restrictions	It is the part where the information is restricting the use of limited real rights in the land register. These restrictions can be listed as representations, rights, and liabilities, annotations, mortgages and easement.
Responsibilities	These are the obligations that an interest holder must fulfill on the real estate.

3.2 Integration of LADM and CityGML for RRR in Turkish Cadastral System

CityGML is standardized by OGC and focuses more on city objects, while ISO has standardized LADM, which focuses on cadastral objects. Both CityGML and LADM were modelled in the Universal Modelling Language (UML). It is more common to see two options for constructing an LADM-based ADE for the CityGML standard. The first option is to create a specific profile of LADM and then implement this profile of LADM as an ADE of CityGML. The second one is to directly implement the fundamental concepts of LADM (Rönsdorff et al., 2014; Góździ et al. 2014; Li et al. 2016; Çağdaş, 2013).

We used the first option for CityGML RRR ADE. CityGML ADE extension is used to represent the RRR on the physically cadastral objects. Thus, the developed new ADE model, which represents RRR on the integrated both legal side and physical side, was done (Figure 3).

So, in the proposed ADE, seven new feature classes and eight sub_classes were added. These classes are TR_Parcel, TR_Building, TR_Condominium, TR_Annex, TR_BuildingUsePart (in green color in Figure 3), TR_SpatialUnit (in blue color in Figure 3) and TR_RRR (in yellow color in Figure 3). The sub_classes are TR_Right, TR_Restriction, TR_Responsibility, TR_Mortgage, TR_Easment, TR_Representation, TR_Annotation, TR_RightAndLiability (in yellow color in Figure 3).

The TR_Party package maintains the basic relationships of LADM as in figure 2. TR_Party package is a class of ownership that corresponds to the LADM Party class in Turkey's Cadastral System. TR_Party class contains the ownership information about the owner of the real estate. Figure 3 shows only the relationship between LADM's administrative package and CityGML ADE.

The SpatialUnit class (in blue color in Figure 3) is the parent class in which all cadastral objects (parcel, building, and condominium) are represented and associated with the other classes (RRR etc.). The TR_SpatialUnit class comprises TR_Parcel, TR_Buildings, and TR_CondominiumUnit. The TR_Parcel are not clearly represented with CityGML, but the OGC specification states that the LandUse class can be used to represent cadastral parcels in 3D (OGC, 2012). The TR_Parcel class is a sub_class of both LADM SpatialUnit, and CityGML LandUse. The TR_Parcel inherits all attributes and relations from the CityGML and LADM. Moreover, it applies to the TR_Bulding class in the same way. The condominium is considered a spatial unit (related to one building). A building can have one or more independent parts. According to the Property Law, the Annex is outside of a condominium. Also, it is referred to directly as allocated to that section. The Annex cannot be registered alone in the land register. Therefore, the type of 0..* (0-lots) relationship is selected between the condominium and Annex.

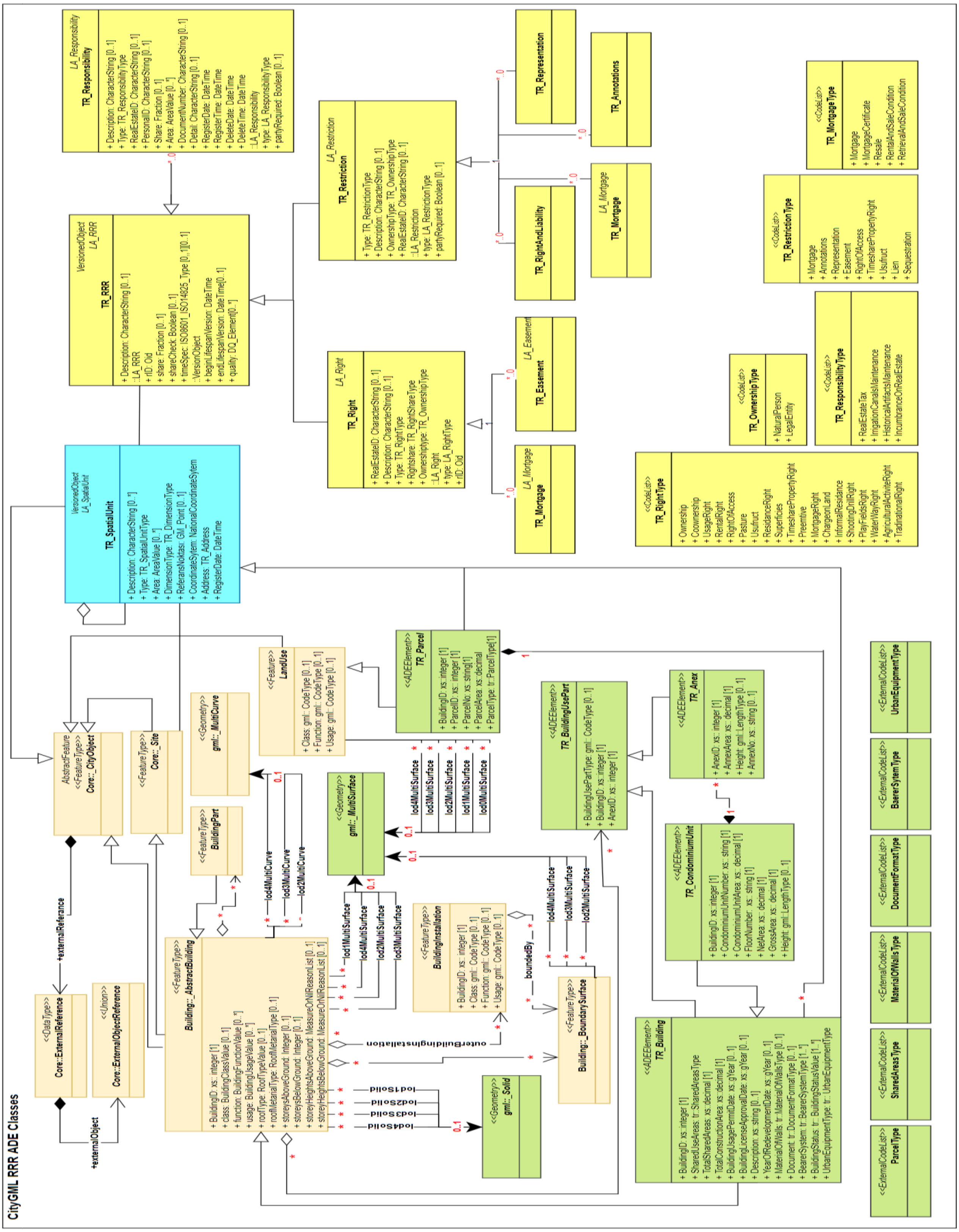

Figure 3. New proposed model for the Turkish cadastral system using, LADM and CityGML combining legal and physical model

TR_RRR (Rights, Responsibility, and Restrictions) is a package in which real or legal persons can represent relationship status on a real estate (Figure 3). TR_Right class represents the right of the owner or legal persons to make all kinds of operations, such as the use of property, purchase, sale, rent, etc. The TR_ Right class is divided into two sub-classes as mortgage and easement. The TR_Restriction class is the part of the information that restricts the use of limited real rights in the title registration, where the restriction information is registered and the information is determined. TR_Restrictions class has four sub_classes; TR_Representations, TR_RightsAndLiability, TR_Annotations, and TR_Mortgages in the land register. The TR_Responsibility class person's obligations are represented. These obligations include paying the tax on the real estate, maintenance, repair, easement according to the type of real estate. There may be one or more types of obligations.

This section has explained the development of an ADE to CityGML for the 3D RRR on cadastral objects for Turkey. The CityGML provides a flexible conceptual model which can easily be adapted to administrative and physical requirements. The research reveals that the CityGML ADE data model, which is supported with legal concepts (RRR) has the potential to be a national data model for 3D cadastre in Turkey.

3.3 3D RRR Queries in a PostgreSQL Environment

CityGML data of 8 real estates from the Sincan region in Ankara were obtained from Sincan municipality for the case study. Then, we integrated data of CityGML and LADM in the PostgreSQL version 13. database. Figure 4 shows the overview of the 3D database procedure packages.

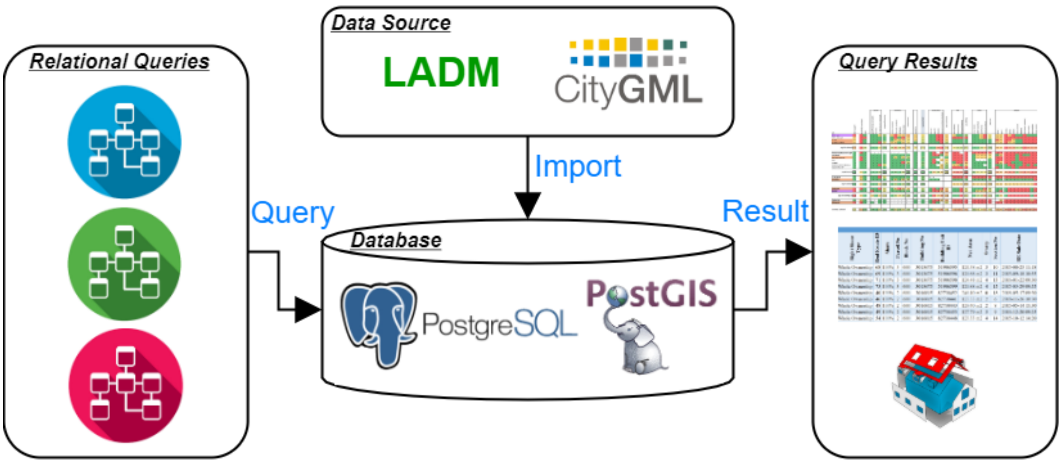

Figure 4. The overview of the 3D database procedure packages

Then, 2 SQL queries were made to test the CityGML RRR ADE model.

<u>Query 1):</u> Showing the mortgaged independent sections between years 2012-2020: The following is the SQL code written to show the mortgaged independent sections within the specified date range.

```
SELECT MT."MortgageTypeText" AS "Mortgage Type",
       M."RealEstateID" AS "Real Estate ID",
```

```sql
       (100 * M."Share" / M."ShareTotal") || '%' AS "Share",
       P."FirstName" || ' ' || P."LastName" AS "Payer",
       PRT."PayeeRoleTypeText" AS "Payee Role Type",
       PC."ParcelNo" AS "Parcel No",
       PC."BlockNo" AS "Block No",
       B."BuildingNo" AS "Building No",
       BU."TakbisPropertyIdentityNumber" AS "Building Unit ID",
       BU."NetArea" || ' ' || BU."AreaUnit" AS "Net Area",
       CG."StoreyNumber" AS "Storey",
       BU."IndependentSectionNumber" AS "Section No",
       M."RegisterDate" AS "Mortgage Start Date",
       M."DeleteDate" AS "Mortgage End Date"
FROM "TR_RightPackage"."TR_Mortgage" M
       INNER JOIN "TR"."TR_MortgageType" MT
             ON M."MortgageTypeID" = MT."MortgageTypeID"
       INNER JOIN "TR_PartyPackage"."TR_Party" P
             ON M."PayerID" = P."PartyID"
       INNER JOIN "TR_RightPackage"."TR_PayeeRoleType" PRT
             ON PRT."PayeeRoleTypeID" = M."PayeeRoleTypeID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_SpatialUnit" SU
             ON M."RealEstateID" = SU."RealEstateID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_BuildingUnit" BU
             ON SU."SpatialUnitID" = BU."SpatialUnitID"
       INNER JOIN "CityGMLPackage"."CityObjectGroup" CG
             ON BU."ParentCityObjectID" = CG."CityObjectGroupID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_Building" B
             ON CG."ParentCityObjectID" = B."BuildingID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_Parcel" PC
             ON B."ParcelID" = PC."ParcelID"
WHERE M."RegisterDate" >= '2012-01-01' AND M."DeleteDate" < '2021-01-01'
```

The above SQL code shows how to write the query to achieve query 1, While fig. 5 shows the result of the query in the TR_Mortgage table.

Mortgage Type	Real Estate ID	Share	Payer	Payee Role Type	Parcel No	Block No	Building No	Building Unit ID	Net Area	Storey	Section No	Mortgage Start Date	Mortgage End Date
Mortgage	64	1	FN015 LN015	İşbankası	3	600	3013675	51906591	124.38 m2	2	6	2013-05-16 16:00	2019-05-17 11:00
Mortgage	71	1	FN013 LN013	Garanti Bankası	3	600	3013675	51906598	124.48 m2	4	13	2012-12-12 12:00	2020-12-14 09:00
Mortgage	73	1	FN011 LN011	Garanti Bankası	3	600	3013675	51906599	120.88 m2	4	15	2012-12-03 12:00	2020-08-03 09:00
Mortgage	80	1	FN022 LN022	Ziraat Bankası	1	1100	3018678	3354122	23.37 m2	1	22	2015-06-05 10:00	2020-07-05 10:00
Mortgage	87	1	FN025 LN025	Garanti Bankası	1	1100	3018678	3354050	83.55 m2	2	5	2014-03-02 11:00	2020-03-02 11:00
Mortgage	94	1	FN016 LN016	HalkBan k	1	1100	3018678	3253059	82.76 m2	4	12	2014-07-14 11:00	2020-07-14 11:00
Mortgage	139	1	FN021 LN021	YapıKred i Bankası	3	1100	3157372	5333375	89.71 m2	2	7	2012-06-21 14:00	2020-04-21 14:00
Mortgage	140	1	FN007 LN007	İşbankası	3	1100	3157372	5333376	89.71 m2	2	8	2012-03-15 13:00	2020-01-15 13:00

Figure 5. Data query TR_Mortgage table using QGIS, there are mortgages in 8 real estates

Query 2): Showing the sold real estates with an area of more than 120 m2 between the years of 2015-2021: In query 2, both the real estate sold within a certain date range (2015-2021) and those real estates are requested to be larger than 120 m^2.

```
SELECT RST."RightShareTypeText" AS "Right Share Type",
       RR."RealEstateID" AS "Real Estate ID",
       (100 * RR."Share" / RR."ShareTotal") || '%' AS "Share",
       PC."ParcelNo" AS "Parcel No",
       PC."BlockNo" AS "Block No",
       B."BuildingNo" AS "Building No",
       BU."TakbisPropertyIdentityNumber" AS "Building Unit ID",
       BU."NetArea" || ' ' || BU."AreaUnit" AS "Net Area",
       CG."StoreyNumber" AS "Storey",
       BU."IndependentSectionNumber" AS "Section No",
       RR."RegisterDate" AS "RE Sale Date"
FROM "TR_RightPackage"."TR_RealRight" RR
       INNER JOIN "TR_RightPackage"."TR_RightType" RT
             ON RR."RightTypeID" = RT."RightTypeID"
       INNER JOIN "TR_RightPackage"."TR_RightShareType" RST
             ON RR."RightShareTypeID" = RST."RightShareTypeID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_SpatialUnit" SU
             ON RR."RealEstateID" = SU."RealEstateID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_BuildingUnit" BU
             ON SU."SpatialUnitID" = BU."SpatialUnitID"
       INNER JOIN "CityGMLPackage"."CityObjectGroup" CG
             ON BU."ParentCityObjectID" = CG."CityObjectGroupID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_Building" B
             ON CG."ParentCityObjectID" = B."BuildingID"
       INNER JOIN "TR_SpatialUnitPackage"."TR_Parcel" PC
             ON B."ParcelID" = PC."ParcelID"
WHERE RR."RegisterDate" BETWEEN '2015-01-01' AND '2021-12-31 23:59:59'
      AND RR."Description" = 'Satış'
      AND BU."NetArea" > 120
```

The real estates that respond to the requirements as a result of query 2 and their information are shown in the result table.

Right Share Type	Real Estate ID	Share	Parcel No	Block No	Building No	Building Unit ID	Net Area	Storey	Section No	RE Sale Date
Whole Ownership	68	1	3	600	3013675	51906595	124.38 m2	3	10	2015-08-25 11:18
Whole Ownership	69	1	3	600	3013675	51906596	120.88 m2	3	11	2015-09-18 10:55
Whole Ownership	71	1	3	600	3013675	51906598	124.48 m2	4	13	2016-01-22 09:30
Whole Ownership	73	1	3	600	3013675	51906599	120.88 m2	4	15	2015-03-29 09:55
Whole Ownership	40	1	2	600	3016815	82738452	246.10 m2	0	18	2018-05-17 09:30
Whole Ownership	46	1	2	600	3016815	82738441	123.33 m2	2	6	2018-11-26 10:30
Whole Ownership	48	1	2	600	3016815	82738443	129.40 m2	2	8	2015-05-14 15:30
Whole Ownership	49	1	2	600	3016815	82738453	127.79 m2	3	9	2016-12-20 09:25
Whole Ownership	54	1	2	600	3016815	82738448	123.33 m2	4	14	2015-10-12 14:20

Figure 6. Data query result table using QGIS, there are 9 real estate that has an area of more than 120 m^2

4. DISCUSSION AND CONCLUSION

The cadastral system should introduce the 3D definition of cadastral objects in Law Regulations, establishing legal instruments to subdivide, consolidate and manage a 3D real property where needed. Cadastral procedures should be defined for the coordination and relationship between involved parties and RRR using international standards such as LADM. It is challenging to represent RRR on the real property completely by 3D cadastral models. To generate a 3D cadastral model profile is necessary to store and integrate cadastral data with physical models at the conceptual level and the geometric level visualising in 3D. When modelling a legal interest (RRR), two points should be considered: the legal interests spatial structure and its attributes. An integrated model should be used to represent the physical provisions of legal interests. The LADM is used to create 3D terminology and establish a common ontology for the legal side. Thus, it enabled introduction to the Turkish cadastral system in national and international platforms during the transition to 3D cadastre with its legal aspects.

The most important factor in choosing CityGML instead of BIM (Building Information Model) in this study is the creation and storage of cadastral objects in CityGML format within the scope of digitalization studies in Turkey. Objects which can be subject to cadastre (energy transmission lines, transportation, utility, etc.) produced by different institutions are also created in CityGML format. There are overlapping attributes when matching LADM and CityGML packages in the study. We preferred physical attributes to be represented in CityGML packages instead of LADM packages. Because the physical properties of objects produced by different institutions are stored in CityGML format. Thus, it is easy to integrate all objects and share data with each other from different institutions. Also, CityGML data from the study area were created according to TAKBIS (Turkish Land Registry and Cadastre Information System) and TUCBS (Turkish National Geographic Information System) standards that are national projects. Thus, the proposed ADE is at a level that can be integrated into national projects. The data of the integrated model created was stored in the open-source PostgreSQL database. With the help of the integrated data, RRRs on real estate can be queried spatially by SQL querying. In this context, two important outputs were developed for this study. The first one is the development of the 3D RRR conceptual model for the Turkish cadastral system using, LADM and CityGML combining legal and physical and the second one is the development of a 3D database design that allows editing and querying of RRR.

This study proposes a general framework for integrating cadastral information with LADM on the legal objects and CityGML on physical objects. Basic requirements for generating a 3D RRR for Turkey are presented from current cadastral objects with legal and physical perspectives. From the Turkish cadastral system, a case study was used to implement and evaluate the use of 3D digital models to represent cadastral boundaries and RRR on the 3D property units. The LADM model was connected to CityGML to generate an integrated 3D cadastral model at the conceptual level. Then, database design was carried out with PostgreSQL based on the conceptual model. This study's main contributions are the modelling of the requirements from legal and physical perspectives and the general framework and application for integrating LADM and CityGML for 3D cadastral models to support these requirements. Furthermore, the newly developed CityGML RRR ADE is valuable for the Turkish cadastral system and can be used as the basis for a 3D national data standard.

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Utilities Data in Land Administration Systems

Grgo DŽELALIJA and Miodrag ROIĆ, Croatia

Key words: 3D Land Administration System, utility network registration, authoritative data, 3D Cadastre

SUMMARY

With growing urbanization and population, management of space and land has become vital part for sustainable growth and development. Additional to urbanization and population growth, industrialization is another factor for rising need for various utilities such as sewage network, water supply, electricity etc. In such conditions, knowing where one can install new underground or overground infrastructure, without destroying existing lines, becomes more and more of a challenge. The need to connect new suburbs to existing infrastructure requires knowledge of availability. Legal issues in relation to utilities are also becoming increasingly important.

Different countries and societies will have various approach to solving certain challenge, same goes for challenge of utility network registration. Some countries register utilities as separate objects with unique cadastral numbers in land administration while others register only easements. Some countries have centralized approach with high government regulations while in other utilities are registered on municipal level or even administered only by private companies.

In this paper different approaches to utility network data management are analyzed. In all countries, utilities data is maintained by their managers sometimes with the help of very sophisticated applications.

Utilities Data in Land Administration Systems

Grgo DŽELALIJA and Miodrag ROIĆ, Croatia

1. INTRODUCTION

Since industrialization and urbanization periods have started, population density increased, as well as the need for various utilities such as sewage, water supply, gas, electricity, communication network and more. With increasing number of various utility cables, pipelines and tunnels, knowing where one can install new underground, underwater or over-ground utility becomes more and more of a challenge. Nowadays, with rapid urban development, population growth and scarcity of space proper administration of land is only more important than ever (Lemmens, 2011).

Land administration is considered to be the process of recording and dissemination of information about ownership, value and use of land and associated resources. Proper land administration system has many benefits for both individual and community, such as security of ownership and tenure, support for land taxation, security for collaterals, reducing land disputes, improve urban planning and infrastructure development etc. (UNECE, 1996).

With introduction of computers and their abilities, during 1990s, land administration is further consolidated as separate discipline. Land administration is considered an operational component of land management paradigm with functions to ensure appropriate management of rights, responsibilities and restrictions in relation to land. Specifically, functions of land administration related to land tenure, use, value and land development, which includes utility and infrastructure planning and development (Williamson et al., 2009).

Every type of society can have different approaches for dealing with challenges. When it comes to utility administration, we have two different approaches, centralized and decentralized. In former communist countries there is authoritative approach with national frameworks and sets of laws regulating utility administration and utility cadastres on national level, while in western countries responsibility for utility administration is on companies that own infrastructure, or in some cases on local authorities (Roić, 2012).

Republics from former Yugoslavia were part of eastern, or authoritative, approach to utility administration. Therefore, those countries passed utility cadastre regulations on national level. Utility cadastre regulations were concerned only about technical data and they are missing framework for legal relations on utilities, such as rights, restrictions and responsibilities. Through years, laws were occasionally renewed and updated, but never fully implemented (Bulatović, 2011).

In most of the world each infrastructure owner had separate and independent utility register, with data necessary for their own operations. In western countries, with rising number of infrastructures, communal infrastructure systems were created by connecting those separate utility registers. Those utility registers were connected either simply through call centers or similar services for data sharing, mostly on municipality level (Roić & Mastelić-Ivić, 1993).

This paper analyzes and reviews various approaches to utility registration around world. Next chapter is a brief retrospection on various research on the topic of utility registration, third chapter analyses FIG's questionnaires conducted on 3D cadastre workshops, concretely questions regarding utility and network registration in land administration systems. While forth chapter reviews general approaches to utility registration in different jurisdictions.

2. RESEARCH ON UTILITY REGISTRATION

Despite utility networks being relatively new phenomenon, their rising numbers represents growing issue. Indeed, insufficient information about location and depth of underground utilities could lead to damage during excavation followed by accidents and financial losses. For instance, US Pipeline and Hazardous Materials Safety Administration reported eight fatalities, 27 injuries and total loss of around 160 million US dollars due to excavation damages from 2017 – 2019 (PHMSA, n.d.). For many years the legal status of utility networks was uncertain, as the rule of vertical access for land ownership applied. In 2003, Dutch Supreme Court ruled that underground lines are immovable and as such registered property (Stoter & van Oosterom, 2006).

Many studies have been conducted on the topic of 3D cadastre and challenges of registering utility networks. In general, it seems that countries have different approach to utility registration. Van Oosterom et al. (2011) presented the survey conducted by FIG joint commission. The purpose of the survey was to show statuses of 3D cadasters in world. In the context of utility registration, it was shown that there are differences regarding registration of utilities between countries, with some countries like Netherlands and Switzerland including utilities in cadastral databases, some dedicating utility maps, and some, like Croatia, having utility registers and some register utility networks only as rights on parcels. It was also shown that different utilities are registered in different countries, with Turkey being an example of country having only high-voltage power lines registered. In another study, Döner et al. (2010) compared physical and legal components of utility registrations in three countries.

The Netherlands, Turkey and Queensland Australia, with three different approaches to utility registration. They showed that registration of utility networks as only rights on cadastral parcel crossing is simply not sufficient enough to easily determine the location of given utility line. In later study, they also distinguished and overviewed three alternatives to register utility networks in cadastre, including linking to the documents with geometry attributes of physical infrastructure, copying geometry attributes of physical infrastructure and referring to external registers of utility networks, respectively. The third alternative showed to be the optimal solution because that way attributes of physical infrastructure would be maintained at their source by utility network owners (Döner, Thompson, et al., 2011). Pouliot et al. (2015) conducted an experiment with end-users of FITNO register, relevant to utility infrastructure registered in Quebec, Canada. It was shown that these end users preferred simple solution with easy access to most important information and a link to essential cadastral information. Additionally, there is a paper based on doctoral dissertation (Mader et al., 2015) dealing with the challenges of linking and compatibility between different registers in Republic of Croatia. Similarly, Lee et al. (2015) suggested 3D Korean LADM country profile which could allow registration of 3D objects such as utility networks and buildings and ensure compatibility between cadastre and other registers. Another doctoral dissertation (Vučić, 2015) further confirmed the shortcomings of a 2D cadastre model for representation of utility networks and buildings, and once again proposed the 3D model for gradual transition from 2D to 3D cadastre. Yan et al. (2018) proposes initial version of 3D data model of utility networks based on LADM and data acquired from ground penetrating radar (GPR). In Republic of Serbia, researchers have proposed extension for utility networks of their country profile, based data from GPR and LIDAR (Radulović et al., 2019).

One of the main roles of cadastre is to keep record of rights, restrictions and responsibilities on land parcels, such as right of ownership or easement. Utility networks physically intersect land parcels and with that converge with rights on them. For that reason, it would be logical to keep record of utilities in public register so that it can be accessed by all concerned parties. Keeping record of utility networks in a register together with land parcels would be easier and more consistent in a full 3D cadastre. However, since many registers do not have 3D properties, it would be more practical to register utility networks and land parcels separately but with unambiguous link between them (Pouliot & Girard, 2016).

Döner et al. (2010) analyzed and showed that certain implementation of 4D cadastre is possible from legal, technical and organizational perspective. They considered three alternatives, creating a link between parcels and information on utilities, copying complete geometry of utilities into cadastre and finally, creating legal space in cadastre with references to the geometry of physical utilities in external registers. With case study on data from Municipality of Rotterdam the conclusions were that third alternative would be the best solution.

3. QUESTIONNAIRES ON UTILITY REGISTRATION

Several questionnaires were conducted by the FIG joint commission during 3D Cadastre workshops on the topic of status of 3D Cadastres in participating jurisdictions where a special chapter was on registration of utility networks. First questionnaire was conducted in 2010 and was completed by 36 jurisdictions (van Oosterom et al., 2011). Second questionnaire was conducted in 2014 and was completed by 31 jurisdictions (van Oosterom et al., 2014). Finally, third questionnaire was conducted in 2018 (Shnaidman et al., 2019). In 2010 survey, questions about infrastructure or utility networks were whether jurisdictions register networks as an entity in the land administration, can the network structure be traced in the database, does the jurisdiction have private networks, are private networks registered as 3D property parcels, is the text of relevant laws or regulations available in original language, is the text of those laws available in English, do jurisdictions have example descriptions of typical 3D parcels for networks, how do they deal with intersecting networks or vertically parallel networks if the network object breaks at the surface parcel, and whether they have any other geometric issues related to the registration of networks. In 2014 and 2018 questionnaire, second question was extended with three more sub-questions: whether jurisdictions can view network structure graphically in their land administration, are networks registered by means of a cadastral identifier and are rights, restrictions and responsibilities (RRRs), and parties attached to those network objects.

Results from those FIG's questionnaires were analyzed, specifically answers to aforementioned questions about infrastructure and utility networks. For each participating jurisdiction last questionnaire was taken into consideration. In total, 46 jurisdictions participated, with 36 administrative units having taken last questionnaire in 2018, four jurisdictions in 2014 and eight more jurisdictions back in 2010.

First question was whether networks are registered as entity in land administration (Figure 1). 16 jurisdictions answered that they do not register networks as an entity in land administration, 14 jurisdictions answered that they do register networks as entities in land administration with additional two countries, Argentina and Costa Rica, stated that they register networks as entities in land administration only in some cases. Former Yugoslav countries, Croatia, Serbia and Slovenia have separate utility cadastre for registering networks. Additionally, 11 jurisdictions answered that they only register easements or tunnel spaces of networks. In conclusion, 41% of questioned jurisdictions at least in some cases registers utility networks in their land administration systems. Easements or tunnel spaces of utility networks are registered in 24% of jurisdictions, while 35% jurisdictions do not register utility networks in any form in their LAS.

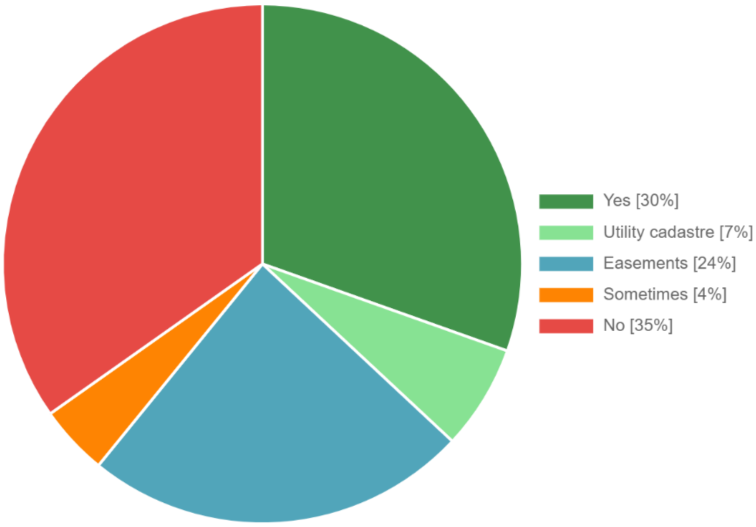


Figure 1. Answers to question 2.1 Do you register networks as an entity in the land administration?

Out of the 19 jurisdictions that at least in some cases register networks as entities in land administration, seven of them can view network graphically in the land administration, can trace network structure in database, have networks registered by means of cadastral identifier and have rights, responsibilities and restrictions, as well as parties attached to concerned network objects (Figure 2). Three countries have three out of those four questions answered with yes or in some cases, with Trinidad and Tobago not having RRRs and parties attached to network objects, and Poland and Argentina not registering networks by means of cadastral identifier. Additionally, in some Swiss cantons network can be viewed graphically in LA and network structure can be traced in database, Scotland can view networks graphically in LA and registers networks by means of cadastral identifier. Two more countries have one question answered with yes, Slovenia can only trace network structure in database while Croatia has only RRRs and parties attached to network objects. Finally, at least in some cases 69% of jurisdictions can view network graphically in the land administration, 74% can trace network structure in the database, 47% have networks registered by means of cadastral identifier, while 53% have RRRs and parties attached to network objects.

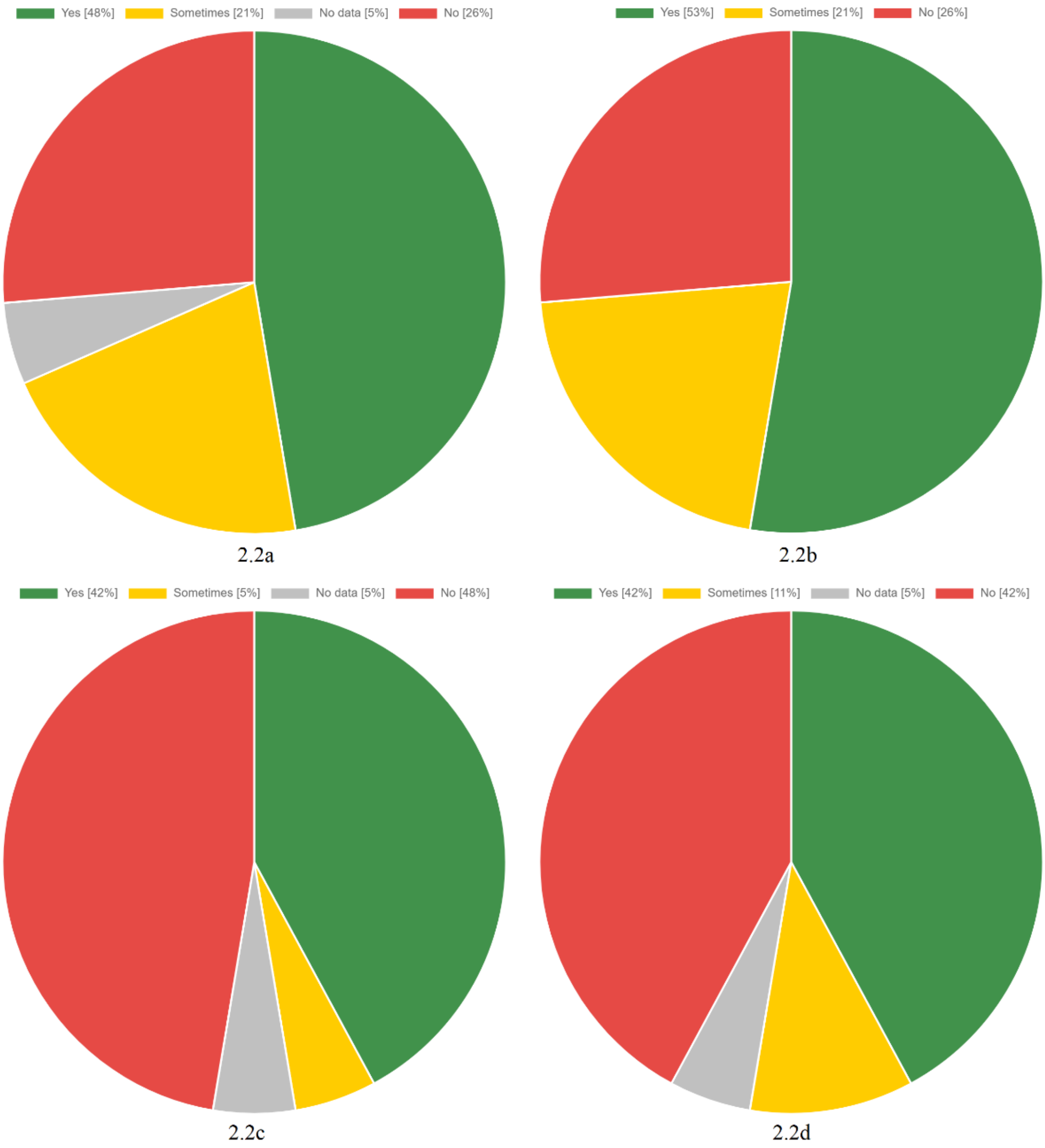


Figure 2. Answers to questions 2.2a Can the network structure be viewed graphically in the land administration?, 2.2b Can the network structure be traced in the database?, 2.2c Are networks registered by means of a cadastral identifier? and 2.2d Are RRRs and parties attached to these network objects? from jurisdictions that register networks as entities in land administration.

Out of the 11 jurisdictions that only register easements or tunnel space of networks in land administration, only Cyprus and Kenya can view easement structure graphically in land administration, can trace structure in database, do register easement objects by means of a cadastral identifier and have RRRs and parties attached to those easement objects. Australian state Victoria doesn't have RRRs and parties attached to easement objects but fulfils other three out of four questioned capabilities. Turkey, New Zealand and Finland have two out of the four questions answered with yes, while Greece has only RRRs and parties attached to easement objects. Additionally, Kazakhstan and Russia had their last questionnaire back in 2010, so they had only question whether network structure can be traced in database included in their questionnaire, which they answered with yes (Figure 3). Results are somewhat lower with jurisdictions that register only easements in LAS, with 46% of jurisdictions can view network graphically in the land administration, 55% can at least in some cases trace network structure in the database, 46% have networks registered by means of cadastral identifier, while 36% have RRRs and parties attached to network objects.

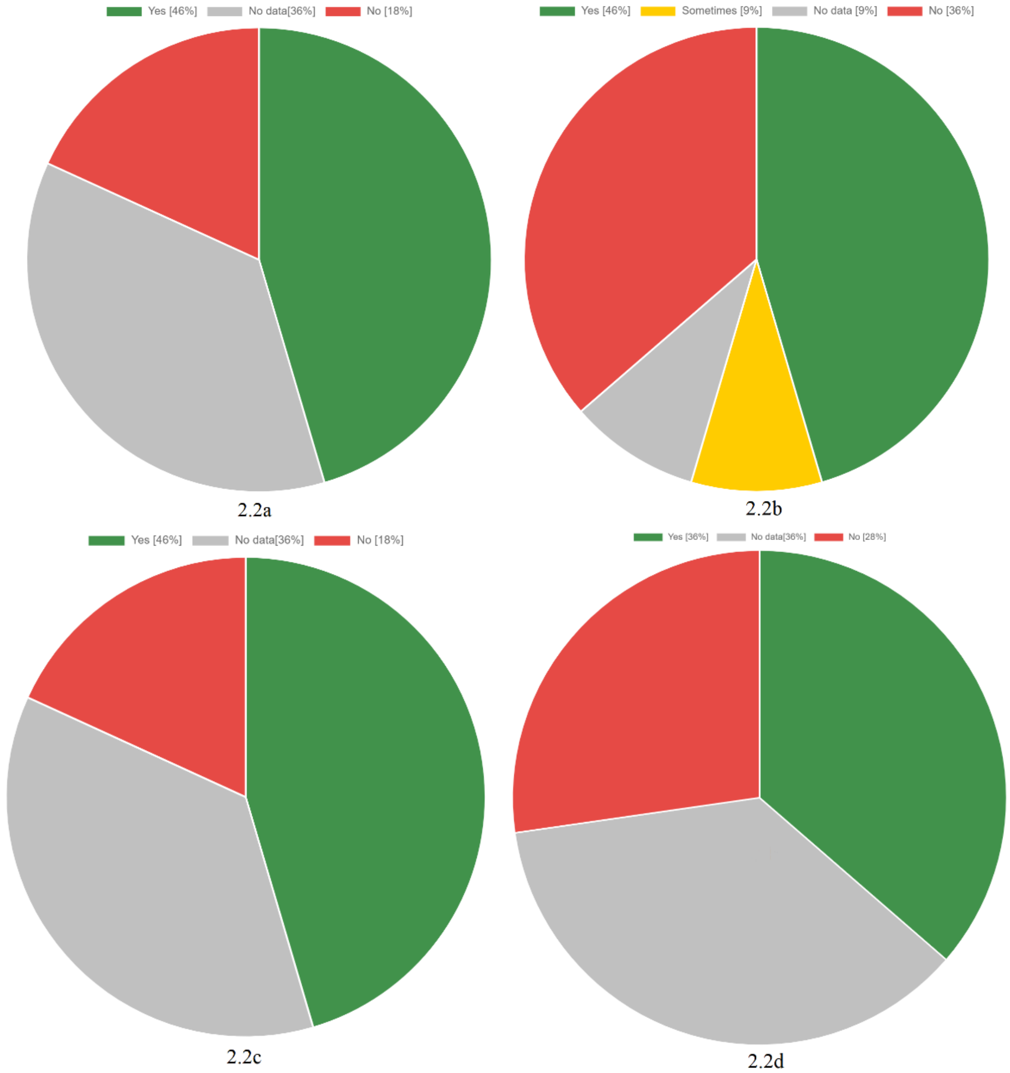
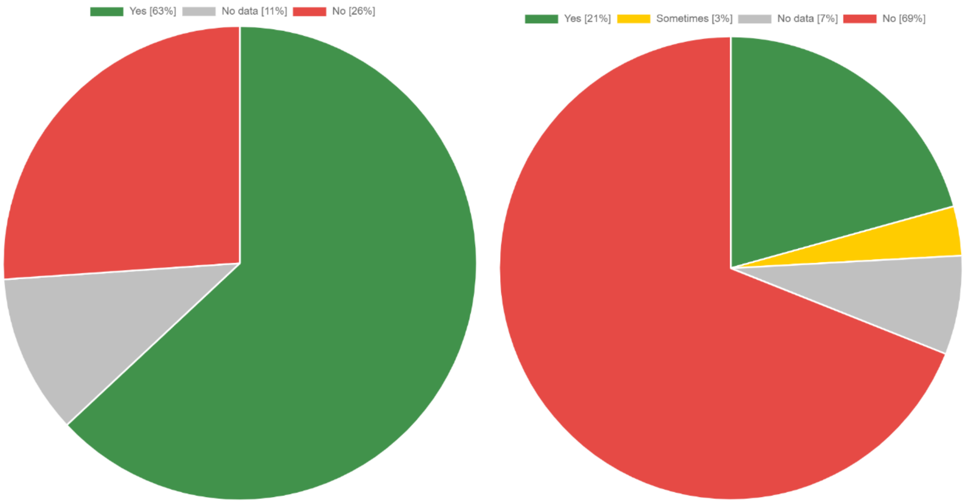


Figure 3. Answers to questions 2.2a Can the network structure be viewed graphically in the land administration?, 2.2b Can the network structure be traced in the database?, 2.2c Are networks registered by means of a cadastral identifier? and 2.2d Are RRRs and parties attached to these network objects? from jurisdictions that register easements of networks in land administration.

When it comes to private networks, 29 questioned jurisdictions, or 63% of them have private networks. Out of those 29 jurisdictions, only six of them register private networks as 3D property parcels, while Croatia registers them sporadically as charges in Land book (Figure 4).



2.3 2.4

Figure 4. Answers to questions: 2.3 Does the jurisdiction have private networks, and 2.4 Are private networks registered as 3D property parcels?

About half of questioned jurisdictions, or 26 of them, have texts of relevant laws and regulations available in their original language. Additionally, 13 of them have laws available in English, while Switzerland and Greece have few of the relevant laws translated to English as well.
Out of 46 total jurisdictions, only 26% stated that they have example descriptions of typical 3D parcels for utility networks, mostly prototypes.

When it comes to challenges of dealing with intersecting or vertically parallel network legal objects if they break at the surface parcel, most jurisdictions state that they treat networks as continuous and independent objects, usually registered separately. Some jurisdictions show networks and their overlaps in 2D with possibilities of manual checks. As for geometric issues related to the registration of networks most jurisdictions that answered the question state that networks are registered as 3D lines, while The Netherlands and Greece stated as an issue that complete geometry of networks is not registered in cadastral system.

Although utilities registration is very diverse, two general approaches can be distinguished. These would be national utility cadastres and other approaches in which a small part of the data on utilities is registered in the existing registers, the companies are the ones that manage most of the data.

4. GENERAL APPROACHES TO UTILITY REGISTRATION

Pipelines and cables of various utility networks, such as sewage, power supply, heat supply, water supply and electronic-communication networks, just to name the few, are crucial infrastructure of any modern city. And as such, administrating utility networks has always been a challenge, due to various issues like insufficient documents and fast industrialization (Du et al., 2006). There are several ways to classify utility registrations, for example (Stoter & van Oosterom, 2006):

- by degree of responsibility, with complete state mandate or shared public and private responsibility
- by location and jurisdiction, with centralized or decentralized approach.

Considered that there are no national regulations for utility registrations in western world, either local governments, or sometimes even only utility owners, are responsible for updating records, with call centers providing the data. In contrast to that, in former socialist countries, such as former Eastern Bloc countries, utility registration is defined by national laws and regulations and usually kept by state (Stoter & van Oosterom, 2006).

4.1 National Utility Cadastres

Approach of national utility cadastres is mainly driven by idea that data about infrastructure should be authoritative. Authoritative data is considered to be most current and accurate, that data can also be verified and certified by authority (FGDC, 2009).

Among the members of EuroGeographics poll and workshop were conducted on the topic of authoritative data. Conclusions showed that countries consider that public organizations and governments should have central role in authoritative data but also showed that they have different viewpoint on which data should be authoritative (Crompvoets et al., 2019). On the other hand, spatial data available in Land administration systems should be accurate, assured and authoritative, or in other words it should be highly accurate, with high integrity and guaranteed by government (Williamson et al., 2012).

In the second half of the 20th century, questions regarding measuring and managing data of public utility infrastructure began to be raised in the territory of former SFR of Yugoslavia. At the 1967 consulting session in Split, present day Croatia, on the topic of surveying and recording of underground utility installations and facilities, some important conclusions were reached. Two years later, they served as the basis of the Rulebook on Methods and Mode of Operation in Surveying of Underground Installations and Objects (Pacadi et al., 2013).

Through next decades, numerous laws and rulebooks concerning utility registration have been passed in Yugoslavia, and subsequently in Croatia. Those laws and rulebooks proscribed and changed what utilities should be registered in utility cadastre, what data that should be kept in utility cadastre, as well as who has the jurisdiction over utility cadastre. However, to this day, no order and systematic management of data on public utility infrastructure have been introduced and only piles of elaborates are accumulating in cadastral offices without further processing into utility cadastre (Blagonić, 2012).

As in other former eastern bloc countries, in Slovenia registration of public infrastructure is regulated by the law. Furthermore, the Surveying and Mapping Authority of the Republic of Slovenia provided the way in which public infrastructure will be administered and maintained.

Organizing model is divided into three levels (Bitenc et al., 2008):

- The Consolidated Cadastre of Public Infrastructure, which includes only basic information about infrastructure, and is managed by the Surveying and Mapping Authority of the Republic of Slovenia (state level).
- Cadastre of Public Infrastructure, which is managed by local municipalities.
- Operative cadastre managed by infrastructure owners.

Excavators do not have to seek for approval for digging, but in case of changes in their infrastructure, they are obligated by law to forward data about new or changed infrastructure to cadastre of public infrastructure and further in consolidated cadastre of public infrastructure. Public infrastructure included in infrastructure cadastre are traffic infrastructure, energy infrastructure, public utilities, electrical communication networks and others (Šarlah, 2010).

4.2 Other approaches to registration?

Western countries went with different approach and let infrastructure owners to keep their own utility databases. With only intermediating through the distribution of the data. Like most eastern countries, there are state level regulations for administrating and maintenance of public infrastructure also in China. There, National Bureau of Construction provides policies and regulations, and data about public infrastructure is handed to the National or Urban Construction Archive. Owner must send the excavation request to the Municipal Bureau of Urban Planning (MBUP) and to the Municipal Administration Commission (MAC) for the approval. Both MBUP and MAC check the files from National or Urban Construction Archive and determine if excavation is feasible. After MBUP and MAC approved the request, excavator sends those two admissions and implementing report to Municipal Bureau of Construction, which finally gives the construction license and guidelines for excavation. During the construction of infrastructure, surveying is done, and data are then stored in Urban Construction Archive. Public infrastructure includes energy infrastructure, public utilities and electrical communication networks (Bitenc et al., 2008).

On the other hand, Sweden belongs to the western type of infrastructure administration, where there are no regulations for administration and maintenance of public infrastructure, and infrastructure is not registered on national level. Infrastructure owners are not even obligated to manage data end keep record about their own infrastructure. Since it proved useful and money saving for excavators to have an easy access to data public infrastructure, some municipalities have started initiatives to collect data about public infrastructure in one place, so anyone concerned can access it easily. Those municipalities organized services, like Grav in Gavle, to which excavator can send a request for digging. The request is then sent to all registered infrastructure owners, who enter restrictions and necessary information for digging next. Services are optional, and infrastructure owners are free to collect needed information in any other way (Bitenc et al., 2008).

In United States of America, there is a service named Call Before You Dig, with special call center for each state. In all states it is mandatory to contact the call center few days before digging. Request is then sent to all concerned infrastructure owners who send locators to mark the pipelines in requested area (Before You Dig | Call811, n.d.).

Similarly, Canada has toll-free one-call number for each province. After contacting call center, call operators will help locate pipelines within two to three days. Both excavators and pipeline operators are responsible for protecting workers, public and environment. Excavators are responsible for contacting call centers and identifying locations of pipelines before digging, while pipeline operators are responsible to construct pipelines in accordance with regulations as well as responding to requests for identifying pipeline locations (PREVENTING PIPELINE DAMAGE Canadian Energy Pipeline Association Our Challenge, n.d.).
In Republic of Turkey there is no organized registration on national level, but it is regulated by law to establish AYKOME if municipality has more than 500.000 people. AYKOME keeps records, provides information and determines when and if the excavation can take place (Döner, Demir, et al., 2011).

Finally, in The Netherlands, private institute, Cable and Pipeline Information Centre (KLIC) was established in 1980s. Excavator could, but was not obligated to, contact KLIC, who would then forward the request to concerned infrastructure owners in area. Infrastructure owners would send back their maps and information about infrastructure in requested area. In 2008, Netherlands' parliament passed an act which transferred KLIC service to the Netherlands' Cadastre and enforced infrastructure owners to participate in the system (Stoter & van Oosterom, 2006).

5. CONCLUSION

From previous research on the topic of utility registration or 3D cadastre, as well as from questionnaires conducted on FIG-s 3D cadastre workshops, we could observe that there are different situations of utility registration around the world. With approaches varying from some jurisdictions having complete governmental responsibility on utility registration, to some jurisdictions having few to no regulations concerning utility registration. In some jurisdictions all utilities are owned by state or state-owned companies, while in others we have private owned utilities.

In most jurisdictions some of main incentives for utility registration are safety and accident prevention. When it comes to legal aspect of utilities, their impact on rights on cadastral parcels that they cross is recognized, usually only in the form of easements. Contrarily, their own legal status and value is rarely recognized. They are still rarely registered as property parcels.

Some noticed shortcomings of the questionnaire were unanswered questions and differences in interpretation of given questions. Some of those shortcomings could be reduced by defining some questions in more detail or by giving precise examples. Also, for the further research, some additional questions could be added to questionnaire for the purpose of showing efficiency among general approaches to utility network registration.

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BIOGRAPHICAL NOTES

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3D Zoning: A Missing Piece to Link Planning Regulations with 3D Cadastre

Saeid EMAMGHOLIAN, Jacynthe POULIOT, Canada and Davood SHOJAEI, Australia

Key words: 3D Land administration, Planning regulation, Spatial representation, 3D zoning, 3D Cadastre

SUMMARY

Interpreting planning regulations could be a challenging task for land surveyors when defining new ownership boundaries and for responsible authorities (e.g., city council) when assessing proposed developments. They need to be aware of the impacts of planning regulations on land parcels and vice versa since these regulations contain legally binding rules for all parties including government and citizens. There is a strong link between planning and cadastral regulations. For example, 3D zoning, with the capability of representing planning regulations in 3D, has a great potential to enable representing restricted and usable spaces for 3D cadastral purposes in a more visual way. This paper aims to offer a discussion about the advantages of enriching 3D zoning with the spatial representation of planning regulations in order to be integrated into a larger land-use information system called multipurpose cadastre to find better compliance between land use, urban planning, and citizen welfare. To this purpose, three groups of planning regulations (i.e., proposed design needed, 3D city model needed, and 3D zoning groups) are proposed in which 3D zoning group seems to be the most valuable one to achieve the overall objective. To support our discussion regarding mapping planning regulations for cadastral purposes, the paper results in a showcase for five planning regulations in the 3D zoning group including height limits, noise impacts, side and rear setbacks, street setbacks (side and front), and flooding limits. Victoria, Australia, was selected as a case study to illustrate some aspects of the discussion.

3D Zoning: A Missing Piece to Link Planning Regulations with 3D Cadastre

Saeid EMAMGHOLIAN, Jacynthe POULIOT, Canada and Davood SHOJAEI, Australia

1. INTRODUCTION

1.1 Context and Problematics

In urban planning, zoning is a regulatory mechanism that categorizes or divides land parcels into areas called zones (Selmi et al., 2017). In each zone, a set of regulations controls uses and developments on land with the purpose of mediating between social space and physical space for orderly urban growth and development (Salsich and Tryniecki, 1998; Selmi et al., 2017). Currently, most cities are using 2D zoning maps with a color-coded system in which clicking on a city zone will bring up general information about that zone. Based on this information, related planning regulations should be found in primary and secondary sources such as regulatory documents (Plazza et al., 2019). This method might cause significant shortcomings like in understanding restricted and usable spaces especially when most of the planning regulations contain 3D components (e.g., building height and setback limits). Usable spaces in this paper refer to spaces that are not restricted by planning regulations and can be used for defining new ownership boundaries.

Beyond visualization capacity, 3D zoning will gain value if they are integrated with the process of checking the compliance of land developments with planning and zoning regulations (Mayer and Somerville, 2000; Noardo et al., 2020a; Valencia et al., 2015; Van Berlo et al., 2013). In addition to preventing new uses and developments from interfering with existing uses and developments, it would be beneficial to use 3D zoning to control strategic planning rules and policies related to urban renewal and developments (Bracken, 2014; Brown et al., 2018; Cann, 2018; Durham Jr and Scharffs, 2019; Kochan, 2014). For instance, one of the difficult tasks for architects and land surveyors is to understand and identify regulations limits in city zones before designing and subdividing a multi-owned development when defining new ownership boundaries (Emamgholian et al., 2020a; Grimmer, 2007).

Due to the complexity and multi-dimensionality of zoning and planning regulations, identifying potential conflicts during designing and subdividing multi-owned buildings is not an easy task and requires lots of expertise, specialized knowledge, and analytical skills especially when 3D components are involved (Benner et al., 2010; Emamgholian et al., 2020a; Noardo et al., 2020b; Olsson et al., 2018; Plazza et al., 2019). In these situations, regulations limits must be accurately identified and considered when defining new ownership boundaries in cadastral plans. Enriching 3D zoning in which planning regulations are instantiated can significantly make the decision-making process faster and more communicable and improve the cognitive understanding of regulations limits for land administration and planning authorities (e.g., urban planners, architects, and land surveyors) (Emamgholian et al., 2021; Faucher and Nivet, 2000; Schaller et al., 2015; Schueren et al., 2016). Therefore, the benefits of enriching 3D zoning with the 3D representation of planning regulations can facilitate identification, validation, and registration of Rights, Responsibilities, and Restrictions (RRRs) for proposed developments in each precinct.

1.2 Objectives

This study offers a discussion mainly based on the findings in a research project started in 2019 in collaboration between Laval University (Centre for Research in Geospatial Data and Intelligence) and the University of Melbourne (Centre for SDIs and Land Administration) focusing on modeling 3D land-use regulations and detecting potential conflicts among regulations and physical objects. As the first phase of the project, Emamgholian et al. (2020a) proposed five variables to classify the potential conflicts as soft and hard conflicts. The variables were: number of 1) regulations and 2) physical objects involved in the conflicts, level of detail of the 3) proposed building and 4) surrounding buildings, and 5) spatial 3D spatial configuration of regulations. As the second phase of the project, Emamgholian et al. (2021) proposed a novel approach for modeling land-use regulations geometrically to validate proposed buildings against regulations in a later stage. From the modeling perspective, the key parameters, and a geometric modeling approach (e.g., extrusion, B-Rep, CSG, sweeping) that best fits with the identified parameters were proposed. Moreover, a level of information need for combining modelled regulations with 3D city models focusing on required planning information as well as physical objects was discussed considerably.

Based on our knowledge and experience, this paper aims to open a discussion about the advantages of enriching 3D zoning with a spatial representation of planning regulations that can be integrated into a larger land-use information system called multipurpose cadastre for 3D cadastral purposes in a later stage. To this purpose, the paper investigates 3D planning regulations and distinguishes the potential planning regulations that can be mapped or visualized into 3D zoning only based on planning information. In addition, for a case study (i.e., Victoria, Australia), this paper showcases an enriched 3D zoning for five identified planning regulations including height limits, noise impacts, side and rear setbacks, street setbacks (side and front), and flooding limits. The showcase aims to support our discussion regarding mapping planning regulations for cadastral purposes (e.g., a building subdivision and defining new ownership boundaries). Finally, the conclusions derived through this study were addressed by presenting issues that require further research.

2. BUILDING SUBDIVISION PROCESS IN VICTORIA, AUSTRALIA

To support our discussion and understand the current practices and existing issues and challenges, Victorian jurisdiction in Australia is selected as a case study. A building subdivision process in Victoria includes four main phases namely planning, certification, compliance, and registration phases (Atazadeh, 2017; Shojaei, 2014). In the planning phase, as the focus of this paper, the proposed design must be approved mainly based on the Victorian planning scheme. The planning scheme, as a legal document, is developed mainly based on Planning and Environment Act (1987). Generally, this planning system regulates "use" and "development" on land by zoning and planning regulations and includes different components such as zones, overlays, Local Planning Policy Framework (LPPF), State Planning Policy Framework (SPPF), general provisions, particular provisions, and schedules.

For a proposed development on a vacant land parcel, the process starts when an owner or a developer identifies an appropriate piece of land for the development. Accordingly, a land surveyor determines the boundaries of land by conducting a site survey and an architect designs the architectural model for the new "development" on the land parcel. The proposed development must be approved based on the Victorian planning scheme and the authority that administrates the planning scheme would be the responsible authority for granting/refusing the permit. In most cases, a city council is a responsible authority and the first point of contact for planning permit applications.

The decision-making stage starts when an application including plans, supporting information, and a copy of the title is submitted to the responsible authority (i.e., council) to get a planning permit or amend an existing permit. In summary, the decision-making stage mainly consists of three steps including referring an application to referral authority (e.g., utility suppliers such as water, electricity, and broadband network), asking for further information, and verifying the application mainly based on the planning scheme ordinance. The responsible authority needs to assess the planning permit application by verifying zoning and planning regulations. After verifying planning and zoning regulations, which usually takes 60 days (excluding additional information requests that can make a delay in the whole process), the responsible authority notifies owners about the potential zoning and planning regulations conflicts.

After receiving the planning permit, the land surveyor prepares subdivision plans based on the architectural design to apply for certifying subdivision plans (i.e., certification phase). This phase can be done concurrently with the planning phase. It should be noted that the certification phase verified by the Subdivision Act (1988) and Regulations (2011) is not the focus of this paper. It should also be noted that this paper only considers available planning regulations for building one, two or more dwellings on a lot, residential buildings, apartments with less than five storeys, and apartments containing five or more storeys.

3. 3D ZONING & 3D CADASTRE

Several software development companies (e.g., ESRI, Archistar[1], Gridics[2], MODELUR[3]) and cities (e.g., Toronto[4], Vancouver[5], Washington D.C[6], City of Miami) are launching their first version of 3D zoning mainly containing a 3D representation of some zoning and planning regulations such as height and setback limits (Quick et al., 2019; Schaller et al., 2015). However, in addition to not being fully operational and accessible, identifying potential zoning and planning regulations that can be represented in 3D zoning as well as its linkage with 3D cadastral purposes are still lacking and need further investigations.

[1] https://archistar.ai/
[2] https://gridics.com/zoning-data-api/
[3] https://modelur.com/
[4] https://map.toronto.ca/maps/map.jsp?app=TorontoMaps_v2
[5] https://www.reddit.com/r/MapPorn/comments/83g7i7/interactive_3d_zoning_map_of_vancouver_canada/
[6] https://maps.dcoz.dc.gov/3D/

Currently, in Victoria, Australia, checking the compliance of land with planning regulations before designing and defining new ownership boundaries when subdividing multi-owned buildings is not reachable unless surveyors lodge an application for a planning permit to a responsible authority (e.g., city council) (Atazadeh, 2017; Emamgholian et al., 2021, 2020a). However, to give an impression to the architects and land surveyors to design and subdivide proposed developments in accordance with the planning regulations, potential planning regulations can be mapped or represented in 3D by enriching 3D zoning. In this way, 3D zoning as the missing piece can link planning regulations with 3D cadastre by specifying usable and restricted spaces in the domain of land administration. In addition to being used for several cadastral purposes such as subdividing multi-owned buildings and defining new ownership boundaries, it can also be integrated into a larger land-use information system called multipurpose cadastre to find better compliance between land use, urban planning, and citizen welfare.

To this purpose, after exploring the characteristics of planning regulations, we propose three groups of 3D planning regulations to identify the potential planning regulations enriching 3D zoning. These groups include: **1)** proposed design needed, **2)** 3D city model needed, and **3)** 3D zoning groups. The main distinction between these groups is whether physical objects are required either in the new development proposal or in surrounding buildings to map or represent these regulations into 3D zoning. Each group with several examples is discussed in detail as follows. It should be considered that this paper focuses on city-scale 3D regulations and does not discuss internal restricted and usable spaces.

3.1 Proposed Design Needed

The first group as specified in table 1 includes 3D planning regulations (including their short description) for which the proposed development design model is required to map or visualize. Since the proposed design is required, these planning regulations cannot be represented in 3D zoning platforms unless we have access to the design model of the proposed development. However, they can be checked by architects and land surveyors after designing and subdividing multi-owned buildings whenever surrounding buildings are not required. This group is not the focus of this study and the importance of having the design model of new developments on modeling planning regulations (e.g., BIM data with sufficient Level Of Development (LOD)) is discussed in Emamgholian et al. (2021).

Table 1. Planning regulations in proposed design needed group

Group	Planning Regulations	Short Description	Design model of proposed developments	Surrounding buildings
Proposed design needed	**Overlooking**	A habitable room window, balcony, terrace, deck, or patio of a proposed building must not provide a direct line of sight into the secluded private open space and habitable room windows of existing buildings.	**Required**	Required
	Daylight to New Windows	Habitable room windows of proposed buildings should provide a light court (or outdoor space) with a minimum area of 3 square meters and a minimum dimension of 1 meter clear to the sky.		Required
	Internal Views	Windows and balconies should not cause an overlooking of more than 50 percent of the secluded private open space of a lower-level residential building directly below and within the same development.		Not required
	Energy Efficiency Protection	It considers the effects of overshadowing on an existing rooftop solar energy system on an adjoining lot.		Required
	Solar Access to Open Space	The southern boundary of secluded private open spaces of proposed buildings should be set back from all walls on the north, at least (2 + 0.9h) meters ('h' is the height of the wall).		Not required
	Overshadowing Open Space	In this case, overshadowing on existing secluded private open spaces will be checked.		Required

3.2 3D City Model Needed

The second group as specified in table 2 includes 3D planning regulations (including their short description) for which the design model of the proposed development is not required but 3D models of surrounding buildings are required. Although these regulations do not necessarily require a design model of the proposed development, for enriching 3D zoning platforms with them, the 3D models of surrounding buildings are required. This is where having 3D city models with existing buildings and city furniture matters. In this case, the planning regulations can be mapped in 3D zoning only if it is combined with the 3D city model. The approach and benefits of combining the 3D city model with planning regulations and a detailed discussion about the importance of having a 3D city model (e.g., CityGML data with a sufficient Level of Detail (LoD)) for mapping planning regulations can be found in Emamgholian et al. (2021). It can be concluded that for the planning regulations that require the 3D model of surrounding buildings, like those listed in table 2, it is possible to enrich the 3D zoning with them only if a 3D city model including existing buildings is accessible.

Table 2. Planning regulations in 3D city model needed group

Group	Planning Regulations	Short Description	Design model of proposed developments	Surrounding buildings
3D city model needed	**Daylight to Existing Windows**	Proposed buildings should provide a light court (or outdoor space) to the existing (adjoining) habitable room windows with a minimum area of 3 square meters and a minimum dimension of 1 meter clear to the sky.	Not required	**Required**
	Buildings Separation	It considers minimum distances between proposed buildings and existing buildings.	Not required	
	North-facing Windows	It considers if a north-facing habitable room window of an existing building is within 3 meters of a boundary on a proposed building's boundary, the proposed building should be setback from its boundary.	Not required	
	Depth Limitation[7]	It restricts any structure to be built over or near any of underground assets or easements.	Not required	

3.3 3D Zoning

The third group as specified in table 3 includes 3D planning regulations (including their short description) for which neither the design model of the proposed development nor surrounding buildings is required. This group with the capability of being mapped in 3D zoning seems to be the most valuable one to achieve the overall objective (i.e., enriching 3D zoning to enable visualizing restricted and usable spaces for cadastral purposes). In this case, 3D zoning potentially can be enriched with a 3D representation of the planning regulations to be linked with 3D cadastral purposes (e.g., subdividing multi-owned buildings and defining new ownership boundaries). It should be noted that this paper does not discuss the geometric modeling stage of specified planning regulations. The modeling parameters and geometric modeling approaches for representing 3D planning regulations are discussed thoroughly in Emamgholian et al. (2021).

[7] Although this regulation does not need the design model of surrounding buildings, it requires some underground assets (e.g., sewer pipes) in 3D city models.

Table 3. Planning regulations in 3D zoning group

Group	Planning Regulations	Short Description	Design model of proposed developments	Surrounding buildings
3D zoning	**Height Limits**	It considers the vertical distance between the ground level and the top of the proposed development.	**Not Required**	
	Side and Rear Setbacks	Proposed buildings should be set back from side or rear boundaries not less than the distance specified in the planning scheme or schedule.		
	Street Setbacks	Proposed buildings should be set back from side or front boundaries adjacent with streets not less than the distance specified in the planning scheme or schedule.		
	Noise Impacts	Residential buildings and dwellings close to busy roads, railway lines, or industry should be designed in a way that limits noise levels in habitable rooms.		
	Flooding Limits	Openings including doors, windows, and entrance level should be designed in an accordance with flooding limits.		

4. SHOWCASE

To support our discussion regarding mapping planning regulations for cadastral purposes, this section presents a showcase for five planning regulations specified in the 3D zoning group (i.e., table 3) including height limits, side and rear setbacks, street setbacks, noise impacts, and flooding limits. In this showcase, land administration and planning authorities are the lead beneficiary of 3D zoning. In addition, 3D representation of planning regulations can give an impression to the land buyers/developers for their investment and it might affect the value of their property significantly (Calder, 2017; El Yamani et al., 2021; Emamgholian et al., 2020b). Please note that this paper does not discuss the geometric modeling aspects of planning regulations and this showcase is only a demonstration of an enriched 3D zoning.

This showcase consists of programming inside a web-based application (i.e., Cesium) using JavaScript. 2D zoning base map (in Shapefile format) for the city of Melbourne that is provided by the Department of Environment, Land, Water & Planning (DELWP)[8] was converted to GeoJSON and imported to Cesium ion (Figure 1(a)). To be more precise about mapping usable and restricted spaces, a land parcel (as an example) was selected located in Fishermans Bend precinct (Figure 1(b)). We assume that a multi-owned development is going to be constructed on this land parcel.

[8] https://www.delwp.vic.gov.au/

(a) (b)

Figure 1. a) Part of Melbourne zoning base map (color-coded based on different zones); b) The selected land parcel (colored in yellow)

Based on the location of the land parcel and its assigned planning regulations summarized in the planning scheme ordinance[9] and complementary documents and guidelines (e.g., for flooding[10]), 3D zoning is enriched with the selected regulations as follows.

- **Height Limits:** According to schedule 67 to clause 43.02 design and development overlay related to Fishermans Bend - Lorimer Precinct (Melbourne Planning Scheme Ordinance, p. 907), a height limit of 36 meters applies to this land parcel.
- **Street Setbacks (front and side):** It is allowed to have a street wall type D (i.e., 8 storeys height) for its front street and type C (i.e., 6 storeys height) for its side street. From that level (i.e., street wall height) up to the height limits, a minimum street setback of 5 meters applies to front and side streets.
- **Side & Rear Setbacks:** If we assume that where the building below the maximum street wall height is built on the boundary, at least side and rear setbacks of 5 meters must be applied to both side and rear parts of the land parcel.
- **Noise Impacts:** For noise impacts, the proposed developments' construction materials need additional verifications if it is at less than 300 meters distance from the nearest lane of a freeway.
- **Flooding Limits:** By considering flooding limits, finished entrance and first floor levels should respect a minimum height limit (based on either predicted 2100 1% Annual Exceedance Probability (AEP) flood level or Nominal Flood Protection Level (NFPL)) to mitigate flooding concerns. Based on the location of this land parcel, 2.4 meters flooding limits are applicable.

Figure 2(a) illustrates enriched 3D zoning specifying the restricted spaces applicable to the land parcel. Accordingly, Figure 2(b) illustrates both restricted and usable spaces for the land parcel.

[9] http://www.melbourne.vic.gov.au/building-and-development/urban-planning/melbourne-planning-scheme/Pages/melbourne-planning-scheme.aspx

[10] https://www.water.vic.gov.au/__data/assets/pdf_file/0025/409570/Guidelines-for-Development-in-Flood_finalAA.pdf

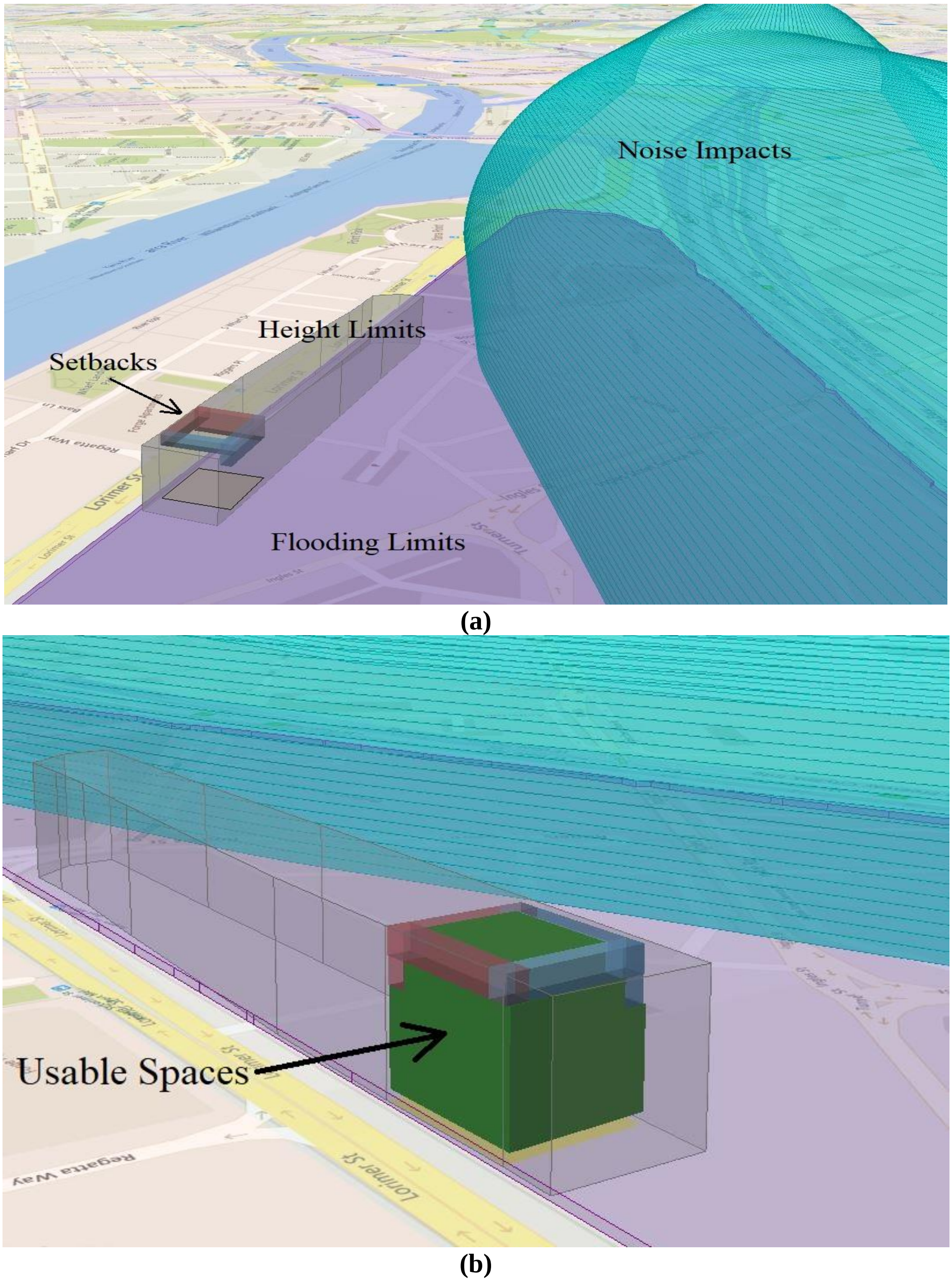

Figure 2. Mapping restricted spaces into 3D zoning by a) height limits (colored in grey), front and side street setbacks (colored in orange), side and rear setbacks (colored in blue), noise impacts (colored in cyan), and flooding limits (colored in purple); b) Usable spaces applicable in the land parcel (colored in green)

5. DISCUSSION & CONCLUSION

In this paper, we argued that to have a multipurpose cadastre, 3D zoning enriched with a 3D representation of 3D planning regulations has a great potential to be integrated into a larger land-use information system called a multipurpose cadastre system. Land administration and planning authorities can benefit from such a system by having access to the restricted and usable spaces in a literally more visual way. To this purpose, planning regulations were categorized into three groups including proposed design needed, 3D city model needed, and 3D zoning. Planning regulations in the 3D zoning group with the capability of being mapped by reaching only planning information was the most potential one to achieve the overall objective (i.e., integrating planning regulations with 3D cadastre in a larger system called multipurpose cadastre accessible to all parties). After identifying the potential planning regulations, with the purpose of supporting our discussion regarding mapping planning regulations for cadastral purposes, the paper resulted in a showcase for five regulations including height limits, noise impacts, side and rear setbacks, street setbacks (side and front), and flooding limits.

During this study, some important points can be highlighted as:

- Identifying more potential regulations: 3D zoning should be taken as a basis of a 3D representation of potential regulations depicting usable and restricted spaces in a multipurpose cadastral system. To this purpose, other potential planning regulations, sub-regulations, and other restrictions imposed on city precincts should be added to such a system.
- Qualitative reasoning: Since planning regulations can contain discretionary (e.g., noise impacts) or mandatory (e.g., minimum setbacks) rules, restricted spaces in the 3D zoning do not necessarily mean that they are not usable. This aspect reminds the importance of having qualitative reasoning in later stages.
- Reaching a generic approach: Planning regulations and their restrictions may not only be diverse in different jurisdictions but may also be distinct in different cities. Although the general rules may be the same, it is not straightforward to achieve a generic approach that maps/represents all the limited spaces applicable in all precincts. However, if the difference in the description of the rules is taken into account, the process can still be the same.
- Data linkage and accessibility: The required data (e.g., planning information, zoning base maps, related guidelines) is provided by different organizations with different levels of accessibility. To achieve having an integrated land-use information system including all required data further studies investigating data integration aspects like data quality and standardization are required.
- 3D city models and BIMs: This study shows that enriching 3D zoning has a great potential to be utilized in land administration systems. It can also facilitate the decision-making process for granting planning/building permits in a later stage. However, as the first step, only one group of planning regulations (i.e., 3D zoning group) could be mapped into 3D zoning. Hence, to represent all restricted spaces, 3D city models and BIMs should also be integrated with the enriched 3D zoning.
- Automatic enrichment: Planning regulations and their related information are mostly summarized in textual documents including lots of complexities that make the automation

process fail. It needs further research as well as collaborative work engaging all parties to facilitate the process of enriching 3D zoning automatically.

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BIOGRAPHICAL NOTES

Saeid Emamgholian is a Ph.D. student in Geomatics Science at Université Laval, where he is working to develop an approach for first, modeling land-use regulations as part of city objects and then, detecting spatio-semantic conflicts among land-use regulations, especially those that comprise 3D components. His research interests are mainly 3D spatial analysis, 3D GIS, 3D cadastre, 3D modeling, and 3D Geo-visualization.

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Organization of rights and responsibilities in complex 3D real property developments - the relevance of bridging research fields

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Keywords: 3D property right, condominium, organization, mixed-use development

SUMMARY

The condominium concept is one form of 3D property that is used in many countries around the world to organize and register 3D real property situations. Condominium property was mainly introduced in various jurisdictions to facilitate homeownership by converting residential apartment units in high-rise buildings into real property. Thus, the legal and organizational aspects of condominiums have been widely discussed in research literature but mostly outside the 3D property research domain. Publications within the 3D property research domain regarding legal and organizational aspects have been relative few in number. We propose the more traditional condominium literature to partly answer the call for more research on legal and organizational aspects within the 3D property research domain. It could provide a broader spectrum of research experiences to be incorporated into the ongoing debate within the 3D property research domain.

Organization of rights and responsibilities in complex 3D real property developments - the relevance of bridging research fields

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1. INTRODUCTION

There seems to exist two different research fields that are concerned with real property situations in 3D. However, one of them is mostly concerned with the condominium concept and the legal structure and organization of property rights and restrictions between condominium unit owners (see e.g. van der Merwe, 2015). And the other is mostly concerned with the challenges of cadastral registration of 3D situations in a system only prepared for 2D registration and propose utilization of technical solutions as a way forward (see e.g. Oosterom et al. 2018). However, technical solutions may not be the only way forward to reduce transactions costs when forming 3D situations. A more context driven and conservative approach that is not proposing major changes in the existing registration system, but only requires minor adjustments in legislation. This might be a more affordable and effective short-term solution to problems addressed by real estate practitioners. In addition, this approach perhaps has the potential to become a springboard for easier implementation of technical solutions in the future.

The aim of this paper is to answer the call for more publications on legal and organizational topics concerning 3D property (see below). We present examples of literature concerning complex 3D situations found outside the 3D cadaster research domain ad propose this partly as an answer. The aim is also to inspire representatives to enter the discussion on how rights and responsibilities are organized in complex 3D developments by introducing their own jurisdiction. We believe this is unique in each jurisdiction and therefore experiences perhaps are kept in national journals (and in a national language) not accessible (or to understand) by a larger international audience.

In addition, we propose a preliminary theory partly to explain why jurisdictions with a long condominium tradition hesitate to implement an independent 3D property form. In 2011 Ekbäck states: *"One important question to which there is no clear-cut answer is whether the cost of co-operation between the different three-dimensional spaces will be greater or smaller with 3D property formation than with the traditional options."* (Ekbäck, 2011). This is an impotent question. In relation to the Danish traditional condominium system, and the method used in practice to split a 2D parcel into 3D units. Ekbäck (2011) concludes that everything seems to be working by using alternative methods such as granted rights, thus only forming use right instead of an ownership right. However, he makes this conclusion based on Sørensen (2009), but we argue that this is not entirely the correct, and today everything does not seem to be working. This raises a new question of why currently no steps are taken to move the Danish system towards a 3D property system. The last time it was discussed by the Danish cadastral authority was in 2009 (Thellufsen, 2009).

The research presented here is part of a Danish research project on 3D property design, see Madsen et al. (2021). The Danish examples are discussed and compared with Swedish examples of 3D property. The reason is that Sweden has a similar legal system and real property formation legislation, but only implemented the concept of 3D property and condominium ownership a few years ago, in contrast to Denmark, introducing the concept(s) of 3D property and condominium ownership more than half a century ago.

2. TRADITIONAL CONDOMINIUM AND 3D PROPERTY RESEARCH

The literature survey is focused on two main groups of research aspect, namely the "traditional con-dominium concept" and "3D property". We begin with a short presentation of 3D proper-ty research and condominium research and outline the general differences. Then continue to present an array of American condominium literature. Then we present the Danish 3D system and the Swedish in many ways are different then we discuss these differences, what they imply and what we can learn from it.

2.1 3D property research

3D property is often referred to as real property delimited with both horizontal and vertical boundaries oppose to a traditional parcel/piece-of -land that is only delimited with vertical boundaries and therefore referred to as a 2D property Paulsson (2007). Changes in society has increased the pressure on urban land use. As a consequence, urban land is exploited vertically in the pursued of more effective land use e.g. to avoid urban sprawl. Building structures have become more complex in 3D and thus they are more complicated to register. This has for the last decades put pressure on existing cadasters that are only designed to register 2D property. To address this challenge researchers began approx. 20 years ago, began to investigate how to improve the formation of 3D property (Oosterom et al, 2018).

Paulsson and Paasch (2013) divides 3D property research publications from the years 2001-2011 into four classes: "Legal", "Technical", "Registration" and "Organizational". This publication and a newly published revision (Paasch & Paulsson, 2021) show that there is a relative low number of publications on legal and organizational aspects compared with technical and registration aspects.

2.2 Condominium research

Condominium property was introduced in many countries around the world in the 20th century. The reasons for implementing condominium law were primarily related to increasing housing shortage in urban areas. The condominium property form was an instrument for a more effective use of land and facilitated a third possibility for housing in addition to traditional forms of renting an apartment or buying a house (van der Merwe, 1994).

Converting an apartment building into condominium property provides for all apartments to become individual 3D real property with vertical and horizontal boundaries. Individual ownership to an apartment can be traced back to ancient Egypt, however modern condominium legislation was only introduced in Belgium in 1924. This, first generation legislation was replaced by second generation legislation regulating the more practical aspects of managing a common property in detail (van der Merwe 1994).

Even though, condominium legislation primarily was created to facilitate apartment owner ship, other types of use are possible to included. Another way to express this is to say that, *"Condominium laws have facilitated the creation of a three-dimensional form of real estate ownership."* (Thorson 1984). A condominium property can take on many faces including hotels, shopping center, parking garages, offices, shops etc. (see e.g., Van der Merve 2015; Madsen et al. 2021). It has been identified that an increase in diversity and mix of use creates the need for more complex organization of rights and responsibilities (se e.g. Madsen et al, 2021).

These authors experiences are that most literature regarding condominium law is related to management issues (legal and organization) and less on technical and registration aspects.

2.3 American condominium literature

The condominium legislation in America was adopted from the European condominium legislation. However, the European legislation was not fit to support the North American market, so legislation was adjusted. Rohan (1978) explains that American first-generation legislation was *"...designed exclusively for use in apartment structures. These statutes were unsuitable for lateral developments, large-scale projects, and staged or sectional construction."* (Rohan, 1978). In response to the challenges an American second-generation condominium legislation (The Uniform Condominium Act) was announced in 1978 (Rohan, 1978).

As a response to the challenges of property developers, Rohan (1978) proposes that legislation must facilitate a split of condominium developments into two categories "simple" and "complex". The complex developments are e.g. such lateral staged developments that include more than one building where each building is constructed in one staged. Or projects including an umbrella organization; mixed-use condominiums; commercial condominiums; condominiums involving "air rights" etc. (Rohan, 1978).

There exist a large body of litterateur in the North America research domain about complex condominium development where the condominium concept is regarded not only as means for dividing a building into subdivided apartments. The condominium concept is regarded as a form of ownership rather than a subdivided apartment (Rohan & Reskin, 1965) or as Thorson (1984) describes *"Condominium laws have facilitated the creation of a three-dimensional form of real estate ownership."* (Thorson, 1984, p. 1). For more information of different issues in the North American literature see e.g. Moriarty (1973); Rohan & Reskin (1965); Rohan (1978); Stokes (1982); Thomas (1978); Thorson (1984); Freyfogle (1987). In addition, through each publication, it is possible to trace a large number of related publications.

The publications cover a time period from 1965-1987. In this period the condominium legislation in America went from first- generation to the implementation of a second-generation. It has been more difficult to find newer publications. However, Rohan & Reskin (1965) "Real

Estate Transactions: Condominium Law and Practice–Forms" is still operational and annually updated in an online version by real estate experts.

2.4 The Danish 3D property legislation and practice

This section is divided into two subsections. Section 2.3.1 concerns the Danish condominium concept and section 2.3.2 concerns the practical method of splitting a 2D parcel into 3D spatial objects in a 2D cadastral registration, using a combination of a 2D parcel and granted rights to declare a use of space above or under the 2D parcel.

2.4.1 Danish condominium (practice)law

In 1966 the condominium concept was introduced in Danish real estate property legislation. The main reason for implementing the condominium concept was related to increasing housing shortage in urban areas (Owner Apartment Committee, 1965). However, the law applies to all type of use and the only obstacle is that a condominium unit's boundaries must follow a delimited room in a construction building. In addition, buildings constructed before 1966 cannot be converted into condominium property. The condominium legislation consists of the condominium law and a standard by-law (Danish Parliament, 2020c) that is activated when the first condominium unit is sold. There is also a registration promulgation (Danish Parliament, 2020b) including rules for documentation etc. in addition to the declaration used to apply the cadastral authority for a building's conversion into condominium property. For further introduction to the Danish condominium system see e.g., Madsen et al (2021).

A study of complex condominium developments (Madsen et al. 2021) has shown that the use of the Danish condominium concept has mutated. At the time when more and more complex building structures became widespread in Denmark the standard by-law was not sufficient to work on complex condominium developments. It became necessary to draw a customized by-laws and organize rights and obligations through granted rights related to the common components of the condominium property. The mutation implies a shift in the use of the condominium concept from simple to complex.

Despite of this mutation, few amendments have been incorporated in legislation. Instead, practitioners have found creative solution by "stretching" the legal frame to fit it into a complex condominium development. Some of these solutions has even become practice law. For example, the possibility to split the standard single management structure into a "two-tier" governance management structure in mixed-use developments. A Tow-tier structure is used when it is necessary to separate parts of the common property so only those units that have an actual benefit are granted the exclusive right to use and maintain that specific common facility or space. For a further introduction to the concept of condominium tow-tier governance and other management structures see van der Merwe & Paddock (2008). The Danish condominium law clearly states that the common property cannot be separated from the ownership right to the condominium unit (Danish Parliament, 2020a, §3 section 3). However, the Danish registration authorities have accepted this for many years so it has become law practice. Blok, a high court judge and expert on condominium property, states in his commentary on the Danish condominium law *that "just because it was not thought about when the law was written* *do not mean it should not be possible to form a two-tier management structure"* (Blok, 1982 [authors translation]).

It is outside the scope of this paper to list all complex condominium situations, however for the reader to get a better understanding of what it might include we will mention two other complex condominium situations:

In some complex condominium situations, the developer has a desire to form an ownership right to part of the common property that cannot legally become a condominium unit. This is e.g. evident in case of a parking lot which cannot become a condominium unit because it has no construction walls. Instead, a granted right is formed. This has been accepted by mortgagees to provide enough security so the parking lot can be included as part of the value of that condominium unit that holds the exclusive use right.

In a complex condominium development, the developer, for financial reasons, has a desire to build in phases (also called stage development). Developers use of a "flexible condominium" used only to park building rights to finish the project when the first stage is sold. In desperate need of room with construction walls a container is sometimes placed on the building site. Or sometimes a "doghouse" (yes, an actual doghouse or sherd) is built to be converted into condominium property, only to be removed when the stage development is constructed and the "doghouse" has been further subdivided into the new construction, as planned by the developer's legal advisor (usually a lawyer and/or charted surveyor).

2.4.2 Splitting a 2D parcel into 3D objects

There are no legislation only alternative solutions of forming indirect ownership in 3D outside a construction where condominium property does not apply.

In Danish real estate legislation, there is no means that directly facilitates forming a 3D property of a parcel. In a 3D situation where there is a need of horizontal boundaries only one layer can be registered in the cadaster. Other layers of the 3D situation boundaries must be formed with alternative means by declaratory rules. This usually includes an exclusive use right placed as a burden on the layer of the 3D situation that is registered in the cadaster.

When a 3D object e.g. an underground parking garage, is crossing parcel boundaries it is not possible to register is as a 3D property with an ownership right. The registration of such a 3D situation is handled in practice establishing a granted right including different rights and restrictions that the parcel owner must respect.

It is the same situation if a building (or part of) is placed above e.g. a public road. However, it is not possible to declare a granted right on a public road in the Danish Land Registry so instead the build-up area above the public road is converted to a parcel. Then the owner of the building has an ownership right to the parcel and the municipality (road authority) a declared granted user right to the public road and mostly also the responsibility to maintain the road. However, in the cadaster the road ceases to exist.

2.5 The Swedish 3D property legislation

Despite, that many other countries in Europe implemented the condominium concept such as e.g., Denmark (van der Merwe, 1994) Sweden did not implement the condominium concept until 2009 (Paulsson, 2012). The Swedish condominium concept differs from the more traditional condominium concepts around the world because only apartments for residential use can be converted into a condominium unit.

In 2004, five years before the condominium concept was introduced the "independent 3D property unit" was introduced in the legal system (Paulsson, 2012). The independent 3D unit has certain characteristics: it must relate to a built construction or other facility; it can comprise a whole built construction or only part(s) of it; it may extend over or under several 2D parcels and if necessary, in order to guarantee financing or the construction of a facility it is possible to form a 3D property unit before constructed (Paulsson, 2012).

The Swedish system also includes a "3D property space". This property form cannot exist within a 3D property unit but must be part of a traditional 2D property that for some reason needs a 3D delimited part of one or several traditional 2D properties. This could e.g., be in a 3D situation where an underground parking garage is extended over one or several 2D parcels.

In a complex mixed-use 3D situation, it is possible to mix the different property types. Paulsson (2013) explains how a mixed-use development can be organized using the Swedish 3D system: The top floors include residential apartments subdivided into a) condominium units. The ground floor consists of several shops included in one b) 3D property unit. The underground floor consists of a parking garage that is part of the c) "traditional 2D parcel". However, part of the underground parking garage extends under the neighboring property so d) a "3D property space" is created (Paulsson, 2013).

2.5.1 Cooperation

When a building is transformed into condominium units it is decided in the cadastral procedure what parts of the property that should be private or common. If a common property is formed an owner's association is mandatory to form (Paulsson, 2012). This is very much in line with a traditional condominium system such as the Danish. However, it seems as if there is less regulation concerning the cooperation between individual 3D property units (Paulsson 2012).

3. DISCUSSION

The mixed-use situation in section 2.4 explained by (Paulsson, 2013) illustrates how different use in a property are separated using different property forms, namely the "independent 3D property unit", the "condominium property", the "3D property space" and the "traditional2D property". In a system with a traditional condominium system such as the Danish this 3D situation will effectively be treated by the use of a two-tier management structure when converting the development into condominium property. However, if there is part of a building construction that extend over or under another 2D parcel it is not possible to secure this with full ownership. Instead, a granted right would be established to regulate rights and restriction.

In general, there seems to be many similarities between the Swedish system and the Danish. However, the Swedish 3D property system seems to be easier to understand and perhaps more capable of handling situations where complex building structures extend over or under other 2D parcels. However, in both systems there is need for organizing rights and restrictions connected to each 3D delimited property object.

Because of the more complex building structures and infrastructure under and above the ground, land administration systems have had to adapt to this new 3D situation. The way nations have dealt with this differ. In some jurisdictions an independent 3D property system has been introduced and in other jurisdictions the existing systems and legislation has been used to work around the challenges, thus avoiding the development and implementing of new more 3D ready systems.

Perhaps there is advantages using an independent 3D property unit instead of arranging rights and obligations of the common property in a traditional condominium system. However, we have not seen such a comparison in any publications. From our point of view, it seems as if combining the experiences of traditional condominium organization of rights and obligations with the benefits of registration 3D independent units could perhaps be a solution, at least to solve the 3D challenges in the Danish 3D property system. The situation simply seems to be working too well to begin considering a radical change to the Swedish model. However, minor adjustments could be done with little investment little by little not confusing the real estate market.

The complex 3D situation in condominium property in terms of choosing a sufficient management structure or using flexible condominiums must likewise exist in the Swedish 3D property system. The actual difference between the extended condominium system and the 3D property lies not in the management of the different interest between more or less independent property units, despite being organized as two-tier governance or a combination of a 3D independent property and residential condominium, they both experience the same challenges of organizing rights and responsibilities to common components of mutual interest.

In order to obtain a full understanding and to decide on pro and cons of both systems it is necessary to make a comparison. In our opinion, it is relevant to bridge research fields in order to push for a more effective system. Research regarding 3D property systems could benefit from the many years of experiences of dealing with 3D situations in general, and the condominium could benefit from learning the advantages from more market adjusted registration boundaries.

It seems as if the study shows that, from comparing Denmark and Sweden that jurisdictions with a long history of condominium legislation and real estate practitioners have gradually adopted to the more complicated cases of building structures, however in terms of infrastructure projects such as the Metro etc. not. In mixed-use cases the condominium has been sufficient, so there has not been enough reason to consider changing the system because the.

4. CONCLUSION

Complex mixed-use condominium developments include a multitude of ownership with different use. Organization of rights and responsibilities over common parts are standard procedure in the formation process so each condominium unit has its own share of the value in the common property and to common expenses etc. If the mix consist of very different use the common property usually is also very different and common components may only benefit one or a few units. Therefore, contributions to common expenses are arranged so those units with no benefit of specific common components are not obliged to contribute to that part of the common property nor to have a share of its value.

In a jurisdiction, such as the Danish, where there is a long history of practical use of the condominium owner ship concept it is normal procedure to "work around" the condominium legislations fundamental rule that states each condominium unit has a share in the hole common property. As explained, this is not financially rational, so each use type or otherwise reasoned segregation of units is isolated and the management of the common property is split into a tow-tier management structure. By doing so, the common components that cannot legally be adopted within the boundaries of a condominium unit are with other means attached to the unit as a granted right.

In a jurisdiction, such as the Swedish, where there is no tradition for using the condominium concept (it was first implemented in 2009) the rising demand for multi ownership in buildings pushed for a real property form to be implemented to facilitate delimitation of real property both vertically and horizontal (3D property). Despite that Denmark, which is neighboring country to Sweden, had a functional land registration system that to a large extend was capable of handling 3D property situations, the legislators choose use another model, the 3D independent property.

5. FUTURE RESEARCH

A case study of the Swedish system used in a complex mixed-use situation could be an important contribution to both traditional condominium and 3D property research. The existing literature on the Swedish system could benefit of more research on how the organization of rights and restrictions regarding the cooperation between different property forms are conducted and how the quality of such is measured. Especially when little is mentioned about this aspect in legislation.

It could be interesting to compare a traditional condominium system, such as the Danish with that of an individual 3D property unit system such as the Swedish system. Perhaps using both systems on the same case of a complex mixed-use 3D development. In doing this experiment it could perhaps be evident to what extend the systems differ and quantified which is the most effective and holds the lowest transaction costs.

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Modelling 3D legal spaces of Public Law Restrictions within the context of LADM revision

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Key words: LADM, ISO 19152, Public Law Restrictions, 3D, Land Administration Systems

SUMMARY

Intense exploitation of land in the vertical direction has brought up complex legal relations between different types of spatial units with various characteristics (e.g., land, marine, air, underground parcels, and infrastructure objects). Therefore, the use of 3D models is required to clearly represent real property and associated Rights, Restrictions and Responsibilities (RRRs), deriving both from Private and Public Law. The latter are either not registered to cadastral systems (i.e., in The Netherlands very few have been registered like the private natural beauty areas, as they came with tax benefits), or are recorded to individual, thematic registries. Public Law Restrictions (PLRs) impose significant impact on ownership rights and land management, thus requiring to be systematically organized and registered. This brings out issues of identifying which types of PLRs need to be registered (based on land administration policies that apply in each country/ jurisdiction), selecting and "spatializing" them (in 2D/3D/nD).

Within the field of land administration, the ISO 19152:2012 Land Administration Domain Model (LADM) plays predominant role in standardizing legal relations between parties (people) and spatial units (land). LADM is currently under revision with its second edition widening its scope as a multipart standard comprising 6 Parts. The revision of LADM stimulates discussion on new concepts that could be included at the Edition II, and possibilities of refining the existing ones. In this context, the paper investigates the option to model PLRs into the multipart standard and investigates how to optimally categorize them based on the LADM Edition II Parts. The paper builds on previous work by the authors and aims to propose a flexible framework to model PLRs at conceptual level in the context of LADM Edition II. To validate the modelling proposal, two case studies of PLRs are studied. The first one relates to the restrictions imposed on land parcels crossed by the Trans Adriatic Pipeline (TAP) in Northern Greece, and they refer to the establishment of protection zones, where construction and agricultural restrictions apply. The second case study refers to land use restrictions in the vicinity of an archaeological site in the municipality of Patras, in southern Greece. Those use cases were selected because of their generic character that may apply to other countries/ jurisdictions, regardless of legal framework differences.

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1. INTRODUCTION

Legal relations applying to different types and shapes of spatial units (e.g land, marine, air, underground parcels, and infrastructure objects) are in many cases best represented in 3D and of significant importance for the Land Administration domain, and they are defined through Rights, Restrictions and Responsibilities (RRRs), deriving both from Private and Public Law. Only the former are generally registered within Cadastral Systems, while the latter are either not required to be registered, or are recorded to individual, thematic registries. Restrictions deriving from Public Law (PLRs) are gradually increasing in number and complexity, following the new fields of the vertical exploitation of land. A characteristic example is the introduction of PLRs related to UAV flights which were introduced in national legal frameworks during the last decade. PLRs impose significant impact on ownership rights and land management, esp. reducing the types of land use allowed, thus introducing the need of systematically organizing and registering them. This brings out issues of identifying which types of PLRs need to be registered (based on land administration policies that apply in each country/ jurisdiction), selecting, quantifying, and "spatializing" them (in 2D/3D/nD), according to qualitative parameters (e.g., physical, natural, or socioeconomic characteristics), and classifying them to be registered in national land registration systems (Kitsakis et al., 2019).

Registration of PLRs has been an issue of scientific research in international literature for almost 20 years (Zevenbergen and de Jong, 2002; Bennet et al., 2006; Givord, 2012; Kitsakis and Dimopoulou, 2016; Kitsakis et al., 2019). However, it faces both theoretical and technical challenges regarding its implementation. Theoretical challenges are related to the stratification of real property rights and its implementation within each national legal system, as well as to the expression of legal statute in terms of quantifiable, physical characteristics (Kitsakis, 2019). Technical challenges refer to the broad variety of restrictions imposed by public law, which brings out issues in terms of obtaining quality of 2D/3D boundaries of the PLR objects' legal spaces level of detail, cost, system architecture requirements, data accuracy and reliability (del Campo, 2012; Lai et al., 2010). Currently, the most mature approach towards registration of land-related PLRs can be traced in Switzerland, where PLR-Cadastre has been developed at cantonal level, registering 17 PLRs that are classified in 8 sectors comprising plans, legal provisions and regulations provided via geo-portals (Swisstopo, 2015, Kaul, 2019).

In parallel, standardization, as a well-known process in the field of Land Administration has strongly developed and formed new potential. Computerized land-related systems require standards to identify objects, transactions, relationships between spatial units and parties, classification of land use and value, and spatial representations of objects. In existing LAS, standardization refers to country-level conceptual modelling approaches, data storage and exchange formats. However, open markets, globalization, and effective and efficient development and maintenance of flexible (generic) systems, require further standardization at an international level. In this scene, the ISO 19152:2012 Land Administration Domain Model (LADM) plays predominant role in standardizing the people to land relations.

Therefore, among others, the revision of LADM initiates a discussion on new concepts that could be included at the Edition II, and existing ones that could be further refined. In this context, the paper investigates the opportunity to include the Public Law Restrictions at the multipart standard and investigates how they can be best categorized to be modelled based on the LADM Edition II. The paper is based on previous research and knowledge (Kitsakis and Dimopoulou, 2016; Kitsakis, 2019; Kitsakis et al., 2018) and aims to initiate a discussion on the registration of PLRs in LAS by presenting several approaches to model at conceptual level PLRs in the context of LADM Edition II.

Therefore, initially, land-related PLRs are categorized and modelled according to LADM structure, concept, and semantics. For the purpose of this paper, the PLRs that are examined, are modelled on Part 2 of LADM Edition II. Selected categories of PLRs are modelled in UML diagrams according to LADM, the respective classes and associations are modelled, and the code list values are populated. To validate the modelling proposal, two case studies of PLRs are studied. The first one relates to the restrictions imposed on land parcels crossed by the Trans Adriatic Pipeline (TAP) in Northern Greece, and they refer to the establishment of protection environmental zones, where construction and agricultural restrictions apply. The second case study refers to land use restrictions in the vicinity of an archaeological site in the municipality of Patras, in southern Greece. Those use cases were selected mainly because of their generic character that may apply to other countries/ jurisdictions, despite the differences of the various legislative frameworks.

2. PUBLIC LAW RESTRCTIONS (PLRs)

Modelling options and registration of land-related PLRs, constitute a highly challenging research task for several reasons including (Bennett et al., 2006; Lai et al., 2010; del Campo, 2010; Kitsakis and Dimopoulou, 2018):

- The significant number of legal provisions that impose restrictions on landownership.
- The relation of PLRs to multiple (in several cases) interdependent scientific fields of different nature.
- Unclear definition of the spatial extent, the duration of the restriction and the people affected
- Legal definitions of PLRs that cannot be easily “translated” into 3D space.
- Definition of PLRs using non-geometrical or implied 3D characteristics (e.g., contaminated soil or subsurface water).
- Technical limitations (e.g., level of detail, cost, system architecture requirements, as well as data accuracy, scale consistency and completeness).
- The legal effect of PLRs on the affected/ surrounding objects.

Bennett (2007) identified five characteristics to distinguish “less important” interests to be registered. By applying this approach to the land-related legal statutes of Victoria in Australia, he managed to reduce their number from 620 to 66. Moreover, technical limitations on system architecture and big data management are easier to address, due to the advances in computer technology and the development of 3D modelling techniques. However, a significant number of PLRs cannot be easily expressed in spatial terms, due to its type (e.g., contaminated sites) or often because of the different existing registries which involve difficulty in collaboration between competent legal professionals, surveyors, and other specialists in this field of non-geometrically defined or implied PLRs. Specifically, in the context of 3D LAS and real property stratification, the lack of interest by legal professionals is noted by several researchers (Banut, 2011; Paasch and Paulsson, 2014; Paasch et al., 2016; Paasch and Paulsson, 202), thus resulting in ineffective implementation of land policies and constraints in Land Administration (Kitsakis et al., 2019).

The existence of a number of jurisdictions each one comprising different legal families, introduces a variety of different approaches on restricting the right of ownership and its equivalents. Therefore, standardisation of PLRs, seems to facilitate communication and interactions between the different legal systems, while ensuring interoperability amongst information systems. At the same time, searching for common ground and compromising between different legal approaches constitutes a highly challenging task and relates both to the classification of PLRs to distinct categories and to the combination of the different legal approaches for each of the distinguished categories.

Categorisation of PLRs may differ, depending on the perspective and the scope of the classification. Based on the legal perspective, PLRs are classified to the branch of Public Law where they belong, for example constitutional or administrative law. If classification aims to their purpose, PLRs can be distinguished to those serving national security, public health, urban planning, social and public policy, environment protection etc. Within a similar concept with the purpose-based classification, is the classification based on thematic fields. In this case, specific themes are defined, on which PLRs are assigned. This type of classification provides more flexibility, as themes can be adjusted to the specifications and the objectives of the research, while retaining the special characteristics of national land administration.

The latter classification option is also preferred in this work. The proposed PLRs’ modelling approach is based on the classification by Kitsakis et al. (2018), mainly within the context of the Roman Law and especially the Greek legal framework, including PLRs that may apply both in 2D and 3D space (Table 1).

Table 1. Proposed classification of PLRs for Greece

Sector	Description
Mining areas	• Health and safety provisions • Restrictions on activities related to the ownership of minerals/quarry material

Cultural Heritage	• Restrictions to avoid harm of underground antiquities (e.g., in-situ preservation of antiquities; Restrictions due to construction of infrastructures or other activities) • Restrictions in constructing new buildings, alteration, restoration and use • Restrictions in maritime activities within or in the vicinity of marine antiquities
Building Regulations and Spatial Planning	• Construction regulations/ Building restrictions (e.g., restrictions on building height for landscape protection; Restrictions on materials, scale, colour, size, architectural style of constructions to match surrounding landscape, etc.) • Urban, zone and spatial planning provisions (e.g., land uses, zoning plans, Shoreline and coastal zones, forest zones etc.)
Civil Aviation	• Non-military manned air vehicles (e.g., definition of special flights' rules such as non-flight zones; Definition of general minimum flight height; Definition of Obstacle Limitation Surfaces, designating the airspace around an airport where restrictions apply to constructions or physical objects' heights) • Unmanned Air Vehicles (e.g., fly under permission above specific heights; Flight prohibition over infrastructures or correctional facilities; Definition of maximum flight height)
Environment protection	• Natural protection zones (such as restrictions on Forest protection; Natural habitats; Biodiversity and Protected areas) • Soil (restrictions regarding soil contamination (deriving from soil geological or chemical characteristics); mitigation measures on contaminated soil) • Water (restrictions regarding the protection of surface and groundwater bodies, stream buffers) • Air (such as restrictions for the protection of public health from contaminants in the air; restrictions regarding radio waves propagation to ensure efficient communication and broadcasting as well as protect public health and the natural environment from extended exposure to electromagnetic fields; restrictions regarding public exposure to electric and magnetic fields due to the installation of antennas. • Noise (such as restrictions on zones of noise propagation and vibration)
Public utility networks	• Land use restrictions • Rights of way • Servitudes of passage
Major infrastructures	• Land use restrictions • Rights of way • Servitudes of passage

Military zones	• Restricted areas • No flight zones

As shown above, this work classifies PLRs in eight sectors, each one pertaining to specific types of restrictions. Compared to the classification by Kitsakis et al. (2019), two new categories are introduced. The category "Environment protection" incorporating restrictions related to the protection of soil, water, air, noise and natural environment, and the category "Landscape and Spatial Planning" that integrates restrictions related to the protection of landscape, urban and spatial planning provisions.

3. ISO 19152 LADM REVISION

The ISO 19152:2012 LADM was published in 2012 to address basic information-related components of land administration, emphasising mainly on land registration processes and (land) parcels of real property. At the first edition of the standard, land valuation, land use and spatial planning were purposely left aside, while the marine domain was not considered as a separate field. Today, there is a need and mature ground for developing a general schema reflecting the main concepts of land administration and structuring implementation solutions. The second edition of the standard is organized into multiple parts, with the following working titles:

- Part 1 - Land Administration Fundamentals
- Part 2 - Land Registration
- Part 3 - Marine Space Georegulation
- Part 4 – Valuation Information
- Part 5 - Spatial Plan Information
- Part 6 – Implementations.

Separate New Working Item Proposals (NWIP) and Working Drafts (WD) will be submitted for each of the parts and the standardisation procedure as defined by ISO will be followed. Till today, the NWIP for Part 1 has been submitted by Standards Australia (SA) with input from the authors' team on behalf of the FIG and positively voted by the ISO Committee members, while NWIPs for Parts 2 and 4 have been submitted by FIG and they are under review from the Committee members.

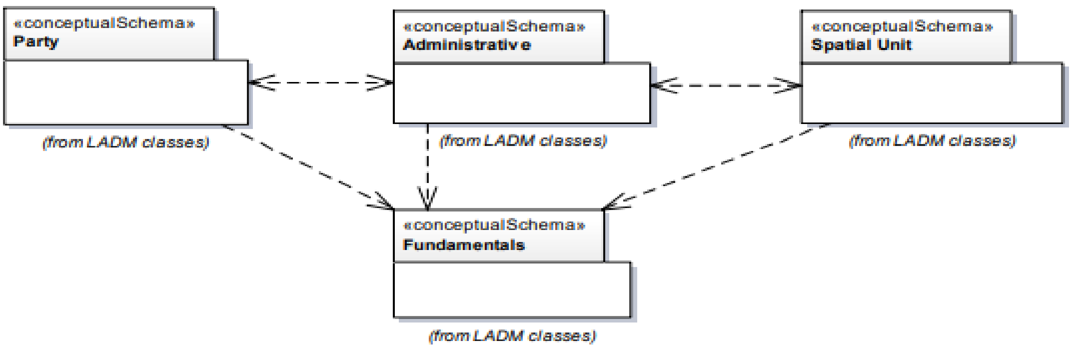

Figure 1. Packages of Part 1 - Fundamentals of LADM Edition II (Lemmen et al., 2021)

Part 1 - Fundamentals will be a high-level umbrella standard that supports all the other parts of the LADM Edition II. Part 1 presents the fundamental notions and defines the basic components and relations shared by all objects created by land administration (Figure 1), as well as provides an overview of all parts (Figure 2). This Part will not only be backward compatible with the previous version of LADM but also with the IHO S-121 Maritime Limits and Boundaries standard, which will be used as basis when developing the Part 3 of LADM Edition II (Lemmen et al., 2021).

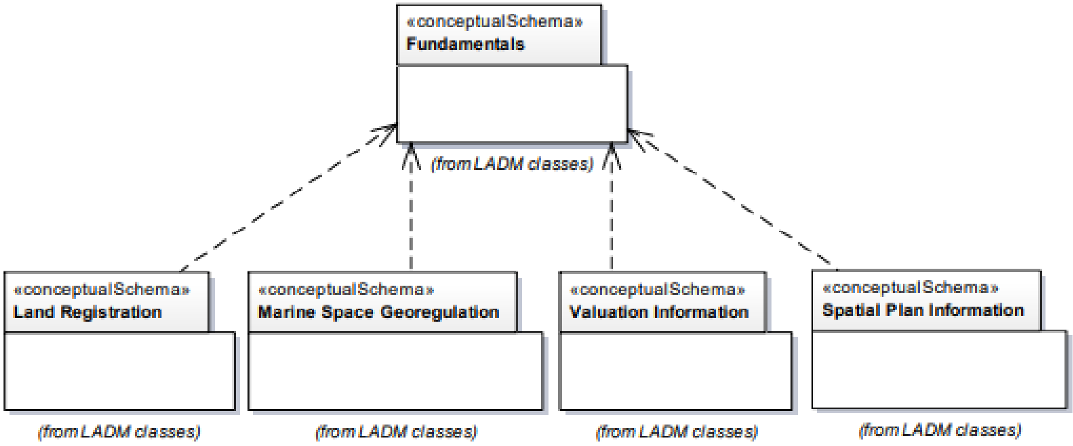

Figure 2. Packages of the extended LADM Edition II including Marine Space, Valuation and Spatial Plan Information (Lemmen et al., 2021)

Part 2 is focused on Land Administration, Land Registration and Cadastre, while some of the existing parts of LADM Edition I are being refined in Part 2 aiming to add more semantics. Representative examples of such improvements are the Survey Model and the semantically enriched, structured, and versioned code lists.

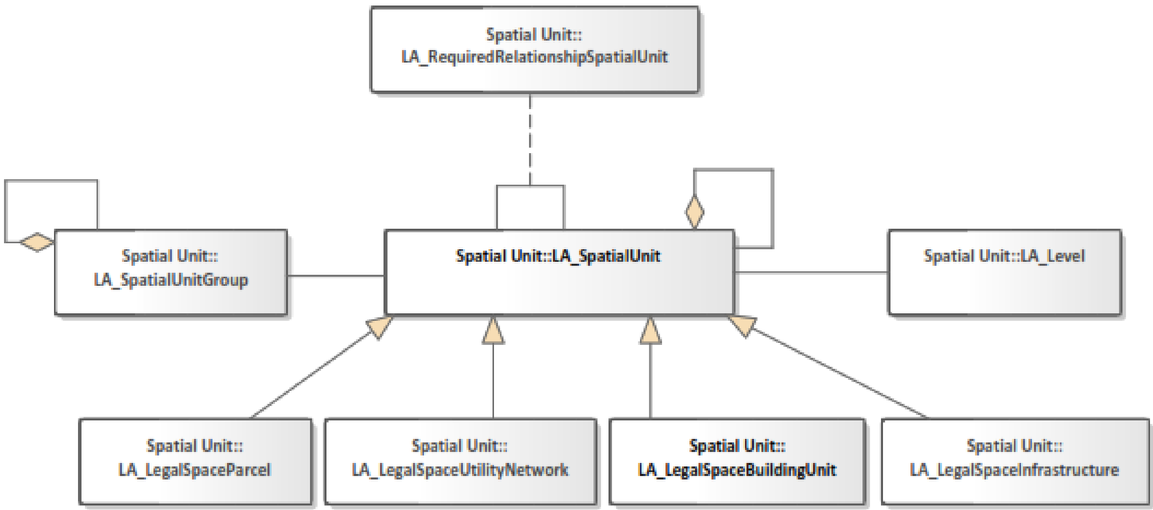

Figure 3. Proposed structure of the refined SpatialUnit Package for LADM Edition II – Part 2

What is more, the LADM Edition I allows a set of possible representations of spatial units in 2D, 3D or mixed dimension (integrated 2D and 3D), providing a framework for categorisation of spatial units. Part 2 of the LADM Edition II will include refined 3D spatial profiles to support the full lifecycle of 3D objects (Thompson et al., 2015, 2016; FIG, 2018b; Kalogianni et al., 2020). An overview of the proposed structure of the refined SpatialUnit Package (as included in the NWIP of Part 2) is presented at Figure 3.

4. PLRS ORGANISATION IN LADM EDITION II

The last decades the documentation and registration of PLRs is increasingly becoming an issue in several countries globally, as the inclusion of PLRs to the cadastral systems, makes the land market more transparent and secure. Standardization in this domain is a challenge, but at the same time an urgent need to enhance information sharing, information integration and interoperability. Kitsakis et al. (2018), provided a brief overview of the standardization approaches of PLRs, highlighting that this activity is still in its early steps, as the enactment of a PLR relates to societal changes, economic needs, demographic data, and environmental factors.

The fact that PLRs may present differences per country or jurisdiction, as well as they derive from multiple authorities and registries operating under different legal provisions, is taken into consideration in the context of this paper. For that reason, a more generic categorization of PLRs, as presented in Table 1, mainly adjusts to the Hellenic reality, while at the conceptual modelling side, the criteria considered for the organization of PLRs and the UML models created are based on Part 2 of the LADM Edition II. Benefits and drawbacks of the alternative modelling approaches are discussed and validated through the use cases (Section 5). From the modelling within LADM, it is expected that the various PLRs will be organized and provide a cost and time efficient basis for their spatialization and analysis on a legal basis.

The modelling alternatives of PLRs that are being developed and examined in the context of this paper are related to their nature and complexity, as well as to the number and variety of organisations involved in their management. In all cases, the proposed modelling is based on the structure of Part 2 of the LADM Edition II, while two main questions/ criteria arise; Whether:

- PLRs should be modelled at the legal part of the LADM or at the spatial part and
- subclasses to organise the various PLR categories (Table 1) should be developed, or a structure with semantically enriched code lists with hierarchical structure should be followed.

Based on those criteria, the following UML models are developed to visualise the alternative modelling approaches for the organisation of PLRs within Part 2 of LADM Edition II.

Modelling the Spatial Part - Alternative 1

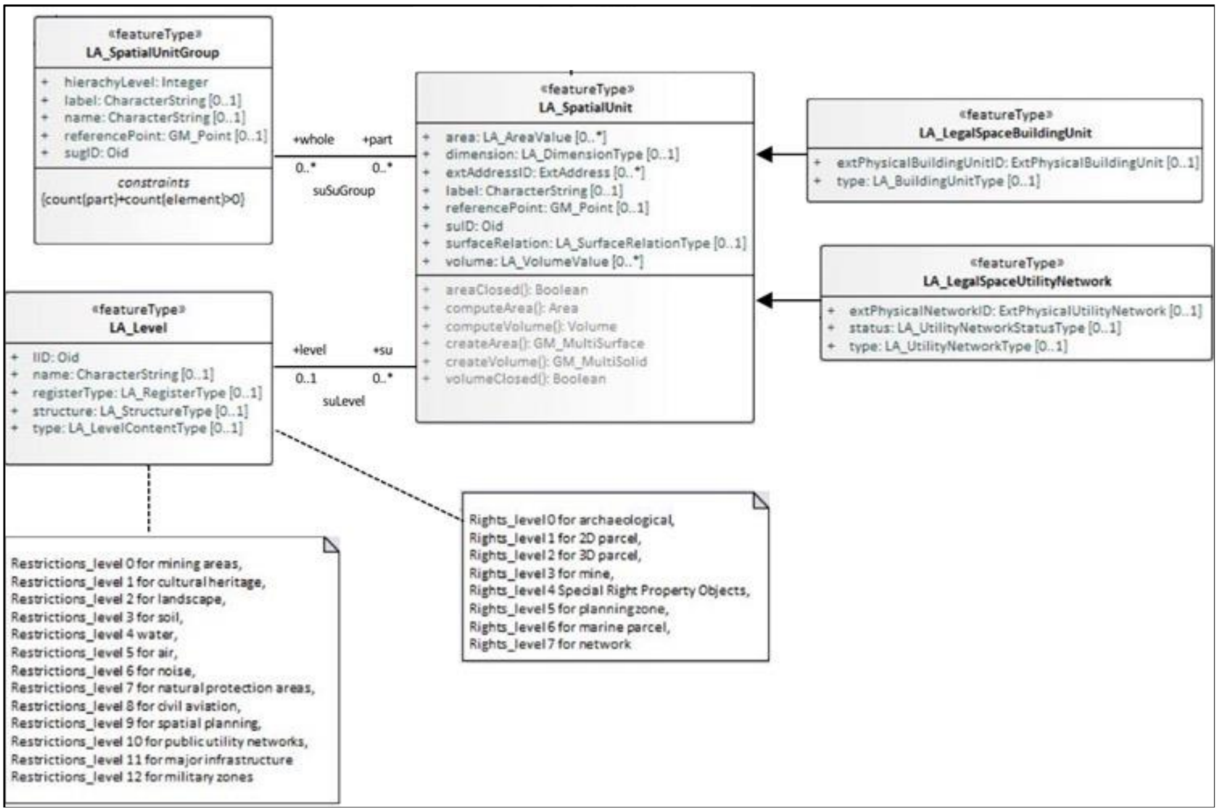

Figure 4. Alternative 1 - modelling PLRs at the spatial part of Part 2 of LADM Edition II

As proposed by Kitsakis et al. (2018), the LA_Level concept of LADM is used to connect the object/zone, on which a PLR is attached to the spatial unit and not directly to the restriction that it imposes, while the type of PLR is defined through the enriched code list values of LA_RestrictionType). A note regarding the proposed Restrictions levels is presented and contains 12 levels, according to the PLR types presented in Table 1. Apart from the restrictions' level, a corresponding note with Rights level is included based on a proposed structure for modelling different spatial units' types and their characteristics, presented by Kalogianni (2015).

Modelling the Spatial Part - Alternative 2: a new class "LA_PublicLawRestrictions" is developed and modelled with an association to the "LA_SpatialUnit" class. All the information related to PLRs is modelled through this class and the corresponding code lists are enriched with the appropriate values according to the categories of Table 1.

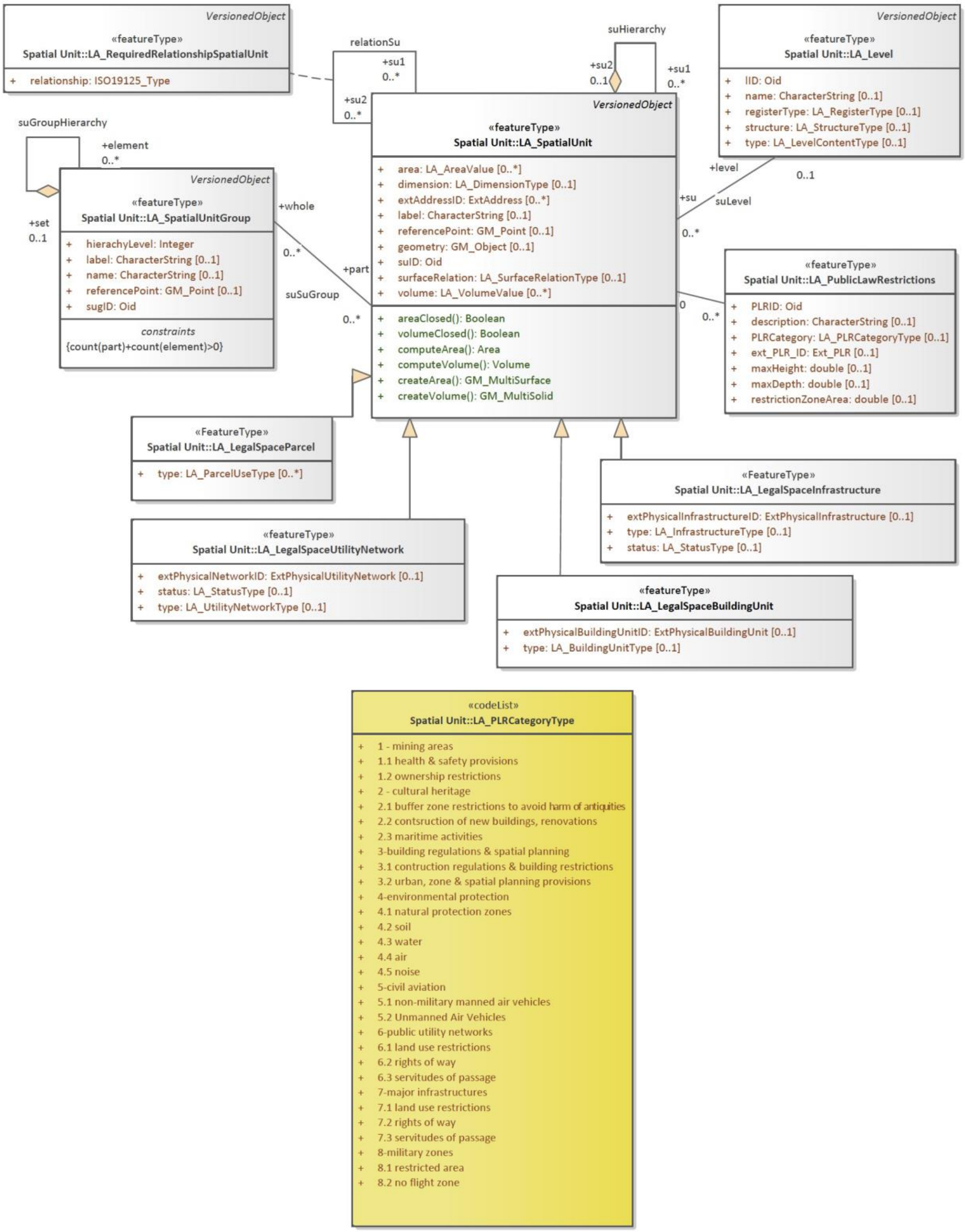

Figure 5. Alternative 2 - modelling PLRs at the spatial part of Part 2 of LADM Edition II

This alternative is further elaborated through the hierarchical code list values that are proposed to be included for the PLR_Category attribute (Figure 6). The proposed approach is simple hierarchical encoding based on the proposed classification of Table 1, namely hierarchical numbering of values in a code list. What is more, to provide further insights for the PLR, an external link with the registry that the PLRs are (or will be) stored and maintained is proposed through the attribute "ext_PLR_ID".

Modelling the Legal Part: The alternative on modelling PLRs on the legal part of LADM is presented in Figure 6.

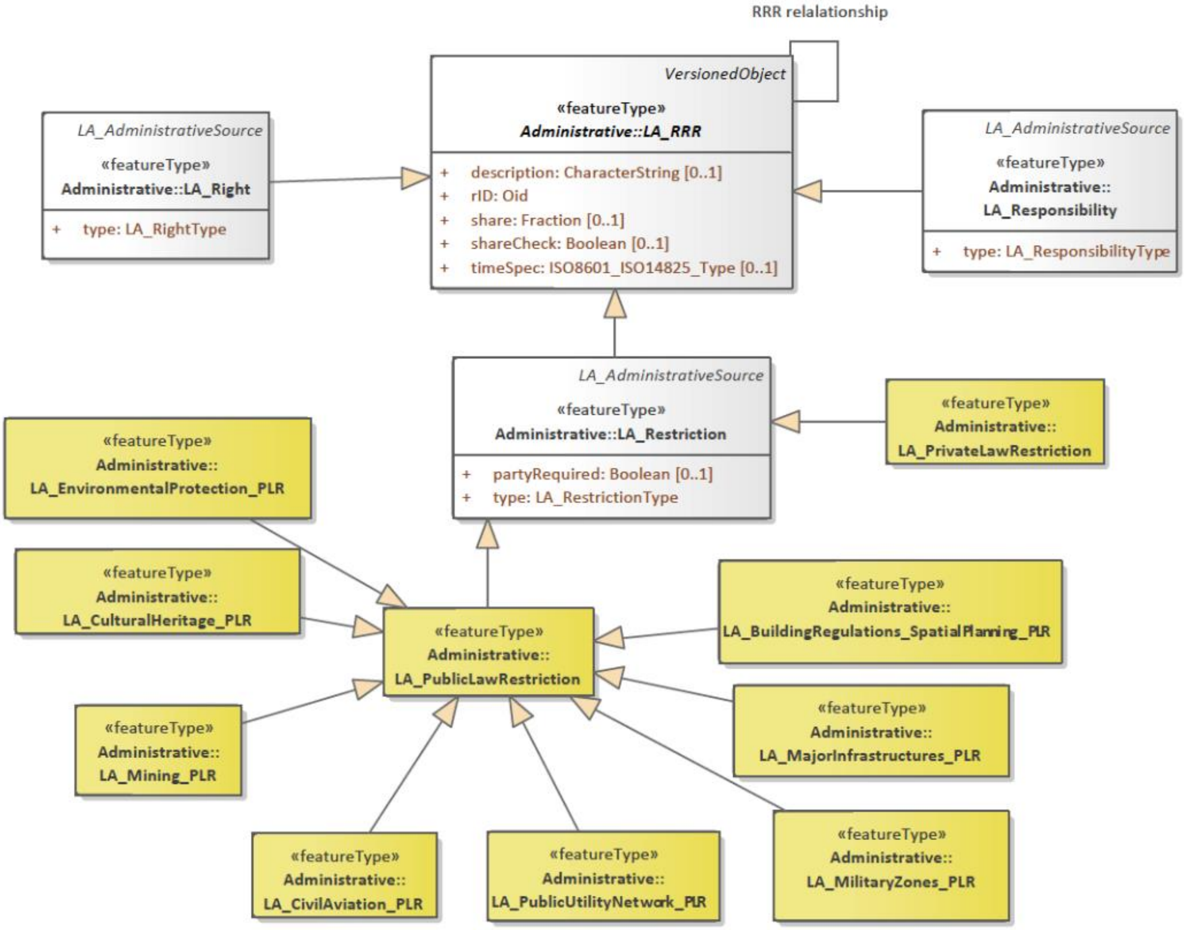

Figure 6. Modelling PLRs at the spatial part of Part 2 of LADM Edition II

Two subclasses are created at the 'LA_Restriction' class, one concerning public law restrictions and the other private law. The 'LA_PublicLawRestriction' class is further classified into 8 subclasses, according to the distinguished categories as presented in Table 1. This approach is considered beneficial when the various PLR categories have different characteristics to be modelled as attributes.

5. USE CASES

The proposed 3D PLR modelling approaches were further examined in two case studies, where restrictions apply in the three-dimensional space, concerning major infrastructures and cultural heritage. The former case refers to restrictions imposed on land for the protection and maintenance of the Trans Adriatic Pipeline (TAP), in Northern Greece, while the latter, examines restrictions that apply on land parcels within a specific perimeter resulting from regulations related to archaeological sites.

Case Study 1. TAP

The TAP crosses about 9.189 land parcels along the regions of Macedonia and Thrace in Northern Greece, covering an area of 4277.7 Ha (TAP, 2016).

Figure 7. TAP route (TAP website, 2021)

The pipeline is constructed at a depth of 1 metre below the earth's surface. To ensure the safety and for the maintenance of the pipeline, the following restrictions are imposed on the land parcels situated in its route (TAP webpage, 2021; Livelihood Restoration Plan):
A Restricted Ownership Zone is established, 4 metres along each side of the pipeline. In this zone, landowners and users are not allowed to:

- Construct buildings of any nature
- To cultivate deep-rooted plants with roots going deeper than 60 centimetres
- Drilling or opening of trenches and/or wells
- Install underground installations at a depth more than 50 centimetres
- Make alterations to the ground morphology in any way (e.g., deep ploughing, excavating, placing of rubble, creating ponds)
- Build new roads

Furthermore, a Building Restriction Zone is established, 20 metres along each side of the pipeline, where landowners and users are not allowed to:

- Construct buildings of any nature and
- Install disposal systems altering the ground's morphology

A 400-metre zone along the pipeline's centreline is established, where restrictions to the number of buildings that can be constructed are imposed. Such restrictions are intended to ensure the security of the pipeline in case of modification of urban plans, or of elaboration of new ones.

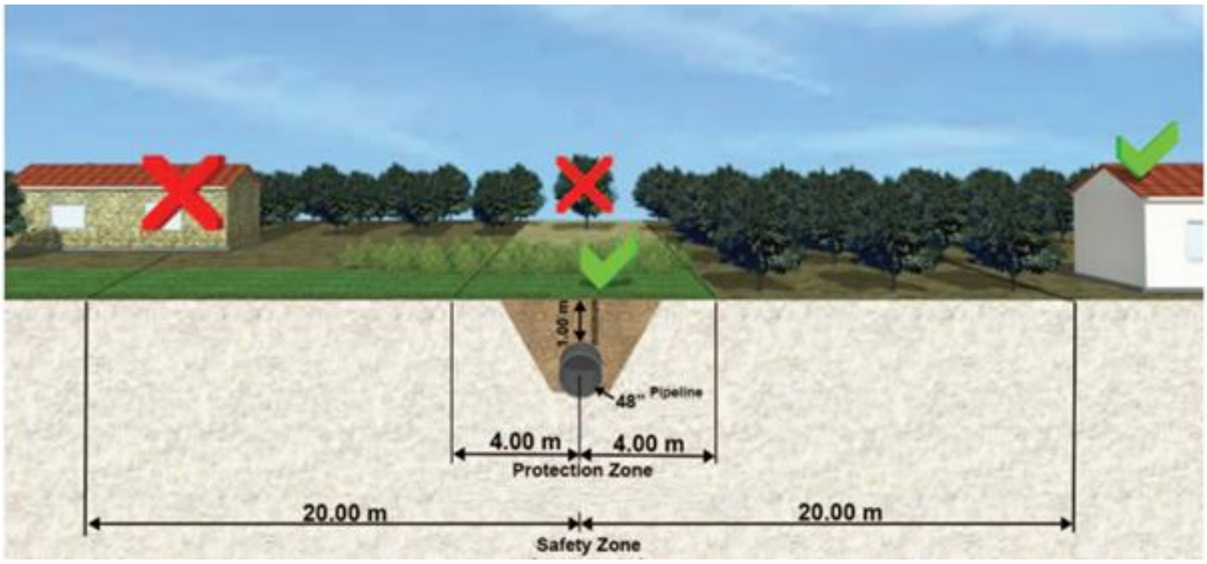

Figure 8. Protection and safety zones along TAP's route.

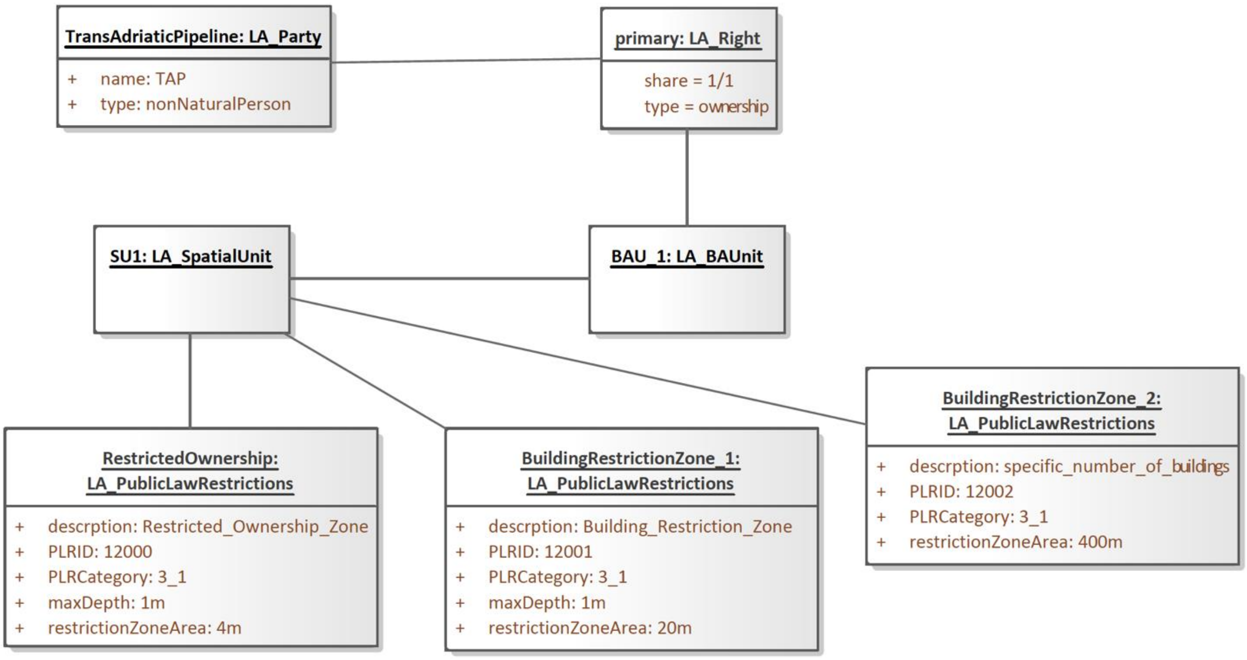

Figure 9. Instance level diagram of use case 1 modelled at the spatial part of LADM.

Case Study 2. Protection zones of the archaeological site of Voundeni

In this case study, restrictions imposed for the protection of the archaeological site of the Mycenaean settlement of Voundeni in the municipality of Patras in Western Greece are examined.

Figure 10. Left: General view of the archaeological site
Right: Zones defined by the restrictions of the archaeological site (red: Zone A, yellow: Zone B)

For the protection of the archaeological site, two zones of protection were established, where specific restrictions apply regarding construction and land exploitation, as stipulated by the relative Ministerial Decision (Greek Government Gazette, Vol. B, Issue 985, 30/12/1994).

- **Zone A:** This zone includes the citadel along with its walls, the remnants of the ancient settlement, as well as the ancient cemetery. Within this zone, only agricultural activities are allowed, opening of rural roads to ensure access to land parcels. A specific region within Zone A, defined in the (2D) survey plan accompanying the Ministerial Decision, is excluded from the non-construction restriction.
- **Zone B:** In this zone, construction is allowed under conditions. Such conditions are defined by Presidential Decree (Greek Government Gazette, Vol. D, Issue 416, 22/5/2002) that sets minimum land parcel area to 4.000 sq.m. Moreover, it defines specific regulations regarding the construction of buildings. Specifically, apart from a minimum land parcel area, it defines the minimum land parcel depth at 50 metres and the minimum façade length on roads to 45 metres. It also sets land parcels' building coefficient to 0.20.

This use case is modelled within the alternative modelling approach for the legal part of LADM, as proposed in Section 4 and the instance level diagram is presented in Figure 11.

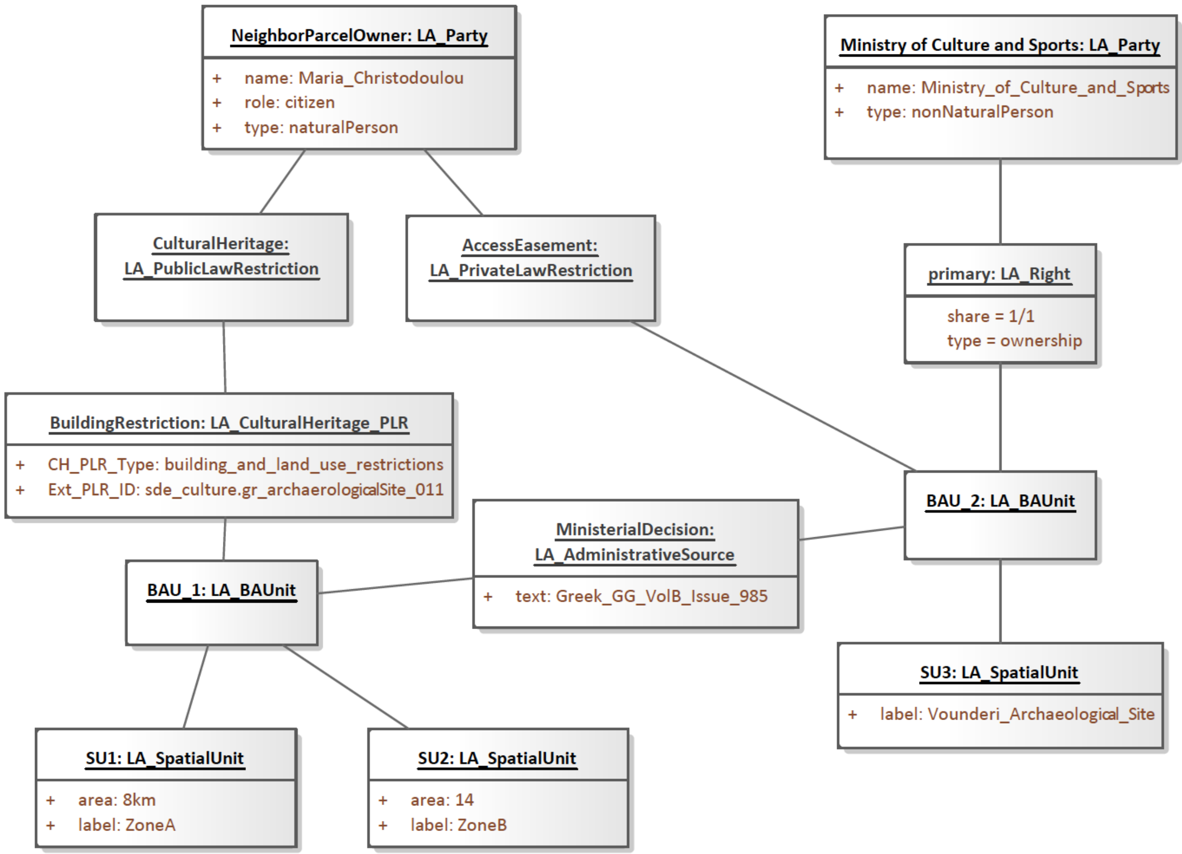

Figure 11. Instance level diagram of use case 2 modelled at the legal part of LADM.

6. DISCUSSION & CONCLUSIONS

Multipurpose and intense exploitation of land in the vertical direction has introduced numerous complexities in LAS, in the form of modelling and registering complex, overlapping private rights, as well as private and public law restrictions in 3D space. Within this context, to secure public benefit, each State imposes PL restrictions on landownership and land-use, concerning the dimensions and characteristics of the buildings, their construction options, as well as specific actions in plot sections.

The registration and 3D modelling of PLRs is a challenging task associated with their characteristics and often with their descriptive character, which in many cases does not refer to a 3D space counterpart. In addition, because of the large number of laws and regulations that govern PLRs, the different time of their creation and the duration of their validity, there is a need to clarify their status and systematically organize them, selecting those that need to be modelled and registered in terms of significance and feasibility. Therefore, different approaches can be identified nationally, depending on the priorities set for national Land Administration System and the technical capacities of national spatial data infrastructures, as stated in the paper. Apart from the previously mentioned factors, significant differences also relate to the legal status of each country/jurisdiction, which is particularly relevant to land ownership issues: PLRs can be regarded as external restrictions on the (unlimited) total, immediate and absolute power deriving from real property ownership, or as restrictions inherent to the nature of ownership, or as restrictions that apply when exercising the powers that result from the right of ownership. Based on those aspects, a classification of PLRs specially to serve the Greek context is proposed in this paper, also considering international experience and knowledge. Following, the umbrella of the various modelling approaches of the PLRs within the LADM revision is proposed, elaborated on the two basic criteria set out above. Advantages and disadvantages are in both approaches, being verified by the implementation of the two use cases through the instance level diagrams. Specifically, the alternatives proposed on the spatial part of the LADM show that the spatial extent of PLRs is emphasized more, while the legal extend is being referred as a code list value or attribute in the level approach. On the other side, the legal proposal is beneficial when the various PLR categories have different characteristics to be modelled as attributes. Therefore, it is considered that the ground is not mature to propose a single solution to model PLRs within Part 2 LADM Edition II.

This paper opens the possibilities and creates the preconditions for a generic model, which will result from the extension of the study to other systems. More use cases from various jurisdictions are needed to validate the proposed solutions and allow for revision iterations at the conceptual level. Having these in mind, different approaches need to be examined, and potential interchanges between different concepts. For example, the bundle of rights concept, best fitting to Common Law based jurisdictions, can be revisited, and investigate its potential application on PLRs, by examining how PLRs "carve away" powers that can be exercised by an owner, deriving from the right of ownership. Therefore, the next step of this ongoing research is to extend on other types of PLRs and on different jurisdictions, so that practical implementation of the investigated case studies can be further examined on real world situations. Moreover, comparative analysis of different jurisdictions will provide feedback on the model's replicability and provide identification of best practices and drawbacks for its further refinement. The PLRs thus modelled, may results in benefits including transparency in land development and innovative products and services in Land Administration practices.

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BIOGRAPHICAL NOTES

Dimitrios Kitsakis is a surveyor engineer, graduated from the School of Rural and Surveying Engineering of the National Technical University of Athens. In 2019, he received a PhD Degree from the same institution for his thesis concerning legal requirements for real property stratification. Since 2012, he is working as a freelance surveyor engineer. He is participating in research projects on 3D modelling, and on climate change, while since 2019 he is participating in the cadastral survey for the development of the Hellenic Cadastre. His research interests include 3D Cadastre and Land Administration, 3D Modelling, Public and Land Law.

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A 3D Approach of Greece's Property Law on Urban Environmental Pollution

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Key words: 3D emissions, property law, building code, Hellenic Cadastre

SUMMARY

The introduction of Greece's Civil Code, in 1946, signaled the transition from the then applicable Roman-Byzantine Law, known as Armenopoulos Exabiblos, to a modernized legal framework. The Greek Property Law, Civil Code Book 3, it is consisting of a bundle of rules, regulations and restrictions on properties, property rights and properties use and exploitation. Even though Property Law was introduced in 1946, it includes a provision, rules and restrictions that were and still are innovative. Besides the definition of rights in rem, like full or limited ownership or usufruct, Property Law introduces legal definitions with technical aspects for rules, regulations and restrictions on property installations that produce emissions, like air, heat, noise or vibrations, creating nuisance or even environmental adverse effects, with negative impact to neighboring properties use and exploitation, so as neighboring properties and their owners are legally protected against any harmful effect.

The explicit technical description of the above mentioned Property Law rules, regulations and restrictions on emission, are included in Greece's Building Code. Building Code sets a detailed legal – technical framework and technical specifications on buildings installations such as central heating systems, restaurants ventilation systems, heating panels, small industry machineries or even advertising signs that could emit dazzling light, so as their emissions are limited to tolerable limits by relevant legislation on air pollutants, noise pollution etc..

Over the years, an important aspect for urban development in Greece is the cleaner urban environment. Thus the incorporation of Property Law and Building Code provisions on emissions in the Hellenic Cadastre is crucial, in order to incorporate environmental parameters monitoring into it, facilitating spatial development, land administration and land monitoring and overall sustainable development.

Herein a research on the environmental aspects of Property Law in three-dimensional level is presented. The research is focused on construction regulations and restrictions for buildings heating and restaurants ventilation systems that are thoroughly-legally documented in Greek Property Law, are in detail technically described in the Greek Building Code and are a serious urban environmental polluter. Further more research is focused on incorporating the above mentioned 3D legally and technically described regulations and restrictions into the 2D Hellenic Cadastre registry.

A 3D Approach of Greece’s Property Law on Urban Environmental Pollution

Dionysia – Georgia Ch. PERPERIDOU and Andreas XYDOPOULOS, Greece

1. INTRODUCTION

From the early beginning of the industrial revolution until nowadays, urban environment is complex, diverse and multidimensional, influenced by resident’s activities and the regulatory intervention of local, regional and state governments or supranational organizations and bodies, whereas urban environmental pollution is one of the biggest problems and challenges that modern societies have to deal with (D. G. Perperidou 2010). Industrial revolution coincided to the fall of the feudal system and the introduction of the *numerous clausus principle* that established the right of individuals to own their own private immovable property/ land, defining that property rights can be created, modified, transferred and extinguished (Van Erp 2003). By mid-18th century and as the first industrial societies were evolving, through the vast urbanization of the then existing cities, urban environment degradation in combination to poor sanitation conditions resulted to population severe health risks. Already from the 18th century building activities restrictions in respect to public health protection were foreseen. Affected by Edwin Chandwick’s 1842 document *The Report from the Poor Law Commissioners on an Inquiry into the Sanitary Conditions of the Laboring Population of Great Britain*, the 1848 UK’s Public Health Act included and enacted for the first time a series of new rules and restrictions on how new houses building and streets would be formation, so as to protect public health (Morley 2007), affecting the exercise of private property rights and property exploitation. In the USA, the 18th century Nuisance Law, permitted state officials to fine or to imprison property owners for their property maluse that caused damage to the community or the neighborhood, while individuals were granted the right to sue and ask for monetary compensation due to injuries caused by neighboring property owners activities or even the right to sue so as the neighboring property’s harmful activities would be stopped (Rosen 2003). In the 20th century and gradually, property rights were defined as a *bundle of rights*, series of legal relationship, also of technical aspects, between individuals or individuals and the state and property owners do not have the right to do whatever they want with their property, but ought to respect and comply to certain rules, regulations and restrictions imposed by public authorities, like land uses, maximum building surface etc. (Johnson 2007).

As by the mid-1950’s urban growth continued, urban pollution from neighboring properties or neighboring public infrastructures, like urban freeways, affected individuals’ health causing serious health problems and property value devaluation, thus those individuals have the right to permeant compensation, like in Boomer v. Atlantic Cement Co case (Schneiderman, Cohn, and Paulson 1970; Farber 2005). In respect to environmental protection, already from the 18thn century the Tort Law affected property rights. In numerus cases Tort Law benefited property owners that polluted with chosen activities installed in their properties and caused adverse effects natural environment (Dewees 1992; Cole and Cole 2002). To limit pollution and environmental degradation, partial or full charges to property owners so as to clean up contaminated sites of their properties leading to cleaner property exploitation practices (Segerson 1994) and those charges could be characterized as a financial restriction to property full use. To protect cultural heritage further restrictions on property exploitation are imposed and in cases of archeological sites of great importance those restrictions are equelevant to expropriation (Theodoropoulos and Perperidou 2019). As human activities get more complex and achievement of individuals financial stability is even more imperative, intermediate property rights arose, like in cases of groups that were granted the free right to install in their properties pollutant and harmful, to others activities, but this free rights is limited to a certain level, after which penalties and fines are imposed (Kotchen and Segerson 2019) as polluter-pays principle defines, but according to ECJ's, polluter –pays principle could not go beyond polluters contribution to the creation of the problem and the pollution imposed fine ought to be proportional (Bleeker 2009).

The challenges that cities have to confront due to climate crisis, the need to reduce buildings energy consumption and the need to construct sustainable and greener buildings, led to the enactment of building regulations that encompass new restrictions to building activities (Sussman 2008; Wong, Chan, and Lam 2012) affecting property rights. Nowadays property development must to comply with certain construction regulation and use specific construction materials, so as property exploitation is not harmful to the environment (natural or man-made) and the common good. For example the USA LEED standards affected properties exploitation due to financial costs of new material and building techniques (Fox 2010).

Properties and properties rights are documented and recorded mainly in cadastral systems. Over the last decade the ongoing research focuses on the development of 3D records or 3D data types to support the development of 3D cadastral systems (Germann, Lüthy, and van Oosterom 2018), to encompass to 3D cadastral data of no legally described objects of the real world like informal settlements (Griffith-Charles and Sutherland 2018), on the 3D aspect of legislation on environmental protection of both natural and cultural environment (Kitsakis 2018). The legal and technical aspect of 3D properties or property rights, rules and restrictions is also an area of research over the last decade (Paulsson and Paasch 2013), but this 3D legal and technical properties is not thoroughly, extensively and in depth examined, compared to 3D properties technical aspects (Paasch and Paulsson 2021).

Herein a research on the environmental aspects of Property Law in three-dimensional level is presented. The research is focused on construction regulations and restrictions for buildings heating and restaurants ventilation systems that are thoroughly-legally documented in Greek Property Law, are in detail technically described in the Greek Building Code and are a serious urban environmental polluter. Further more research is focused on incorporating the above mentioned 3D legally and technically described regulations and restrictions into the 2D Hellenic Cadastre registry.

2. GREECE'S PROPERTY LAW: AN OVERVIEW

Greek Property Law (PL) was enacted in 1946, Book 3 Greek Civil Code, even though it was originally presented in 1939. The 1946 Greek Property Law replaced the precedent Byzantine

– Roman Law legislation, which was officially enacted in 1832 by King Otto, the first King of the then newly established Greek State. Greek Property Law defines 4 property rights: ownership, easement, pledge and mortgage, subjected to restrictions imposed by various other legislations, in respect to common interest and common good, forming a sphere of public power exercise in private property rights (Balis 1951). 1946 Greek PL direct reference on restrictions of property rights or on regulations impose to property exploitation, addresses property rights in the aspect of bundle of rights and not as a stand-alone definition of owners absolute right to exploit their property as they please, in a period that bundle of rights was under discussion, thus the Greek PL is an innovative legal framework on properties and property rights.

Greek PL Art. 1000 defines that "*the owner of the thing can, as long as there are no conflicts to the law or the rights of third parties, to use it as the owner pleases and to exclude any third party action on it*", regulates property use and exploitation in respect not only to the rights of third parties, but mainly in relation to other legislations, e.g. on land uses, building codes, transportation, sanitation – hygiene or even protection of the environment, in respect to State's obligation to safeguard common good and common interest. In general, those Greek Property Law restrictions, e.g. due to air flights, underground development or utilities network development, are three – dimensional **Figure 1** (D.-G. Perperidou et al. 2021).

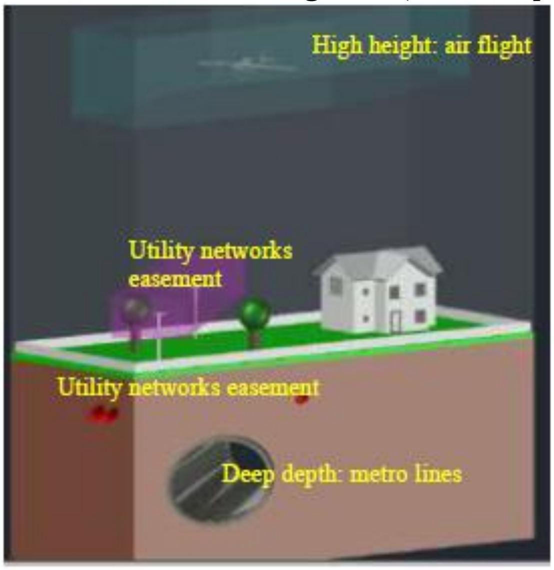


Figure 1: 3D property right and restrictions acoording to Greek PL (Perperidou et al. 2021)

Greek Property Law reference to the "law" and restrictions or regulations impose to absolute property use derives from the precedent legislation, the Byzantine – Roman Law, the "*Hexabiblos of Armenopoulos*". The Hexabilos of Armenopoulos is an official and complete legal handbook on valid legislation from 1345 (late Byzantine Era) to 1946, was the legal code that Greeks used for their affairs arrangement during the Ottoman era (Penna 2015; Christakou 2019), is the fundamental legal document that affected modern Greek legislation on properties and property rights and which also combined property rights with environmental protection and nuisance, caused to neighboring properties, control and minimize.

In his second book Armenopoulos includes and presents a series of detailed rules, regulations and restrictions on buildings construction in respect to neighboring properties and buildings, new building's main use and dominant wind direction, in order for smoke coming out of chimneys not to cause air pollution nuisance to the neighboring properties and prevent fire spreading in case of fire incidence (Spanos 1793). For example in the case of private baths ventilation chimney should be constructed in a distance from neighboring properties, in adequate high and in respect to dominant wind direction and wind flow of the building location, so as the emitted smoke would not cause nuisance to neighboring properties. For professional buildings, distinct regulations were in force depending on building category and use, e.g. bakeries should be in a distance from residencies and preferably in a higher altitude from residential areas, while workshops for pottery, forges, glassworks, dye houses, lime kilns etc. certain rules/regulations and restriction regarding their distance from other buildings, the chimney height of their ventilation systems, their spatial location in respect to residential areas (Spanos 1793), ought to be respected and followed.

3. LEGISLATIVE & REGULATORY FRAMEWORK ON PROPERTIES EMISSIONS AND EMISSIONS INSTALLATIONS AND 3D

3.1 Greek Property Law and environmental protection

Greek PL includes provisions on environmental protection in various sections and articles. Articles 966-971 forbid any transactions on commonly owned immovable things, like waters of free and perpetual flow, seashores, ports, navigable rivers (including their banks), major lakes (including their banks), streets or squares. For surface running waters PL foresees that low level agricultural plots/properties owners do not have the right to build any construction, that could change or prevent waters natural flow on steep slope or rough terrain (Art. 1024) (Balis 1951), **Figure 2**. In properties that are within the regulatory framework of urban plans buildings' rooftops must prevent rain-water from entering neighboring properties respectively and accordingly to relevant legislation provisions so as rain-water would be directed either within property boundaries or to street kennel (Balis 1951), **Figure 2**.

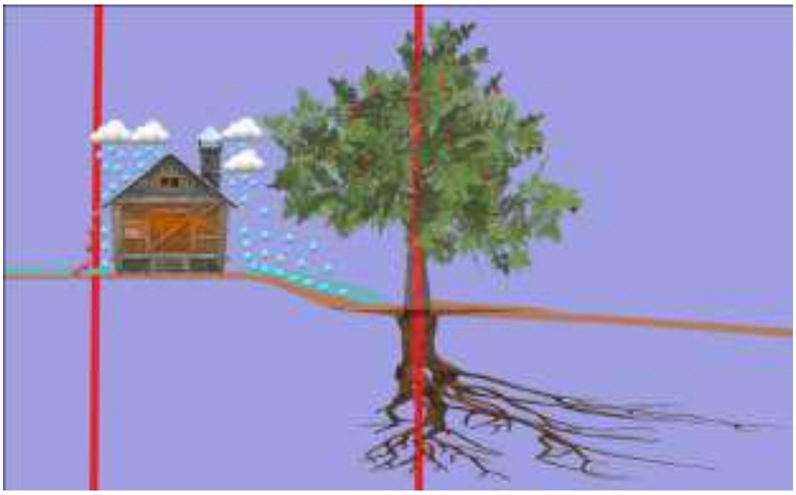


Figure 2: Cross-section of plot and its boundaries according to Greece's PL's rights & restrictions on rain water surface/ roof (Perperidou et al. 2021).

Greek PL also includes provisions that ensure high standards in living conditions and build -environment protection, e.g. window natural light entering easement, view easement and non in-height development easement, technically and in detailed described in relevant to buildings construction legislation.

In respect to common good and society's economic development, a plot owner has to tolerate under or over the ground easements for utility networks development and operation, e.g. water, rain or gas tubes and pipes and overhead or underground electric cables, passing through his property, Figure 1. Owner is eligible for receiving an appropriate compensation, and even if those utility network easements might cause environmental degradation to his property, he has no right to object to them, as common good is prioritized and served (Balis 1951).

A property owner is obliged to tolerate environmental pollution from emissions like, smoke, soot, fumes, heating, noise, vibrations, electromagnetic energy, or brilliant light, coming from installations on neighboring property under the condition that those emissions are not essentially harmful to property use and are common to all the properties of the area (Art. 1003). Emission tolerance of PL derives from BLR the equelevant provisions. In Art. 1003 by introducing the term "usual use of all properties located within a specific area", Greek PL directly addresses to official land use enacted by official administrative and regulatory acts, thus PL foresees that a private property is subjected to the regulatory framework of urban and spatial planning. In respect to the "usual use of a property and its neighboring ones", PL recognizes that this usual use differs in city centers compered to rural settlements or to areas that attract tourist and are holidays destination, while residential areas have different property usual use than industrial areas. The installation of a factory in a residential area does not meet the criteria of "properties usual use" and is a pollution source, while a property owner cannot forbid the operation of a factory in an officially characterized industrial area, even if this factory is a pollutant factor. Consequently, it is essential when examining the tolerance or non-tolerance of a property owner to neighboring property emissions, first to examine land uses regulatory framework and respectively, pollution regulatory framework. However, a property owner can prevent a construction or an installation in neighboring property that definitely harms and pollutes, in short or long term, his property, even if this construction or installation has obtained an official permit according to the law (Art. 1004, 1005).

3.2 Property Law, air emissions and the third dimension

Characterization of air emissions, e.g. emitted from heating ventilation systems due to fossil fuels combustion, as not harmful hence no-pollutant to neighboring properties, their spatial and 3D dispersion must be also thoroughly examined, besides installation usual use compered to neighboring properties. In residential areas heating systems are of common use, so they are not considered as harmful to neighboring buildings, as long as emissions are emitted in an adequate height and thus 3D emissions dispersion could not directly affect neighboring properties, Figure 3. To safeguard tolerance to emissions/ pollutants, combustion fuels used for heating systems are regulated by official governmental acts.

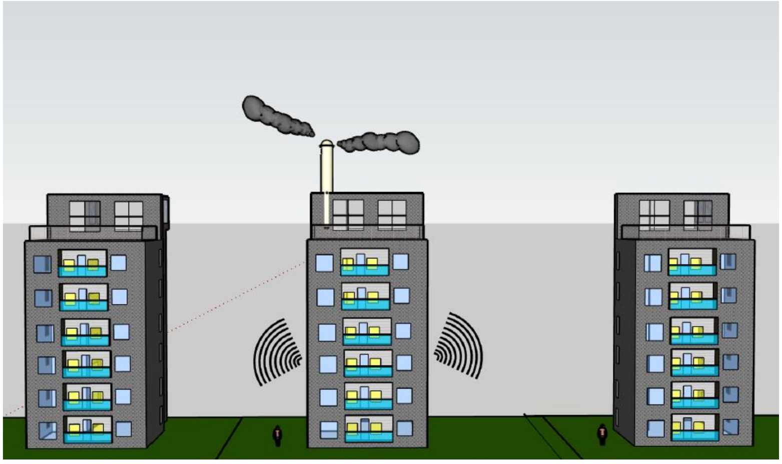


Figure 3: Tolerant emisssions of heating vendilation systems in urban residential area, 3D reprasantation , (3D representation writers own processing)

Respectively emissions emitted from restaurants ventilation systems, that their installation and operation in residential areas is allowed, should also be tolerated as long as emissions are not 3D dispersed directly on neighboring properties, Figure 4, and emissions/ pollutants concentration levels are below official regulative acts.

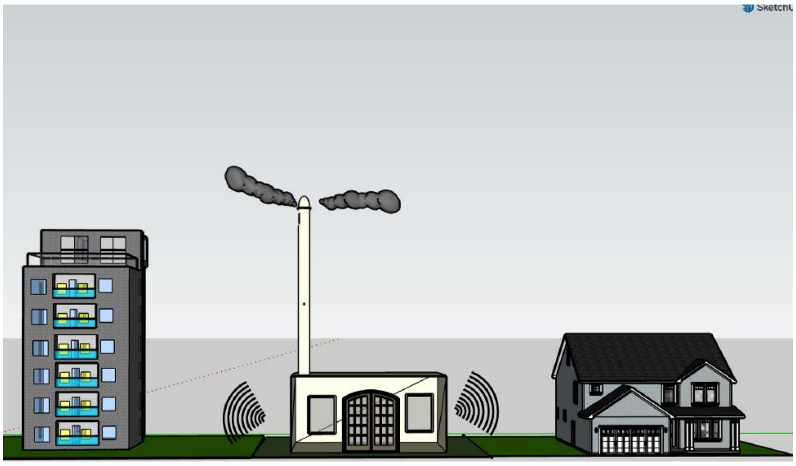


Figure 4: Tolerant emisssions of Heating vendilation systems in urban residential area, 3D reprasantation, (3D representation writers own processing)

On the other hand a factory operation within in a residential area cannot be tolerated, as the factory does not fall under the definition “property usual use”, emissions levels are way above officially defined for urban areas and consequently, emitted emissions are harmful to neighboring properties, polluting the environment, affecting air quality and consequently the main factor for downgraded urban environment, Figure 5.

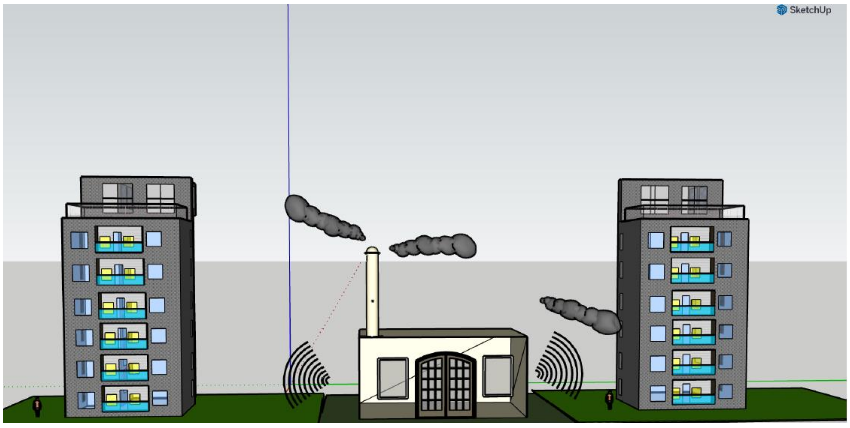


Figure 5: 3D representation of direct adverse effects of harmfull instalations to neighboring properties, (3D representation writers own processing)

Property owners are obliged to obtain an official building or authorization permit from the competent public authorities before the construction and the operation of any installation emitting emissions, in respect to relevant general or specific legislation on constructions, combustion fuels use and pollutants emissions concentration levels. For example if restaurant installations, e.g. cuisine chimneys, are not in compliance to official regulation, violating authorization, excessing official pollutants concentration levels and directly polluting neighboring properties, Figure 6, authorization could be suspended and recalled after an official complain to public authorities.

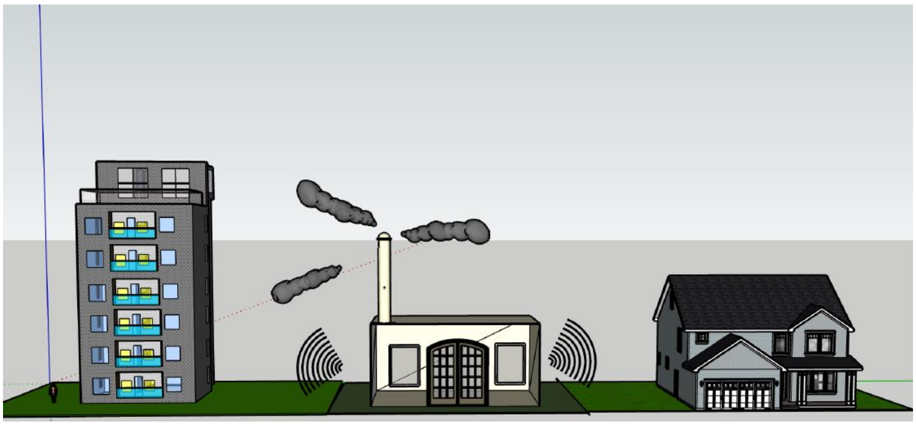


Figure 6: 3D representation of direct affects to neigboring properties of no-comliant to permission regulations installation (3D representation writers own processing).

PL recognizes owner's right to prohibit construction or operation of "harmful installations" in neighboring properties, emitting pollutants harmful for his property and his property interests. Thus a property owner can prevent construction of a factory or a heating ventilation chimney in neighboring property, in case that emissions are directly emitted to his property or if official regulations and legislation on installations and pollutants concentration levels are not met, as such installations have direct adverse effects on his property due to 3D dispersion of excess air pollutants, and contribute to overall degradation of environmental conditions (Figure 5, Figure 6).

3.3 Correlation between 3D provisions on air emissions of Building Code and Greek Property Law:

The legal framework on central heating and restaurants cuisines ventilation system construction, emissions control and prevention is today regulated by the 2012 Building Code, the General Building Regulation, a detailed technical legal document on construction specifications on buildings and installations and the 2017 Ministerial Decision on Sanitary regulations and conditions for the operation of food sector, in respect to minimum nuisance of neighboring properties as Greek Property Law explicitly defines.

The 2012 Building Code includes the general principal on ventilations installations and chimneys construction (for buildings heating or restaurants cuisines ventilation). Chimneys ought to be constructed on the top of the building so as to cause the minimum nuisance to property owners and neighboring properties, **Figure 3**, as emissions are 3D spatially dispersed through the air. Buildings central or individual heating ventilation systems technical specifications are defined in General Building Regulation in respect to 3D spatial dispersion of air emissions. Heating systems chimneys must be constructed:

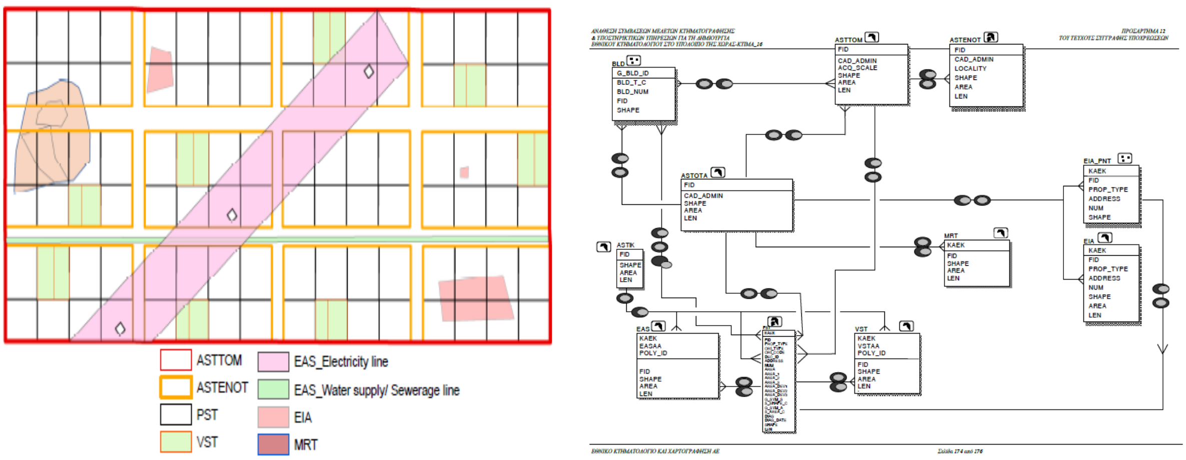
- above the building,
- at least 1 meter above their exit point,
- 0.7 meter above any other building infrastructure (e.g. staircase or/ elevator terminal end) that are within an horizontal distance of 3 meters,
- higher form neighboring buildings openings (e.g. windows, doors etc.) with horizontal distance less than 10 meters, Figure 3 and Figure 4.

Emissions nuisance, e.g. air pollutants levels is controlled and documented by competent authority that has the right to impose administrative measures such as chimney uplift or supplementary measures on emissions nuisance control, so as nuisance is limited to tolerant levels as the Property Law defines. Restaurants ventilation systems must prevent air 3D dispersion of smokes and fumes produced during food preparation, so as to minimize or even to prevent any nuisance that could be caused to customers, employees and neighbors. The Minister Decision on sanitary regulations etc. foresees that restaurants ventilation systems should prevent smoke & fumes 3D spread in indoor restaurant environment in order to avoid indoor air pollution and 3D low height spread in the outdoor environment in order to avoid low level air pollution. Restaurant ventilation systems chimneys construction must:

- comply to urban planning regulations,
- be at least 0.5 meters above the building top
- be in that proper height from the building or any other neighboring building, so as there is no nuisance to neighbors in general, Figure 4.

4. LEGISLATION ON EMISSIONS AND INCORPORATION ON THE HELLENIC CADASTRE

Cadastral legislation explicitly defines that Hellenic Cadastre records rights on immovable things, properties, and any other stand-alone and firmly connected to the ground property object. Each land parcel on which property rights are exercised is in detail depicted in 2D cadastral diagrams as part of the ground regardless of its use or its owner, documented in Hellenic Cadastre spatial (**Figure 7**) and descriptive data base.



ASTENOT: Cadastral Section (building block in Urban Areas)
ASTTOM: Cadastral Sector (10-15 Cadastral sections in Urban Areas
PST: Land parcels
VST: Easements/ Exclusive use
EAS: Utility networks personal limited easement
EIA: special property objects
MRT: Mines

(a) **(b)**

Figure 7: Hellenic Cadastre spatial data base, (a) spatial levels depiction (processed by Perperridoy, (b) ER diagram, source Hellenic Cadastre

However there is no technical and in detail depiction of parcel's components like buildings, other installations, trees, etc.. Only descriptive parameters on building's floors, properties floor and general properties or land parcels use, are documented during the cadastral survey, but those data are not officially available by operative Hellenic Cadastre. But according also to Hellenic Cadastre legislation, detailed records and additional information on the State's official administrative acts or court decisions e.g. land uses, building regulations etc., that contribute to State's organization and sustainable development, should be also incorporated.

4.1 Integration of 3D air emissions regulations and restrictions on the Hellenic Cadastre

Even though property law and relevant legislation on properties clearly and in detail describes legal and technical 3D property rights and restrictions there are not technical specifications for their 3D representation (Perperidou et al. 2021). Building or authorization permits include official approved 2D top views, cross sections and longitudinal models of buildings or installations, while detailed reference on official building regulations and restrictions is incorporated in their 2D land parcel topographic diagram (also including area's contour lines).

The 3D aspect of the Greek Property Law provisions on emissions, correlated to Building Code detailed technical provisions and urban air quality official regulations, could be incorporated into Hellenic Cadastre Spatial and Descriptive Data Base as either legal or technical information on "Land Parcels" entity, parameterized in respect to emission levels, tolerance to pollutants, usual use description and authorization technical details.
The definition of properties usual use is feasible by incorporating to Hellenic Cadastre system additional information on:

- Official acts on land use and spatial planning: municipal/ urban unit level correlated to Hellenic Cadastre "land parcels" entity Hellenic Cadastre Spatial Data Base.

- Official acts on building regulations: building height, total surface, total plot coverage area by the building, correlated to Hellenic Cadastre "land parcels" entity Hellenic Cadastre Spatial Data Base - descriptive information.
- Official regulations on property exploitation and use described in legal documents and deeds and accepted by all property owners within a land parcel: Land parcels entity, Hellenic Cadastre Spatial Data Base - descriptive information.

Tolerance to emissions nuisance by heating or restaurants cuisine ventilation systems definition is feasible by incorporating to Hellenic Cadastre system additional information on:

- Official legislation on air pollutants limits: stand-alone spatial information on Hellenic Cadastre Spatial Data Base.
- Official pollutants spatial dispersion maps: stand-alone spatial information on Hellenic Cadastre Spatial Data Base.

Definition of property owners' rights to emissions installations is feasible by incorporating to Hellenic Cadastre system additional information on:

- Official Building Permits: 2D top views, cross sections and longitudinal models: documents attached to spatial entity Land Parcels.
- Official permissions /authorizations of heating and restaurant ventilation systems: descriptive information for Land Parcel/ Property Entity on Hellenic Cadastre Descriptive Data Base.
- Maximum building height: descriptive information for Land Parcel entity on Hellenic Cadastre Descriptive Data Base.
- Construction characteristics of ventilation system chimney:
    a. Descriptive information: land parcel entity on Hellenic Cadastre Descriptive Data Base.
    b. Official approved drawings: attached to spatial entity Land Parcels.

5. CONCLUSIONS

Greek Property Law foresees regulations and restrictions on emissions, in respect to property owner's right to protect his property from nuisance but defines that owner is obliged to tolerate emissions that do not directly harm his property and are a common and usual characteristic of neighboring buildings such as heating or restaurants ventilation systems. Property law also guaranties a property owner's right to issue an official permit for construction and operation of such installations in respect to specific building regulations and fossil fuels use restriction. All the above mentioned Property Law provisions on emissions and on property owner rights and obligations regarding emissions installations are 3D legal provisions, technically applied in real world 3D space and 3D objects.

Building Code includes the regulatory framework and the detailed technical specifications on construction process, authorization and operation permission of emissions installations, in respect to tolerant nuisance levels, provided by environmental legislation, so as neighboring properties are protected by harmful and pollutant emission levels, as the Property Law explicitly foresees. The construction regularity framework of buildings heating and restaurants ventilation systems, defines 3D legal and 3D technical restrictions in respect building use, building characteristics and height, the horizontal distance from other constructions on building's top, and the horizontal distance from the 3D neighboring constructions. Thus, the integrated regulatory framework on a property's emissions rights, restrictions and obligations, produces a 3D space for real world objects that are in detailed legally described in three-dimensions, but technically authorized in two-dimensions as relevant constructions and installations are depicted in 2D top views, cross sections and longitudinal models.

The Hellenic Cadastre is developed in 2D and includes technical and descriptive information on land parcels and on other properties developed within land parcels. The real world 3D space on emissions that is legally described in Greek Property Law, in detailed technically documented in Building Code and regulated by environmental legislation, could be incorporated into Hellenic Cadastre Spatial and Descriptive Data Base, through legal and technical information on Spatial Entity "Land Parcel". Thus a hybrid 3D description of real world 3D space, 3D objects and 3D environmental conditions, like emissions, on a 2D cadastral system is feasible. Future research could focus in detailed quantitative and qualitative documentation of Property Law and Building Code 3D emissions provision, in respect to Hellenic Cadastre Data Base development specifications and emission monitoring legislation.

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Towards Design and Development of a BIM-based 3D Property Formation Process

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Key words: 3D property formation, Building Information Modelling, Information Delivery Manual, Level of Information Need, 3D Cadastre

SUMMARY

With the increased interest and demand for 3D property, 3D property formation has shown increased significance. It is important to provide efficient, clear and unambiguous methods to form 3D property units, as well as register 3D property RRRs (rights, restrictions and responsibilities). The 3D property formation process should facilitate solutions to complicated problems within building projects (for example space above and below the ground) and provide secure and lasting rights in complex situations. Therefore, 3D property formation could use the same processes as for the formation of other property units, but adding specific rules and standards concerning the use of 3D models.

Building Information Modelling (BIM) contains rich details of building characteristics such as structures, elements, spaces, schedules, etc. that can form the physical models of the 3D cadastre. The 3D property formation process requires that BIM data are exchanged between actors. To model this exchange, we utilize an open BIM process standard Information Delivery Manual (IDM). IDM helps to clarify the detailed property formation process, facilitates actors' communication, harmonizes different product data models delivered and stored, identifies the results of that activity, as well as improves the management more efficiently and collaboratively. Level of Information Need (LOIN) is a framework that defines the extent and granularity of information, in order to prevent delivery of too much information. The LOIN specifies the granularity of information exchanged in terms of geometrical information, alphanumerical information and documentation, which should be used to specify the information delivery between actors.

In this paper, we use LOIN as a basis to specify information requirements according to the 3D property formation purposes, and design a developed process of the Swedish 3D property formation in IDM. In the study, LOIN fulfills the requirements of forming 3D cadastral property in BIM models and harmonizes all involved actors in the whole process in IDM with a more common and standardized approach. The proposed methodology aims to facilitate a standardized and unambiguous digital 3D property formation process on a national level in order to improve and enhance the digital Swedish Cadastral and Land Administration Systems.

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1. INTRODUCTION

A cadastre contains property unit information (e.g. rights, restrictions and responsibilities) used by countries' legal systems to define the dimensions and location of land parcels described in legal documentation and to record values of land and of landholders. The reason for introducing 3D cadastre can be to enhance the possibilities of constructing and financing often large and more complex facilities, create more secure and clear ways of constructing e.g. infrastructure objects, as well as facilitate the management of these properties (Paulsson, 2013; Andrée et al., 2018). 3D property units can be described as closed 3D volumes bounded both horizontally and vertically. To form property units, the cadastre process requires that the involved actors share information between each other. Much of the cadastral information sharing is still using textual description and non-machine-readable data formats during the formation process.

With the increased interest and demand for 3D properties, the 3D property formation has shown increased significance (Choon and Hussin, 2012; Andrée et al., 2018; Larsson et al., 2020). It is important to provide efficient, clear and unambiguous methods to form 3D property units, as well as register 3D property RRRs (rights, restrictions and responsibilities). It facilitates solutions to complicated problems within building projects (for example space above and below the ground) and provides secure and lasting rights in complex situations (Paulsson, 2013). Therefore, 3D property formation could use the same processes as for the formation of other property units but adding specific rules and standards concerning the use of 3D models (Larsson et al., 2020).

Most documents used in the property formation process are recorded and registered in paper format or frozen digital images (Andrée et al., 2018). In Sweden, the cadastral authorities use 3D CAD drawings containing the 3D real property boundaries in the cadastral formation process, but these drawings are not formally archived in the national real property register (Larsson et al., 2020). Moreover, the organizations and different stakeholders involved in the 3D property formation process reveals it as an unclear and ambiguous process. To overcome these problems several authors have proposed a 3D property formation process based on exchange of 3D digital models, especially Building Information Models (BIM) (see e.g. Olfat et al., 2019; Larsson et al., 2020; Sladić et al., 2020). However, what has been missing is a comprehensive study that describes the information need in the exchange of BIM data between the actors in the property formation process. The aim of this paper is to fill this gap.

In this study, we design and develop a 3D property formation process to provide guidelines of uniform cadastral documents and access to uniform data throughout the process. In the process, we utilize Building Information Modelling (BIM) as a digital representation of a building, containing rich details of building properties such as structures, elements, spaces, schedules, and other aspects of a construction project. The 3D cadastre formation process requires that BIM data are exchanged between actors. To model this exchange, we utilize the Information Delivery Manual (IDM), which is an open BIM process standard, to capture and specify the processes and information flow during the lifecycle of a facility by bringing many different stakeholders together in a project-specific organization (ISO, 2016). Level of Information Need (LOIN) is a framework that defines the extent and granularity of information, in order to prevent delivery of too much information (ISO, 2018). LOIN provides methods for describing information according to exchange information requirements, applicable to the whole life cycle of any built asset (SIST EN 17412-1:2021). In this paper, we use LOIN as a basis to specify information requirements in the 3D property formation process, and design a developed process model of the Swedish 3D property formation with IDM.

2. LITERATURE REVIEW

2.1 BIM

Building Information Model (BIM) is not only a model or tool but also a process and technology of creating, maintaining, using and exchanging building information (Sacks et al., 2018). In the Architecture, Engineering and Construction (AEC) industry, BIM is a digital representation of a building in the life cycle phases, containing rich details of building properties such as structures, elements, spaces, schedules, and other aspects of a construction project. When integrating with cadastre, BIM models provide detailed spatial information about physical components of buildings, which could address the problems with good capabilities as a physical model to generate a 3D cadastral model.

BuildingSMART has developed international open standards for the building industry worldwide (see Figure 1): Industry Foundation Classes (IFC) enable digital storage for interoperability; International Framework for Dictionaries (IFD) to specify the terminology; and Information Delivery Manual (IDM)/Model View Definitions (MVD) identify the process (buildingSMART, 2019).

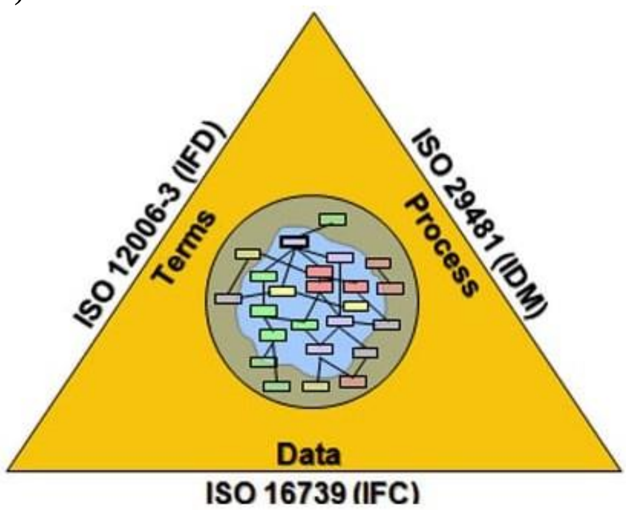

Figure 1. Open BIM standards: IFD, IFC, IDM (buildingSMART, 2019)

IFC is the most spread open international standard in the BIM domain, which is designed to exchange and share information among software applications by many different stakeholders (Borrmann et al. 2018) and supports definition of building elements and the spatial relationship between the elements. Because IFC has powerful capabilities to model detailed physical information and represent 3D property boundaries accurately, BIM/IFC has attracted a wide attention and been used to integrate with 3D cadastre (Sun et al., 2019). For instance, Atazadeh et al. (2017) performed a case study to explore the feasibility of BIM to model the boundaries of ownership spaces inside buildings and identified relevant geometric and semantic IFC entities. In a recent study Asghari et al. (2021) validated cadastral data based on BIM, where they propose a systematic approach to utilize IFC models.

2.2 IDM

Information Delivery Manual (IDM) is a BIM methodology to capture and specify processes and information flow during the lifecycle of a facility by bringing many different stakeholders together in a project-specific organization (ISO, 2016). It clarifies detailed process, helps all actors' communication, harmonizes different product data models delivered and stored, identifies the results of that activity, as well as improves the management more efficiently and collaboratively. IDM can specify information requirements for specific information use cases in a structured manner and is mainly composed of three parts: a process map, exchange requirements, and a model view definition (MVD) (Sacks et al., 2018). Recently, some studies have utilized the IDM process to describe cadastral information exchange between stakeholders following international standards in the 3D property formation process (Oldfield et al., 2017; Sladić et al., 2020).

2.3 LOIN

The level of information need, LOIN, provides methods for describing information to be shared according to exchange information requirements between actors. In relation to IDM, with the model view and the exchange requirements, LOIN defines the characteristics of the exchanged objects both as the requirements and the realized exchanged information. As a new European standard EN 17412-1, LOIN specifies the granularity of information exchanged in terms of geometrical information, alphanumerical information, and documentation, which should be used to specify the information delivery between actors, see Figure 2.

Each exchange of information must consider each recipient's needs and the purpose for supplying that information. LOIN can be seen as replacing the combination of Level of Detail (LoD) and Level of Information (LoI). In the delivery phase of projects/assets, the appointing party (project client) should consider the method of assignment for LOIN and what is required to meet each information requirement.

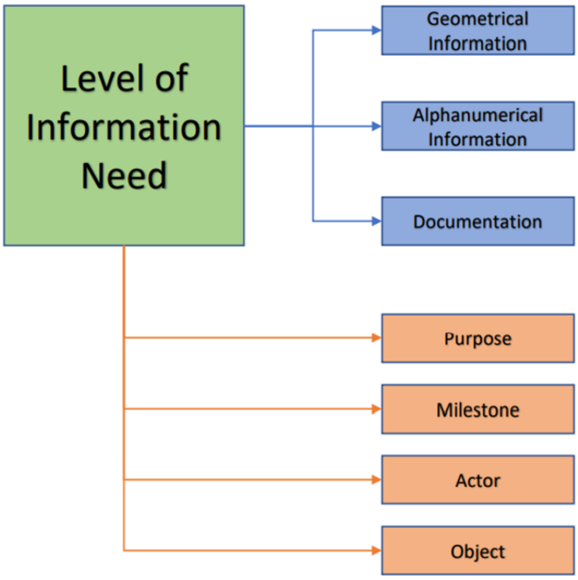

Figure 2. Characteristics of the exchanged object (CEN-CENELEC, 2019).

3. CURRENT PROPERTY FORMATION PROCESSES IN SWEDEN

Swedish real property formation is a responsibility of the national government. The Swedish mapping, cadastral and land registration authority (Lantmäteriet) as a public authority has the overall responsibility for the formation of real property including making decisions on new property units, making changes to existing boundaries, and making decisions concerning joint properties, easements and rights of way. Selected municipalities have their own property formation cadastral and land registration authority after fulfilling certain preconditions in the law and obtaining permission from the Swedish Government. Lantmäteriet has recommended the Swedish Government to modernize the legal statutes for real property registration to facilitate a smooth transfer from today’s handling of information to an information infrastructure of tomorrow.

The increased interest in 3D property formation in Sweden requires an effective formation process. Swensson and Juulsager (2014) has illustrated the Swedish property formation process: application, investigations/consultations, field survey map, meeting decisions, conclusions of procedure, invoice sent and registration. Sun et al. (2019) have formulated general basic requirements for 3D cadastral formation and proposed a framework to integrate 3D cadastre and 3D digital models, both BIM and 3D GIS (see Figure 3). However, no detailed description was presented of the digital data delivery between the actors as well as actions from the actors to obtain an unbroken digital flow of data in the 3D cadastre process. The main difficulties and drawbacks are how the cadastral information should be shared among the different stakeholders in the 3D property formation process.

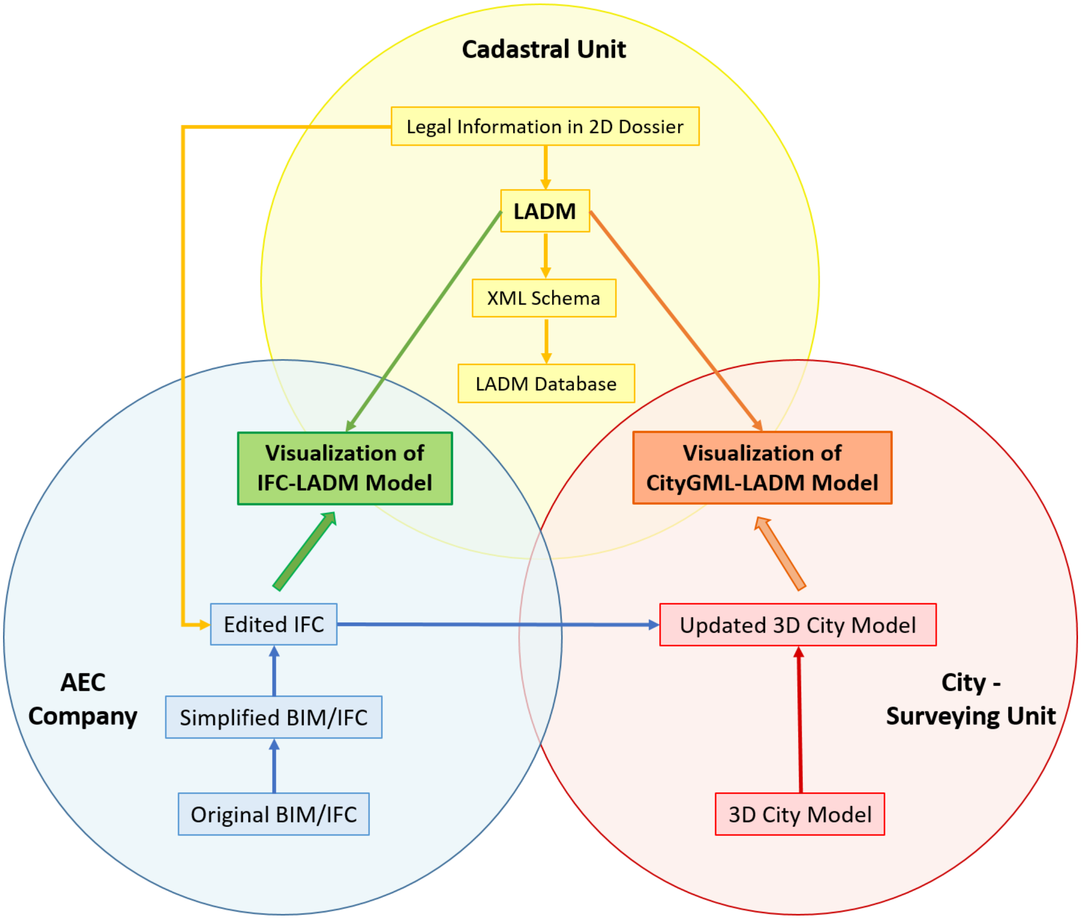

Figure 3. A general framework for integrating 3D cadastre with BIM and GIS (Sun et al., 2019).

4. PROPOSAL OF 3D PROPERTY FORMATION PROCESS

4.1 The real property formation phases

The 3D property formation process can be divided into five phases (Figure 4). Details of data exchange in these phases are given below, but first we provide an overview of the process.

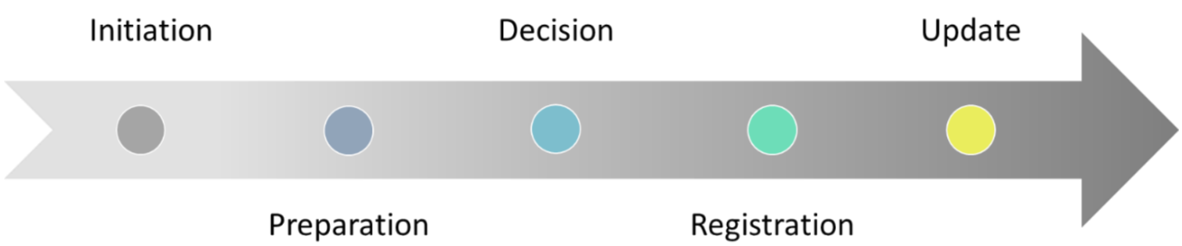

Figure 4. The five phases in the 3D real property formation process.

4.2 Overview of the proposed 3D property formation process

In this paper, we use LOIN as a basis to specify information requirements according to the need of the actors in the 3D property formation process, and describe the data exchange in the process in an IDM process map (Figure 5). We identify four main actors when forming a 3D property: applicants, the cadastral authorities, cadastral surveyors and municipalities. A lane named “Data exchange and store” illustrates which and how the data exchange and store among different actors during the process.

In the study, LOIN are used to harmonize all involved actors in the whole process and support cadastral information exchange in IDM with a more common and standardized approach. To specify how the information is going to be delivered, as shown in Figure 2, the following shall be considered:

- Purposes: for the use of the cadastral information to be delivered in BIM models
- Information delivery milestones: for the delivery of the information, including geometrical information, alphanumerical information, and documentation
- Actors: who are going to request and who are going to deliver the information during the 3D property formation process
- Objects: organized in one or more breakdown structures, for example IFC_Space.

The proposed methodology aims to facilitate a standardized and unambiguous digital 3D property formation procedure on a national level in order to improve and enhance digital Swedish Cadastral and Land Administration Systems. The proposed property formation process is based on the results from previous research (Andrée et al., 2018 and Sun et al., 2019), where a possible future process for 3D property formation was described and how to integrate 3D cadastre with BIM. A developed vision for a future process for 3D property formation is described below.

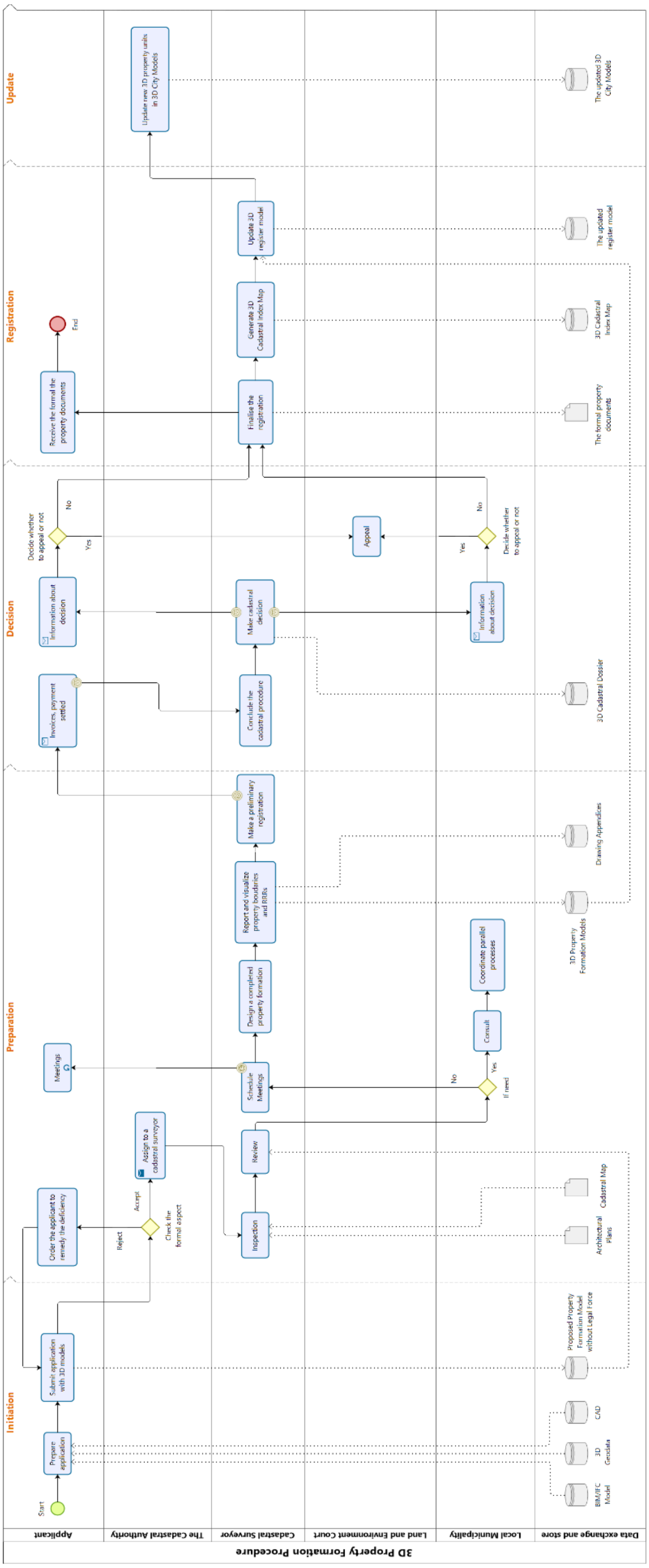

Figure 5. A developed process of Swedish 3D real property formation in IDM.

4.2.1 Initiation phase

The initiation phase is the initial phase of a 3D property formation process where the applicant, typically a property developer, prepares and submits an application to the cadastral authority (Figure 6).

The initiation phase starts prior to the application for property development, when a digital 3D model (BIM or similar) has been developed by the applicant. The 3D model contains, among other things, existing property boundaries (2D and 3D) and rights in the affected area retrieved from the cadastral authority, desired new property boundaries and associated rights, as well as physical BIM details, such as walls and load-bearing structures, for existing and planned buildings that are affected by the planned 3D property formation. The applicant can, in addition to entering new own data, access data for his/her 3D model from a register model (register map in 3D, responsible cadastral authority), geodata model (responsible municipality), plan model (current planning regulations in 3D, responsible municipality) and / or building permit model (current building permit in 3D, responsible municipality) and digital models of e.g. existing building structures used in previous cadastral processes. These are accessed through a proposed common platform for built environment data, which can be used by all the actors in the process and where the platform mainly functions as a peephole where the applicant can compare his/her data with other actors' / authorities' data, but from where certain data can also be downloaded / copied for use in the applicant's 3D model.

In connection with the application, the applicant produces supplementary documentation. The application is prepared by the applicant, sent to the surveying authority and supplemented early in the process with a digital property formation model. The submitted model is a suggestion for property formation and has no legal force. It may be changed – in cooperation with the applicant – by the cadastral surveyor during the preparation phase. It is important that the property formation model states both existing and proposed changed, revoked and new boundaries and rights, respectively. This is to be able to see in retrospect what changes took place with the cadastral procedure.

4.2.2 Preparation phase

The preparation phase starts with a technician at the cadastral agency checking the formal aspects of the submitted application, e.g. that the application is signed by the applicant. If not accepted, the application is returned to the applicant for revision and resubmission. If accepted, the application is then assigned to a cadastral surveyor who is in charge of the entire property formation and registration process (Figure 6).

The surveyor inspects the applicant's architectural plans and the necessary cadastral map(s) on footprint level, for example property boundaries and easements, to see the overall extent of the legally affected area subject to property formation.

The cadastral surveyor reviews the suggested property boundaries and the need for rights, restrictions and responsibilities (RRR) in 3D by using the information in the 2D/3D cadastral dossier stored in the Real Property Register. He/she also makes inquiries about existing RRRs. If needed, the cadastral surveyor will consult with the local municipality (typically regarding water supply, sewerage, and/or development plan issues) and/or regional or governmental agencies, such as the national Transport Administration (typically regarding road access). Ongoing parallel processes for building permits and detailed plans are coordinated through consultation and/or other contact with the relevant stakeholders.

Work meetings and other contacts are held continuously with the applicant. The applicant may then, if necessary, update his/her 3D model with correct reporting of suggested rights and new demarcations. The real property formation model, which is created by the cadastral surveyor, contains all spatial cadastral information in 3D. Prior to the cadastral decision, a completed design of the property formation is ready. The phase ends when the cadastral surveyor makes a preliminary registration of his/her decision in the Real Property Register.

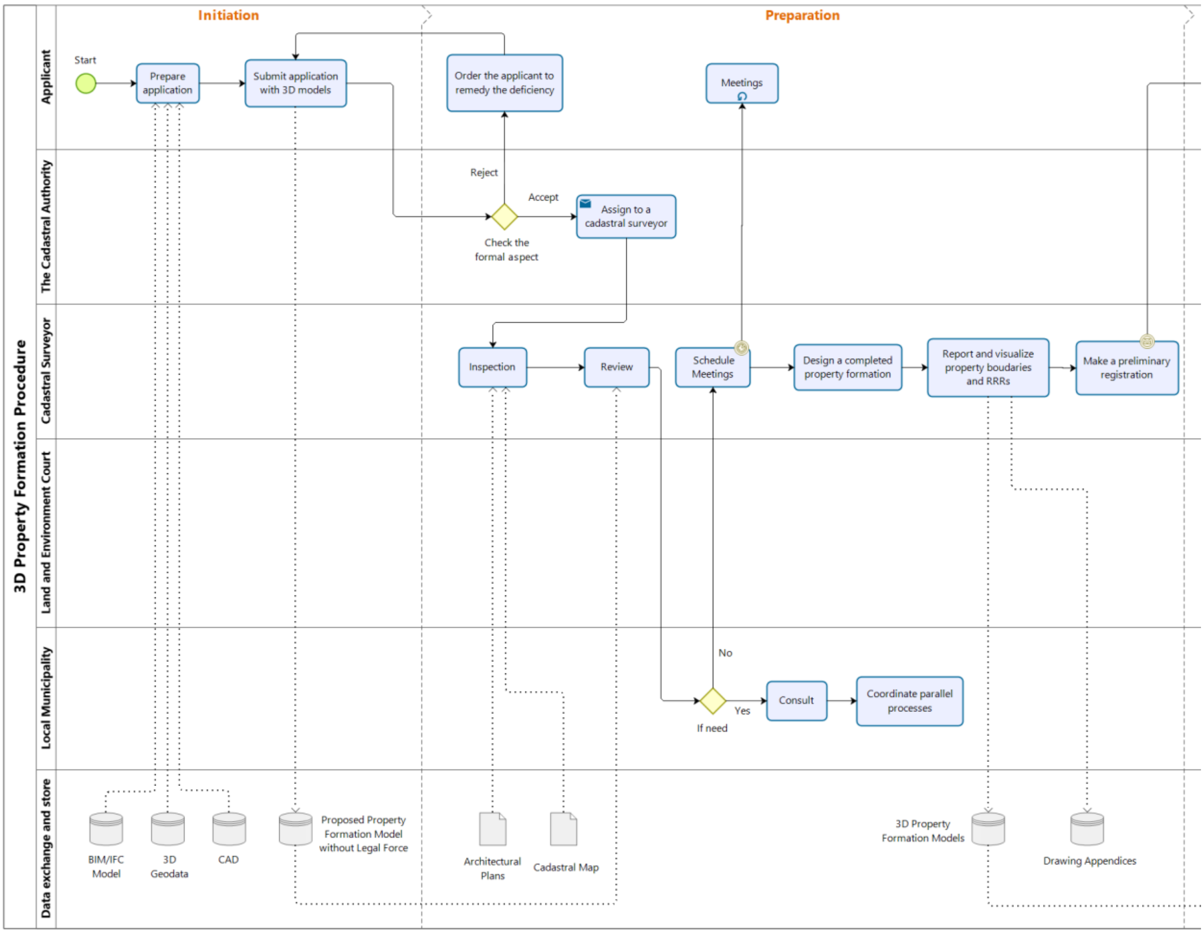

Figure 6. The proposed initiation and preparation phase in the IDM.

4.2.3 Decision phase

After the payment is settled, the cadastral surveyor will conclude the cadastral procedure and make a final decision (Figure 7). Both the applicant and the municipality will receive the decision information and decide whether to appeal or not to the Land and Environment Court.

The cadastral decision is confirmed by the cadastral surveyor. In addition to the map, description and minutes, the decision also includes a property formation model, 3D visualization and appendices (paper/pdf) which are stored in the 3D cadastral dossier.

4.2.4 Registration phase

The cadastral surveyor will finalise the registration of the new real property unit in the Real Property Register national cadastre after the mandatory appeal period has ended and no appeals have been made. The new or altered 2D and 3D real properties are registered in the agencies archive and shown in the 3D cadastral index map. Finally, the applicant will receive the formal property documents and the property formation process ends. The cadastral dossier is stored in the agency's digital archive. The property formation model is used to update the register model, which can handle 3D. In the register model, only property boundaries and rights are included, not construction elements etc.

4.2.5 Update phase

The cadastral surveyor will update the new 3D property units in the 3D city model after registration.

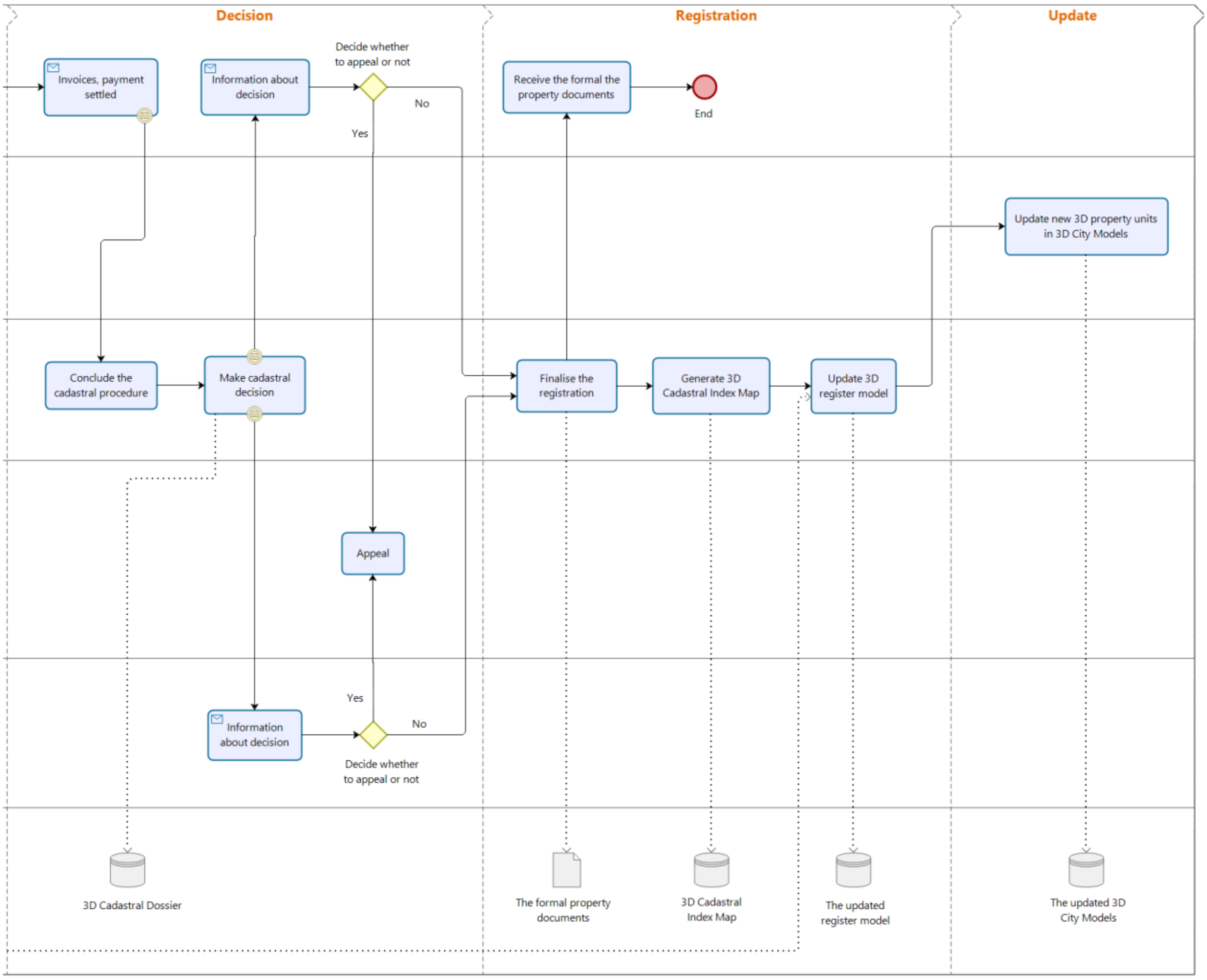

Figure 7. The proposed decision, registration and update phase in the IDM.

5. CONCLUSIONS

Traditional cadastral systems register property and share cadastral information in 2D. From a technical aspect, 3D property registration can represent and form legal objects in a 3D reality world in order to investigate complex spatial structures and avoid ambiguous property boundaries. However, within the 3D property formation process, this faces practical difficulties. For instance, when and which cadastral data should be exchanged and stored by which organizations/ actors. Therefore, in this study, we presented and designed a BIM-based 3D property formation process. LOIN has been used to specify information requirements according to the 3D property formation purposes, and IDM as the international standard process of BIM has been used to design a developed process of Swedish 3D real property formation including four actors and clear data exchange flow. The proposed methodology facilitated a standardized and unambiguous 3D formation process and enhanced a holistic cadastral management in 3D for sustainable development in economic, social and environmental aspects. In this paper, even though the BIM-based approach has been developed from organizational and technical aspects, more detailed data and steps still need to be further investigated. Therefore, practical case study will be considered in further studies.

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The focus of the 7th International FIG Workshop on 3D Cadastres was on adressing the challenges related to the increasing complexity of infrastructures and densely built-up areas, which requires a proper registration of the legal status (private and public), that can only be provided to a limited extent by the existing 2D cadastral registrations. Therefore 3D representations of legal space can be seen in other phases of the spatial development lifecycle: planning, design, permitting, constructing, enforcement, and so on. 3D data sharing and reuse are topics of growing importance. The Workshop on 3D Cadastres 2021 addresses developments in the following areas:

- Operational experiences of 3D Land Administration Systems (LASs) worldwide
- 3D LAS cost-effective workflow for new / updated 3D parcels = 4D (part of whole spatial development lifecycle: from planning / design / permit in 3D, to registration / use in 3D)
- 3D LAS web-based dissemination prototypes (usability, man machine interfaces, including mobile / AR)
- Legal aspects for 3D LAS and good legal practises in various legislation systems
- Focus on large cities and developing countries
- 3D in the revision of ISO 19152, the Land Administration Domain Model (LADM), covering domains of: Land Registration, Marine Space Georegulations, Valuation Information, and Spatial Plan Information.

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