Proceedings

12^{th} INTERNATIONAL FIG WORKSHOP ON THE LAND ADMINISTRATION DOMAIN MODEL & 3D LAND ADMINISTRATION

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Preface

These proceedings reflect the content of FIG's (International Federation of Surveyors) 12th International Workshop on the Land Administration Domain Model and 3D Land Administration (LADM & 3D LA), 24-26 September 2024, Kuching, Malaysia. It was organized as a joint event together with: Geoinformation Week 2024 (including Exhibition from vendors), FIG Commission 5 (Positioning and Measurement) Annual Meeting, FIG Commission 7 (Cadastre and Land Management) Annual Meeting, and the UN Habitat Social Tenure Doman Model (STDM papers also included in the proceedings).
The city of Kuching is located in the state of Sarawak, which does have its own land-related legislation. The state of Sarawak has an integrated organization, the Department of Land and Survey Sarawak, which is responsible for all the land administration functions: Land Registry, Planning, Valuation, Title Registration, Survey and Cadastral Mapping, etc. Covering all land administration functions is also the aim of the multi-part LADM edition II (under development).
The LADM & 3D LA workshop in Kuching (3DLA2024, in short) will offer a great opportunity to exchange the requirements, developments, and experiences when addressing integrated land administration.
The 3DLA2024 Workshop is one of the activities of the LADM & 3D LA Working Group (WG), which belongs to FIG Commission 3 'Spatial Information Management' and Commission 7 'Cadastre and Land Management'. Under the responsibility of this WG two event series (the FIG LADM workshops, and the FIG 3D Cadastres workshops) are merged in the current series of LADM & 3D LA workshops. The current edition is the 3rd workshop of the merged series.
Let's first reflect on the past FIG 3D Cadastres (Land Administration) workshops:

1. November 2001, Delft, the Netherlands;
2. November 2011, Delft, the Netherlands;
3. October 2012, Shenzhen, China;
4. November 2014, Dubai, United Arab Emirates;
5. October 2016, Athens, Greece;
6. October 2018, Delft, the Netherlands;
7. October 2021, New York City, USA (→online);
8. June 2021, LADM & 3D LA, online (part of FIG eWW); and
9. October 2023, LADM & 3D LA, Gävle, Sweden

The history of the FIG LADM workshops is summarized in the list below:

1. March 2003, Enschede, the Netherlands;
2. December 2004, Bamberg, Germany;
3. November 2009, Quebec City, Canada;
4. July 2012, Rotterdam, the Netherlands;
5. September 2013, Kuala Lumpur, Malaysia;
6. March 2017, Delft, the Netherlands;

7. April 2018, Zagreb, Croatia;
8. October 2019, Kuala Lumpur, Malaysia;
9. June 2021, LADM & 3D LA, Amsterdam, The Netherlands (→online, part of FIG WW);
10. March-April 2022, Dubrovnik, Croatia; and
11. October 2023, LADM & 3D LA, Gävle, Sweden

In total seven FIG 3D Cadastres workshops and nine FIG LADM workshops, and two FIG LADM & 3D LA workshops (a total of eighteen workshops) precede the current event. This is the third time in Malaysia, as two times earlier the LADM workshop was conducted in Malaysia (Kuala Lumpur), but it is the first time for the 3D Land Administration workshop (part) to be conducted in Malaysia.

Based on the call for participation, 33 submissions were received. Each submission, in the form of an extended abstract, was typically reviewed by five or more Programme Committee members. This finally resulted in 23 accepted full papers included in these proceedings. The result is a full programme as the workshop is organized as a single track. The on-line proceedings (papers and presentations) are available on the FIG LADM & 3D LA workshop website: http://www.gdmc.nl/3DCadastres/workshop2024/programme/.

Finally, we would like to thank all the authors for their submission, the Programme Committee members for their diligent work in assessing the quality of the contributions and providing many constructive comments and the Local Organizing Committee for organizing the event. We are looking forward to the 12th LADM & 3D LA Workshop and stimulating interactions in Malaysia!

Delft, September 2024,

Peter van Oosterom, Alias Abdul Rahman, Abdullah Kara, and Eftychia Kalogianni,
the Editors.

3D Perspective towards the Modelling and Applications of Cadastral Building Data in Taiwan

Jung-Hong HONG, Vincent CHIANG, Chin-Sung YANG, Yi-Chen TSIA, and Sin-Yi HO, Taiwan

Key words: 3D building, 3D spatial representations, CityGML 2.0 ADE

SUMMARY

In recent years, Taiwan has been actively advancing a nation digital twin project that leverages multi-dimensional geographic information technology. Three-dimensional building data has been identified as a fundamental component of the national base map. In addition to the 3D building data generated through photogrammetry and topographic mapping, data managed by cadastral organizations is considered a valuable resource for representing 3D buildings from a property rights perspective. Currently, Taiwan has amassed over 8 million building registration records, each uniquely identified by a building number. This paper examines the strategies for establishing and sharing building numbers and their corresponding 3D spatial representations to enhance their utility in GIS-based applications. Two distinct types of 3D representations have been developed: building number positioning points and cadastral building property model. Based on Taiwan's existing building registration framework, a schema for 3D cadaster buildings has been designed utilizing CityGML 2.0 Application Domain Extensions (ADE), which offers advantages in terms of alignment with international standards and the facilitation of open format data sharing. The proposed schema, characterized by clear semantics, is capable of accommodating the modeling of various types of building, including apartments and high-rise structures. Furthermore, new construction procedures have been integrated into the existing building registration process. Cadastral building data in the future will not only feature three-dimensional spatial representations but also improve interoperability through standardized models. This advancement is expected to yield significant benefits by fostering innovative multi-purpose applications of three-dimensional building information and supporting the development of the national spatial data infrastructure.

3D Perspective towards the Modelling and Applications of Cadastral Building Data in Taiwan

Jung-Hong HONG, Vincent CHIANG, Chin-Sung YANG, Yi-Chen TSIA, and Sin-Yi HO, Taiwan

1. INTRODUCTION

The digital cadastre system in Taiwan is overseen and administered by the Ministry of the Interior (MoI) and has experienced several phases of development. The existing cadastre database serves as a comprehensive national repository that encompasses both cadastral maps and building data. The cadastral map data is based on two-dimensional parcels and associated land adminstration information, while the building data is presented in a tabular format containing registration details. Although this building registration data may be supplemented by building plane survey data to visually depict the spatial extent of individual properties, its content nevertheless lacks the recording of geographic coordinates.

In Taiwan, the integration of three-dimensional geographic information has emerged as a pivotal component of the national base map. The absence of spatial representation for the current 8 million building registration records has impeded the optimal application of geographic information system technology and the effective support of cadastral data-related activities from a locational standpoint. In response, the MoI has initiated the "Towards 3D Smart Land - National Base Map Spatial Data Infrastructure Project," which provides financial assistance to municipalities and county (city) governments nationwide for the implementation of the "Three-Dimensional Cadastral Building Integration Project." The overarching objective is to realize the three-dimensional representation of nationwide cadastral buildings within a five-year timeframe, spanning from 2021 to 2025.

The building number serves as a unique identifier assigned to each registered building property, corresponding to the three-dimensional spatial extent of that property. In this paper, the spatial representation is conceptualized in two distinct manners: as positioning points or as a cadastral model of building properties. From a geometric representation standpoint, building number positioning points abstractly represent the spatial extent of a property through a singular point defined by three-dimensional coordinates. When integrated with the attributes of the building registration data, this representation can adequately fulfill the requirements for various three-dimensional cadastral applications pertaining to buildings. Conversely, the cadastral building property model employs the concept of boundary representation to spatially delineate the three-dimensional extent of various building units. This three-dimensional representation is based upon the property boundaries documented in the building plane survey data, as well as the default heights or actual floor heights derived from completion work charts. Unlike the building number positioning points, the three-dimensional spatial representation is further categorized into two types of property units: main buildings and ancillary buildings, allowing for the establishment of spatial relationships with the building or floor in which they are situated. Given the substantial number of registered buildings accumulated over the years, the retroactive construction of a nationwide three-dimensional database necessitates significant financial investment(more than 100 million US dollars). The Ministry of the Interior's promotion plan encompasses two primary strategies: commencing in

2021, all newly constructed houses will generate their three-dimensional cadastral building property model data through newly established registration procedures and systems, while buildings registered prior to 2021 will predominantly utilize building number positioning points, as illustrated in Figure 1.

Figure 1. Building number positioning points and cadastral building property model

The objective of this study is to establish a three-dimensional framework for cadastral buildings in Taiwan, enabling the modelling and sharing of various types of building from a standardized perspective. The creation of a data model that accommodates three-dimensional cadastral information presents significant challenges, necessitating the consideration of factors such as data redundancy, application dependencies, scalability, integrity and consistency, as well as security (Višnjevac et al., 2019). Furthermore, the dynamic nature of cadastral data requires continuous updates, which in turn necessitates ongoing modifications to the three-dimensional cadastral building data (Olfat et al., 2021). CityGML 2.0 (OGC, 2012), an internationally recognized standard advocated by the Open Geospatial Consortium (OGC), offers semantically rich three-dimensional models for various urban phenomena. However, its building module currently lacks semantic considerations from the perspective of property rights (Saeidian et al., 2022; Góźdź et al., 2014). In their work, Góźdź et al. (2014) integrated CityGML with the Land Administration Domain Model (LADM) in the context of developing a three-dimensional cadastre in Poland, leveraging the spatial representation capabilities of CityGML alongside the legal property concepts inherent in LADM. They proposed classes such as "PL_LegalSpaceBuilding," "PL_3DParel," and "PL_CadastralParcel," establishing relationships with the "_AbstractBuilding" class of CityGML 2.0. Given that Taiwan's existing cadastre system has been operational for an extended period and that current regulations and database mechanisms already incorporate semantic considerations pertinent to land management and registration, this paper aims to investigate the design of a three-dimensional cadastral building data model following existing mechanisms and international standard technologies (CityGML). The proposed model will also be pragmatically operational, thereby laying the groundwork for future cross-domain sharing and integration.

2. CADASTRAL BUILDINGS IN TAIWAN

2.1 Models of building property rights

In Taiwan, the procedure for building registration encompasses an optional survey of the building, which can be requested by property owners. Since this is a necessary document for housing loans, almost all newly built houses will apply for it. The building plane survey data serves as a reference for documenting the spatial extent of property rights, each identified by a unique building number. The initiative to develop a three-dimensional (3D) property rights model utilizing building plane survey data commenced a decade ago (Chiang, 2012). The results of the paper-based surveys are digitized through scanning, and a vector data file is manually created based on individual floors. The recorded data encompasses the spatial representation of both the main building and ancillary building, along with the registration data corresponding to each building number on the respective floor. The 3D representation is achieved by extruding the height of each building unit, which is determined either by the predetermined height of a single floor or by the specific floor heights indicated in the building completion chart. For multi-story buildings, the 3D data for each floor is stacked accordingly. Given that the original building plane survey data lacks geographic coordinates, the positioning of the 3D buildings is established by referencing reliable geospatial sources, such as cadastral maps, aerial photographs, and digital elevation models (DEM). Furthermore, more detailed 3D building models can be enhanced through on-site surveys, including drone aerial photography and the placement of indoor furnishings.

The advancement of building survey methodologies has led to the substitution of traditional building unit surveys with digital surveying techniques. This transition allows the cadastral office to simultaneously fulfill legal requirements for the generation of building plane survey data and the establishment of three-dimensional (3D) cadastral building property right information. Given that the newly developed system is seamlessly integrated into the existing building registration process, it is anticipated that all future constructions will be accompanied by corresponding 3D cadastral building data.

2.2 Building number position point

The substantial expenses associated with the construction of property models render it impractical to retroactively create such models for the over 8 million registered buildings established prior to 2021. The objective of the "Building Number Positioning Point Project" is to assign three-dimensional coordinates to each building number, thereby facilitating their application within three-dimensional Geographic Information Systems (3DGIS). Each building number is mandated to possess a singular positioning point (TGIS, 2022). Initially, the central coordinates of the land parcel housing the building are calculated as a preliminary value. Subsequently, manual adjustments are made by referencing scanned building plane survey data and other credible sources, such as electronic map building data, to ascertain the most accurate locations for each building number. For instance, in cases where a building comprises multiple floors, each with distinct building numbers, the initial values may coincide and require further adjustment. The final positioning outcomes must adhere to specific topological constraints, such as remaining within the parcel and the building itself. Additionally, building numbers within the same structure require manual adjustments to ensure consistency across different floors. The elevation of the building positioning points is estimated based on the respective floor, with the elevation determined by the vertical center of

that floor. In instances where the actual floor height is unavailable from the building's completion chrat, a predetermined floor height is utilized instead. In cases where multiple floors within a single building share a single building number (e.g., a townhouse), only one positioning point corresponding to the floor nearest to the ground is recorded (first floor or basement). Ultimately, the generated building number positioning points are linked to building registration data and disseminated in shapefile format. It is anticipated that the establishment of building positioning point data for buildings registered prior to 2021 will be completed by 2025. At that juncture, all cadastral buildings in Taiwan will be geospatially represented either by building number positioning points or by cadastral building property models.
As the data creation process is executed by local cadastral offices nationwide, the National Land Surveying Center (NLSC) has initiated a verification project aimed at assessing and ensuring the quality of the completed data. The project's objective is to identify prevalent error patterns within operational procedures and to develop a toolkit to enhance verification efficiency. Given that the data creation process necessitates a significant allocation of human resources to master newly developed systems, comprehensive guidelines providing standard operating procedures have been established, including the "Building Number Positioning Operation Guidelines" and the "S09 Platform Verification Tool" (TGIS, 2023). The principal processes and verification operations are elaborated as follows.
(1) Phase 1 Inspection: Systematic checks with registration data.
This phase entails a thorough evaluation to ascertain the consistency of the building number positioning points with the building registration data. This includes an examination of the coordinate system, attribute schema, as well as the quantity of building numbers.
(2) Phase 2 Inspection: Evaluation of Location and Attributes.
In this phase, an initial assessment is conducted to determine whether the location of the building number positioning points adheres to the requisite topological constraints. For instance, it is essential that the positioning points are situated within the designated land and the corresponding buildings.
(3) Phase 3 Inspection: Review from a Property Perspective.
This phase is subdivided into two components: automated checks, which identify overlapping building number point locations at the same level, and manual verification, which addresses tasks that cannot be assessed automatically. This includes evaluations such as confirming that the building number positioning points are accurately located within the appropriate building units, among other considerations.

All data submitted by local cadastral offices must undergo a verification process via the S09 platform to guarantee data quality. Table 1 enumerates the types of errors that can be automatically detected by the S09 platform, with each error type distinguished by a specific color to facilitate operator awareness. For a more in-depth examination of manual errors, please consult the project report (TGIS, 2023).

Table 1. The automatic check patterns of errors by S09

Pattern	Explanation	Color
Not within parcel	Building number positioning point is not within the related parcel.	pink
Not within building	Building number positioning point is not within the building polygons in the electronic maps.	light blue
Attribute mismatch	The attribute value of building number do not match the content in the cadastral database.	blue
Share the same coordinates	Building numbers at the same floor share the same coordinates.	orange
Redundant/repeated positioning points	Every building number corresponds only one positioning point.	green
Multiple errors	More than two types of errors found	red

3. SCHEMA DESIGN

3.1 Design strategy

This paper introduces a model for the three-dimensional (3D) cadastral building framework in Taiwan. Building upon the results of this design, a preliminary draft of the "3D Cadastral Building Data Standard" is currently being developed, with the intention of submitting it as a domain data standard to the National Geographic Information System (NGIS) standardization committee in 2025. Among the standards that have already been published, the "3D Building Model Data Standard" was primarily created for 3D building data derived from aerial or terrestrial surveying methods. Since this standard is implemented in accordance with CityGML 2.0, a similar design approach is employed in the "3D Cadastre Building Data Standard" to enhance interoperability. Although CityGML includes a building module, it falls short in adequately representing the diverse cadastral characteristics from a semantic perspective. The model for building property rights encompasses various units associated with the building, such as individual buildings, floors, primary buildings, and ancillary buildings, each possessing distinct semantics and fulfilling different roles in the management of building registration data.

To effectively integrate existing cadastral systems while adhering to open GIS standards, the application schema for the 3D Cadastre Building Data Standard is developed utilizing CityGML Application Domain Extensions (ADE) (Biljecki et al., 2018). Furthermore, it is essential to account for the information pertinent to the registration of property rights for buildings in Taiwan. A feature class based on building numbers is also proposed. The design of the application schema must thoroughly consider the interrelationships among classes, including buildings, floors, building numbers, primary buildings, and ancillary building, to ensure accurate modeling of various types of building in real world. Proposals for application schemas concerning the cadastral building property model and the positioning points of building numbers are presented. While the design of the former application schema is based on the CityGML 2.0 standard, the latter is developed using GML 3.1.1, as CityGML 2.0 does not accommodate the use of 3D points for modeling Level of Detail 0 (LOD0) buildings.

Figure 2 illustrates the UML application schema for the property rights model, which encompasses four feature classes: "Property Building," "Floor," "Property Unit," and "Building Number Management Unit." The design and semantics associated with each class are elaborated upon below:

- The "Property Building" class is utilized for modeling the characteristics of the property of a single building.
- The "Floor" class captures the spatial extent and attributes pertinent to an individual floor within a building.
- The "Building Number Management Unit" class documents the spatial extent and attributes associated with a specific building number. This feature class serves as a fundamental reference in the proposed schema, necessitating the establishment of relationships with other feature classes, including "Property Buildings," "Floors," and "Property Units."
- The "Property Unit" class records the spatial extent and attributes of both the primary and ancillary buildings corresponding to a specific building number.

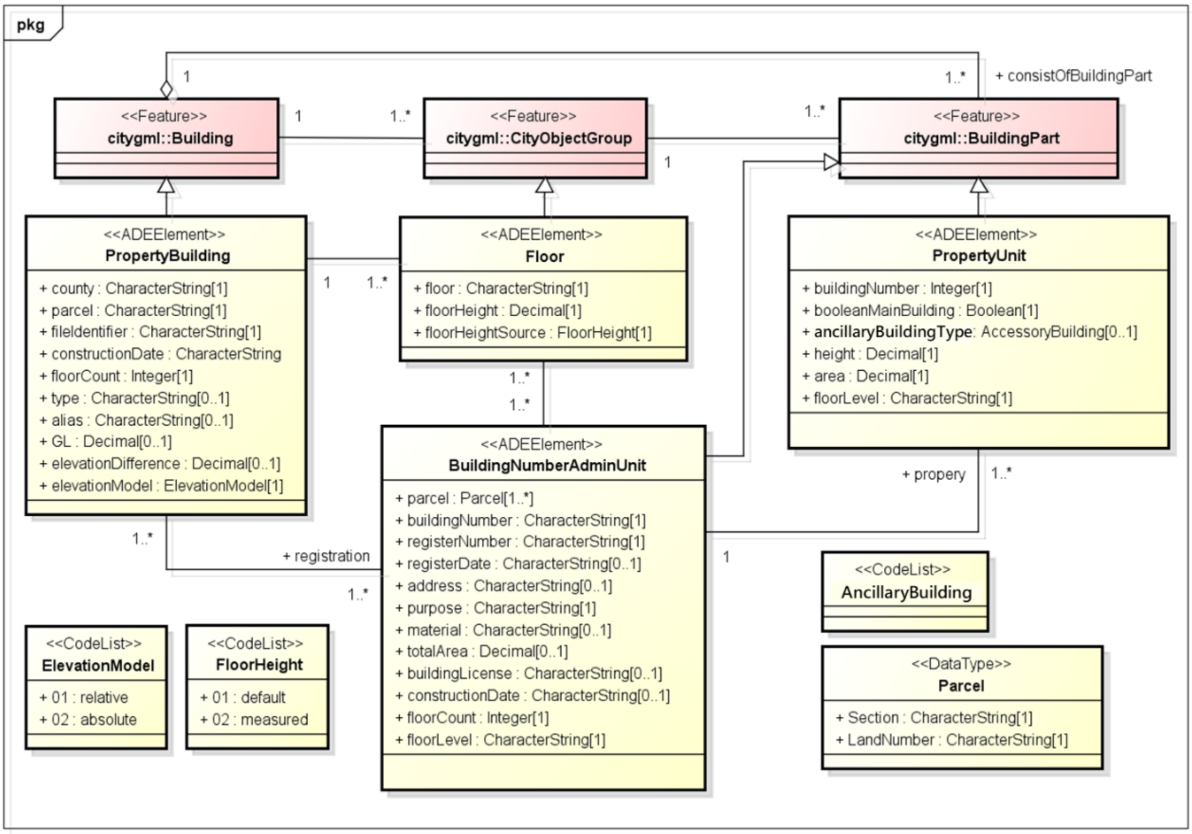

Figure 2. Schema for the building property right model

3.2 Property Building

The "Property Building" class is designed to inherit from the "Building" class as defined by the CityGML standard. Given that the "Building" class itself inherits from the "_AbstractBuilding" class, the "Property Building" class similarly inherits the attributes of the "_AbstractBuilding" class. Additional attributes specific to the "Property Building" class include: county/city, section code, building number, completion date, number of floors, building type, building alias, ground level (GL), elevation difference, and elevation model. The "GL" attribute records the elevation of the terrain on which the building is situated, expressed in orthometric height, utilizing the coordinate reference system TWVD2001 (NLSC, 2001). This information provides useful height reference to the building data.

3.3 Floor

The polygon-based building unit information recorded in the building plane survey data is systematically organized by individual floors. A three-dimensional model can be created by extruding the polygon based on either a predetermined height or the actual height indicated in the completion work chart. The combination of the outer wall, ceiling, and floor defines a three-dimensional volume referred to as the "floor." This classification of "floor" is derived from the "CityObjectGroup" class within the CityGML standard and includes attributes such as class, function, and usage, as well as relational elements like groupMember and geometry. The CityObjectGroup class is a subclass of CityObject, which employs the groupMember attribute to record the CityObjects (including Building, BuildingPart, or other CityObjects) that form the structural components of a specific floor within the three-dimensional building model. Furthermore, the floor class encompasses attributes such as floor, floor height, and floorHeightSource. The floorHeightSource attribute utilizes a codelist to indicate whether the height information is based on a standard floor height (e.g., 3.3 meter) or the actual measured floor height.

3.4 Building number management unit

The class of "Building Number Management Unit" records the spatial extent and attributes identified by a unique building number. This class is designed to inherit from the BuildingPart class of CityGML. As the BuildingPart class inherits from the AbstractBuilding class, thus the class of "Building Number Management Unit" also inherits from the AbstractBuilding class. Additional designed attributes include parcel, buidlingNumber, registerNumber, registerDate, address, purpose, material, totalArea, buildingLicense, constructionDate, floorCount and floorLevel.

3.5 Property Unit

In accordance with the prevailing cadastral regulations, the property associated with a building identified by a unique building number encompasses two categories: the main building and ancillary building. The "property unit" class is intended to extend the BuildingPart class as defined in CityGML. Given that the BuildingPart class itself derives from the AbstractBuilding class, the "property unit" class similarly inherits from the AbstractBuilding class. This property unit class is responsible for documenting the spatial extent and attributes of both the main and ancillary buildings. The attributes defined for this class include the building number, booleanMaineBuilding, the type of ancillary building, height, area, and floor level. The boolean attribute serves to specify whether the property described is classified as a main building or an ancillary building.
Each feature class is modeled at a specific Level of Detail (LOD) in accordance with CityGML 2.0 (refer to Table 2, where "X" denotes not applicable). Both the property building class and the floor class are represented as LOD3 three-dimensional surface data. The property units class encompasses both LOD3 and LOD4 three-dimensional representations. The selection of LOD4 is contingent upon the type of ancillary building; for instance, indoor

ancillary buildings are modeled as LOD4 spatial units. Consequently, the building number management unit is capable of representing both main and ancillary buildings in either LOD3 or LOD4. The modeling approach may utilize MultiSurface or classes with specific semantics, such as WallSurface, InteriorWallSurface, FloorSurface, CeilingSurface, and RoofSurface.

Table 2. Designed feature classes and LOD

Class name	Inherited class	LOD 3	LOD 4
PropertyBuilding	Building	MultiSurface	X
floor	CityObjectGroup	MultiSurface	X
PropertyUnit	BuildingPart	MultiSurface	MultiSurface
BuildingNumber AdminUnit	BuildingPart	MultiSurface	MultiSurface

3.6 Establishment of Building Number Positioning Points

In order to facilitate the distribution of point-based building number positioning data, the "BuildingNumber" class has been developed. The corresponding UML diagram is illustrated in Figure 3. The geometric data pertaining to the building number positioning class refers to the GM_Point class as outlined in ISO 19107. The attributes incorporated into this design are derived from building registration data and encompass parcel, buildNumber, address, registerDate, registerReason, purpose, material, totalArea, floorCount, floorLevel, constructionDate, buildingLicense, floorHeightSource, and elevationModel. Given that the elevation of the building number positioning point is contingent upon its reference source, two additional attributes have been introduced: the source of floor height, which differentiates between default and actual floor heights, and elevationModel, which specifies whether the height information is relative to the terrain.

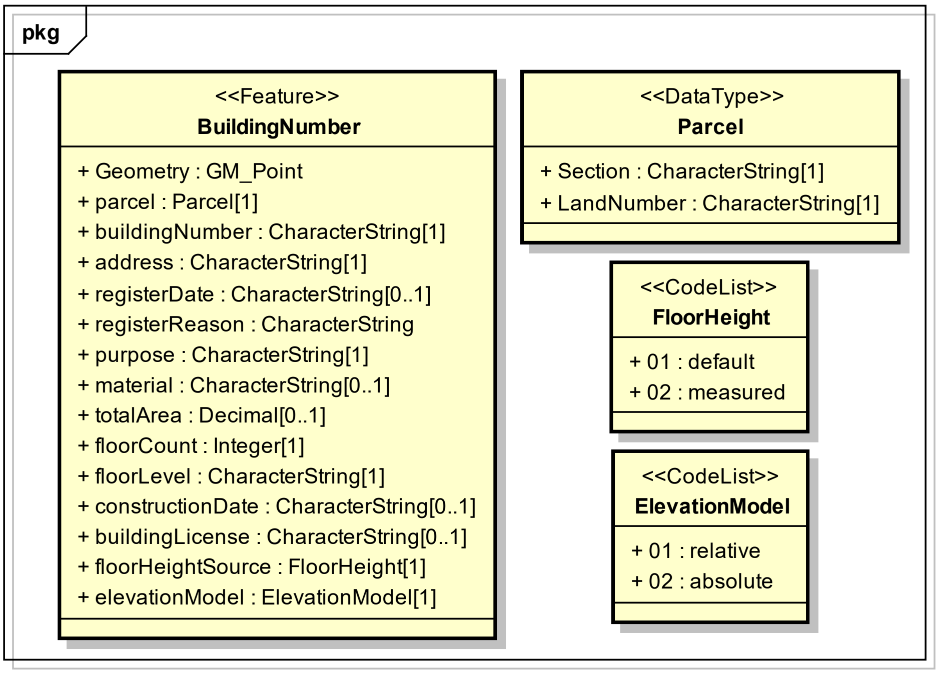

Figure 3. Schema for the building number position point

4. CASE ANALYSIS AND APPLICATION

4.1 Case analysis

This study develops an XML schema in accordance with the principles of UML application schema and XML schema. The resulting data file is structured to represent each property building as a singular CityModel, which encompasses multiple cityObjectMembers. One cityObjectMember is designated to document a property building, while the others provide details regarding individual floors. This modeling approach is applicable to all types of buildings. The property building is intended to encapsulate the overall property of the entire building. In addition to its inherented attributes, it incorporates the <register> tag to establish a connection with the corresponding “BuildingNumberAdminUnit”. This design facilitates geospatial referencing for individual buildings or households, utilizing the street address attribute from the “BuildingNumberAdminUnit”.

To accurately depict the complete structure and aesthetic of individual buildings, it is advisable to extract the exterior walls corresponding to each building units in order to create a three-dimensional representation. Each floor of a building is modeled using the "LOD3MultiSurface". An individual floor is modelled as a CityObjectGroup, which utilizes the groupMember attribute to document the distinct wall surfaces. The exterior walls are categorized as WallSurface, ceilings as CeilingSurface, and floors as FloorSurface. Special considerations are required for the roof and the first floor; the roof is represented by RoofSurface rather than CeilingSurface, while the first floor is represented as GroundSurface instead of FloorSurface.

Case Study 1: Detached House or Townhouse

This case study examines a three-story townhouse. In the recording data, <CityModel> comprises four <cityObjectMember> elements: one designated for <PropertyBuilding> and three allocated for <Floors>. The gml:id attribute serves to uniquely identify each building within the dataset. Multiple instances of the <consistOfBuildingPart> tag are employed to document the associated <PropertyUnit>, with each <PropertyUnit> representing either a main building or an ancillary building. Additionally, the corresponding <BuildingNumberAdminUnit> for the described building is recorded. In the case of a townhouse, which possesses a singular building registration, it is documented only once.

Case 2: Congregate Housing

In Taiwan, residential structures are classified into three categories based on their height and the availability of elevators: "apartments," which lack elevators and consist of five floors or fewer; "condominiums," which are equipped with elevators and contain ten floors or fewer; and "high-rise buildings," which also have elevators and exceed eleven floors. The proposed model is applicable for modeling all three types of buildings, with the primary distinction being the number of associated building numbers and property units. In this particular case, the structure comprises seven floors, leading to the inclusion of eight <cityObjectMember> elements within the <CityModel>, one designated for <PropertyBuilding> and seven for <Floor>. A notable difference between apartment buildings and other residential types, in contrast to detached houses, lies in the number of associated building numbers and more complicated interrelationships among the building units. Even a single floor may correspond to multiple building property units, each identified by distinct building numbers. Provided that the interrelationships among various building property units are effectively established, the reading and processing of data can be conducted seamlessly.

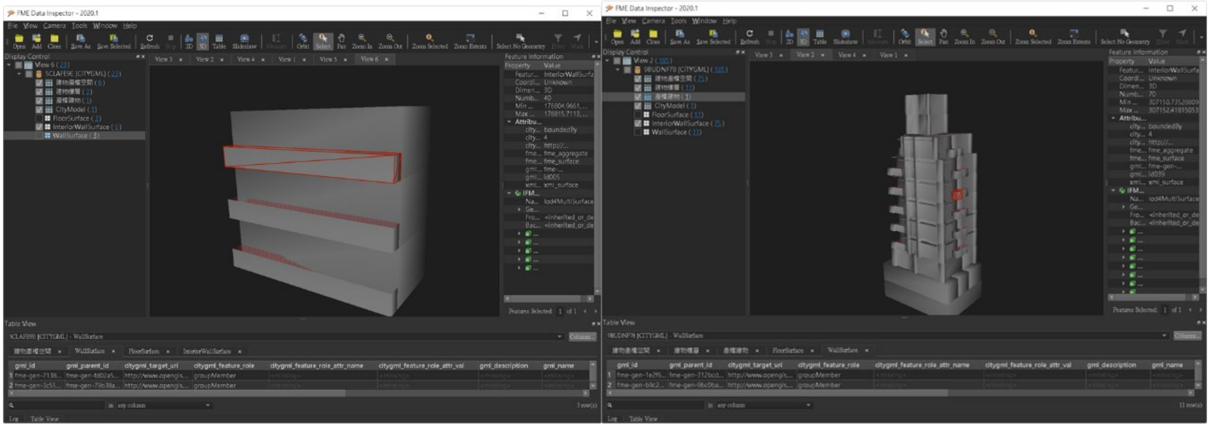

Figure 4. 3D property buildings for case 1 and 2

4.2 Applications

The intricate relationship between human economic activities and buildings facilitates the development of diverse applications when these elements are integrated. The realization of the 3D cadastral building plan not only marks a significant milestone in the evolution of Taiwan's cadastral system but also serves as a pivotal element in the advancement of national geographic information.. This research addresses the issue from the cadastral building perspective, proposing the establishment of building units with 3D spatial representations, which can lead to significant advancements across various application domains.

(1) Advancements in Land Administration Applications

The findings of this study present a 3D model that aligns with the existing building registration system in Taiwan. This model not only fulfills the requirements of the current building registration process but also facilitates various applications within 3D contexts. These applications may widely include the representation of actual 3D property boundaries, the analysis of 3D spatial relationships, the composition of 3D relationships among building units, the promotion of real estate activities, and the execution of visibility analyses. Furthermore, 3D buildings can be integrated with parcel data, thereby providing more accurate references for regional planning. Notably, the establishment of 3D building points and property models allows for a closer integration of land administration tasks related to buildings with geographic information system technology.

(2) Diverse Representations

Together with the 3D building data from photogrammetry and topographic maps, 3D cadastral buildings serve as a reliable source of multiple representations for the national base maps. These 3D buildings are characterized by clear specifications and are established according to standardized design procedures, which help mitigate the risk of erroneous applications. Beyond their property-related implications for building units, the compositional relationships of these units can yield building content that diverges from visual representations, thereby enhancing the flexibility of building data provision, including information pertaining to buildings, floors, and individual units.

(3) Cross-Domain Applications

The establishment of spatial representations for property units, facilitated by unique building numbers and associated addresses, offers a significant advantage by overcoming the current limitations of primarily visual displays and the challenges associated with accurately determining address locations. Three-dimensional cadastral building data is currently the only dataset capable of providing precise positioning for individual household, thereby advancing existing applications that are restricted to approximate 2D geocoding service to a more accurate 3D spatial positioning or distribution. This enhancement can substantially improve decision-making quality, particularly in densely populated metropolitan areas. When decision-making applications can evolve from being confined to a specific building (or a number of buildings) to accurately identifying the location of designated addresses, including further accessing information about nearby addresses and conditions within an entire building segment, it can yield direct benefits for applications such as building management, disaster prevention and response, logistics, and healthcare. Moreover, through the association of domain identifiers, a substantial amount of domain-specific data related to buildings can acquire 3D coordinates, thereby strengthening the applications of three-dimensional geographic information.

5. CONCLUSION

The advancement of national spatial data infrastructure has identified three-dimensional (3D) building models as a significant innovation. However, the transition from two-dimensional (2D) to 3D modeling presents considerable challenges, primarily due to the absence of technological solutions and the substantial volume of analog data accumulated over the years. This paper examines the strategies for the creation and sharing of 3D cadastral building data in Taiwan. Specifically, a 3D cadastral building property model and the corresponding building number positioning points have been developed to accommodate registered building data from both before and after 2021. These models are implemented using open technology to promote the development of interoperable applications. The proposed schema categorizes building units into four classes, based on the extension of the CityGML 2.0 Building module. A notable advantage of 3D cadastral building data is its capacity to provide household-level geospatial reference, which enhances the potential for smart city and digital twin applications through precise positioning. Additionally, the design ensures that 3D building data in Taiwan, derived from both survey and cadastral domains, is compatible with CityGML 2.0 standards. Building numbers can also be linked to various identifiers, such as street addresses, land numbers, and tax identification numbers, thereby facilitating a wide range of value-added applications, including real estate price registration, Internet of Things integration, logistics delivery, disaster prevention and relief, business registration, and social security systems. This interconnectedness has the potential to generate extensive and far-reaching impacts.

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Incorporating Legal Space Details of Building from BIM/IFC to the LADM Sarawak Country Profile

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Key words: LADM Sarawak Country Profile, LADM Edition II, BIM/IFC, Legal Space

SUMMARY

This paper expands the Land Administration Domain Model (LADM) Sarawak Country Profile by incorporating legal space details from Building Information Modelling (BIM). Sarawak, located on Borneo Island, practices a distinct land administration system compared to Peninsular Malaysia. While Peninsular Malaysia follows the National Land Code of 1965, Sarawak adheres to the Sarawak Land Code 1958, which includes provisions for indigenous customary land rights. The Malaysia country profile has been developed based on the LADM standard, considering the 3D situation. Since both regions (Peninsular Malaysia and Sarawak) are under different legal frameworks, this study attempts to further develop the Sarawak country profile based on its current land administration system, including adopting some classes and attributes from the existing Malaysia country profile. The study investigates the potential of incorporating legal space details from the BIM/Industry Foundation Class (IFC) model into the Sarawak country profile. The conceptual model details the fundamental LADM components (Party, Administrative, and Spatial Unit), along with details on the legal space sourced from BIM/IFC. This mapping process requires BIM/IFC data to contain sufficient information for distinguishing property spaces and their boundaries.

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1. INTRODUCTION

Digitalizing the built environment represents one of the most profound transformations in industry and profession, especially in rapidly developing countries. At the forefront of this transformation is Building Information Modelling (BIM), which has emerged as a primary contributor to spatial development. Over the past decade, many country profiles have been developed based on the Land Administration Domain Model (LADM) Edition I to represent the legal aspects of land administration, covering land tenure (Kalogianni, 2021). While LADM provides a robust framework for legal entities (e.g., parcels, rights, and restrictions), it lacks detailed semantic components related to buildings. BIM, on the other hand, excels in capturing rich 3D data about building elements and materials (Zamzuri et al., 2024). Several studies (Mao, P., 2024; Guler et al., 2022; Broekhuizen, 2021) have discussed the implementation of BIM in land administration, highlighting its potential to contribute valuable semantic information. Therefore, integrating BIM's detailed building information with LADM's legal framework can significantly enhance the precision and utility of land administration. Incorporating legal space details, particularly in buildings, is crucial to ensuring that all descriptions of spaces (e.g., property boundaries, ownership rights, and restrictions) are well-defined. This integration ensures land records accurately reflect the physical reality of buildings and their legal status, which is essential for sustainable development and planning (Alattas et al., 2021). Clear and precise legal details are vital in preventing conflicts related to property boundaries and rights. Furthermore, aligning legal space details with physical building models, such as those provided by BIM, supports digital transformation. It enables the creation of integrated digital records that can be used for various purposes, including land management.

Sarawak possesses a unique land administration system, where all land-related activities and registrations are managed by a single agency, namely the Department of Land and Survey Sarawak. This department serves as the leading entity in managing land surveys, land registration, valuation, and spatial planning, with all related branches (Land, Survey, Valuation, and Planning) located under one 'roof' (Zamzuri et al., 2023). Sarawak has a well-established and unified land administration and registration system based on Torren's principle. The system ensures a secure and efficient method of recording land ownership and transactions, providing legal certainty by maintaining a register of land titles (Osman & Kueh, 2010). Within this system, cadastral information such as parcel boundaries, spatial features and land rights are meticulously recorded. Sarawak features a variety of land tenure systems, including strata titles for multi-story buildings. These titles, encompassing both individual and shared ownership of common areas, require a clear approach to legal space delineation. Integrating BIM/IFC data with the LADM Sarawak Country Profile ensures that the legal complexities of strata titles, such as boundaries of individual units and common properties,

are accurately represented. Now, Sarawak is embracing digital transformation in its governance and development strategies. Integrating BIM/IFC data with the LADM Sarawak Country Profile aligns with these initiatives, creating a robust digital infrastructure for land administration. This technological integration facilitates data sharing, improves decision-making processes, and supports smart city development. Therefore, this paper develops a unified model that integrates both legal information from LADM with BIM's spatial and semantic information. BIM data has been explored, and several details of legal space (e.g., spaces in particular units, common units, private units, determination of boundaries for each unit) are linked to the suitable classes in LADM. Throughout the process, bridging the gap between the legal context (LADM) and spatial representation (BIM) within buildings required careful alignment, considering the challenges encountered during the integration process – most cases outlined that BIM data are not fully ready for the modelling task.
The paper is structured as follows: Section 2 covers the integration of LADM and BIM/IFC, including details on strata management in Sarawak. Section 3 outlines the methodology, starting with the identification of legal spaces and types of rights (restrictions, responsibilities), followed by the implementation and development of a conceptual model that integrates LADM and legal space details. Finally, Section 4 discusses the results and issues encountered during the integration process.

2. BIM/IFC AND LADM

There are several works of literature related to BIM and LADM. For example, Atazadeh et al. (2017) examined methods for storing legal property within an IFC model and developed a prototype model for a 3D LAS with input from the model. Moreover, Oldfield et al. (2018) investigated the BIM as input for 3D LAS. They proposed using IfcSpace to represent legal spaces and IfcZone to group these spaces into legal zones. Furthermore, Olfat et al. (2019) investigated the integration of BIM into the workflow of sharing, documenting, visualizing, analyzing, interpreting, and reusing 3D LA data throughout a building's life cycle. Also, Meulmeester (2019) enriched an IFC model with legal data allowing integration in LA (e.g., unit Id). He investigated the requirements for IFC models to be defined as legal spaces within the Dutch LAS. Sun et al. (2019) proposed a framework for integrating BIM with land information, where both the IFC and CityGML models were stored in an LADM database. Moreover, Atazadeh et al. (2021) used the IFC schema to model features and attributes in LADM. Furthermore, Alattas et al. (2021) developed an approach that integrates IFC and LADM to represent the legal spaces of properties in Saudi Arabia. Barzegar et al. (2020) proposed a schema for a 3D LAS in which 3D spatial queries can be performed. Further, Guler et al. (2022) suggested a conceptual framework for Turkey that integrates digital building permitting and 3D representation of condominium rights using BIMs. Broekhuizen (2021) evaluated BIM/IFC models in terms of IfcSpace existence, geometric validity, overlap, and the ability to georeference, identifying several technical issues that still need to be addressed. Finally, Mao, P. (2024) investigated novel 3D LA visualization techniques including rights, restrictions, and responsibilities (RRRs). The RRRs visualization for instance, information of the particular apartment unit is shown in detail via representation of relationship between the related to the properties and ownership (e.g., LA_Party, LA_BAUnit, LA_SpatialUnit).

Previous research shows that there are some integration challenges between BIM and LADM. Existing studies have explored various aspects, including legal-spatial fusion, semantic alignment, and interoperability. However, challenges persist in seamlessly linking the legal context (LADM) with detailed spatial information (BIM). Researchers have proposed several solutions, such as using IfcSpace for legal spaces, enriching IFC models with legal data, and integrating BIM into land administration workflows. The synergy between LADM and BIM aims to create context-aware building models that benefit land professionals, urban planners, and policymakers.

BIM/IFC files contain much information, including 3D geometries of indoor spaces, constructions, and building infrastructure. However, no explicit information defines individual units (property units). Therefore, the IFC is enriched with legal space (from LADM) to fully automatically extract the 3D spaces that belong to one unit. Some main benefits are that open data formats enable different software vendors to cooperate better and increase efficiency by eliminating interoperability problems when files are exchanged. However, the concept of registering rights using the IFC format as a source for legal space is still missing. Second often occurring problem is missing geo-referencing in national Coordinate Reference System (CRS). Hence, this study aims to enrich the IFC data model with legal information and to extract 3D legal spaces from existing IFC BIMs for the registration of strata buildings.

2.1 Strata Management in Sarawak

Transactions or applications for strata titles in Sarawak are mostly in 2D representation. Although there have been attempts to address this in 3D, these efforts fall short of providing a comprehensive 3D solution. As mentioned by Meulmesteer (2019), BIM is the main source of 3D information, but the application of BIM and these types of IFC files are not freely available. Current BIM implementation in Sarawak is hardly available due to a lack of BIM knowledge and awareness. The readiness for BIM adoption is still low due to the absence of supportive policies, inadequate training for staff, and insufficient investment in software and hardware (Lee et al., 2022). Thus, our research aims to raise this awareness among the related parties.

An integrated e-submission system for Strata Titles Application and Strata Titles Survey has been developed by the department, requiring the standardization of digital submission mediums. The Strata Titles Plans can be submitted in .dxf (Drawing eXchange Format), .pdf (Portable Document Format), and .xls (digital spreadsheet) formats. The Certified Strata Plans (CP) shall have the prefix CP, as a filename followed by the Division number, allotted serial number, and suffix ISP with a running number (e.g., CP_01_132_ISP2). Strata Subdivision Plans (SSP) follow a similar naming standard but with a different prefix, SSP (e.g., SSP_01_132_ISP3). The boundaries of each proposed parcel within the floor shall be defined by reference to walls (centre/external of wall/permanent features), and the total area shall be calculated from the defined boundaries specified in the SSP. The Survey Strata Title System (SSTS) is being implemented to facilitate and pre-check the approval of strata subdivision plans, operating from the initiation of the submission to the endorsement of the subdivision plan. The system has the following aspects: submission of SSP, checking of SSP, verification of SSP, submission of Limited Common Property Plans (LCP), checking of LCP, verification of LCP, viewing of full computation reports, viewing maps in 2D/3D, and CadViewer, including pre-check and fieldbook entry. There are nine categories of personnel that are able

to access the system, namely, private surveyor, survey technical assistant (TA), staff surveyor, planning branch TA, planning officer, land TA, land officer, superintendent, and registrar.
The issuance of strata titles legally defines the boundaries of individual units (parcels) and common property. These titles are registered with the land office, providing legal recognition and protection of ownership rights. The management corporation is responsible for the administration, management, and maintenance of common property, operating in accordance with the guidelines established in the Strata Management Ordinance, 2019. All parcel owners share the responsibility for maintaining common property (relation to a sub-divided building or land). This includes contributing to maintenance fees and participating in decision-making processes through the management corporation. While parcel owners have the right to use the common property, they must comply with the rules and regulations set by the management corporation to ensure the proper upkeep and harmonious use of shared facilities.

3. METHODOLOGY

Figure 1 illustrates the methodology for implementing legal space details from BIM/IFC into the LADM Sarawak Country Profile. The flowchart indicates a process where the legal spaces and types of ownership involved are identified, followed by the development of the Sarawak country profile and the implementation of extracted legal space details.

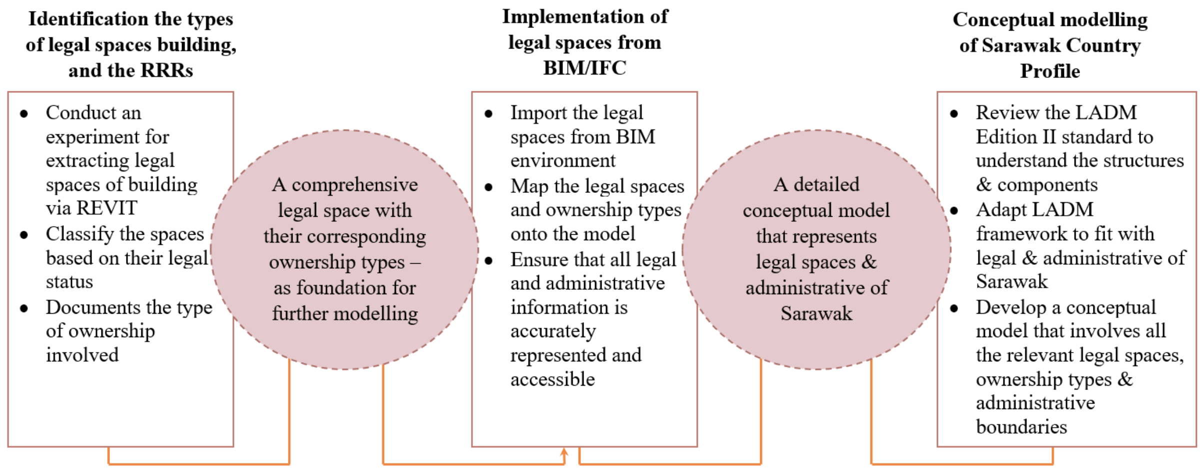

Figure 1. The methodology for implementing legal space details from BIM/IFC onto LADM Sarawak country profile

The following sections explain Figure 1 in detail.

3.1 Identification the types of legal spaces building, and the RRRs

This step involves identifying and classifying the legal space information within buildings, such as individual units, common areas, and other relevant spaces. According to the Survey Administrative and Technical Circular No.1/2022, the legal spaces are divided into several classes: prominent common areas (e.g., elevator, lobby, and staircase), non-prominent common areas (e.g., storage room and car park), and individual units. The example of the IFC model (residential building) is shown in Figures 2a and 2b. The goal is to extract legal space information from the IFC model via Autodesk Revit, which is widely used in the BIM environment and supports parametric modeling and detailed 3D design. This software offers several tools for designing, documenting, and managing building projects. It also supports integration with various data formats, making it suitable for linking BIM data with LADM.

Figure 2a. A 3D model of residential building

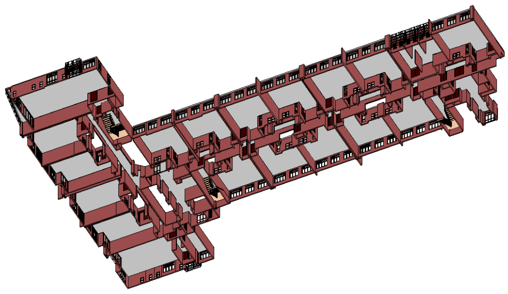

Figure 2b. 3D view of selected level

Sarawak consists of two types of ownership, namely individual units (parcels) and common property (prominent and non-prominent), as shown in Figure 3. According to the Strata (Subsidiary Titles) Ordinance 2019, an individual unit, also known as a parcel, refers to a specific portion of a subdivided building that is individually owned. Each parcel is defined by its boundaries and is legally recognized as a separate property. The owner of a parcel holds a subsidiary title, which grants them exclusive ownership rights over their unit, including the rights to occupy, use, and transfer the property. Some parcels may have accessory parcels attached, such as parking spaces or storage rooms, which are used in conjunction with the main unit. Meanwhile, common property refers to all parts of the subdivided building that are not included in any individual parcel. This includes areas and facilities also roof and facades that are shared by all parcel owners.

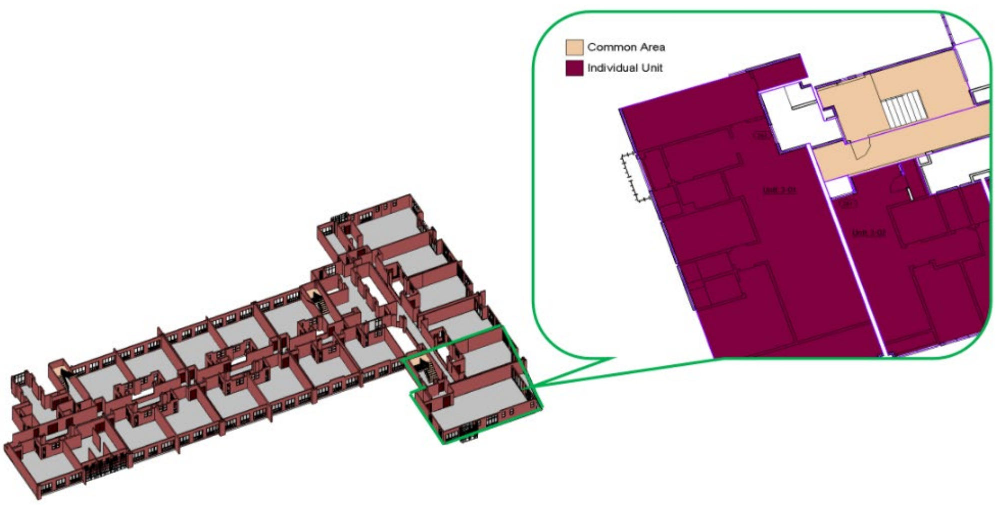

Figure 3. Types of ownership

Since BIM/IFC contains extensive semantic information, it is essential to selectively filter elements for LADM integration. The filtering process need to consider the elements that relevance to LADM such as elements (e.g., IfcSpace) that define legal spaces (unit boundaries, common areas, and accessory parcels). It also important to include the elements (e.g., IfcBuildingElement) that contain information about RRRs. The filtering process can be done via software-based filtering, for example Autodesk Revit by using filters and views button. During the exploration of the 3D model of the building, issues of missing elements and spaces need to be resolved before applying the current unit's subdivision procedures. The missing elements, such as walls, are shown in Figure 4. Autodesk Revit is used to explore the IFC-model as well as generating rooms in the model where rooms (IfcSpace) was not present. Missing elements result in an incomplete 3D model, which leads to inaccuracies in representing the physical and spatial characteristics of the building. Walls and other structural elements play an important role in defining the boundaries and spatial relationships within the building. Another issue is the absence of IfcSpace. The spaces are used to define the ownership unit's legal boundary for the 3D representation of legal spaces.

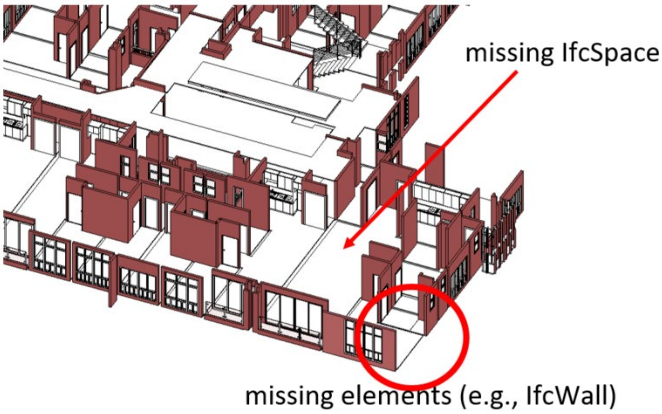

Figure 4. Missing elements (e.g., IfcWall) in 3D model

The missing architectural components, such as walls and floors, are generated through the software. After the elements have been edited, then the IfcSpace for each unit can be generated. The IfcSpace contains information on area, volume, ownership type, floor number, etc. These IfcSpace are later implemented into the unified model (Sarawak country profile).

3.2 Implementation of legal spaces from BIM/IFC

This step focuses on integrating the identified legal spaces from BIM/IFC. It includes mapping the legal spaces and ownership types onto the physical building model within the BIM environment. The IfcSpace (rooms) were generated, covering the inner surfaces of the walls, floors, and ceilings following the Strata (Subsidiary Titles) Ordinance, 2019 guideline. This means;

- Walls: The boundary is usually the inner surface of the wall
- Floors: The boundary is the upper surface of the floor
- Ceilings: The boundary is the lower surface of the ceiling

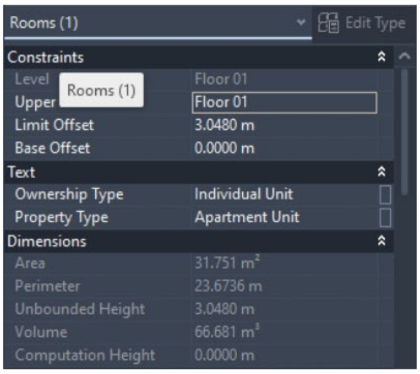

Figure 5a. Part of the 3D space information

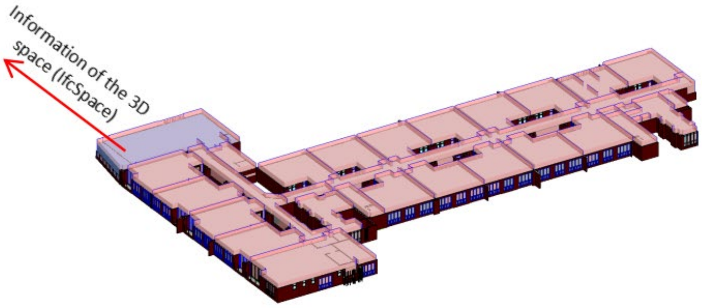

Figure 5b. 3D spaces of units

Each building's space consists of additional information representing the building's information and ownership, such as individual units or common property (see Figure 5a; Figure 5b indicates the 3D spaces). Several attributes have been added to the model, as shown in Table 1. The proposed attributes are adopted and revised by Alattas et al. (2021) following the Sarawak strata legislation.

Table 1. Attributes and their description for the 3D building space

Attributes	*Description*
Building Unit Type	The type of the building (e.g., apartment, office)
Property No	The property number as the ID
RRR Type	Represents the types of ownership
Accessory Type	The type of facility (e.g., car park, garden, storage place)
Common Unit Type	The type of service (e.g., elevators, escalators)
Limited Common Unit Type	The type of limited common area (e.g., balcony, rooftop)
Void Unit Type	The type of void area (e.g., stairs, corridors, air ducts, chutes)
Zone	Used as ID corresponding to the attached properties such as apartment unit and parking space

The integration of IFC elements with the LADM by Al-Attas et al. (2021) and Guler et al. (2022) served as a guide for mapping IFC data to land administration systems. Their studies provide a foundation for understanding how to align the detailed spatial and semantic information from BIM/IFC with the legal and administrative structures of LADM. Table 2 illustrates the proposed IFC elements and its mapping to LADM, demonstrating how specific IFC entities correspond to LADM components. This mapping ensures that the legal spaces and attributes defined in the IFC model are accurately represented within the LADM framework (see Appendix B and Appendix C), facilitating a seamless integration of spatial and legal data.

Table 2. Proposed IFC entities and its mapping to LADM (adopted and revised from Meulmeester, 2019)

IFC Entity Type	*LADM*
IfcZone: unit number, space type	WS_SpatialUnit, WS_BAUnit
IfcBuildingElement: structural building	WS_BoundaryFace, WS_BuildingElement
IfcSpace: IfcGloballyUniquedId ; geometric representation	WS_LegalSpaceBuildingUnit, WS_SpatialUnit, WS_BAUnit

3.3 Conceptual modelling of Sarawak country profile

The conceptual model is developed based on the existing land administration in Sarawak. Some of the classes from the LADM standard (ISO, 2012) have been adopted, and the concept of associating the related classes is referred to previous studies such as Guler et al. (2022), Al-Attas et al. (2021), Meulmeester (2019), and the existing Malaysia country profile (Zulkifli, 2014). The unified model is discussed based on three parts: party, administrative, spatial unit, and surveying & representation packages together with the Ifc elements.

3.3.1 <u>Party package with IFC element</u>

WS_Party inherits all the LADM attributes with some additions to LA_PartyRoleType (landOfficer, planningOfficer, privateSurveyor, staffSurveyor, superintendent, and surveyTechnicalAssistant) considering the current strata administration in Sarawak. IfcActor can be used to depict the WS_Party feature. A party is associated with zero or more [0..*] instances of a subclass of WS_RRR. WS_Party is also associated with WS_BAUnit to cater for the fact that a basic administrative unit can be a party (e.g., a basic administrative unit holding an easement on another basic administrative unit). A party may be associated with zero or more [0..*] administrative sources via the WS_RRR class. Meanwhile, WS_GroupParty inherits all the attributes from WS_Party with some additions to LA_GroupPartyType (native), representing the indigenous people in Sarawak, such as the Dayak communities and the Orang Ulu. Class WS_GroupParty is a subclass of WS_Party, thus allowing instances of class WS_GroupParty to have an association with instances of class WS_RRR (and thereby also to class WS_BAUnit). A group party consists of two or more [2..*] parties. Conversely, a party is a member of zero or more [0..*] group parties (see Appendix A).

3.3.2 <u>Administrative package with IFC elements</u>

WS_BAUnit is associated with the class WS_Party (a party may be a basic administrative unit in exceptional cases). A basic administrative unit should be associated with one or more [1..*] instances of right, restriction, or responsibility. IfcZone can be used to depict the WS_BAUnit feature. A basic administrative unit can be associated with zero or more [0..*] administrative sources. WS_BAUnit has a constraint requiring that the sum of all the shares for one basic administrative unit and no overlap be allowed between timeSpecs for the same RRR type and the same basic administrative unit shall equal 1 for the same subclass of class WS_RRR. Considering the rights of indigenous people in Sarawak, extra information in the code list LA_BAUnitType has been added, such as NCRLand, individualParcel, communalLand, reserveLand, and state-ownedLand. In LA_MultimediaType, additional information, namely dxf, xls, and pdf, are added to comply with the Sarawak strata management. A basic administrative unit is associated with zero or more [0..*] spatial units. A basic administrative unit can be associated with zero or more [0..*] spatial sources (depicted by IfcSpace). IfcDocumentInformation can be used to depict the WS_SpatialSource feature. Class WS_RRR is an abstract class. Subclasses of WS_RRR are WS_Right, WS_Restriction, and WS_Responsibility. If it is a right or responsibility, then it is associated with exactly one [1] party and exactly one [1] basic administrative unit. If it is a restriction, then it is associated with zero or one [0..1] parties and exactly one [1] basic administrative unit. An instance of a subclass of WS_RRR shall be associated with one or more [1..*] administrative sources (see Appendix B).

3.3.3 <u>Spatial Unit and Surveying & Representation packages with IFC elements</u>
WS_SpatialUnit (depicted by IfcSpace) is associated with zero or more [0..*] WS_BAUnit. WS_SpatialUnit may be associated with zero or one [0..1] WS_Level (it cannot be associated with more than one level). Level 1 is for customary, level 2 for 2D lots, level 3 for 3D lots, level 4 for strata, and level 5 for utility. WS_SpatialUnit is associated with one or more [1..*] WS_SpatialSource and can include zero or more [0..*] other spatial units for further specialization into building units. Classes WS_Customary, WS_ReservedLand, WS_GenericLot, WS_Lot2D, and WS_Lot3D are adopted from the existing Malaysia country profile. The LA_BuildingUnitType has been expanded into several categories based on Sarawak legislation, which are:

- WS_TypeOfCommonUnit (e.g., escalator, elevator, swimming pool)
- WS_TypeOfLimitedCommonUnit (e.g., balcony, rooftop, garden area)
- WS_TypeOfIndividualUnit (e.g., residential unit)
- WS_TypeOfVoidUnit (air ducts, corridor, lobby, chutes)
- WS_TypeOfAccessoryUnit (car park, air conditioning ledge)

All the classes and code lists in this package are illustrated in Appendix C.

4. DISCUSSION AND RECOMMENDATIONS

This paper produces a conceptual model for integrating BIM/IFC data into LADM. The integrated model comprises nine (9) main classes of LADM and 12 sub-classes, whereas the Ifc information has been connected to into the existing LADM classes as additional attributes and code lists. This model still has to be validated for the Sarawak land management scenario. At the moment, various aspects of the land administration (LA) have been considered in the modelling process; however, they have yet to be tested. The model could be improved by having more attributes related to the details of building elements, especially for other disciplines and usage in the state of Sarawak. As it is, the model is valid for land administration, as declared in the Strata Management Ordinance, 2019.
Integrating BIM and LADM can benefit data harmonization, where BIM data, which includes detailed spatial and semantic information about buildings, can be synergized with LADM, which focuses on legal and administrative aspects. Additionally, the spatial data in LADM

can accurately reflect the real-world locations and dimensions of properties, while BIM data provides precise 3D models of buildings that can be georeferenced to align with cadastral maps and other geospatial datasets. Moreover, using BIM input for several LADM classes allows for automated validation processes. For instance, the physical dimensions in BIM and legal boundaries in LADM can be automatically detected and resolved, ensuring data accuracy. Inevitably, integrating BIM with LADM would enhance detailed semantic information for complex situations and generate quick and accurate information. Furthermore, all relevant information about a certain property can be shown in a single, unified model.
For the 3D LAS input, the IFC model should contain IfcSpace (for SpatialUnit), which represents rooms for each unit. These rooms can be grouped as a unit (IfcZone for BAUnit). Since the usage of BIM is still at an early stage, most of the information is handled in an analogue manner. We believe integrating BIM/IFC-based systems, e.g., digitizing the analogue documents into a 3D model, will be beneficial. Once digitized, the extracted data must be integrated into the BIM/IFC environment. This involves mapping the information to the corresponding entities and attributes in the IFC schema. For instance, legal boundaries and ownership details can be mapped to IfcSpace and IfcZone entities. The digital data should then be validated against the original analogue documents by cross-referencing to ensure all legal and spatial information is correctly represented. The validated data can then be used to create 3D models of the legal spaces within the BIM domain, including defining the geometry and spatial relationships of the legal spaces, such as boundaries, ownership units, and easements. Finally, updating and maintaining the digital cadastral information is crucial to ensure that changes in ownership, boundaries, or other legal details are reflected in the BIM/IFC model.
In these ongoing efforts (this paper) to enhance land administration processes, several innovative directions need to be explored. Firstly, the aim is to incorporate 3D legal objects beyond traditional apartment settings, such as tunnels, underground and above-ground utilities, and water columns. This will provide a more comprehensive representation of legal spaces. Additionally, BIM database and registration system that aligns with the physical concepts of the LADM for legal information need to be established. This database will serve as a foundational platform for various applications, facilitating seamless integration and data sharing. The developed Sarawak country profile will be incorporated with Part 4 – Valuation Information for better land administration and validated where FME will be utilized to extract and convert the legal spaces from the enriched IFC files, including storing legal spaces in a PostgreSQL database with a PostGIS extension. CesiumJS will be incorporated as part of the validation and visualization processes. Lastly, future workflows and legislative frameworks for registering BIM/IFC models in LA and other related domains need to be explored and to ensure the approaches remain at the forefront of technological and regulatory advancements.

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BIOGRAPHICAL NOTES

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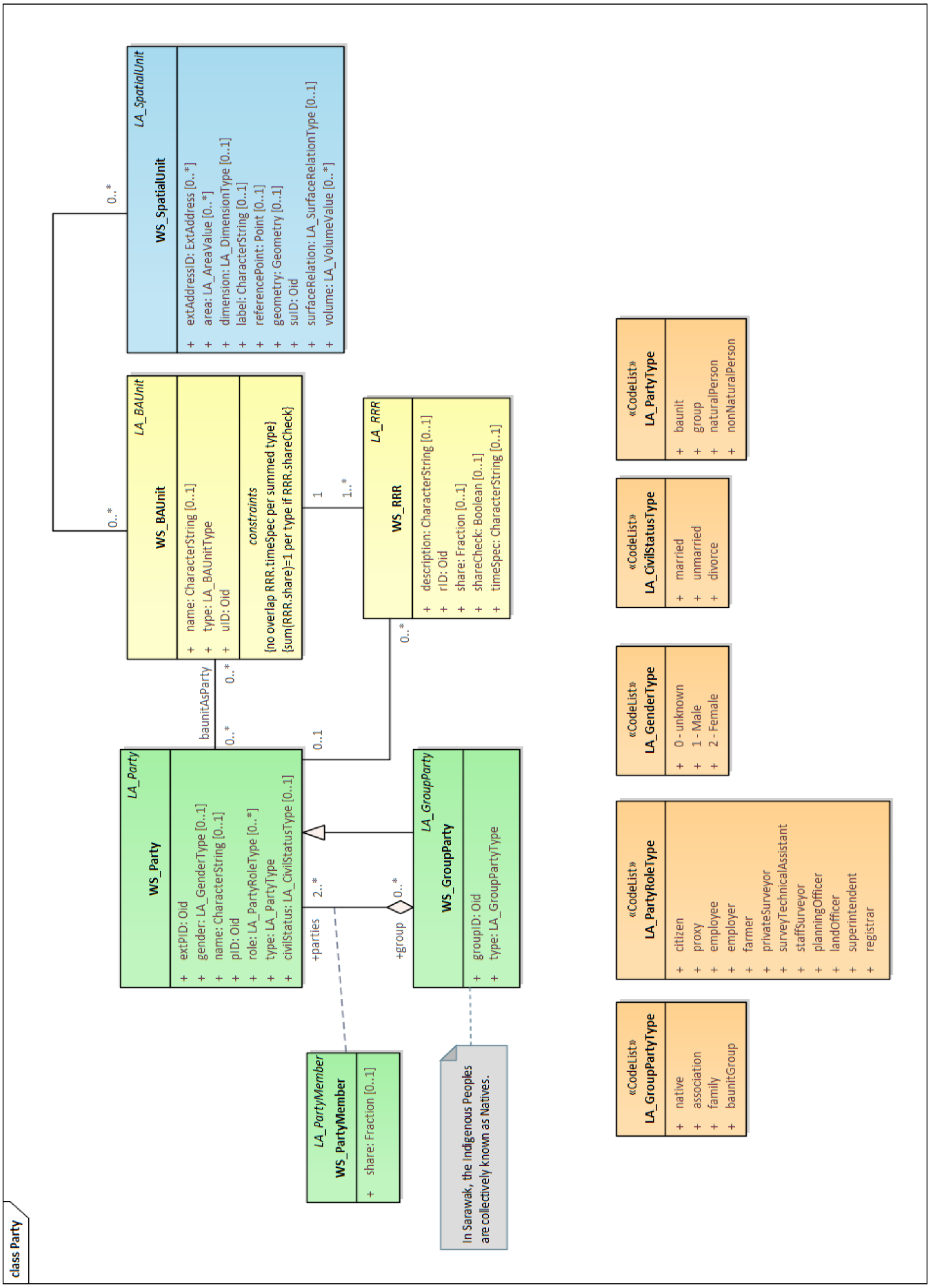
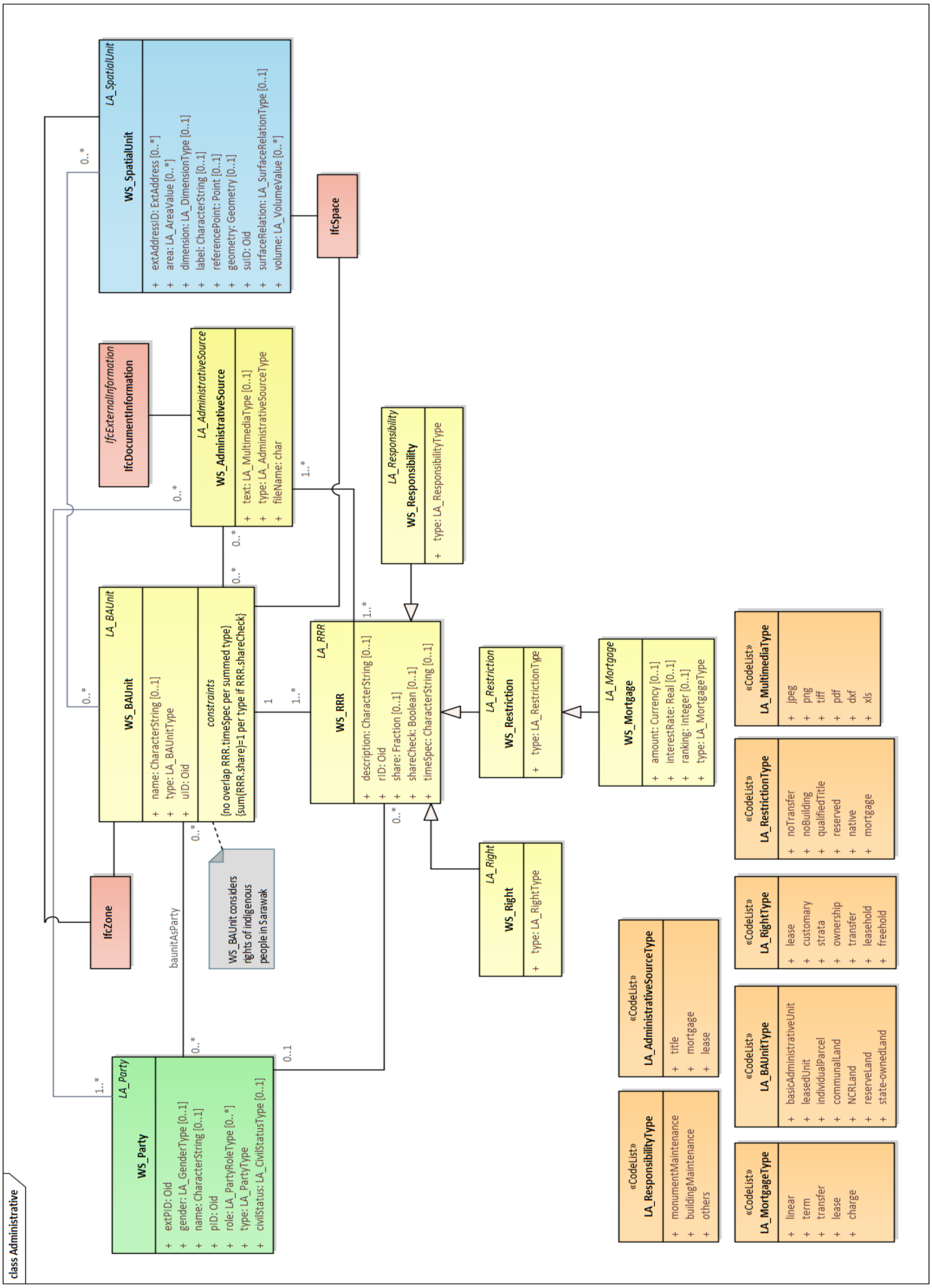
APPENDICES

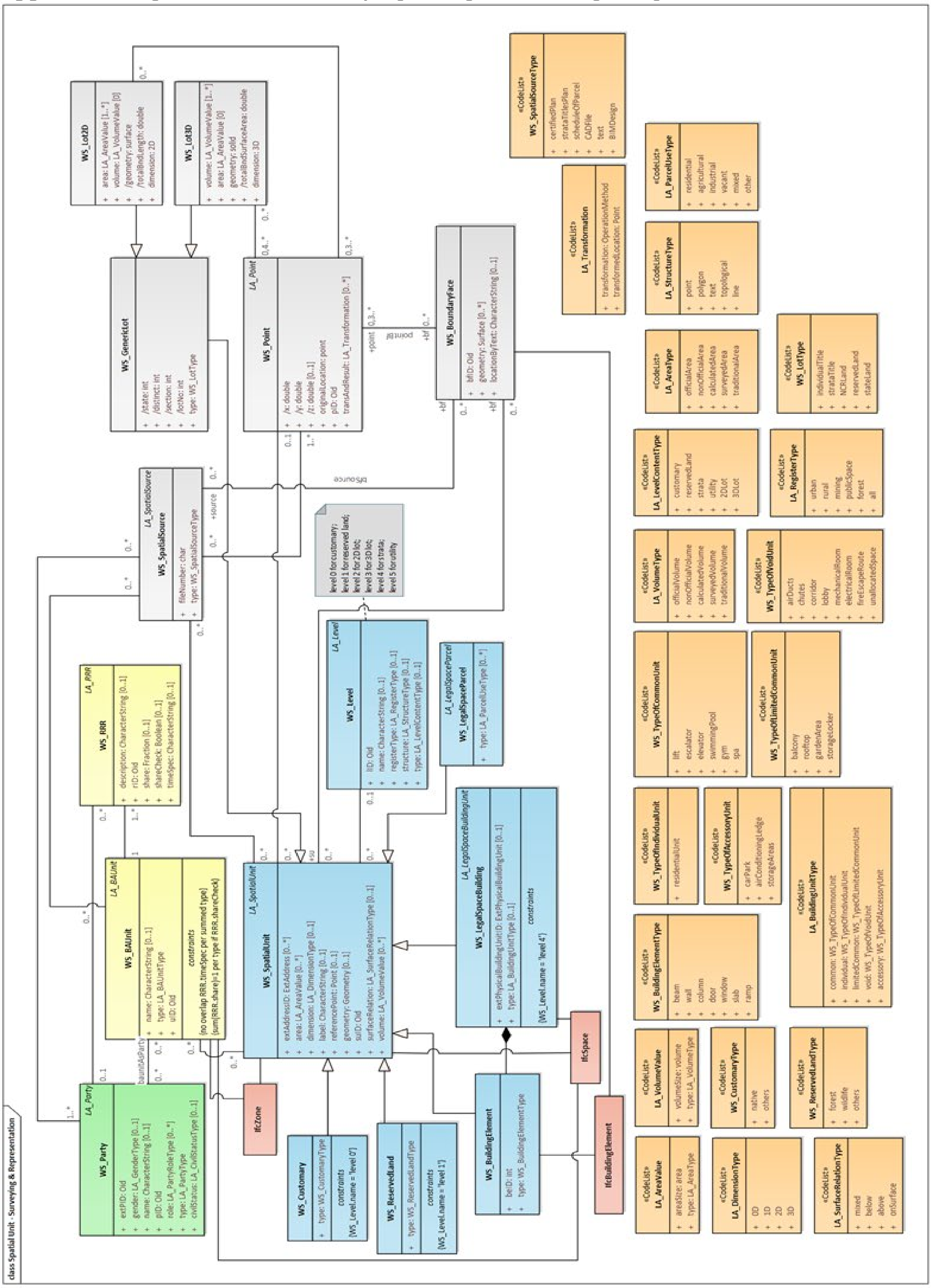
Appendix A: Party package



Appendix B: Administrative package with Ifc elements



Appendix C: Spatial Unit and Surveying & Representation packages with Ifc elements



Proposal for the integration of a Building Material part: (ISO 19152-7) within the Land Administration Domain Model

Aswathy CHANDRAN, Peter VAN OOSTEROM, Wilko QUAK, Pablo VAN DEN BOSCH, and Frederique VAN ERVEN, The Netherlands

Key words: LADM, Land administration, Circular Economy, Building Materials, Material Passport

SUMMARY

The growing global consumption of non-renewable resources is a significant societal concern. The shortage of primary raw materials and the decreasing availability of space for final waste disposal present an alarming situation. Improperly assigning materials to their recycling potential often results in high-potential materials being downgraded to lower potential uses. Transitioning to a Circular Economy, as proposed by the European Union (EU), offers an effective solution to this problem. A Circular Economy is an economic system designed from societal production and consumption patterns that maximizes the services derived from the linear flow of materials and energy between nature and society. It achieves this by utilizing cyclical material flows, renewable energy sources, and cascading energy flows. To ensure materials remain available indefinitely, they must be documented and registered while in use. The EU has proposed Material Passport for buildings which is an electronic set of data and evaluates the recycling potential and environmental impact of materials embedded in buildings.

Land Administration is the process of efficient management of land and its associated information, facilitating communication among various stakeholders both within one country and internationally. In this research, land administration is utilized because ownership information from the land administration can be applied to the registration of building materials. It also provides data on location and distance details. The registration methods used in land administration are well-suited to the concept of a material passport. Hence, this research combines the concepts of Circular Economy and Land Administration. The Land Administration Domain Model, LADM ISO19152–6 edition II contains six parts- Conceptual Model, Land Registration, Marine Georegulation, Valuation Information, Spatial Plan Information and Implementation. Building Materials registration has a lot of links to the Land Administration, like owner, valuation. Introducing the "Building Materials ISO 19152-7" standard can significantly contribute to the Land Administration Domain Model (LADM). It allows building materials registration to be aligned with (inter)national standards, ensuring consistency and improving the overall quality and reliability of land and property management. The main contribution of this study lies in evaluating the application of Building Materials and establishing a standardized Material Passport, including its basic requirements and conceptual information model. This research identifies and explores the connections between the Material Passport and its integration with the core LADM creating a multipurpose harmonized information model.

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1. INTRODUCTION

The building and construction sector significantly influences both the economy and the environment, contributing substantially to the Gross Domestic Product (GDP) and representing a major consumer of resources (Norouzi, 2021). According to Global Status Report for Buildings and Construction, a report by the UN Environment Programme (UNEP) and Global Alliance for Buildings and Construction (Environment n.d.), 21% of global greenhouse gases were emitted by the building and construction sector. By 2022, buildings accounted for 34% of global energy demand and 37% of energy and process-related carbon dioxide (CO2) emissions. The growing global consumption of non-renewable resources is a significant societal concern (Honic et al, 2021). In addition to consumption, Construction and Demolition projects are responsible for the solid wastes. The shortage of primary raw materials and the decreasing availability of space for final waste disposal present an alarming situation. The primary factor contributing to increased waste is the use of a linear economic model, where raw materials are extracted from the earth, processed, and assembled into buildings. However, at the end of the building's lifecycle, it is demolished, resulting in waste that is often disposed of in landfills without recycling (Korhonen et al, 2018).

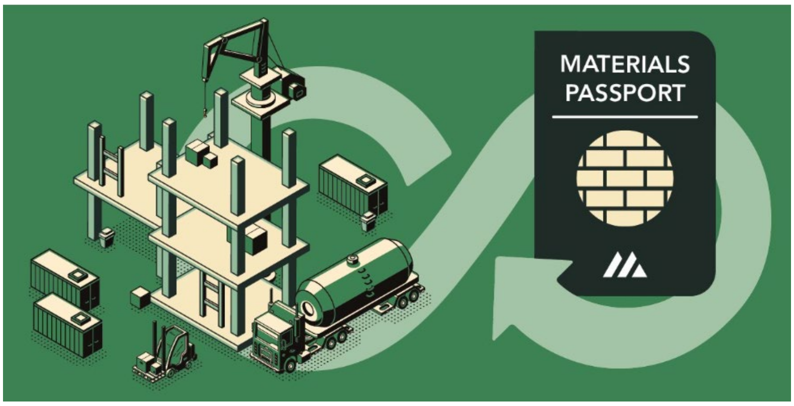

Figure 1. Materials Passport for tracking and reusing building materials (Malone, 2023)

Transitioning to a Circular Economy, as proposed by the European Union (EU) (McMillan, 2019), offers a solution to this problem. See figure 1, in the Circular Economy models, the end-of-life building materials should be reused and their components and parts deconstructed, to act as material banks for new buildings, keeping the components and materials in a closed loop (Benachio et al, 2020). Sometimes improperly assigning materials to their recycling potential often results in high-potential materials being downgraded to lower-potential uses. This is due to the inefficient transition from linear to circular economy which requires a systemic approach that considers the entire building life cycle and construction value chain (Munaro et al, 2021). The Building as Material Banks (BAMB) project of EU's Horizon 2020 is an initiative that aims to enhance the value of used building components and materials through circular solutions. This has led to the creation of Material Passports, reversible building design, business model policy agendas to aid in the implementation of the circular economy. Materials Passports aim to optimize the value retention of materials, products, and components throughout their lifecycle by providing comprehensive information about their composition, properties, and potential for reuse or recycling. By providing transparency and traceability, Materials Passports can indirectly incentivize suppliers to prioritize the production of healthy, sustainable, and circular materials and building products, which aligns with the goals of Reversible Building Design. These passports simplify the decision-making process for developers, managers, and renovators in selecting healthy, sustainable, and circular building materials. They also facilitate reverse logistics and the take-back of products, materials, and components, promoting a more sustainable lifecycle for building materials (Materials Passports- BAMB — bamb2020.eu n.d.).

The objective of this paper is to investigate how building materials registration can be implemented in accordance with (inter)national standards. The paper provides a comprehensive review of the literature on relevant topics focusing on the significance of building materials and their registration processes. This review included an examination of ongoing projects related to building materials registration, particularly the concept of the Material Passport, and an evaluation of its implementation. Simultaneously, consultations with experts using the Madaster platform and TU Delft's Circularity Hub, combined with insights from the literature, highlighted the necessity of establishing a standardized approach. Based on these findings, the fundamental requirements for creating a Material Passport were identified and subsequently refined to streamline the registration process for building materials. The Land Administration Domain Model (LADM), an international standard (ISO 19152), offers a conceptual framework for land administration systems. It is suitable standard as building materials registration is closely related to land administration, involving aspects such as ownership, registration and valuation. Subsequently, the building materials registration part were developed using the necessary components and integrated into the Land Administration Domain Model (LADM).

The paper is organized as follows: Section 2 provides the background relevant to the research. Section 3 provides the applications of the building materials registration. Section 4 presents the gap analysis and standardisation of MP. Section 5 outlines the development of the harmonized information model. Finally, Section 6 discusses the results and suggests directions for future research.

2. BACKGROUND

This section reviews previous research relevant to the topic of this paper, providing context to Land Administration and its international standard ISO, the Land Administration Domain Model. It also examines the concepts of Circular Economy and the Material Passport, concluding with an exploration of Madaster.

2.1 Land Administration

Land in Land Administration is defined as an area of the surface of the earth together with the water, soil, rocks, minerals and hydrocarbons beneath or upon it and the air above it. It is a combination of both physical, spatial or topographical and thematic attributes like legal status, value, tax data (Henssen 1995). Land Administration can be described as the process of efficiently managing the land and information about the land. Its two main aspects are Land Registration and Cadastre. The process of recording legally recognized interests (ownership and/or use) in land is called Land Registration which can be done through deeds or title registration. Cadastre is an official record of information about land parcels, including details of their bounds, tenure, use, and value (Zevenbergen, 2004). They both complement each other as the land registration answers the questions as to who and how, the cadastre answers the questions as to where how much. Land Administration is important as it supports economic development, environmental management and social stability of the country (Williamson, 2001). However, there is inadequate documentation and a lack of standardization in practice coupled with the global diversity and complex legal and administrative aspects of land administration. These challenges were addressed by developing an international standard, (Kalogianni et al, 2024).

2.2 Land Administration Domain Model

The Land Administration Domain Model, LADM is an international standard (ISO 19152: 2012) that provides a conceptual framework for land administration systems, aiming to align their design with societal demands embedded in national and state land policies, (Lemmen et al, 2015). It is a conceptual model delineating the information content of land administration, designed to be interoperable, extendable and adaptable to specific contexts (Kara et al, 2024). During revision of ISO 19152:2012, it was decided to make the standard multiparts based on the following packages. The packages of LADM are (Kara et al, 2024), see figure 1:

- **Party Package**- A party can be individual or organizations like companies, municipalities or a 'group party' comprises multiple parties forming a distinct entity.
- **Administrative Package**- It consists of Rights, restrictions and responsibilities (RRR) and basic administrative units (BAUnits).
- **Spatial Unit Package**- It can be represented as a text, a point (or multi-point), a line (or multi-line), area or volume based on the spatial extend.
- **Generic Conceptual Model**- It contains the basic requirements that form the basis for each part of Edition II.
- **Source Group Package-** It represents the inclusion and updation of data by integrating both administrative sources and spatial sources.
- **Valuation Information Package-** The Part 4, Valuation Information is organised into a single package.
- **Spatial Plan Information Package-** The Part 5 is organised into a single package based on definitions from Part 1 and 2.

And one subpackage, **Surveying and Representation subpackage** is included in the Part 2 allows the representation of spatial units.

The LADM is multipart, where each part constitute separate standards, with the latest edition comprising six parts. Each part will go through the full standardization process (Kara et al, 2024). See figure 2. The parts are as follows:
Part 1- Generic Conceptual Model- This part provides the scope, definitions, a general overview of the model, its core classes and its individual packages and a more detailed examination.
Part 2- Land Registration- This part introduces the Land Registration Standard incorporating a refined Survey and Representation package featuring various measurement techniques.
Part 3- Marine Space Georegulation- This part provides the structure and concepts for standardisation of georegulation in the marine space.
Part 4- Valuation Information- This part specifies the characteristics and semantics of data in valuation registries maintained by public authorities.
Part 5- Spatial Plan Information- This part includes planned land use (zoning) to be converted into rights, restrictions and responsibilities (RRR).
Part 6- Implementations- This part will address a range of topics needed for implementations of LADM: developing a country profile, modelling processes/ workflows, and encodings, (Unger et al, 2023).

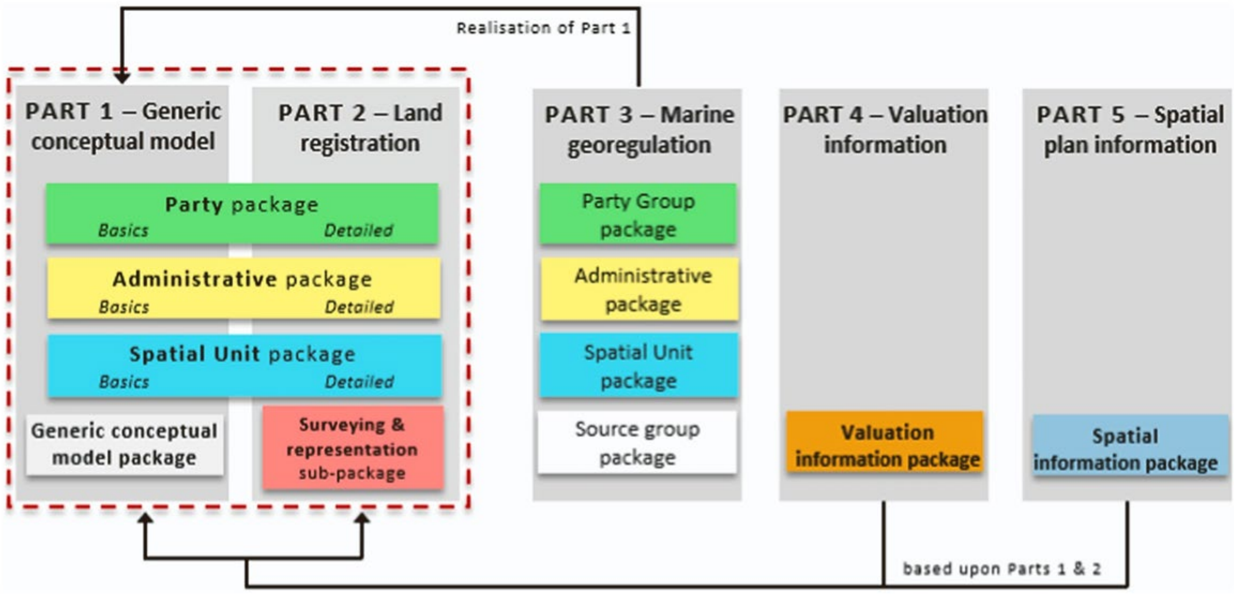

Figure 2. Parts and Packages of LADM II, (Kara et al, 2024)

2.3 Material Passport

Building as Material Banks (BAMB) was part of EU's Horizon 2020 research and innovation funding programme which aims to enable a shift to a circular building sector. As a part of BAMB's objective to enable the transition to a circular building sector, the availability of structured information on materials is crucial for the shifting from the linear economy. A Circular Economy is an economic system designed from societal production and consumption patterns that maximizes the services derived from the linear flow of materials and energy between nature and society. It achieves this by utilizing cyclical material flows, renewable energy sources, and cascading energy flows. Adopting Circular Economy principles in the

construction industry promotes the use of sustainable materials, maximizes material recovery, and reduces unnecessary waste generation and landfill disposal, (Korhonen et al, 2018).
Material Passports consist of digital datasets details including the quality, quantity, locality of materials and components within products and systems, enhancing their value for current utilization, recovery, and reuse. These digital datasets capture comprehensive information on the materials and components within a building, encompassing their quality, quantity, location, and potential for reuse or recycling. By exceeding the scope of traditional certifications and documentation, Material Passports provide valuable insights for material recovery assessments, disassembly instructions, and life cycle analysis. They address aspects typically overlooked by other documents or certifications concerning the circularity of building products, offering information that aids in assessment and certification by third parties, while also enabling the inclusion of existing assessments and certifications as source documents (Copeland et al, 2020). The Material passports comprise multiple hierarchical levels see figure 3, which include the level of materials, components, products and systems that make up the building. For the material level, material passport can define its value for recovery. At the material level, the passport can specify its recovery value, while at the product and system levels, it can outline both general and specific characteristics that render them valuable for recovery (Materials Passports- BAMB — bamb2020.eu n.d.).

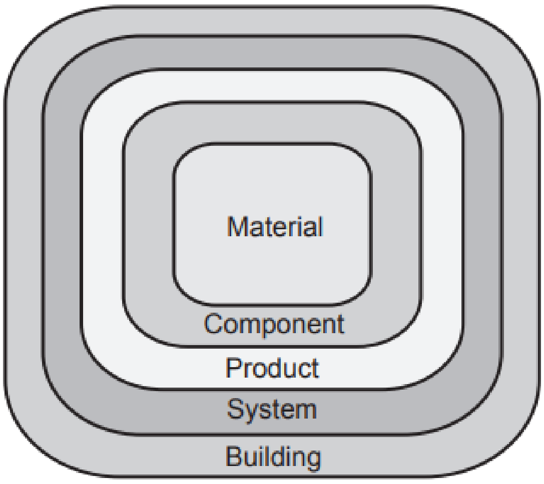

Figure 3. Hierarchy level in Material Passport (Materials Passports- BAMB,bamb2020.eu n.d.)

2.4 Madaster

Madaster is the brand name of the Madaster Foundation, which aims to ensure the availability of materials across all economic cycles. This objective is achieved by registering materials, thus facilitating their accessibility at the highest possible level. Madaster is an online Platform to create Material passport for building. The platform contains library of materials in the built environment and links the material identity to the location and records this in a Material Passport. By creating a comprehensive database of materials through material passports, Madaster contributes to resource conservation, waste reduction, and the overall circularity of the construction sector. With detailed information on material composition, properties, and quantities readily available, Madaster empowers stakeholders to make informed decisions

about material selection, reuse, and recycling. Currently Madaster operates in Netherlands, Germany, Belgium, Austria, Norway, Switzerland and UK.
To create a material passport for a new or existing building in Madaster, accurate and comprehensive building data is essential. The more precise and complete the input data, the more reliable and detailed the generated Material Passport will be. Madaster accepts two primary source file types, see figure 4:

- IFC files- derived from a 3D/BIM model.
- Madaster Excel template- Used when a 3D/BIM model is unavailable, ref Annex.

While various 3D CAD applications exist, the universal IFC file format enables data exchange. For buildings without detailed 3D models, the Madaster Excel template can be used.
Madaster then categorizes and summarizes the information contained in the source files, allowing for detailed insight into the types and quantities of materials present in a building or its individual sections. The geometric data and quantities are directly imported from the IFC model. All calculations within Madaster are based on this and inaccuracies in the results may arise if the source files contain incomplete or missing information, affecting the precision of the outcomes. Additionally, the platform enhances the Material Passport by assessing the financial residual value of materials, evaluating comprehensive circularity through material flow analysis and component detachability, and conducting a Life Cycle Assessment (LCA) to determine the building's Global Warming Potential (GWP) and overall environmental impact.

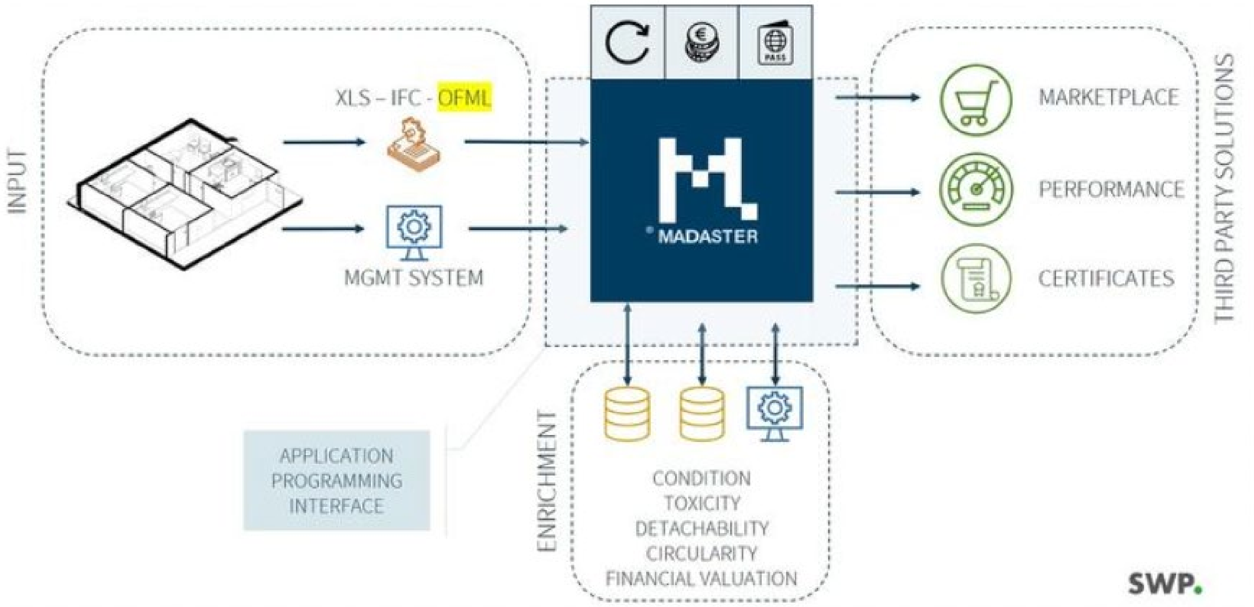

Figure 4. Madaster Framework (Honic et al, 2024)

3. APPLICATIONS OF THE BUILDING MATERIAL REGISTRATION

The registration of building materials has several different applications, below are some of the important applications and merits.

- *Circularity*- A detailed understanding of the materials used in buildings is essential for enhancing their recycling potential. Accurate classification of recycling potential is crucial to preventing material downgrading, enabling reuse at the highest possible quality. Also, proper registration allows easy identification and separation of reusable materials. Furthermore, reusing materials significantly reduces the demand for already depleting natural resources.
- *Valuation of Building*- When the materials are well documented, it will be easier to evaluate their quality and durability, which in turn facilitates accurate building valuation. This documentation also enables a comprehensive assessment of the long-term risks associated with the materials, allowing for informed analysis of renovation costs and more precise pricing of the building.
- *Environmental Impact*- The material used in the building have direct impact on the environment. Material passports contribute to understanding a building's environmental footprint by providing data on embodied energy, carbon emissions throughout its life cycle and material toxicity.
- *Safety and Security*- Maintaining an inventory of all the materials used in the building ensures compliance with safety standards and regulations. This inventory is instrumental in the identification and removal of hazardous materials within the structure. Documenting structural properties and the inclusion of fire-resistant materials are crucial for ensuring overall safety. In emergencies, having a detailed plan of the building and an inventory of materials is essential, as it provides critical information for first responders, facilitating effective and safe interventions.

This means that registration of building materials is serving multiple purposes, which all benefit from the efforts to set up this registration.

4. GAP ANALYSIS AND STANDARDIZATION

The Material Passport is a generally accepted tool for documenting building materials in EU, yet it presents certain ambiguities (Honic et al, 2019). For instance, when generating a Material Passport on the Madaster platform, the source file can either be a BIM model or a detailed Excel sheet. Although both files can represent the same building, the level of detail in the information they contain may differ significantly. Also, the source file can be provided in various formats, further contributing to inconsistencies. Moreover, there are no mandatory requirements for the creation of a Material Passport. Discussions with the TU Delft's Circularity Hub and Madaster consultant revealed that it is possible to generate MP with minimal informations. However, the level of detail in the Material Passport is directly proportional to the amount of information provided. Therefore, there is a need to establish standardized Material Passport guidelines with defined minimum requirements to ensure consistency and comprehensiveness.

The initial step in the standardization process involves shortlisting all the essential requirements necessary for the Materials Passport (MP). Following, the next step was to identify the most suitable data format capable of accommodating all or most of these requirements. Based on the source files of the Madaster platform, the two primary data formats considered were BIM and Excel, which were subsequently compared based on the requirements. The shortlisted requirements are presented in figure 5.

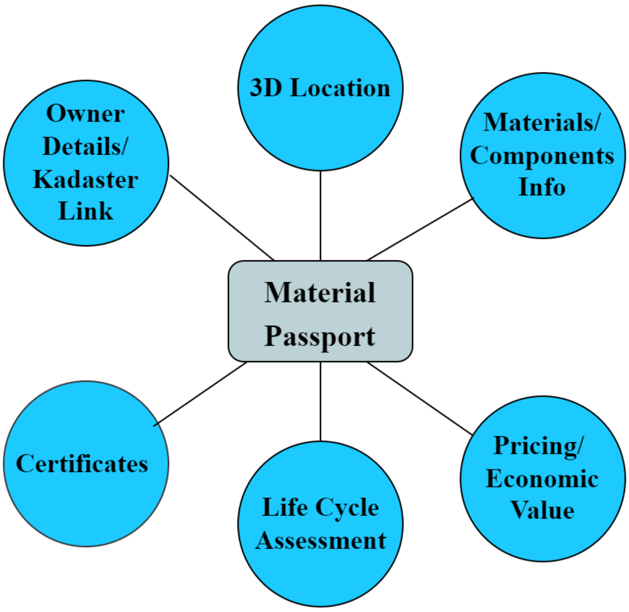

Figure 5. Material Passport and its essential requirements (own illustration)

The data must be maintained in a standardized 3D format that is compatible with visualization, manipulation, and integration processes. It will facilitate easy updates and ensure seamless access across various platforms and stakeholders, thereby ensuring that the information remains readily available and functional throughout the building's lifecycle. The main requirements for the standardised Material Passport are:

- Location is a critical requirement, which includes both the geographical location of the building and the precise placement of materials and components within the building. Accurate location data for materials within the building facilitates efficient retrieval and extraction during deconstruction, minimizing the risk of damage.
- Materials and components data are crucial requirements, providing detailed information about each material or component used in the building, including type, quantity, and quality. This data also includes information regarding the producer or supplier of the materials, ensuring traceability. Materials/components data is an important requirement, it includes detailed information about each materials/components used in the building including its types, quantity, quality. It specifies information about the producer or supplier of the materials to ensure traceability.
- Information about the current owner of the building along with the link to the Kadaster for legal property documentation. This ensures transparency and traceability, making it easier to manage ownership transitions and access necessary legal information.

- The pricing and the economic value reflect the economic value of the materials, both at the time of installation and projected future value. Understanding the economic value helps in making informed decisions about material recovery and reuse.
- A comprehensive analysis of the materials throughout their lifecycle, from production to disposal. It includes carbon footprint, energy and environmental impacts. This is crucial for promoting sustainable building practices and minimizing environmental impact.
- Documentation of any certification standards met by the materials, such as sustainability labels (e.g., FSC for wood), safety certifications, or environmental impacts marks suitable requirement. These certificates validate the quality and sustainability of the materials, ensuring they meet required standards for reuse or recycling.

To compliment the generic requirements with more specific and detailed information, two different source files were analyzed. The second step involved comparing the requirements against the two primary source files: the BIM model and the Excel template. The BIM model is defined as a "shared digital representation of the physical and functional characteristics of any built object" (ISO, BS, 2010). It encompasses information on the geometry, spatial relationships, quantities, and properties of building elements, as well as cost estimates and material inventories. This model contains essential data required for design and construction activities. Table 1 presents a comparison between these two formats, evaluating their feasibility for the intended purpose. From table 1, it can be inferred that the BIM model is a more suitable source data format for the Material Passport.

The updated requirements based on the data derived from the IFC file are illustrated in Figure 6, the solid line represents the mandatory requirements while dotted lines represents optional requirements. While pricing and economic value can be extracted from the source, they are not directly provided. Instead, they are secondary information inferred from the details of components and materials. Therefore, this requirement is not included in the essential requirements.

Table 1. Comparing IFC and Excel data formats based on the requirements

Requirement	IFC	Excel
Location	✓	✗
Materials/ Components Info	✓	✓
Owner Details/ Kadaster Link	✓	✓
Pricing/ Economic Value	✗	✓
Life Cycle Assessment	✗	✗
Certificates	✗	✗

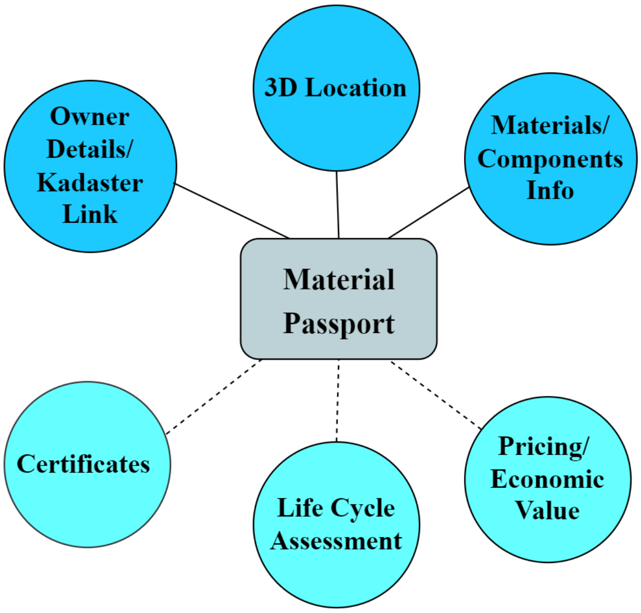

Figure 5. Updated requirements for Material Passport, the dark blue represents the mandatory requirements while light blue represents optional requirements. (own illustration)

5. HARMONIZED INFORMATION MODEL DEVELOPMENT

For Simplifying the Registration and Management of Material Passports and to increase their use both national and international levels, integration with the Land Administration Domain Model (LADM) is recommended. Building materials could be introduced as a new component within the LADM framework. The primary challenge will be integrating this new component with the existing key parts of the model. The new part can be developed using the VersionedObject and LA_Source classes as they supports the registration of building materials. and integrated into the LADM through the VM_Building class from Part 4.
The VersionedObject class is an abstract class in the LADM for the management and maintenance of historical data (ISO, 2012). History requires that both newly inserted and updated data be recorded with a timestamp. This class provides (optional) begin and (optional) end lifespan and real-world timestamps (optional) to the inheriting classes. All LADM classes are directly or indirectly subclasses of VersionedObject, with the exception of LA_Source and its subclass LA_AdministrativeSource. In this way, the contents of the database can be reconstructed, as they were at any historical moment (Kara et al, 2024).
The LA_Source class supports various types of sources and represents the event that triggers changes in the registration process. All dates and times associated with this class are recorded as system (or database) time, reflecting the moment when the event was processed and stored. The association between VersionedObject and LA_Source enables the versioning of source instances (ISO, 2012) see figure 6. Constraints are implemented to ensure that dates and times in VersionedObject and LA_Source correspond accurately. Both VersionedObject and LA_Source include a second set of optional temporal attributes which represent the relevant valid times in the real world (Kara et al, 2024).

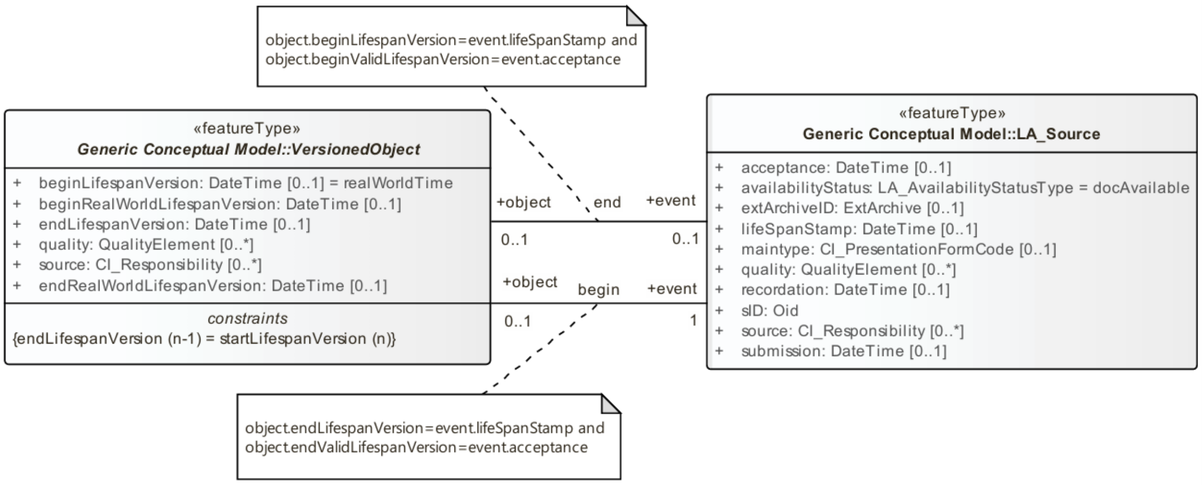

Figure 6. The association between the LA_Source class and the VersionedObject class

The four fundamental classes of the LADM are LA_Party, LA_RRR, LA_BAUnit and LA_SpatialUnit. For simplified registration, it is preferable to integrate the source file through a one-to-one mapping of all requirements of the Materials Passport (MP) to the LADM classes. The LA_Party can be mapped to the IFC attribute classes IfcPerson, IfcOrganisation, and IfcPersonAndOrganisation, depending on the nature of the party involved. For LA_RRR and LA_BAUnit there is no equivalent IFC attribute. The LA_BAUnit refers to multiple spatial units, this can be represented as its attributes are specified as a property set that can be applied to IfcSpatialZone and IfcZone entities. The LA_SpatialUnit can be represented by a wide range of attributes, IfcSite, IfcSpatialZone, IfcSpace, IfcAreaMeasure, IfcCartesionPoint and boundaries reprensing the topological relation can be represented by IfcConnectedFaceSet and IfcPolyLoop (Atazadeh et al, 2018).
To develop the building material part, the requirements for the material passport (see Figure 5) were reviewed. The person involved and their relationships will be recorded in the LA_Party and LA_RRR classes, respectively. The 3D location will be represented in the LA_SpatialUnit. For material and component data, two new classes—BM_ComponentLevel and BM_MaterialLevel were created. The VM_Building class will aggregate instances of the BM_ComponentLevel class, while BM_ComponentLevel will aggregate instances of the BM_MaterialLevel class. The BM_Certificates class will be optional for the VM_Building class, as it is not mandatory and is issued based on specific needs. Additionally, the VM_Building class includes a codelist to account for different building types, each with distinct purposes and taxation requirements. Refer to Figure 7 for further details.

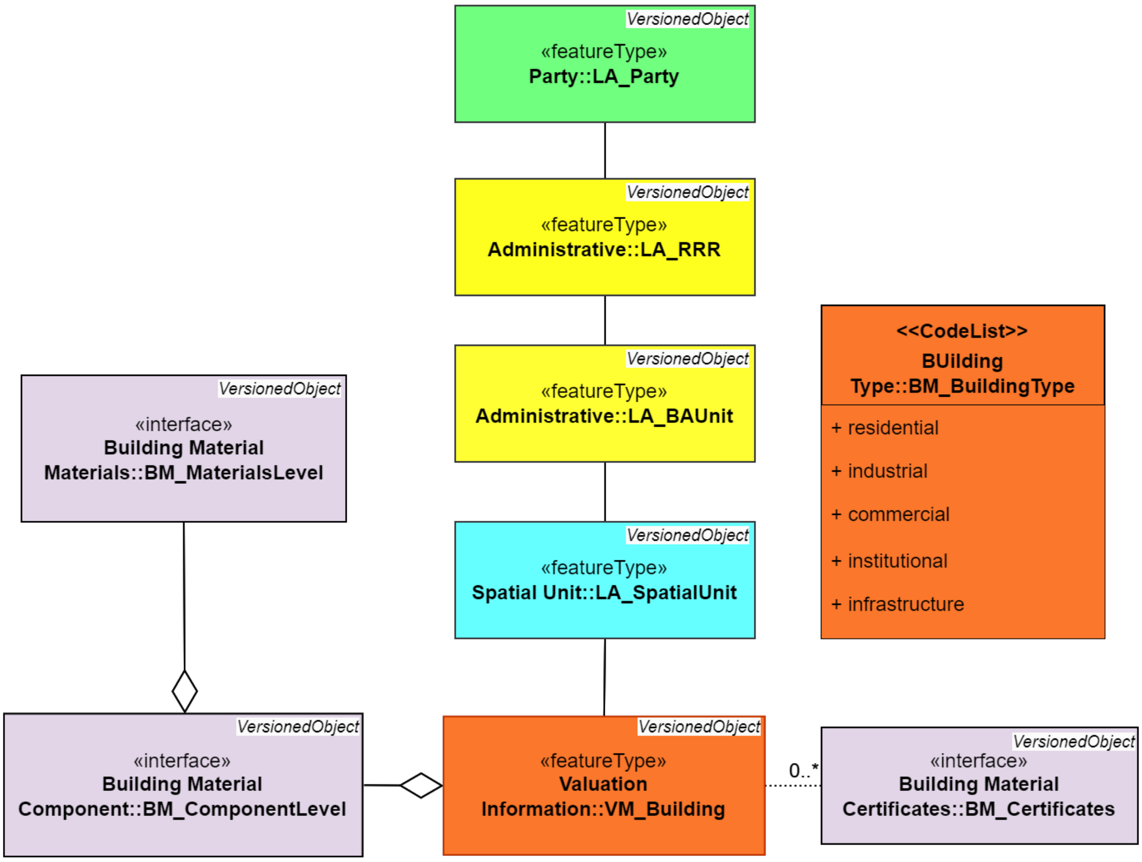

Figure 7. UML diagram showing the classes of Building materials part and its relation to the core LADM classes

6. CONCLUSION AND FUTURE WORK

The integration of a Building Materials registration in the LADM through the proposed Building Materials ISO 19152-7 makes a significant advancement in the sustainability and circular economy. Having a standardised MP improves the circularity by increasing the recycling potential of the building as the materials are recorded accrately it prevents the downgrading of the materials and reusing high quality materials. Additionally, a detailed materails registration helps track what is available for future use, which can reduce the environmental impact of the building , simplifies valuation processes, and supports the implementation of effective safety measures. This research addresses existing gaps in standards and data requirements by developing a standardization for the MP with essential requirements for its creation. By having a standard MP set up, and link to the LADM data model, you increase interoperability between data repositories like local/governmental land administrations and cadasters and international market initiatives like Madaster. With better interoperability, the chance that data stays available and supports circularity increases. Also it improves benchmarking and ‘competition’, ergo it increases overall value and quality. The paper also highlights that incorporating building materials into the LADM information model

can make the materials/components registration process smoother, improve data consistency, and support informed decision-making. Harmonized information model was devolped .
Future research could investigate the testing multipurpose harmonized information model using Madaster platform for different types of building see figure 7 evaluate its effectiveness for new and old building. Another Additionally, future studies might explore the integration of resources and information regarding materials through a unified procedure involving various levels of public administration, including tax offices, which frequently handle the standardized calculation of base rates for taxation.

ACKNOWLEDGEMENTS

The authors would also like to acknowledge Karlijn Kokhuis and Nikki van Oppenraay from TU Delft's Circularity Hub for their insightful contributions regarding the material mapping and circularity. The authors would also like to thank the reviewers for their constructive comments.

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BIOGRAPHICAL NOTES

Aswathy Chandran is an MSc in Geomatics at Delft University of Technology, the Netherlands and her master thesis research is reflected in this paper.

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. Since 2000, he is professor at the Delft University of Technology, Chair GIS Technology, the Netherlands. He is the current chair of the FIG Working Group on the 'Land Administration Domain Model/3D Land Administration (LADM/3D LA)'. He is co-editor of the International Standard for the Land Administration Domain, ISO 19152 and co-chair of the Land Administration Domain Working Group of the Open Geospatial Consortium.

Wilko Quak has an MSc in computer science from Utrecht University, The Netherlands (UU). He worked for several years (1993-2001) as a researcher at the Dutch research center for mathematics and computer science (CWI) and University of Amsterdam (UvA) on Spatial DBMS performance. Since 2001 he has been a researcher at the Section GIS Technology, Delft University of Technology. At Delft University his research focus is moving towards spatial data modeling, data interoperability and standardization. Since 2007 he has been working part-time for Geonovum (the National Spatial Data Infrastructure (NSDI) executive committee in the Netherlands).

Pablo van den Bosch has an MSc in public administration from Erasmus University Rotterdam, The Netherlands. He was the founder of Double Effect BV in 2003, a consultancy firm that works for the financial services industry. In 2013 Double Effect joined Synechron, where Pablo was Managing Director until 2016 growing the business consulting activities for clients in the financial services industry. He also started two other companies: CI Zeist (2016) and Return on Projects (2017). Since 2017 he is Director of Madaster aiming to empower humanity to stay within planetary boundaries so that everybody can live in an environment without waste.

Frederique van Erven has an Master of Architecture from Delft University of Technology (2019, Cum Laude). After working at various architecture firms (HOH Architecten, Atelier van Berlo, Marc Koehler Architects, Turner & Townsend), she joined now Madaster in 2024 as Expansion Manager, committed to embedding circularity within the construction industry. By harnessing the power of digital tools and collaborating across borders, we are driving the adoption of circular economy practices to create a more sustainable built environment.

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ANNEX. MADASTER EXCEL TEMPLATE

The first sheet of the Madaster excel template provides an instructions on how to use the excel template giving an overview of the process. It is categorized into 6 more sheets/tabs: 4 for data (Demolition, Preserved, Construction Waste, and New materials) and 2 for code lists (Shearing layers and European Waste Codes); see tophalf of Figure A1. All the properties (attributes/ columns) of data tabs are same and used to document the actual bulding instances (see bottom half of Figure A1 wih properties overview). A brief description of the data tabs:

- **Demolition** phase of construction data is added in the Demolition sheet.
- **Preserved** focus on materials or components that are to be preserved during renovation or construction.
- **Construction Waste** sheet deals with the waste generated during the construction process, includes data on types of waste, methods of disposal, recycling options.
- **New materials** lists new materials that are being introduced into the construction project.

A brief description of the code list tabs:

- **Shearing Layers** sheet likely provides a detailed breakdown of the different layers in a building; see Figure A2 with 6 classifications.
- **European Waste Codes** (EWC) are standardized codes used across Europe to classify different types of waste; see Figure A3. Note that this tab contains 2 more code lists: **Nature of waste** and **End of life scenario**.

This document can be used as source file for the calculations on the Madaster platform. Below you can find a short explanation about the correct layout of this document.

Tabs	Explanation
Demolition	Describe here the materials and products that will be removed from the building during the 'Demolition' phase.
Preserved	Describe here the materials and products used in the current situation of building and remaining in the building.
Construction Waste	Describe here the sorting and reuse of construction waste to minimize waste during the construction waste phase.
New materials	Describe here the completely new (primary) and/or recycled materials and products that are added to the building.
Shearing layers	Here you can find all Shearing layers codes, of which the code notation is used to indicate where a material or product can be found
European Waste Codes	Here you can find all the waste codes, which can identify and classify waste into categories based on how they were produced.

GTIN	ArticleNumb	Madaster Id	External Database Identifier	Description	Material/
A	B	C	D	E	

A	Optional, for use in matching: GTIN (EAN) of the product
B	Optional, for use in matching : Manufacturer's article number, Eventually concatenated with the manufacturer's GLN (format [article
C	Optional, for use in matching: The identifier of the product in a database of the Madaster Platform.
D	Optional, for use in matching: The identifier of the product in an external database supported by Madaster.
E	Optional: add a description/typename for the element
F	Enter your material- or product name.
G	Enter the code from the classification.
I	Enter the floor on which the supplied material/product is located.
J	Optional, enter the number of elements (when empty, it is considered 1).
K	Enter the area in m^2, or
L	Enter the length in m
M	Enter the volume in m3, or
N	Enter the weight in kilograms.
O	Optional, enter the thickness of the element in m.
P	Optional, enter the height of each element in m.
Q	Optional: Enter the width of each element in m.
R	Optional, Enter the diameter of product if relevant.

Figure A1. Madaster Excel Source file

Classification code	Classification name
1	Surroundings
2	Structure
3	Skin
4	Services
5	Space plan
6	Stuff

Figure A2. Classifications of Shearing layers

Waste codes	
Classification code	**Classification name**
16 02	Wastes from electrical and electronic equipment
16 02 09*	transformers and capacitors containing PCBs
16 02 10*	discarded equipment with PCBs other than those in 16 02 09
16 02 11*	discarded equipment containing chlorofluorocarbons, HCFC, HFC
16 02 12*	discarded equipment containing free asbestos
16 02 13*	discarded equip. with haz. components other than 16 02 09 to 16 02 12
16 02 14	discarded equipment other than those mentioned in 16 02 09 to 16 02 13
16 02 15*	hazardous components removed from discarded equipment
16 02 16	components removed from discarded equip. other than those in 16 02 15
17 01	Concrete, bricks, tiles and ceramics
17 01 01	concrete
17 01 02	bricks
17 01 03	tiles and ceramics
17 01 06*	mix. or separate fractions of concrete, brick, tile&ceramic cont. dang. subs
17 01 07	mix of conc., brick, tile&ceramic other than those mentioned in 17 01 06
17 02	Wood, glass and plastic
17 02 01	wood
17 02 02	glass
17 02 03	plastic
17 02 04*	glass, plastic & wood containing or contaminated with dang. substances
17 03	Bituminous mixtures, coal tar and tarred products
17 03 01*	bituminous mixtures containing coal tar
17 03 02	bituminous mixtures other than those mentioned in 17 03 01
17 03 03*	coal tar and tarred products

Nature of waste			End of life scenario	
Id	**Name**		**Id**	**Name**
NonHazardous	Non-hazardous		10	Reuse of OO element/material
Hazardous	Hazardous		15	Reuse of CW (preparation for)
Inert	Inert		20	Onsite recycling
			25	Offsite recycling
			30	In-situ remediation/recycling of contaminated soil
			35	Ex-situ remediation/recycling of contaminated soil
			40	Onsite recovery as backfill/ landscaping
			45	Offsite recovery as backfill/ landscaping
			50	Waste to energy plant
			55	Incineration plant
			60	Inert waste landfill
			65	Non-hazardous waste landfill
			70	Stable non-reactive hazardous waste landfill
			75	Hazardous waste landfill

Figure A3. Classifications of European Waste Codes

Automatic DTM and Building Footprint Extraction from Imageries and Point Clouds in Indonesia's Land Registration Drone Survey: A Roadmap Towards Reconstruction of LOD1 3D building model

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Key words: Building footprint, ground extraction, Geo-Carta, LOD1 building model

SUMMARY

Accurate and automatic Digital Terrain Model (DTM) and building footprint extraction from drone survey has become essential and challenging work for cadastre verification, modernization and updating. In the context of multipurpose cadastre, the integration of land parcels with other spatial information such as building footprint, terrain elevation, and 3D model, allows for detailed representation of land information. This facilitates spatial analysis and adjacency information within the real-world objects above the ground. In this paper, we introduce an approach for automatic DTM and building footprint extraction by implementing deep-learning methods (i.e., YOLO v8 and CNN) using true-orthoimage UAV and point clouds. We first apply photogrammetric processing through SfM pipelines to produce 3D point clouds and true-orthophoto. To extract DTM, CNN deep learning is implemented to classify point clouds into ground and non-ground objects. The detection of building footprint, as an important spatial information in the cadastral intelligence, is performed by implementing YOLO v8 deep-learning using custom trained data. To ensure that users, irrespective of their technical skill levels, can easily navigate and utilize those two algorithms, we build a GUI for a desktop application using Python, namely Geo-Carta (Geospatial-Cadastre with Artificial Intelligence for Generating LOD 3D City Model). It consists of four features dealing with the detection of building footprint from orthophotos, ground extraction from point clouds, land parcel editing feature, and generation of LOD-1 3D building models.
We tested the Geo-CARTA app for detecting building footprints across various building types (with different shapes and patterns) in several provinces in Indonesia, i.e., Papua, West Sulawesi, East Borneo, Riau, West Java, and Yogyakarta. The results show that the detection of building footprint reached the accuracies of 88.47%. For the accuracy assessment of ground extraction, we tested with the UAV dense clouds in West Java and Yogyakarta, achieved an accuracy of 0.969. The resulting building footprints, DTM, and DSM were then used for reconstructing 3D building models in LOD1 which were implemented automatically using Geo-CARTA app and exported the 3D model into cityjson format.

Automatic DTM and Building Footprint Extraction from Imageries and Point Clouds in Indonesia's Land Registration Drone Survey: A Roadmap Towards Reconstruction of LOD1 3D building model

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1. INTRODUCTION

Accurately and rapidly extracting building footprint information from remote sensing imagery is an essential step for reconstructing 3D building model. The common approach for extracting building footprint is by implementing image segmentation, a procedure for detecting the roof outlines and the reconstruction approach of the buildings. The objective of segmentation is to cluster point clouds or partition a digital image with similar characteristics into homogenous regions [1]. In the past several decades, various image-segmentation algorithms have been proposed and developed. It is generally divided into four categories: thresholding, clustering, edge or contour detection and region extraction [2]. For detecting the building footprint, clustering and edge detection are commonly used. However, for complex and closed buildings, they are not fit to delineate the building boundaries individually. In addition, some proposed methods have difficulty separating the building boundary where dense vegetation partially obscures buildings.

The implementation of deep learning for building footprint extraction has shown significant advancements to solve those limitations. Various deep learning architectures like U-Net, ResUnet, and their variants have been successfully combined with multi-resolution segmentation techniques to enhance the accuracy and efficiency of building footprint extraction from high-resolution satellite images [3, 4] [5]. These approaches address challenges such as geometric inaccuracies and occlusions in building segmentation by leveraging binary semantic segmentation, regularization, and vectorization methods. Additionally, novel networks like MSA-UNET and MSA-ResUNET have been developed to aggregate multi-scale feature maps and improve robustness in cross-domain settings, showcasing superior performance in building footprint extraction tasks [5]. The proposed methodologies aim to provide accurate predictions with refined boundaries, essential for applications in urban planning, change detection, and population density estimation.

Object detection, a fundamental and challenging problem in computer vision, aims to identify object instances from a wide range of predefined categories within natural images. Deep learning techniques have become a powerful approach for learning feature representations directly from data, leading to significant advancements in the field of generic object detection [6]. One of the best and fastest of one-stage object detection networks was proposed by [7], which is able to process 45 frames per second while easily running the detection in real time. From its speed, it was called the You Only Look Once (YOLO) algorithm, then also been improving since it was introduced, by involving all its yolo variations [8]. YOLO offers strong real-time performance, reducing considerable time and effort in practical applications.

In this study we propose building footprint extraction based on YOLO-v8 network with custom trained data.

In the context of multipurpose cadastre, building footprint can be used to represent detailed land information together with the integration of land parcels and other spatial information such as terrain elevation and object height model (OHM) that represent building heights in 3D city models. Forming the foundation for constructing precise OHM, the ground extraction process is a critical component. This process is particularly challenging, especially when aiming for automation. Ground extraction methods are generally categorized into two approaches: (1) classic ground filtering, which relies on geometric features, and (2) learning-based pipelines that treat the process as a classification task [9]. Each method excels in different scenarios for extracting ground points. Common classic filters like Cloth Simulation Filter (CSF) [10, 11] and Progressive TIN Densification (PTD) [12, 13] are widely used across various applications. With advancements in Artificial Intelligence (AI), machine learning and deep learning algorithms, such as Random Forest [14], XGBoost [15], and PointNet/ PointNet++ [16, 17], have also been applied to ground extraction. In this study, we implement CNN with dynamic graph convolution (DG-CNN) that was originally proposed by [18]. This algorithm has demonstrated greater accuracy compared to traditional methods.

Ensuring the users can easily navigate and utilize those two algorithms (YOLO and CNN), we introduce a novel interface for a desktop application using Python, namely Geo-Carta (Geospatial-Cadastre with Artificial Intelligence for Generating LOD 3D City Model). Geo-carta has been established through a collaborative research between the Department of Geodetic Engineering, faculty of Engineering UGM with Indonesian Ministry of Agrarian and Spatial Planning / National Land Agency. It comprises four interconnected steps for generating LOD1-3D model automatically, i.e., generating building footprint based on true-orthoimage with YOLO v8 deep learning, extract ground objects with DG-CNN to produce DTM, and 3D reconstruction of LoD1 models **(Fig 1)**.

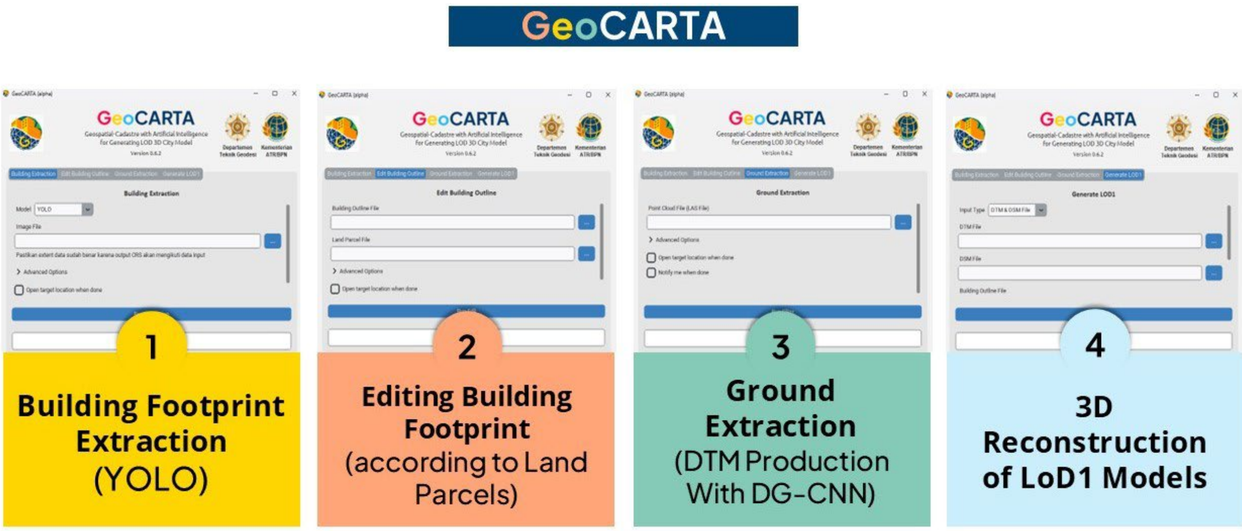

Figure 1. Interconnected steps for generating LOD1-3D in Geo-Carta App

1.1 Building footprint

A building footprint is a polygon or set of polygons in vector format representation of the base of a building or structure (https://www.lawinsider.com/dictionary/building-footprint). This base is defined as where the walls intersect with the ground (**Fig 2**). Several approaches can be implemented for extracting building footprint, including segmentation-based, classification-based, or hybrid method [19]. Building footprint play significant role in the generating 3D building model. Extruding the building footprint according to the height of the building will generate a LoD1 building model. In the generating LoD2, building footprint must be integrated with roof structure, thus, the type of building roofs plays a crucial role in fitting a 3D model to each building [20].

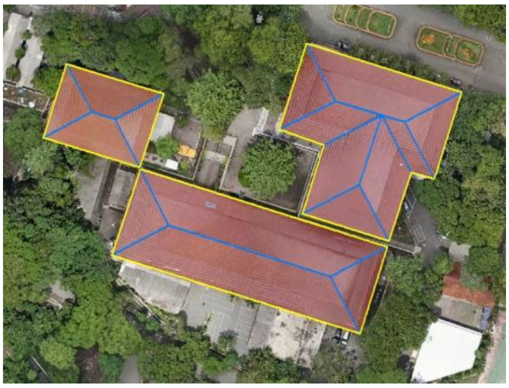

Figure 2. Building footprint (yellow polygons)

1.2 Digital Terrain Model

The automated generation of the LOD-1 building model required the DSM and DTM data. DSM represents the elevation surface of buildings and other objects which can be produced by creating TIN surfaces of original point clouds data. Point clouds data need to be classified as ground and non-ground to generate DTM. The generation of ground point cloud as a surface represents the elevation of ground/terrain object/DTM (**Fig 3**). An accurate estimation of building footprint and DTM is a key step toward 3D city modeling both in model-driven and data driven approaches which directly affects the final precision of the LoD1 3D building model. Building height can be extracted by subtracting the DSM with DTM. LoD1 building model was then generated by extruding building footprint according to this height.

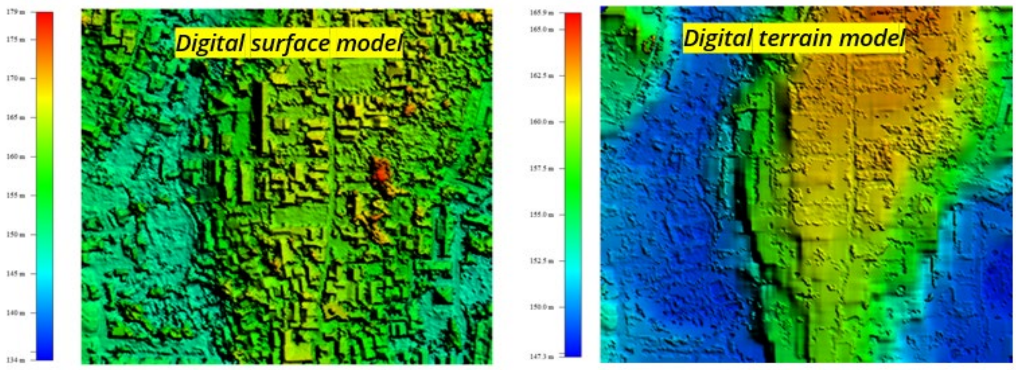

Figure 3. DSM and DTM

2. RESEARCH METHOD

2.1 Study area and datasets

The study areas of this research are part of six provinces in Indonesia, i.e., Papua, West Sulawesi, East Borneo, Riau, West Java, and Yogyakarta (**Fig 4**). The entire images were captured by using UAV platform with the ground sampling distance of 10 cm.

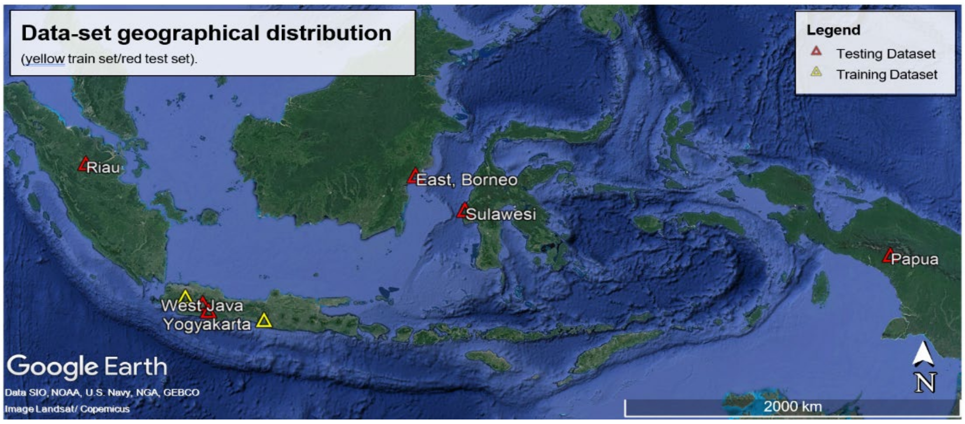

Figure 4. The study areas over six provinces in Indonesia

The images were processed by implementing structure from motion – multi view stereo (SfM-MVS) algorithm through Metashape software to produce dense clouds and true-orthophoto. **Fig 5** shows the visualization of true-orthophoto in six provinces.

Figure 5. True-orthophoto on the six provinces in Indonesia

2.2 Proposed Method

The general workflow of the proposed application is described in **Fig 6**. The first phase focuses on building footprint extraction through YOLO algorithm utilizing true-orthoimage UAV. Here, orthophoto was generated through SfM-MVS pipelines from UAV imagery. This orthophoto was used as input data for the YOLO algorithms. For the training dataset, an area of 20 Ha in West Java was used for the training sample. We created, trained, and deployed YOLO v8 models in a Jupyter notebook. YOLO algorithm works by reframing object detection as a single regression problem, straight from image pixels to bounding box coordinates and class probabilities. A single neural network is then deployed to predict bounding boxes and class probabilities directly from full images in one evaluation [7]. YOLO uses the entire image as input for the network, allowing a neural network to determine both the location of bounding boxes and their corresponding categories [21]. The process creates an extremely fast process, due to not using a complex pipeline. With its rapid object detection capabilities, we have selected and trained YOLO algorithms in this paper to detect building footprints, thereby developing an automated method for segmenting building outlines.

The second step was generating DSM and DTM by implementing CNN deep learning based on UAV dense clouds. CNN has been utilized for ground filtering from airborne LiDAR data, offering a local topological information-aware deep learning method [22]. The model incorporates a local topological information mining module and modified graph convolutional networks for improved ground filtering performance. Using custom data, we split into validation and actual training data for training the CNN model and testing it using the validation set. We use the Pytorch framework to build the model, originally from [18], then modified into ground classification problems. The algorithm has been proven to attain the new state of the art performance in solving point cloud classification and segmentation tasks [23].

The CNN model, especially dynamic graph CNN leverage local geometric structures by building a local neighborhood graph and performing convolution-like operations on the edges connecting adjacent points, following the principles of graph neural networks [18]. DGCNN's key component, EdgeConv, captures the local geometric structure of the point cloud while maintaining permutation invariance. Combined with the dynamically updated K-NN algorithm, which considers geometrically distant points, EdgeConv enabled DGCNN to capture both local and global information effectively [24]. Since CNN deep learning aims to extract ground objects to produce DTM, we classify the point cloud data into two classes, i.e., ground and non-ground point.

Based on the building footprint and DTM, we calculate the difference between the DSM and the DTM to generate the normalized digital surface model (nDSM) or object height model (OHM). The last step of the proposed method was generating the LOD1 building model by extruding building footprint according to UHM. The resulting 3D model was then stored and exported into cityjson format.

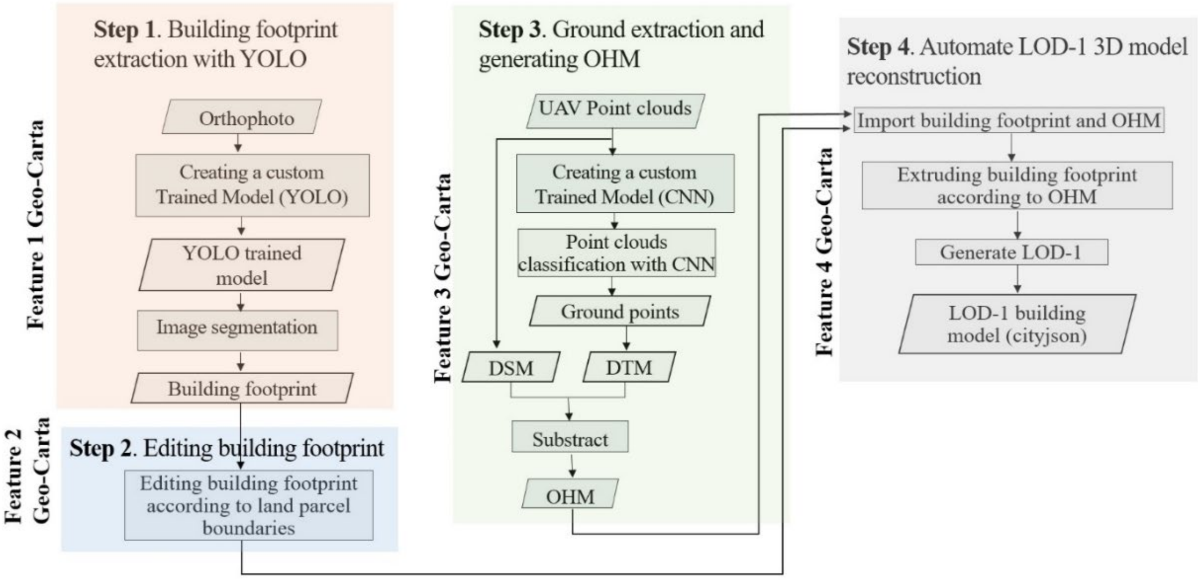

Figure 6. General workflow

2.3 Geo-Carta App

Geo-Carta app comprises four features that integrate several steps in the automate generation of LOD1-3D model. The first feature is building footprint extraction. Here users can select deep learning models of the two designated deep learning models, i.e., YOLO v8 and Modified Vision Transformer (MVT). MVT represents a deep learning framework predicated on the CSwin transformer architecture, which endeavors to implement the foundational principles inherent to transformer models. Given that YOLO deep learning exhibits a good performance in delineating building outlines and is more aptly suited for deployment within the Indonesian context, this study accentuates the utilization of YOLO v8. Furthermore, users may select the desired detections level in the predefined YOLO type, i.e., rapid, medium, highest. Those levels indicate the different levels in the detection, the higher level type the higher detail of the resulting segmentation. As shown in **Fig 7**, users can extract building footprint beginning from import true-orthoimage (square image with tiff format) then execute “run prediction” according to the predefined trained model.

The performance of Geo-Carta to segment the building footprint indeed depends on the quality of the trained model. It is advisable to revise and enhance the trained model in specific regions where it exhibits divergent characteristics relative to our model. To facilitate this, Geo-Carta provides users with the capability to substitute and update the trained model in accordance with their building characteristics. This process can be accomplished by selecting the model path within the advanced options and inputting the new trained model file in Pytorch model format (.pt).

Figure 7. The window of feature #1 in Geo-Carta

The second feature is a tool for editing the building footprint according to the land parcel boundary (**Fig 8**b). This feature comes from the fact that the generated building footprint in the complex and closed buildings are not fit to delineate the building boundaries individually (**Fig 8**a). To recover this condition, users can apply this tool to edit or modify the original building footprint and get a refined one (**Fig 8**c). For more detailed illustration, the process can be seen in **Fig 8**. The red polygons are the extracted building footprint, the green polygons are the land parcel boundaries, and the yellow polygons represent the refined building footprint separated by land parcels.

(a) (b) (c)

Figure 8. The process of editing building footprint according to the land parcel boundary

The third feature aims to extract ground point from a set of point clouds. The input data for this task is point clouds file in .las format (**Fig 9a**). DG-CNN uses six statistical features to determine the class of ground and non-ground, i.e., coordinates of points in x,y,z, and color

RGB channels. Prior to the ground prediction, users need to determine “batch size” and “predict area” in the window. Batch size indicates the size of point feed into the deep learning model, while the predicted area represents ID or order to choose which area wants to process. The current version of Geo-Carta allows classification of both point clouds from photogrammetry and Lidar, however the intensity value was not used as a feature in the statistical model. We consider incorporating the intensity value in the further version. The last feature of Geo-Carta is an interface for generating LOD-1 models based on three input data, i.e., building footprint, DSM, and DTM (**Fig 9b**). We also facilitate the generating LOD-1 model directly from classified point cloud files together with building footprint.

(a) Ground extraction menu (feature #3) (b) Generating LOD-1 menu (feature #4)

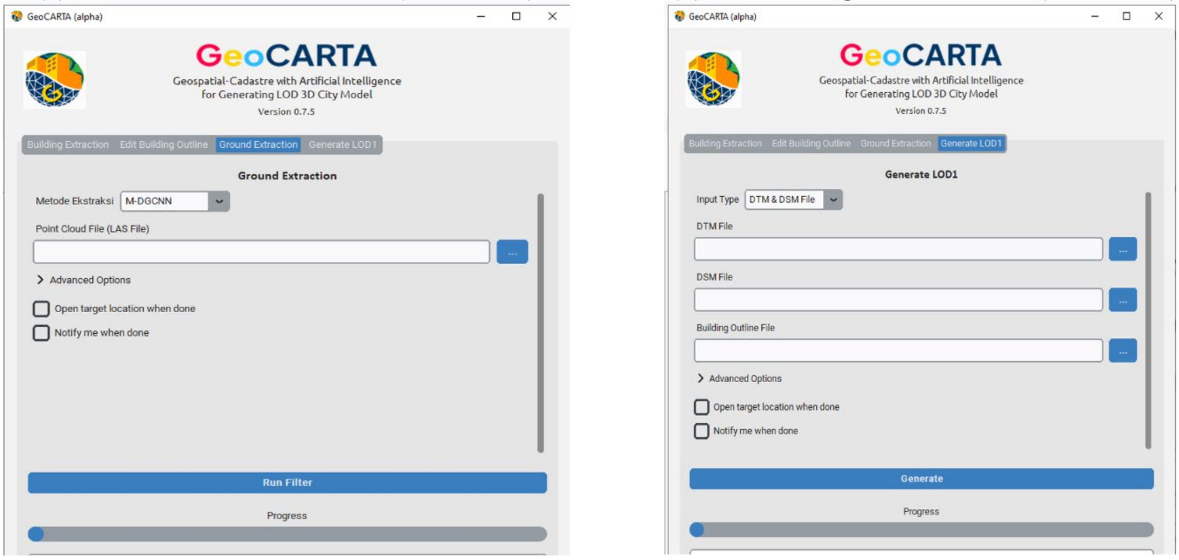

Figure 9. Window menu of feature #3 and #4 in Geo-Carta

Geo-Carta App can be downloaded from the website www.geocarta.id. However, right now only users who have an account in the geo-kkp BPN RI can install and utilize these features.

2.4 Reconstruction of LOD-1 3D building model

The 3D model resulted in Geo-carta represented by BREP (boundary representation) format as a collection of NURBS surfaces. Each individual face within this model is encompassed by a closed loop structure, composed of one or multiple edges. This sophisticated representation of the 3D model through the BREP format highlights the complex interplay between surfaces, edges, and vertices, illustrating the advanced principles of computational geometry. The reconstruction of BREP 3D model starts from the building footprint (vector 2D), which then extrudes the height of every surface (roof, wall, and ground) according to the OHM. The reconstruction process of BREP 3D models are illustrated in **Fig 10**. For example, the green wall is reconstructed by creating a face between four edges (1,2,6,5). The elevation of 1,2,3 and 4 are determined by calculating the average of height in every edge according to the OHM. The model then stores and exports into CityJSON format, an alternative to the GML encoding of CityGML, which can be verbose and complex to read and manipulate.

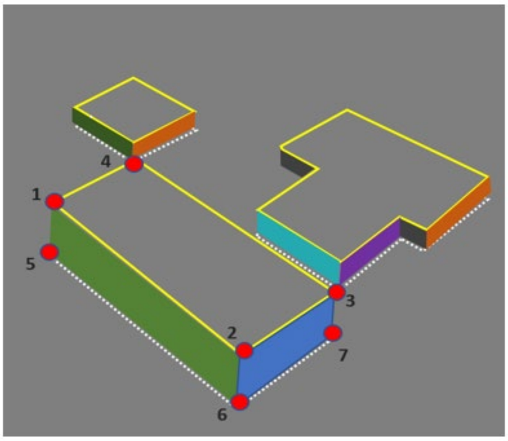

Figure 10. Reconstruction of BREP 3D model

3. RESULT AND DISCUSSION

Three experimental results of the proposed approach (i.e., building footprint extraction, ground extraction, and 3D BREP LOD1 generation) across various building shapes and patterns in six provinces in Indonesia are presented in this section. The trained model of YOLO was built over 40 Ha in some areas in West Java, whereas the DG-CNN model was trained over 55 Ha of urban and suburban areas in West Java and Yogyakarta province.

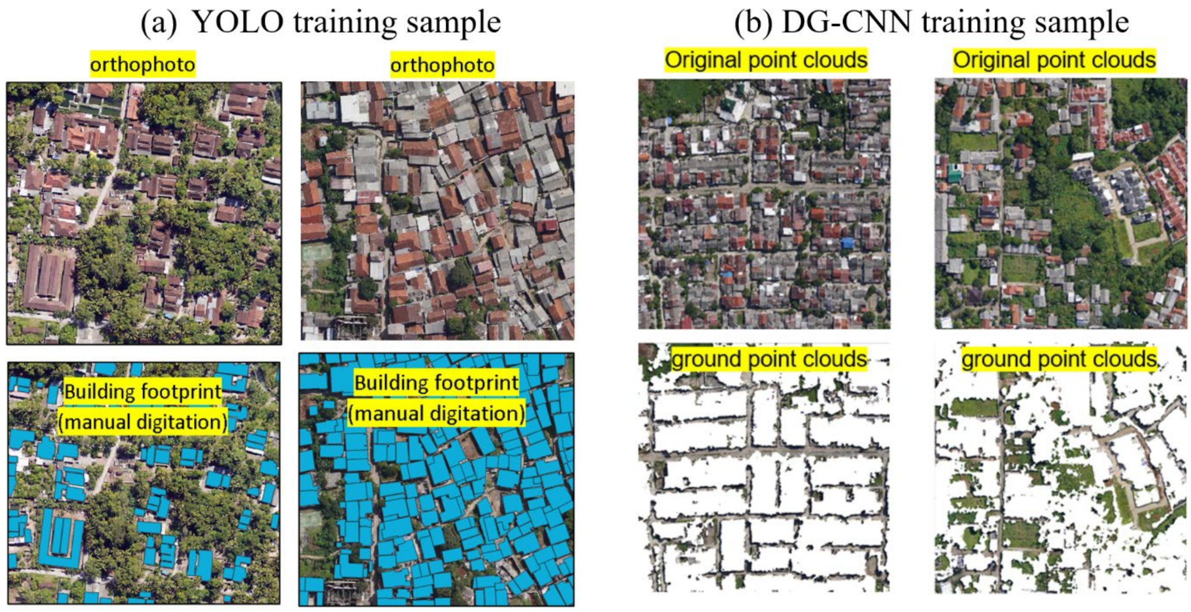

Figure 11. Training sample of YOLO and DG-CNN

3.1 Generated building footprint and accuracy assessment

According to the YOLO trained model (**Fig 11**a.), we implement Geo-Carta App for generating building footprint. Through the YOLO deep learning with a custom trained model, our program can recognize and separate each building precisely. The final results of building footprint of six datasets were illustrated in **Fig 12**. However, some buildings are not properly segmented, particularly at the flat, dense and connected buildings.

Figure 12. The resulting building footprint by YOLO deep learning with a custom trained model

According to the ground truth data formed by manual digitization, we compare and analyze the accuracy of the detected building footprint. We use F1 score to evaluate the deep learning model that measures a model's accuracy. It combines the precision and recall scores of a model, yielding the score of 93.88%. The overall accuracy as indicated that the predicted values match the actual values (ground truth) yielded an accuracy of 88.47%. We also compare the detection building footprint by Geo-Carta with the Mapflow, a QGIS python plugins repository by Geoalert to extract real-world objects from satellite imagery. In the area with connected buildings, Geo-Carta can recognize and separate each building more precisely (yellow circles in **Fig 13**). We also found the resulting building footprint with Mapflow has inaccurate orientation (black circles in **Fig 13**), while the detected building footprint with Geo-Carta demonstrates correct shape and orientation.

Table 1. Accuracy of detected building footprint

Indicators	Score
Accuracy	88.47 %
Precision	90.59 %
F1 Score	93.88 %
Commission Error	9.32 %
Omission Error	2.58 %

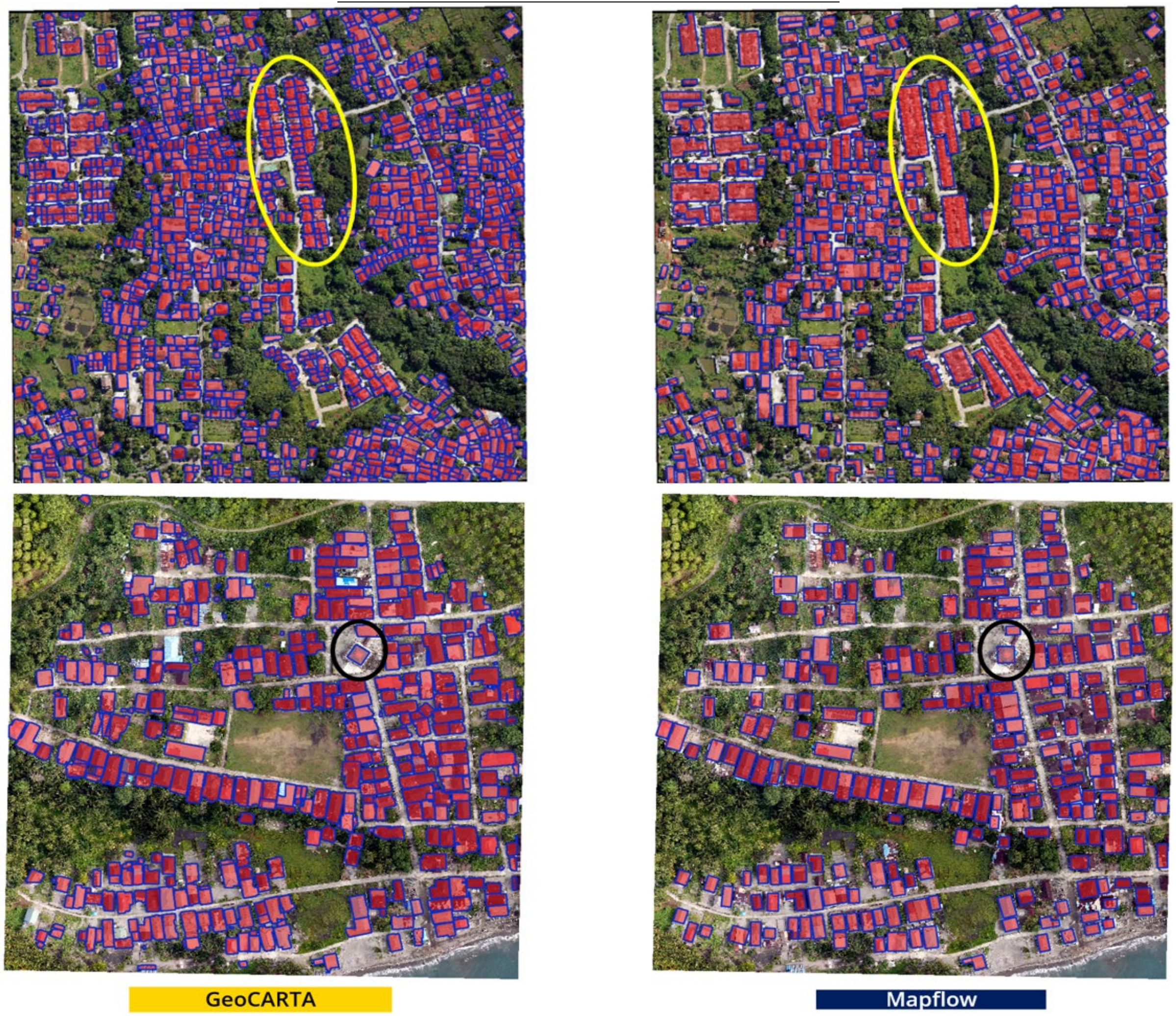

Figure 13. Comparative results between Geo-Carta and Mapflow

3.2 Generated DTM and accuracy assessment

The term DTM refers to a model in which the elevations are referred to the bare ground. DTM can be formed based on point clouds (photogrammetry and Lidar) or other spatial data sources like terrestrial survey, satellite imagery, etc, The third feature of Geo-Carta app is an application to extract ground features from unclassified points. It means that the input data source is a set of object points (vegetation, building, car, water body, etc). In the context of multipurpose cadastre, the land parcels data need to be referred with terrain elevation on the same coordinate system. Therefore, the referred land parcels can be integrated with other spatial information.

We have built a custom DG-CNN trained model and are available to use in the Geo-carta App. However, to the best of our understanding, our trained dataset is not adequately suited for the prediction and extraction of ground points across the Indonesian archipelago. Consequently, it is imperative to implement updates or modifications to the trained models to achieve enhanced accuracy in ground prediction. We have facilitated for users to build, import and implement their own trained model in the prediction process. By using our trained model, we have tested some point clouds data generated from UAV photogrammetry in West Java and Yogyakarta. The result can be seen in **Fig 14**. According to the extracted ground points, we have evaluated the accuracy of Geo-Carta prediction compared with the ground truth. It yielded the intersection over union (IoU) score and overall accuracy of 0.906 and 0.969, respectively.

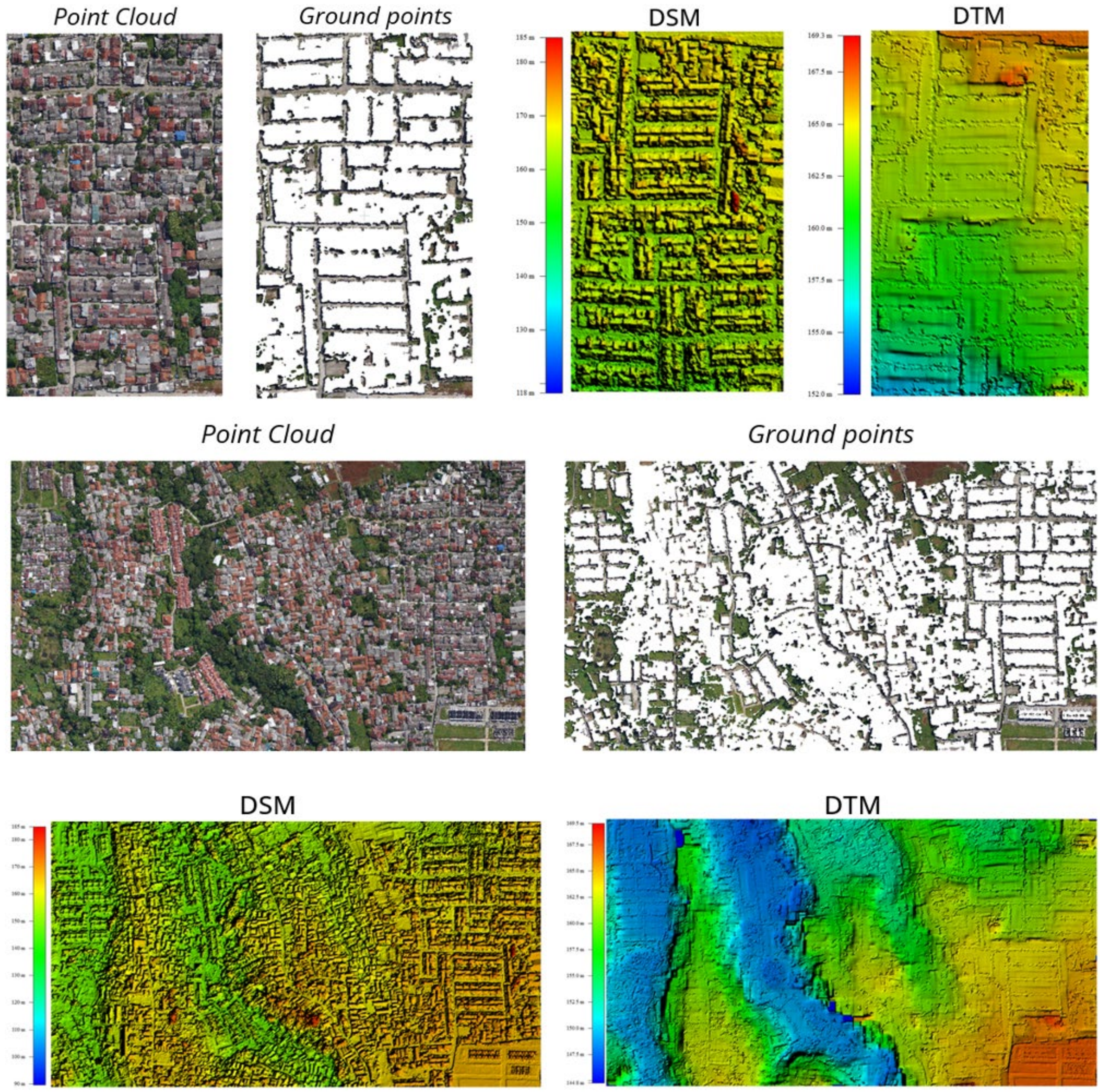

Figure 14. Original point clouds, extracted ground point and generated DTM by implementing Geo-Carta

3.3 Generated LOD-1 3D building model and accuracy assessment

The generation of BREP 3D LOD1 model can be applied by two input data options, as a point cloud that has been classified into ground and non-ground or in raster data including DSM and DTM. We have implemented Geo-Carta for the 3D model reconstruction over four locations in three provinces, i.e., Yogyakarta (UGM campus), West Java (Bogor icon building), and DKI Jakarta (Trunojoyo). The results of LOD1 models were illustrated in **Fig 15**. Those 3D models were built automatically, beginning with the detection of building footprint followed by extracting ground points and generating DSM and DTM. Once those data are available, the generation 3D model can be performed automatically.

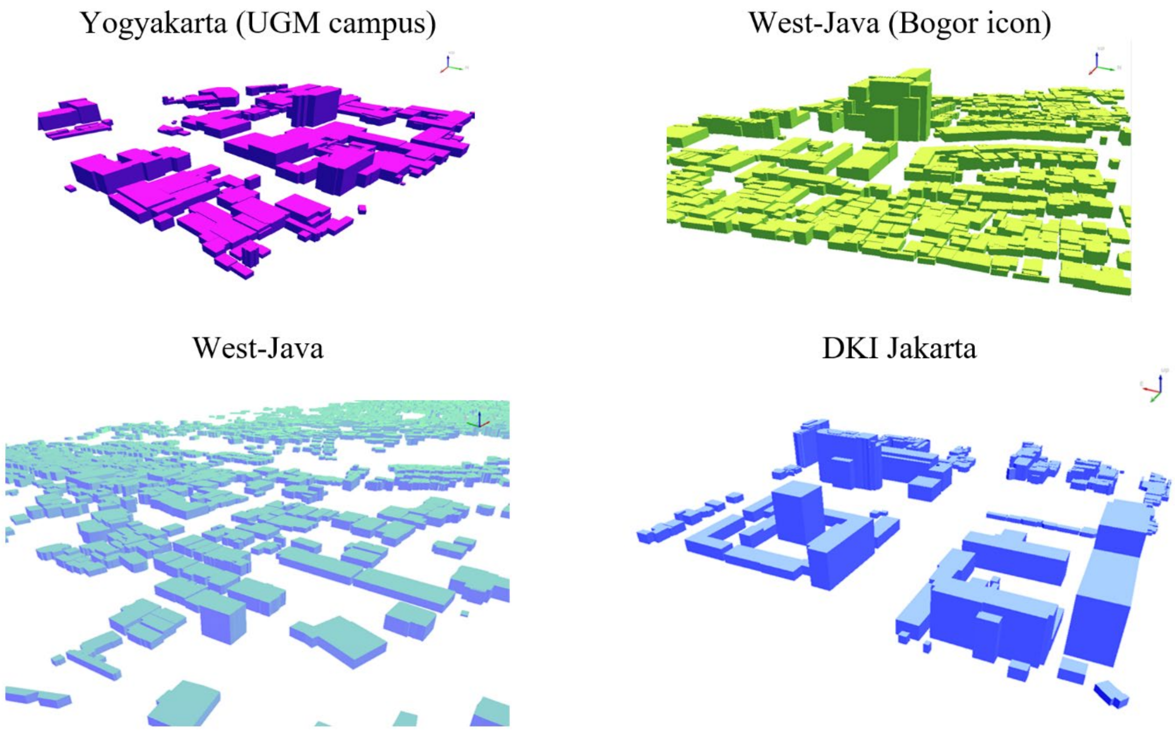

Figure 15. The generated 3D LOD-1 model in city-JSON format

4. CONCLUSIONS

This paper presents an automatic method for detecting building footprint, ground point extraction and 3D model in LOD-1 based on UAV orthophoto and point clouds. Those steps were integrated into a single interface application, namely Geo-Carta, a desktop application using Python. The building footprints are extracted from orthophoto through YOLO deep learning and the ground points as an input data to produce DTM is extracted from UAV point clouds by implementing DG-CNN algorithm. Results show that the building footprint can be well recognized and it can separate each building precisely. However, in the dense and connected buildings, they are not properly segmented, introducing irregular patterns. Therefore, editing building footprint with land parcel should be performed.

In the context of multipurpose cadastre, it is essential to reference land parcel data with terrain elevation within a uniform coordinate system to facilitate its integration with other spatial information, including land parcel height, building information, and three-dimensional models. Through the utilization of Geo-Carta, these procedures can be executed in a straightforward manner, delivering high accuracy in the geometric components involved.

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BIOGRAPHICAL NOTES

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STDM Valuation of Unregistered Land

**Eva-Maria MORSCHER-UNGER, Austria, Abdullah KARA, Türkiye,
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Key words: LADM, STDM, valuation, unregistered land

SUMMARY

The importance of assigning value to unregistered land may play a crucial role for efficient land management, including acquisition, taxation, and transfer processes. This valuation could be central to establishing tenure security and recognizing legitimate land rights, impacting local and regional economics, governance strength, and the functionality of land markets. The New Urban Agenda highlights the need for competent valuation of unregistered land, which involves a transparent and accountable process, often hindered limited professional expertise, and overall data scarcity. Significant research and guidelines from various organizations, including FIG, FAO, GLTN, Namati, and RICS, have contributed to the understanding of the valuation of unregistered lands. These efforts have resulted in publications such as the Valuation of Unregistered Lands: A Policy Guide by UN-Habitat, providing practice-based guidance for valuation related to land-based financing, taxation, and fair compensation assessments. This guide together with the manual developed is universally applicable, offering a comprehensive framework for valuing unregistered land in various contexts and locations. It incorporates established best practices and protocols, detailing key valuation concepts, professional capacity-building, and includes practical tools for valuation professionals. As part of the ongoing revision of the ISO 19152 the Land Administration Domain Model (LADM), which includes a Part 4 focused on valuation, questions arise concerning the adaptability of the Social Tenure Domain Model (STDM) to address the valuation of unregistered land. This paper investigates whether STDM can be extended to accommodate the specific demands of the valuation of unregistered land and explores the necessary modifications required to develop such an extension that is both sophisticated and practically applicable in an informal setting. To effectively extend STDM for valuation purposes, it is crucial to incorporate specific valuation functions capable of capturing land values based on various criteria like location, land use, and potential for development. These functions must be adaptable to different economic conditions and real estate markets to ensure accuracy and relevance also in an informal setting. The model must also enhance its data integration capabilities to manage a range of data sources effectively, including market data, but also not formally recognised supporting documents. Considering the contexts in which STDM is typically used, the model should feature user-friendliness and not too complicated procedures that are intuitive and accessible for individuals without formal training. Simplifying both the input and output processes is crucial to ensure the model's usability and clarity. Furthermore, the model should be scalable to handle various sizes and types of buildings and plots and flexible enough to adapt to diverse local legal and economic environments. Further, and this is crucial to any standard development, interoperability must be ensured so that the data can also be included in any formal system used within the specific

country. This paper describes the development of the STDM Valuation of Unregistered Land and how specific aspects and considerations were derived from literature and practical experiences to develop such an extension. With the development of the STDM Valuation of Unregistered Land the aim is to contribute to more equitable and effective land administration practices worldwide.

STDM Valuation of Unregistered Land

Eva-Maria MORSCHER-UNGER, Austria, Abdullah KARA, Türkiye, John GITAU, Kenya, and James KAVANAGH, UK

1. INTRODUCTION

The significance of assigning value to unregistered land is increasingly recognised as a critical component in effective land administration (UN-GGIM, 2020). This valuation process plays an essential role in land acquisition, taxation, and the transfer of property, thus forming a cornerstone for establishing tenure security and legitimising land rights (UN-Habitat, 2018; Kara et al. 2023; Lemmen et al. 2019; OGC, 2019). These factors, in turn, significantly influence local and regional economic development, governance strength, and the functioning of land markets (UN-Habitat, 2021.

As highlighted in the New Urban Agenda, the competent valuation of unregistered land necessitates a transparent and accountable process. However, this task is often complicated by limited professional expertise and a chronic scarcity of data. Addressing these challenges, various organisations—including FIG, FAO, GLTN, Namati, and RICS—have contributed extensive research and guidelines to improve understanding and practices related to unregistered land valuation. Notably, the publication of the Valuation of Unregistered Lands: A Policy Guide by UN-Habitat provides a comprehensive framework for professionals engaged in valuation tasks associated with land-based financing, taxation, and fair compensation (UN-Habitat, 2018).

This policy guide, along with its accompanying manual, offers globally applicable recommendations, incorporating best practices and standardised protocols for the valuation of unregistered land in diverse contexts. The guide also addresses key valuation concepts, professional capacity-building, and the integration of practical tools for use by valuation professionals.

In parallel with these developments, ongoing revisions to the ISO 19152 Land Administration Domain Model (LADM) have prompted inquiries into whether the Social Tenure Domain Model (STDM) can be adapted to address the specific demands of unregistered land valuation (Morscher-Unger et al., 2024). This paper explores the potential for extending STDM to accommodate valuation functions tailored to different economic conditions and real estate markets, ensuring accuracy and relevance even in informal settings.

The extension of STDM for valuation purposes necessitates the inclusion of specialised functions capable of capturing land values based on criteria such as location, land use, and development potential. Additionally, the model must enhance its data integration capabilities to effectively manage a range of data sources, including both market data and informal supporting documents. To ensure accessibility, the model should feature user-friendly processes that are intuitive for individuals without formal training, while also being scalable and flexible to adapt to various local legal and economic environments.

Ultimately, this paper outlines the development of the STDM Valuation of Unregistered Land, incorporating insights from literature and practical experiences. The aim is to contribute to more equitable and effective land administration practices on a global scale, supporting the broader goals of sustainable development and social justice.

2. STDM BACKGROUND AND GOALS

The Social Tenure Domain Model (STDM) emerged as an initiative by UN-HABITAT, designed to bridge the gap between formal and informal land administration systems (Augustinus et al., 2006; Lemmen, 2010; UN-Habitat, 2008)). STDM is fundamentally about recognising and recording the diverse relationships between people and land, irrespective of the formalisation or legality of those relationships. This model was developed with a focus on pro-poor land administration, targeting regions where conventional cadastral systems are either absent or insufficient, such as in urban slums, rural customary areas, and post-conflict zones. STDM represents a significant shift from traditional land administration by acknowledging that land rights extend beyond formal titles to include social tenure relationships like occupation, tenancy, and customary rights (Zevenbergen, 2021; Van Oosterom et al., 2022).

In many developing countries, the majority of land and property is unregistered, and traditional land administration systems often fail to recognise the ways in which people interact with land. STDM provides a flexible model that accommodates these various forms of tenure, allowing for the documentation of land rights in all manner, leaving no one left behind (Zevenbergen et al., 2016; UN-Habitat, 2017). This adaptability makes STDM particularly valuable in areas where conventional land administration methods are either inapplicable or impractical.

The need for STDM in the valuation of unregistered land is increasingly apparent as governments and international organisations seek to improve land tenure security, facilitate land markets, and support sustainable development. The valuation of unregistered land is a complex task that requires consideration of not only market values but also social, cultural, and environmental factors. Traditional valuation methods, which are typically designed for formal, registered properties, often fall short when applied to unregistered lands where land rights are informal and not legally recognised (UN-Habitat, 2018).

Incorporating STDM into the valuation process for unregistered land ensures that all forms of land tenure are considered, providing a more comprehensive and equitable approach to land administration. By recognising and valuing the diverse relationships between people and land, STDM helps to legitimise the land rights of vulnerable populations, thereby contributing to poverty reduction, conflict resolution, and improved tenure security. Moreover, STDM's integration with existing land administration systems allows for the gradual formalisation of informal land rights, providing a pathway for the inclusion of marginalised communities in the formal land market.

In summary, the STDM and its application in the valuation of unregistered land is a critical step toward ensuring that all people, regardless of their socio-economic status, have access to secure and recognised land rights. This, in turn, supports broader goals of equitable development and governance, making STDM an essential component in the ongoing efforts to reform and improve land administration systems worldwide.

2.1 STDM Valuation for Unregisterd Land

2.1.1 LADM II part 4

The Land Administration Domain Model (LADM), established by ISO 19152, is an international standard designed to provide a comprehensive and flexible framework for land administration systems. The initial edition of LADM focused primarily on the legal, spatial, and administrative aspects of land administration, offering a robust foundation for the management of land-related information. However, it recognised that the valuation of property, a key component of land administration, was not fully addressed in the original model (Lemmen et al. 2015; OGC, 2019, Janecka et al. 2018, Kalogianni et al. 2021).

To bridge this gap, ongoing developments in LADM, particularly the introduction of LADM II, include a dedicated section on valuation—referred to as Part 4. This addition marks a significant advancement in the standard, focusing on the integration of property valuation information within the broader land administration framework. Part 4 of LADM is designed as a conceptual model rather than a data product specification, providing a formal information model that facilitates communication and interoperability between different countries and organisations involved in property valuation (Kara et al., 2023b).

The main objectives of LADM Part 4 are twofold. Firstly, it aims to establish a common basis for representing and managing property valuation information across various jurisdictions. This includes the identification of properties, the assessment of their value through both single and mass appraisal methods, the recording of transaction prices, and the management of sales statistics and appeals processes. Secondly, it seeks to provide an extensible framework that supports the development and refinement of property valuation systems, ensuring they are efficient, effective, and aligned with international standards.

LADM Part 4 is particularly relevant for public bodies, offering guidance for developing local and national information models and databases. It also serves as a resource for the private sector, facilitating the integration of valuation databases with existing land administration systems. The model is designed to cover common aspects of valuation shared globally, based on the conceptual framework of the International Federation of Surveyors (FIG) Cadastre 2014 and the international property valuation standards.

Overall, the inclusion of Part 4 in LADM II represents a crucial step toward creating standardised, interoperable, and comprehensive land administration systems that incorporate property valuation, thereby enhancing the accuracy, consistency, and transparency of land-related data worldwide. This development is expected to play a significant role in supporting sustainable development goals and improving the management of land resources on a global scale.

The LADM II Part 4 model, as currently proposed, does not adequately address the complexities of informal settings because it is primarily designed for formal land administration systems that rely on structured, legally recognized property data.

In contrast, the Social Tenure Domain Model (STDM), a generalization of LADM, is specifically tailored to accommodate the diverse and informal land tenure relationships often found in unregistered land contexts. Therefore, using STDM to develop a model for the valuation of unregistered land is essential to ensure that all forms of land rights, including those in informal and customary systems, are recognized and valued appropriately.

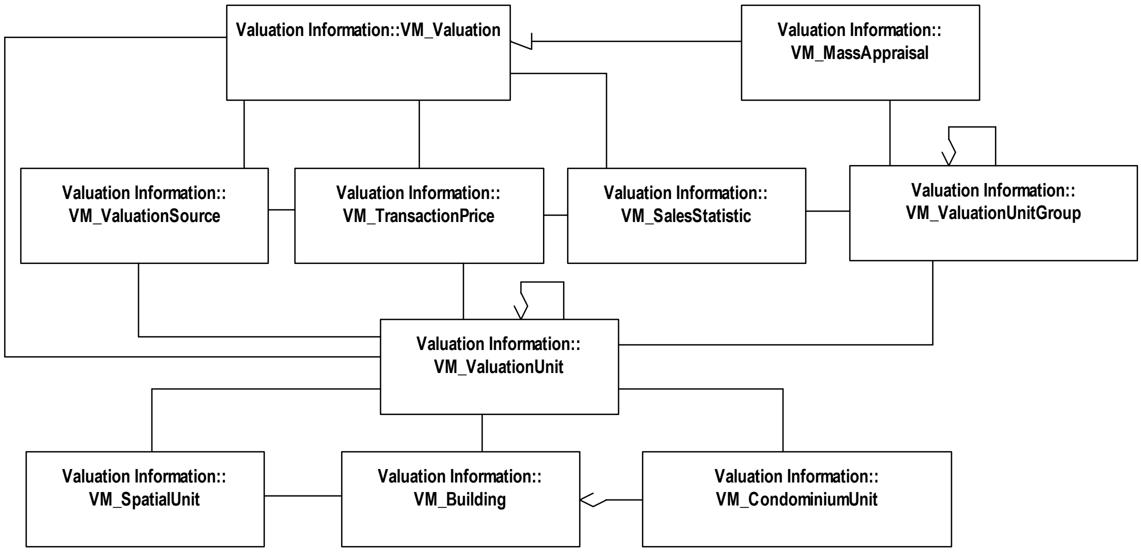

Figure 1. LADM II part 4 (Source: ISO 19152-4 approved and registered for the DIS stage)

2.1.2 STDM Valuation of Unregistered Land

The Glossary/Key Terms from the GLTN Publication 'Valuation of Unregistered Land – A Practice Manual' were carefully considered to develop a comprehensive model for the valuation of unregistered land using the Social Tenure Domain Model (STDM). This approach draws from the International Valuation Standards Framework (IVSC, 2019), which defines three principal bases of value: Market Value, Investment Value, and Fair Value. These definitions are crucial for ensuring that the valuation of unregistered land aligns with globally recognised standards while being adaptable to the conditions found in informal settings.

The STDM Valuation of Unregistered Land model is built upon a detailed analysis of the GLTN Publication, specifically examining how its key aspects can be incorporated into the existing STDM model. The resulting decisions highlight where additional classes, attributes, or overlays are necessary to extend STDM's capabilities to support the complex valuation processes required for unregistered land. The table provided offers an overview of how the various aspects of the GLTN Publication are addressed within the STDM model, identifying existing STDM core classes that exist and proposing enhancements where gaps exist.

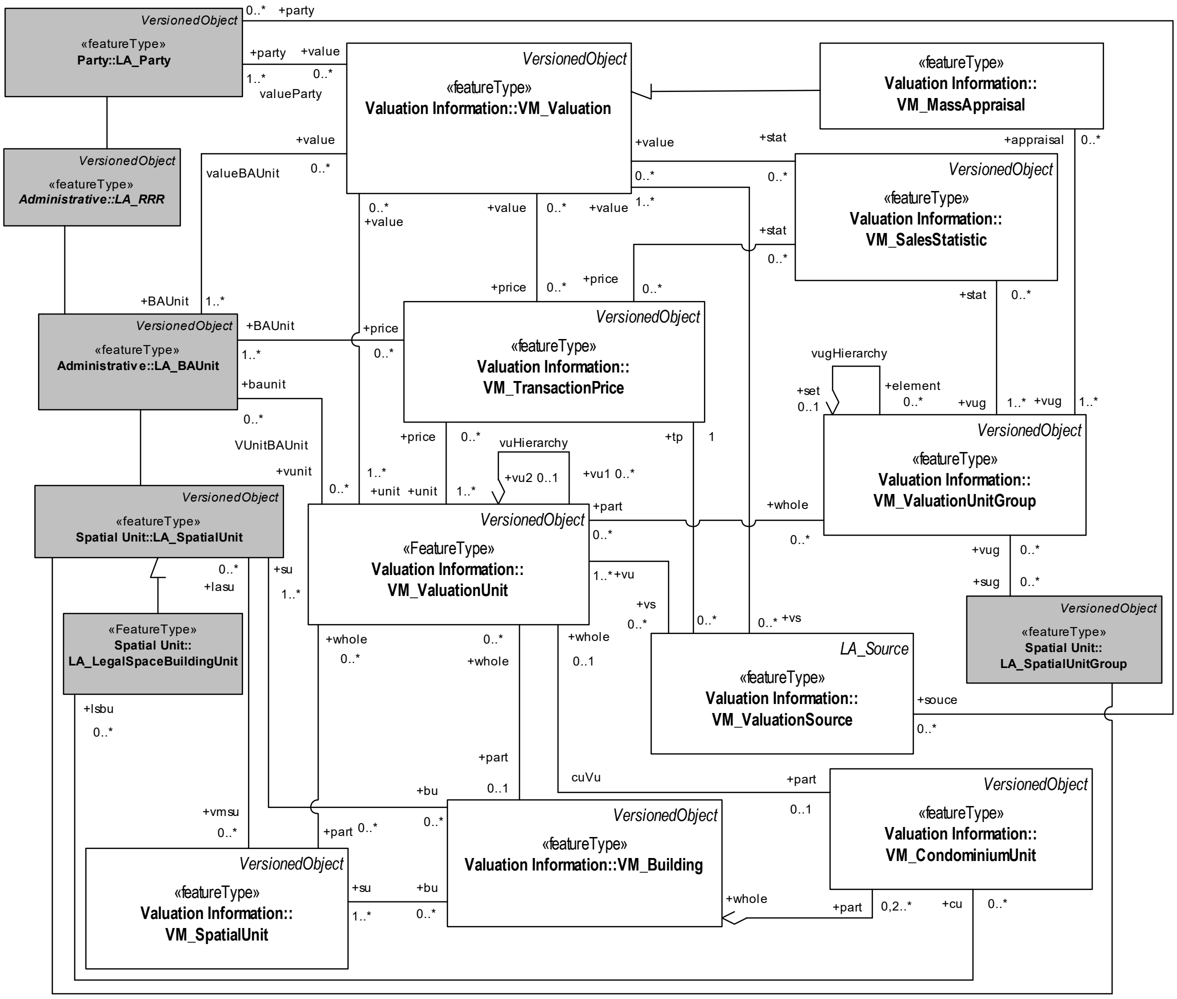

Figure 2. LADM II part 4 (Source: ISO 19152-4 approved and registered for the DIS stage)

Table 1. Analysis of the GLTN Publication 'Valuation of Unregistered Land – A Practice Manual'

GLTN Publication	Analysis	Decision
1. General		
1.1 Summary of the land rights being valued	Information provided by STDM core classes	No additional action needed
1.2 Definition of the market value, including any distinctions between market value and the value(s) being assessed under the instruction	Requires additional attributes for valuation of unregistered land	Introduce Social Market Value class
1.3 Date of the inspection and valuation	Needs to capture specific dates for valuation and inspection	Add ValuationDate (DateTime) and DateOfInspection (DateTime)
2. Details of the land rights		

2.1 Definition of the land	Information provided by STDM core classes	No additional action needed
2.2 Description of the land rights in the area	Information provided by STDM core classes	No additional action needed
2.3 Description of the land rights being valued	Information provided by STDM core classes	No additional action needed
2.4 Real property description	Information provided by STDM core classes	No additional action needed
2.5 Possessor(s) of the land rights being valued	Information provided by STDM core classes	No additional action needed
2.6 Benefits of, and encumbrances to, those rights	Information provided by STDM core classes	No additional action needed
2.7 Previous transfers	Information provided by STDM core classes	No additional action needed
3. Description of the relevant governance		
3.1 Local, regional and national authorities	Partially provided by STDM core classes	Create overlay zone VM_ValuationUnitGroup (similar to part 4 VM_ValuationUnit and VM_ValuationUnitGroup) where this source document is added
3.2 Value-relevant policies and laws at each level of governance	Not covered by STDM core classes	Include in VM_ValuationUnitGroup
4. Land and Locality Description		
4.1 Land area, locality and description	Information provided by STDM core classes	No additional action needed
4.2 Situation and identification	Not provided by STDM core classes	**Decision:** Create an overlay zone VM_ValuationUnitGroup (similar to LADM Edition II part 4 VM_ValuationUnit and VM_ValuationUnitGroup) where this information is added for the 'zone' (e.g. situation, general locality and surrounding, services and amenities, social and environmental statement etc.); **Additional:** Include the attribute land use (Codelist) in the SpatialUnit class of STDM. That land use attribute could use/refer to the ISO classification (ISO 19144-2 and -3).
4.3 General locality and surrounding development	not provided by STDM core classes	Include in VM_ValuationUnitGroup
4.4 Services and amenities	not provided by STDM core classes	Include in VM_ValuationUnitGroup
4.5 Social and environmental statement	not provided by STDM core classes	Include in VM_ValuationUnitGroup

5. Existing Improvements and Use		
5.1 Introduction	not provided by STDM core classes	Add 'ImprovementsandUse' attribute
5.2 General construction and fixtures	not provided by STDM core classes	Add 'ImprovementsandUse' attribute
5.3 Condition of improvements and utility	not provided by STDM core classes	No additional action needed
6. Lease Summary/Occupancy Details		
6.1 Regardless of whether written statements exist, the following information or its applicable equivalent should be included in this section: • – Lessor • – Lessee • – Commencement date • – Expiry date • – Option period • – Initial rental • – Rent reviews • – Current rental • – Outgoings and who pays them	provided by STDM core classes through Supporting Document also within LADM Edition II Source Document and Versioned Object can have different timestamps	No additional action needed
6.2 Strengths, weaknesses, opportunities and threats related to the relevant land rights	Not necessary	No additional action needed
7. Comparative Market Information	Supported by STDM core classes	It could be argued that this information is provided by STDM core classes through Supporting Documents but after consultation with GLTN it was decided to include a 'Transaction' class
8. Basis of the Valuation		
8.1 Highest and best sociolegal use	not provided by STDM core classes but also not necessary as an attribute	No additional action needed
8.2 Valuation methodology and calculations	not provided by STDM core classes	Add 'ValuationMethod' attribute
8.3 Insurance assessment	not provided by STDM core classes but also not necessary as an attribute	No additional action needed

This structured approach ensures that the STDM model is appropriately extended to support the valuation of unregistered land, aligning with best practices and international standards while remaining flexible enough to address the unique challenges of informal settings.
Other Technical Considerations for STDM Valuation of Unregistered Land regarding the Relationship/Multiplicity and the Versioned Object in STDM

Relationship/Multiplicity: In the context of the Social Tenure Domain Model (STDM) for the valuation of unregistered land, it is essential to understand the relationship and multiplicity between classes. In LADM Edition I, there is an external class related to valuation named ‘ExtValuation,’ which is associated with the Basic Administrative Unit (BAUnit). However, within the STDM framework, the ‘Social Market Value’ class is appropriately linked to the *Spatial Unit* rather than the ‘Social Tenure Relationship.’ This distinction ensures that the valuation reflects the characteristics of the physical land or property. Additionally, the ‘Transaction’ class is related to the ‘Social Tenure Relationship,’ capturing the dynamic and transactional aspects of land tenure within informal settings.

Versioned Object in STDM: A notable enhancement in LADM Edition II is the expanded attributes within the VersionedObject class. In STDM, the ‘SocialTenureRelationship’ is designed as a subclass of the VersionedObject, allowing it to inherit these new attributes. Specifically, LADM Edition II introduces two distinct timestamps: one representing real-world time (begin and end real-world lifespan version) and another for database time (begin and end lifespan version). This dual timestamp system enhances the model's ability to track both the temporal changes in the real world and the updates within the database, offering a more comprehensive view of tenure relationships over time.

Furthermore, the LA_Source class is now versioned, unlike in LADM Edition I. This improvement allows for the versioning of source documents, ensuring that all historical changes and updates to land-related documents are accurately recorded and maintained within the system. This capability is crucial for the reliable and transparent management of land information, particularly in informal settings where documentation may be less formalised and more prone to changes.

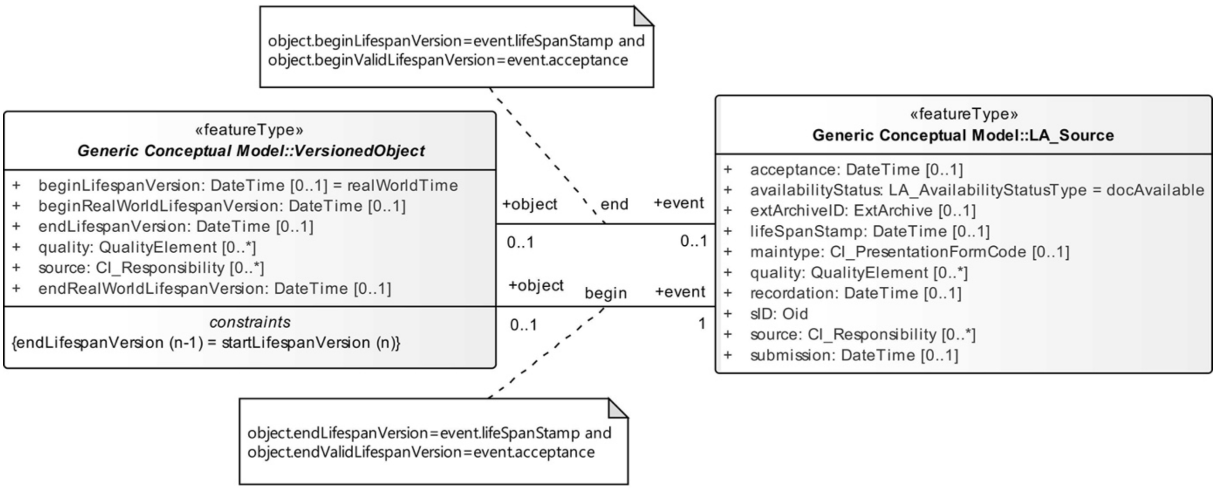

Figure 4. Versioned Object in LADM II (Source: ISO 19152-1 Generic conceptual model https://www.iso.org/standard/81263.html)

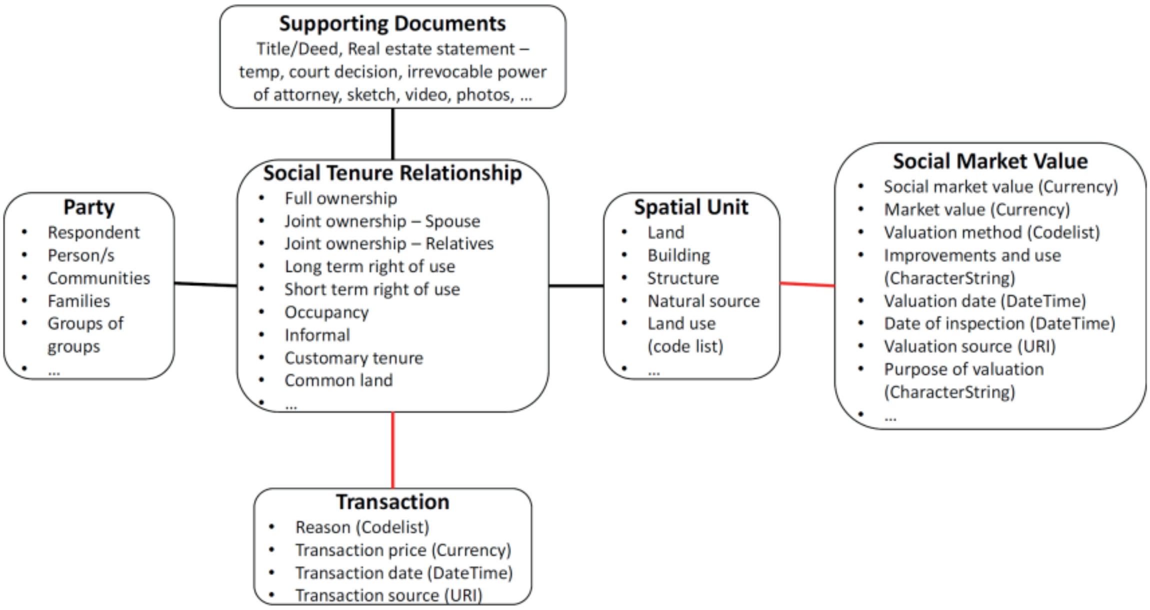

Figure 5. STDM Valuation of Unregistered Land (Source: ISO 19152-4 approved and registered for the DIS stage)

3. CONCLUSIONS AND RECOMMENDATIONS

The development of the Social Tenure Domain Model (STDM) valuation of unregistered land represents a significant step forward in creating more inclusive and equitable land administration systems. As a generalisation of the Land Administration Domain Model (LADM), STDM offers a flexible and adaptable framework, particularly suited to the complexities of informal land tenure systems. By incorporating STDM into the valuation process, diverse forms of land tenure, including those in informal and customary contexts, are recognised and valued appropriately, supporting broader goals of tenure security, poverty reduction, and social justice.

STDM provides a robust foundation for addressing the valuation needs of unregistered land, further refinements are essential to fully meet the demands of this context. Enhancements such as the introduction of the 'Social Market Value' class and the expanded attributes in the VersionedObject class within LADM II part 4 are crucial developments that ensure the model accurately reflects the dynamic nature of unregistered land.

To ensure the ongoing relevance and effectiveness of STDM in valuing unregistered land, refinement of the model were necessary, particularly in enhancing its capacity to handle the unique challenges of informal land tenure systems. As STDM is further developed, efforts should focus on its seamless integration with existing formal land administration systems. This integration will facilitate the gradual formalisation of informal land rights, providing a pathway for the inclusion of marginalised communities in the formal land market.

Given the complexity of valuing unregistered land, investment in capacity building and training for land professionals is essential. Equipping them with the necessary skills and knowledge will enable effective use of STDM in various contexts. To maintain the relevance of STDM, it is crucial to establish mechanisms for ongoing monitoring and feedback from

users, allowing for continuous improvements to the model and ensuring it remains responsive to the evolving needs of land administration in both formal and informal settings.
Fostering global collaboration among land professionals, governments, and international organisations will be key to the successful implementation of STDM valuation of unregistered land. By sharing experiences and best practices, the global community can work together to refine and expand the use of STDM, contributing to more equitable land administration systems worldwide.

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BIOGRAPHICAL NOTES

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Customary Land Tenure in the LADM

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Key words: Customary Land Tenure, LADM, Land Administration, Land Information System, Bronislaw Malinowski.

SUMMARY

Incorporating customary land tenure relations into Land Information Systems (LISs) presents knowledge modelling challenges arising from the complex and dynamic nature of customs. We present a case study using descriptions from Bronislaw Malinowski's Coral Gardens and their Magic (1935) to illustrate how some complex land tenure concepts can be represented in LADM. In the society described by Malinowski kinship relationships play a central role and form the means by which identity, through membership to a clan, is reproduced. Residence, rights to farmland, and acquisition of titles and responsibilities all depend on clan membership. But more importantly, the responsibilities of the individual to the family and the clan form the central pillar of the sustainability of the society. These responsibilities introduce complications for the land information modeler because they are regulated by the conditions extant at the time of observation. For example, farmland is assigned on an annual basis and depends on the needs and capacities of each household of the community.

Our analysis shows how rights to farmland as described by Malinowski can be addressed and how to model other socially mediated aspects in the LADM. We present a model of the unregular annual allotment of farming plots to families. The plots that each family will farm in a given year will be allotted to them that same year at the Gardening Council. This requires consideration of time which we address with simple versioning.

Our case study brings out the realization that land rights can appear in different, separated dimensions. The spheres of production and consumption are separated in our case study. A substantial part of what is produced by one group is distributed through well-defined networks to end up in the food stores of a different and clearly distinguished group. Thus the tenure on land is not absolute in the sense that the benefits of certain entitlements are not enjoyed exclusively or in great part by those holding said entitlements. To complicate matters, the norms associated with one's place of dwelling and marriage ensure the right to a dwelling without explicitly assigning a specific "real property" at which the right is exercised.

We explore possible solutions to this challenge, separating the different dimensions of the tenure on land (i.e. the stable land allocations, the production side, the consumption side, and the distribution dynamic) and using the LADM Basic Administrative Unit to represent dynamic people-to-land relations.

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1. INTRODUCTION

Incorporating customary land tenure relations into Land Information Systems (LISs) presents several challenges often overlooked when considering LIS design and implementation. These challenges arise from the fact that the nature of "rights" under customary tenures, as opposed to statutory ones, is often fluid in the sense that a "right" may exist to a lesser or greater degree and dynamic, that is, coming into force conditionally or subject to other factors. Beyond this, the degrees and conditions are not always quantifiable rendering some obvious approaches for representing and manipulating this information in a computer system inapplicable.

The challenge is one of having appropriate means of modelling the diversity of customary land relations. From the perspective of official land administration systems, the Land Administration Domain Model (LADM) provides a possible means of modelling customary land tenure relations. LADM standardises the relationships between people and land in a land administration (ISO/TC211, 2012; Lemmen et al., 2015). The LADM derivative appropriately called the Social Tenure Domain Model (STDM) attempts to represent customary land rights categories in a way that is compatible with the LADM, effectively forming an LADM profile (Lemmen, 2013). The problem one faces in assuming accuracy of such representations is that they are forced to ignore the dynamic nature of the land relations involved.

We present a case study using the Trobriand community described in Bronislaw Malinowski's Coral Gardens and their Magic (1935) to illustrate how some complex land tenure concepts can be represented in LADM. In the society described by Malinowski kinship relationships play a central role and form the means by which identity, through membership to a clan, is reproduced. Residence, rights to farmland, and acquisition of titles and responsibilities all depend on clan membership. But more importantly, the responsibilities of the individual to the family and the clan form the central pillar of the sustainability of the society. These responsibilities introduce complications for the land information modeller because they are regulated by the conditions extant at the time of observation. For example, farmland is assigned on an annual basis and depends on the needs and capacities of each household of the community.

In section 2 we briefly review some of the complexities of formally representing knowledge about customary land tenure. Section 3 presents a description of a simplified rendition of Trobriand land tenure using UML modelling as an aid. The LADM model to support representing certain aspects of this complex tenure system is presented in section 4 and a short summary closes the paper in section 5.

2. COMPLEXITY OF CUSTOMARY LAND TENURE

The complexities of customary tenure have challenged state administrators possibly since the emergence of the first states. Scott (1998) refers to the problem as one of the illegibility of evolutionary social (and natural) phenomena such as land tenure from the perspective of the administrative functions of the state. These complexities, however, are not mere decorations on an otherwise straight forward system of relations. Neither do they imply a lack of structure in said relations. Rather, the systems that they emanate from follow a local logic that is at variance with the logic of formal administration (Scott, 1998, p. 25).

Meek (1946) presented a seemingly endless list of customary practices to help show why the British colonial administrations continued to flounder in their task of pacifying the local populations in the colonised lands. For example, in describing the tenure system of the Wa-Bena of Tanzania, Meek, notes that use rights to a piece of land are created by the labour expended in making it usable (p. 19). Once these rights are obtained they can be transferred for some compensation but such compensation is only in acknowledgement of the labour expended in making the land usable and perhaps for any crops still on the land. The question comes then of what happens if the land is left to fallow for an extended period and needs to be cleared again? Does the original labour input expire?

Meek, as a colonial administrator seems to have been more concerned with understanding how to achieve administrative goals. Malinowski (1935) on the other hand appears to have been more interested in describing the social and economic structure of the native society of Papua New Guinea before the entrenchment of European influence. Despite the differences, a common thread in both expositions is that land under customary tenure is often allocated so as to ensure that individuals and households have enough land for self-sustenance. El-Amin (1990) makes the same observation for the case of parts of the Darfur region of Sudan. Here state structures are decentralized such that local administrators follow centuries old traditions in the allocation of land for permanent or temporary, private or collective use (El-Amin, 1990; Abdul-Jalil, 2006). Each family must have sufficient land their sustenance subject to rules regarding ranks and titles among the community.

From Scott's perspective it is partly this outcome or goal oriented organization of customary tenure systems that makes them illegible to officialdom (pp. 25-33). For example, measuring land in terms of its sufficiency to provide for the annual nutritional needs of a family of 5 is much harder than measuring it's area given appropriate instruments. To make matters worse, the question is not merely the nutritional need. It also depends on the capacity to use the land and other temporally and spatially varying factors. Among nomadic pastoralists, the size of pastures must be measured relative to both herd sizes and movement patterns.

It is these complexities that the increasing standardization of measurement were intended to simplify. With increasing sophistication of measurement and representational tools for knowledge across many domains, it might become possible, as in other domains, to better approximate the complexities and, more importantly, render them legible through the lens of official land administration. Malinowski's study of Trobriand tenure provides us with a well-defined challenge for exploring the application of these modern tools to said effect.

The spatial and legal aspects of land, while related, each require special attention in their own right. The concept of levels (Lemmen, 2010) was introduced to in LADM to allow for varying levels of measurement and representational precision in the spatial component of the land records. In this paper we focus primarily on non-spatial aspects. Space is considered only in its broad categories but not in its measured form: we are interested in spaces rather than space perse.

3. LAND TENURE IN THE TROBRIANDS

Coral Gardens and Their Magic (Malinowski, 1935) presents an in-depth ethnographic study of one of the main settlement in the Trobriand Islands off the coast of Papua New Guinea at the beginning of the 20th century. In the following we use the present tense to describe historical situations to avoid confusion. Relevant concepts are illustrated with UML diagrams which will form the basis for our LADM approximation of the tenure system.
The Trobriands are a coral atoll north east of the Papuan main Island. Malinowski's study focusses on the central village of Omarakana which has the status of a capital of sorts on the island. A map of the layout of the Islands and of Omarakana territory can be found in the book[1] (p. 2 and p. 430 respectively).

3.1 Social Organization

Omarakana is the seat of the paramount chief over the entire islands. As an agrarian society, farming (or, as written in the text, gardening) is the predominant means of self-sustenance in the Trobriands. Farming is supplemented by fishing and to a lesser extent, hunting and the gathering of fruit.
The Trobrianders are a matrilineal society. As such inheritance of social rank, titles, and descendancy are all determined through the mother's lineage and not the father's. The entire society is divided into four clans (p. 35). The more relevant grouping for our purposes, however, is the subclan (pp. 35-38, 84-85) which is the main determinant of ranks and titles. For brevity, in this paper we will use the term clan to refer to both clans and subclans.
According to Malinowski (p. 37, also Ch. VI, XI, and XII) social reproduction is achieved within two overlapping units of social organization. The patriarchal household and matrilineal filiation group formed by a woman, her brother (or other appointed male maternal relative), and her children. The parties with interests on land can thus be grouped into three: natural persons are the finest unit of interested party. Natural persons obtain new interests when they act as part of one the two kinship units – the patriarchal family or the matrilineal filiation unit (see Figure 2). The family unit can be seen as the constituent ingredients to the village community – i.e. the latter is a composition of the former. The filiation unit is a basic unit of the clan. It is the structure through which the clan reproduces itself. Figure 1 shows a UML model of the relationships between the main units of social organization. As will be seen in section 3.3 below, rights to land accrue to each of these units of social organization and in the context of LADM they all correspond to a Party of one kind or another.

[1] A digital copy can be rented at the Internet Archive https://archive.org/details/coralgardensandt031834mbp

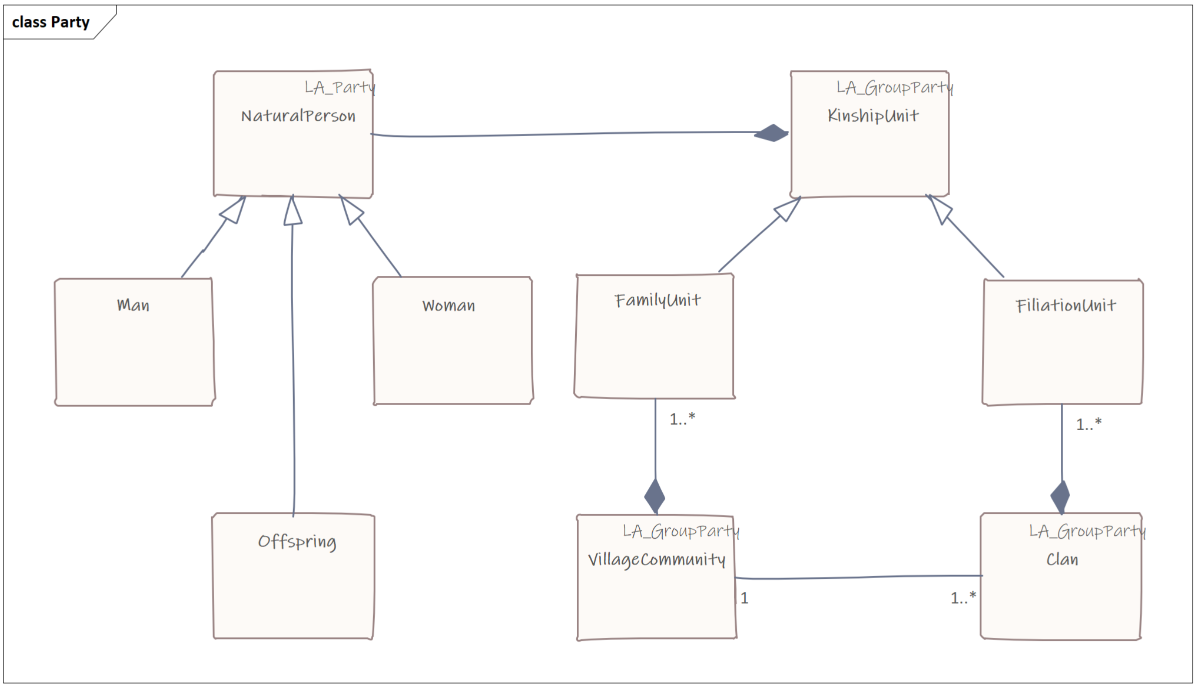

Figure 1. Simplified UML class diagram representing Parties involved in land relations

3.2 Spatial Organization

Land in the Trobriands is divided into territories comprising one or more villages, a number of garden fields, sacred grooves, and public spaces within and outside the villages. A territory may comprise a few garden fields that are spatially disjoint from the main body of the territory. As illustrated in Figure 3 the Village and Field are made of Homesteads and Plots respectively, in LADM these would correspond to SpatialUnits.

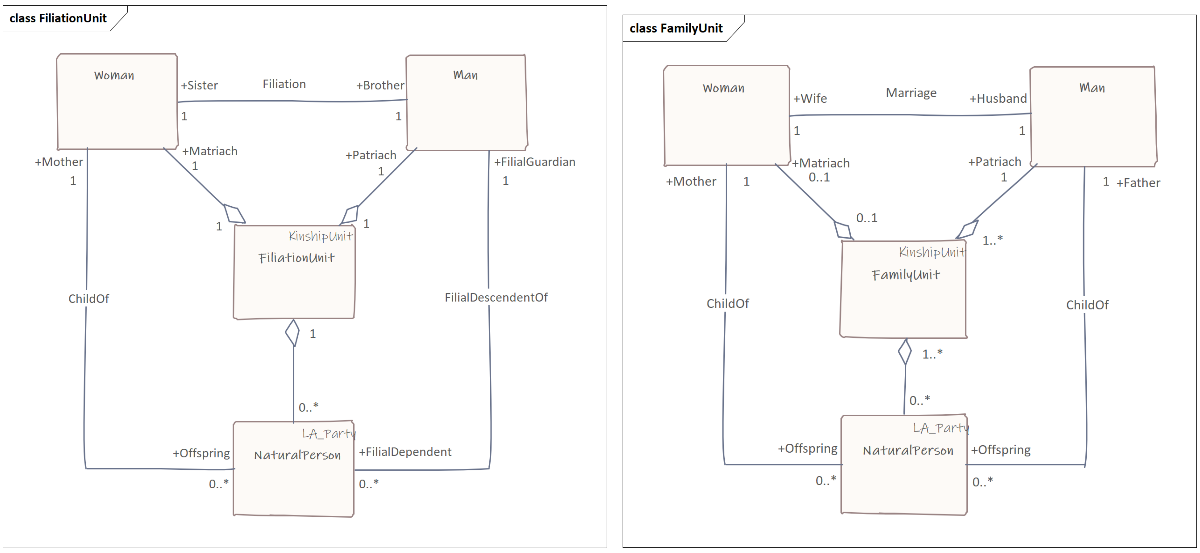

Figure 2. The relationship of individual persons to the kinship units

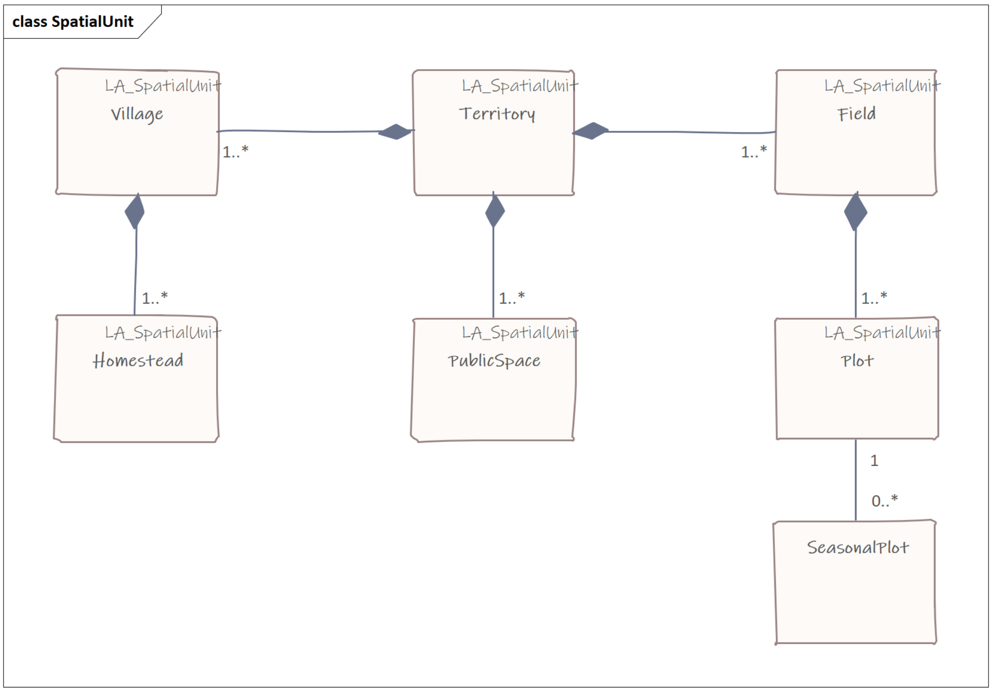

Figure 3. Spatial entities of interest for describing land tenure in the Trobriands

3.3 Tenure relations

Some rights to land in the Omarakana appear as fixed, permanent rights. Others are dynamic, varying in time and space. Some rights are held by group parties, others by individuals. Malinowski lists 9 claims he considered most relevant in characterising the tenure (pp 328-329). Here we focus on only those rights corresponding to the main parties and spaces outlined above. The village community as a whole has an ownership right over the territory and a right to allocate space for families to establish their homesteads in the village (Figure 4). On the other side, the clan determines control over farmland. Notice that a Filiation Unit or even an entire Clan may have zero or more areas of farm land over which they exercise control.

3.3.1 OCL rules for ensuring instance uniqueness for stable land rights

At this point we encounter our first modelling challenge. The semantics of associations in UML do not restrict the instances of Plot controlled by a particular FiliationUnit instance to only Plots that are parts of Field instances controlled by the FiliationUnit's Clan instance. This is because associations in the class model are, generally, independent of each other. As can be seen in Figure 5 a perfectly legal scenario that violates the FiliationUnit-Clan-Field constraint can be instantiated in this model.

What we would like is to have each minimal cycle in the diagram of Figure 4 to commute – be navigable in any direction. Achieving this requires the use of constraint rules which UML admits in the form of Object Constraint Language expressions (Pilone, 2005). For example, in the case of an instance of Plot, a constraint might be written as

$$self.field.controller\ = self.controller.clan$$

and attached to the Plot class so that an implementation would be left to address the challenge mentioned above by enforcing the constraint.

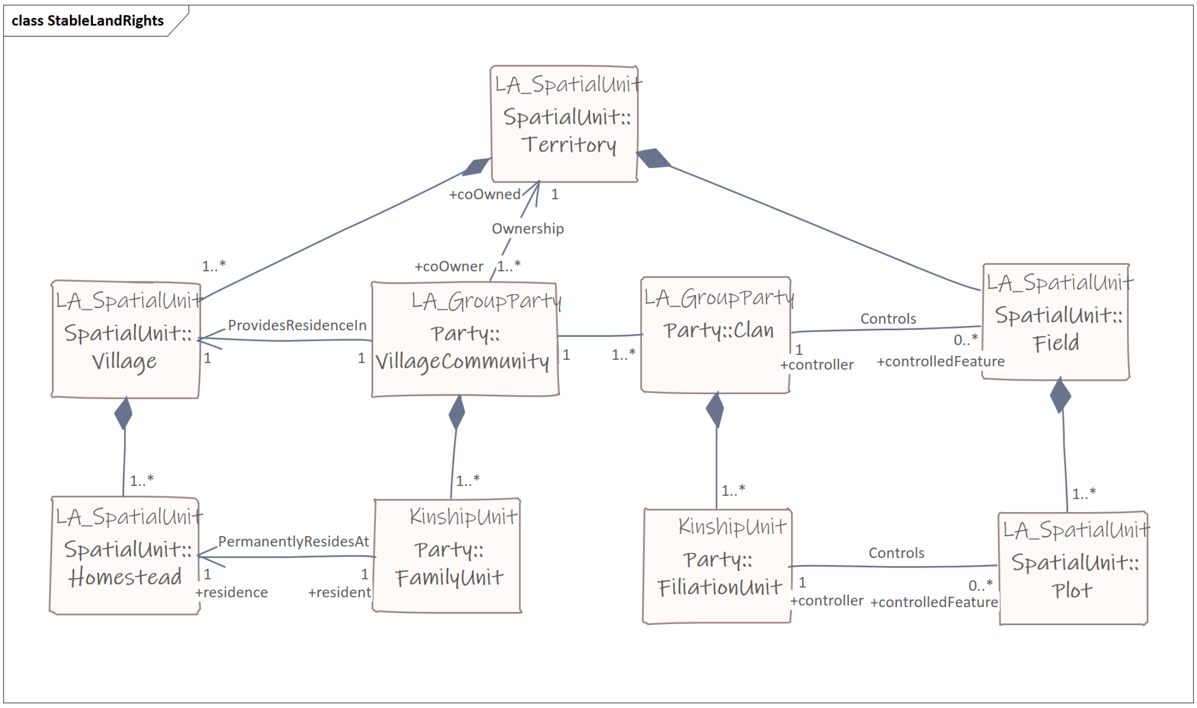

Figure 4. Stable land tenure relations

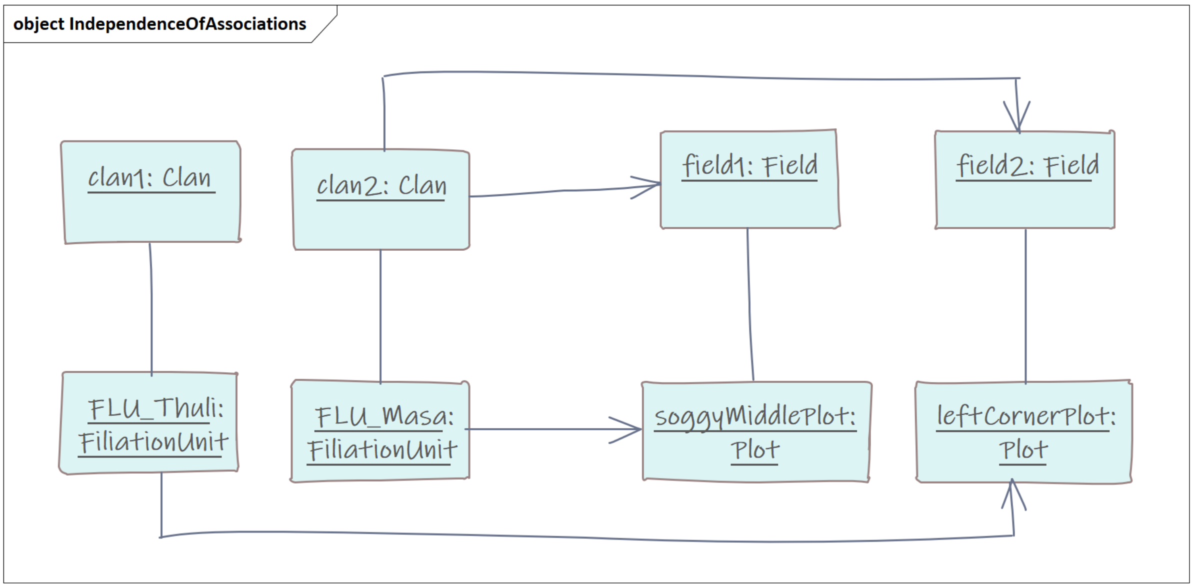

Figure 5. Incorrectly linked instances violating the constraint that a Filiation Unit can control only plots in Fields controlled by its Clan

3.3.2 Dynamic land rights

The most complex of rights to land in Malinowski's description are those to do with the right to sustenance at the household level. Land for cultivation is availed to citizens at the

gardening council – a meeting of all the adult male members of the community where the forthcoming growing season is planned. There is much else that is decided at the gardening council but the most important is the allocation of plots to households. The relationship between the patriarch of a Filiation Unit and the plots under its control is that the man's consent is required for the allocation of such a plot.
Before allocation begins, a number of fields are declared for cultivating that year. The remaining fields are left fallow to regain fertility. Plots are then allocated so as to balance between the needs of a household and its capacity to cultivate the allocated land (see Ch. II of Coral Gardens for details). The left panel of Figure 6 shows part of the model representing the seasonal production of staples. As can be seen, production occurs at the household level. The model associates with each household a Seasonal Plot object which is a container (a map in programming terms) associating a FamilyUnit, Plot, Season, and SeasonalHarvest instance. As in the situation in subsection 3.3.1, within this diagram it is also possible to associate the same plot and season pair more than once using different SeasonalPlot instances. In this case a uniqueness constraint must be placed on the class pair Plot and Season (i.e. a plot can only be cultivated once per season) by connecting them with an association. The class Season models time through a reflexive precedence relationship. As with other LADM classes it is possible subclass it to the VersionedObject in order to inherit its versioning capabilities.
Trobriand culture imposes through the Filiation Unit an obligation (called urigubu) on the household of the patriarch of that filiation unit to provide roughly half of the staple harvest consumed by household of the matriarch of that Filiation Unit. In plain English, every man is paired up with one of his sisters or possibly a female maternal cousin or other relative to form a filiation unit. This unit is the basis of inheritance to the nephews of the patriarch as well as the means by which the sister exercises her claim on her ancestral land and its produce. The portion of the harvest which a man sets aside for purposes of meeting his urigubu obligations to his sister is called Taytuwala. The remainder left for own consumption is called Taytumwala.

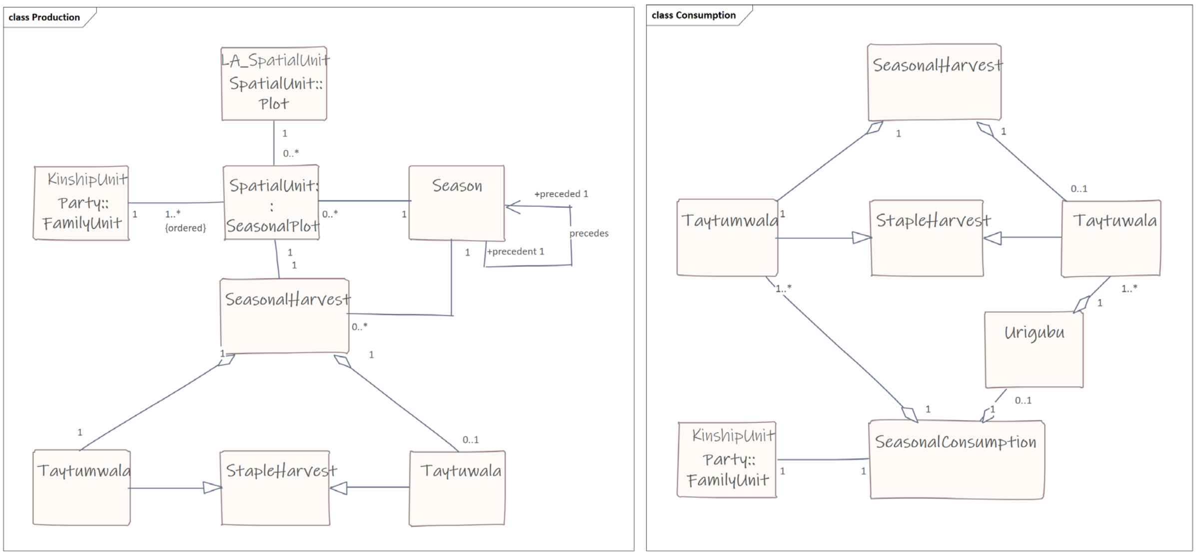

Figure 6. Production and consumption side models

The two portions of Taytumwala and Taytuwala can also be observed from the consumption side of the food supply chain (right panel in Figure 6). Like production, consumption occurs at the household level. The total amount of staple crops available for consumption in a given season is the sum of Taytumwala crops from the households own harvest and the roughly equal amount of urigubu crops from the household of Filial patriarch.
Now that we have given a somewhat broad description of our understanding of Trobriand land tenure as described by Malinowski we proceed to present how this simplified model fits into the LADM.

4. APPROXIMATING TROBRIAND LAND TENURE IN LADM

Some of the rights to land described thus far can directly be translated into LADM. The Parties and SpatialUnits are obvious candidates as can be gleaned from the superclass labels in top-right corners of the classes in Figure 4. To see how this would look like in a scenario consider the object diagram of Figure 6. A man named Masa is married to a woman called Thuli. This is indicated by the shared FamilyUnit labelled FMU_ThuliMasa. The model captures also the fact they have an offspring called Thembi. FMU_ThuliMasa is a member of the VillageCommunity called community, they have a permanent right of residence at spatial unit Homestead which is a part of Village mainVillage.

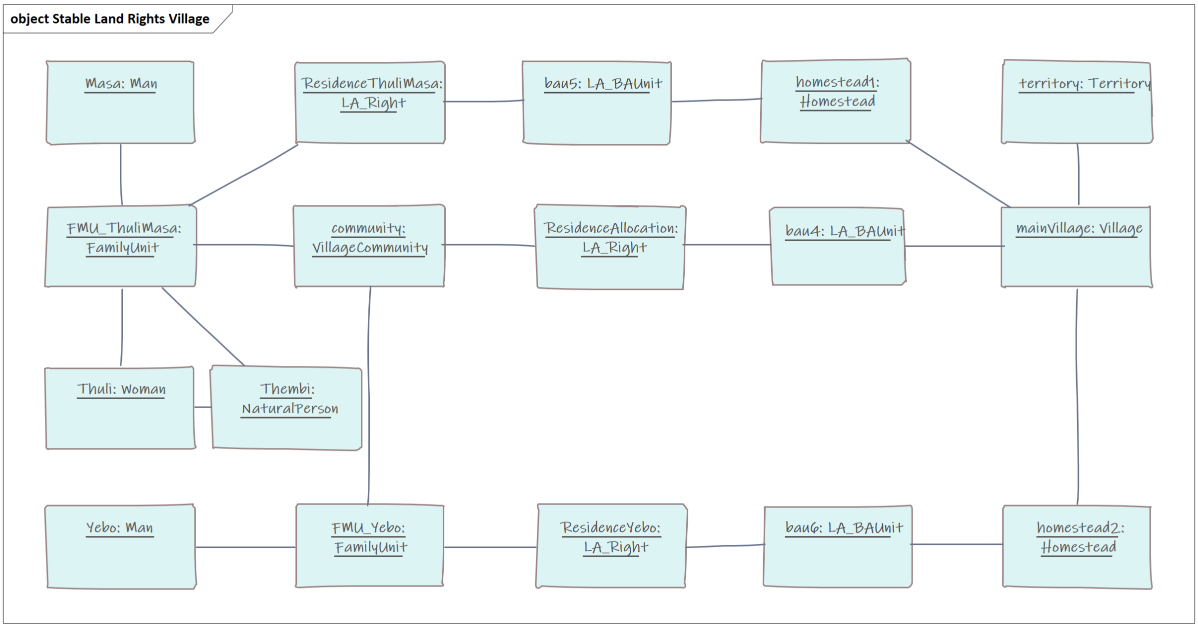

Figure 7. Object diagram illustrating a snapshop of the land tenure system as captured by the model

Notice that the FamilyUnit instance FMU_Yebo is associated with only one Man object and no other NaturalPerson objects which is allowed reflecting the part of the model shown in Figure 2. A similar scenario can be generated for Clan, FiliationUnit, Field, and Plot objects among others.
Let us now turn our focus to an LADM extension to handle the annual land allocations. The model is shown in Figure 7. The model distinguishes three types of RRR by subclassing. The preferred LADM approach is to use codelists to distinguish primitive types of the land

administration domain. The Taytuwala responsibility is dual to the Urigubu right and thus the classes must reference each other.

The Seasonal Value Unit (SVU) is a basic administrative unit which is based on the value derived from the rights and responsibilities incident on it. An SVU is associated with a history of Seasonal Harvest records and a set of plots that have ever been associated with the SVU. The historical information is captured in the sequence of Season instances respecting the precedence relation of the Season class. Like the BAU, the SVU must do a share check on the incoming RRRs. However, share of Taytuwala Responsibility must equal the sum of Urigubu rights shares.

Like the model of Figure 5, the model in Figure 7 allows duplication of Plot-Season pairs. A specification of uniqueness can be achieved by associating the two classes but we leave out the connecting line to reduce clutter in the diagram.

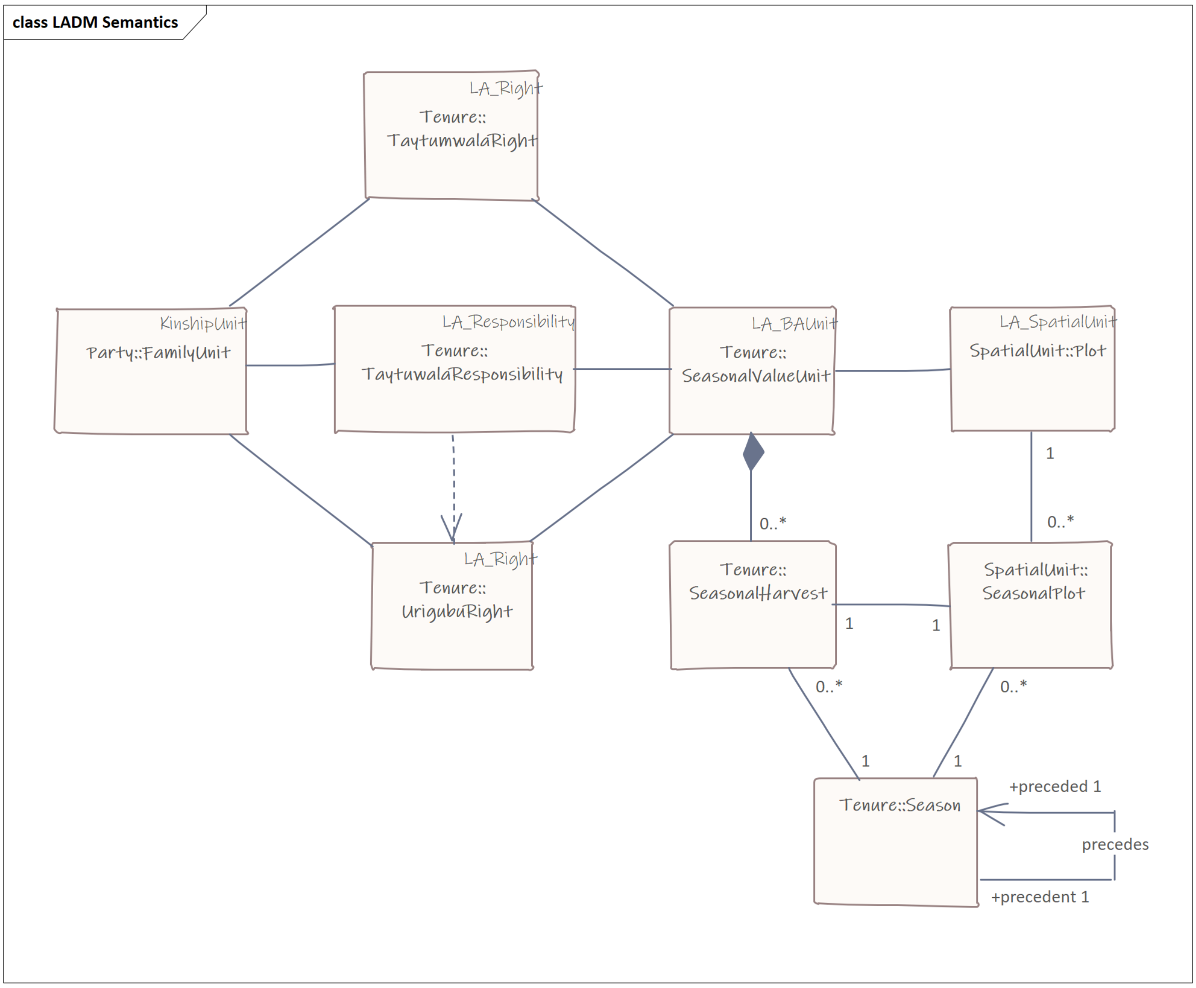

Figure 8. Core LADM derivative classes plus extension classes to capture additional details relevant to the local tenure system

The object diagram in Figure 8 illustrates an instantiation of the model in Figure 7. The link between the producing household to the household receiving the urigubi can be seen to clearly go through the Filiation Unit. In Figure 8 we see only the Seasonal Value Unit corresponding to Yebo's cultivation activities. A more extensive diagram would also show the controlling rights over the plots.

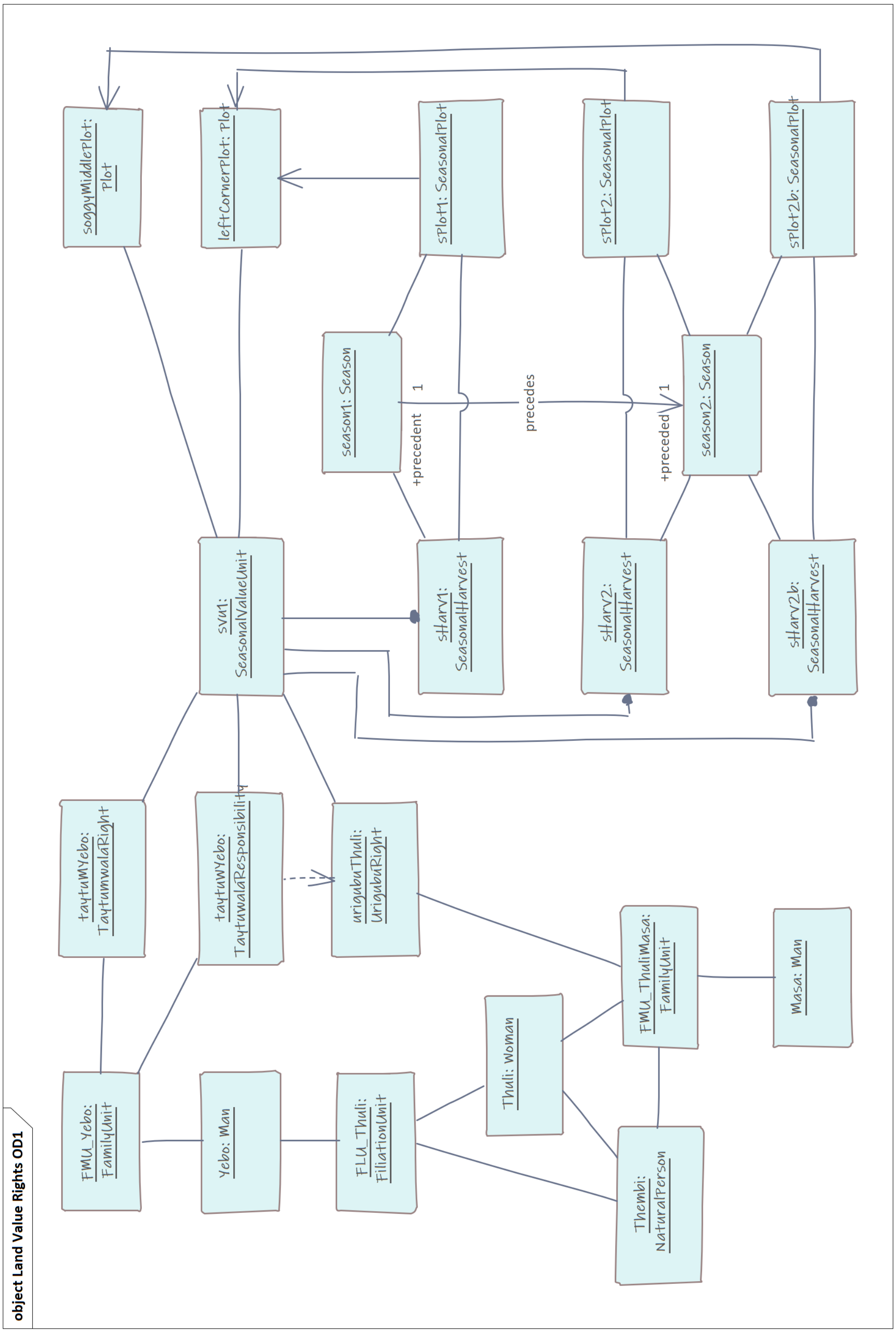

Figure 9. Object diagram illustrating model capturing annual usage of farm plots.

The successive Season instances – season1, season2, etc. – provide a filter through which a snapshot for a particular season can be retrieved from the underlying database. In the scenario in Figure 8 the amount of farmed area has increased over the two seasons. With this model, it is also possible to tell whether the yield has also increased or not.

5. SUMMARY

Tenure on land governed by local social norms often takes a form that is difficult to fit in official Land Administration models. In this paper we explored an LADM model extension to support dynamic land allocations based on the case described by Malinowski (1946). Several lessons can be learned from this exercise.

First it is important to note that a highly simplified rendition of Malinowski's account has been used here to aid both understandability and to make the modelling feasible. Also, no internal details of the classes presented have been outlined. The focus here was on the structural aspects of the model. What classes make sense and what class relationships are required?

It is clear that a separation of the different dimensions of the tenure on land (i.e. the stable land allocations, the production side, etc.) is necessary in order to arrive at a model that can be analysed using, for example, object models. The different dimensions diverge and converge in different points of the analysis. For example, the production and consumption models converge at the season harvest and at the role of the woman as matriarch in both the Family Unit and the Filiation Unit. The stable land rights meet the more dynamic ones through the Plot, the unit at which agricultural activity actually takes place and is subject to both annual and perennial interests from different parties.

The Seasonal Value Unit can be thought of as a cup from which certain rights drain. Someone must fill the cup (e.g. via the Taytu**w**ala Responsibility) for the rights attached to it to be satisfied. The right cultivate is met by the provision of a Plot which is recorded in the Seasonal Plot slot for that season. In this way the SVU plays at the very least the role of an administrative object, a BAU.

There still remains to build an actual simulation of the situations described in the text and examine how well, if at all, a simulation based on the models presented in this paper capture the meanings documented by Malinowski. Additional directions of research such as Chipofya et al's (2020) implementation of semantic web rules on top of an OWL model of LADM (Soon, 2013) to isolate the dynamic elements of customary tenure could be explored in conjunction with the present model.

Our results are relevant for other modelling work in the Land Administration domain, especially for the STDM. Further exploration of the phenomena that Malinowski's book brings to light will help us identify modelling techniques that may be useful in any upcoming major upgrades of STDM. Like STDM, the extension presented in this paper provides a basis for developing LADM customary domain profiles. Contemporary knowledge could be integrated following insights on country profile development presented by Kaloggiani et al (2021). These profiles would be especially applicable to legal regimes like the one established by the Community Land Act (CLA) of Kenya (2016). In the CLA case, the territory over which the customary tenure system applies is considered as a single cadastral object in the national cadastre while customary law has legal force insider the territory and is recognized as such in the Kenyan constitution.

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BIOGRAPHICAL NOTES

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Bringing Subsurface Information Models and Climate Adaptation Design into LADM Part 5 Spatial Plan Information

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Key words: climate adaptation, urban design, subsurface, information model, LADM part 5

SUMMARY

The Netherlands aims to achieve climate resilience and water robustness by 2050, necessitating an interdisciplinary approach to spatial planning due to the complex nature of climate adaptation. A critical need exists for subsurface data, especially for interventions related to underground elements like water storage, soil infiltration, and subsurface management. This need became particularly relevant when the Dutch government adopted 'water and soil guiding' as a core principle for spatial planning in 2022 (Ministerie van Infrastructuur en Waterstaat, 2022). Translating this principle into practical solutions is complex, requiring detailed knowledge of subsurface characteristics. The absence of such information can lead to issues like groundwater contamination and high-maintenance parks.

Despite the necessity for interdisciplinary and subsurface data, organizational, technological, and institutional barriers hinder the use of information models and standards in climate adaptation design. Currently, even though there are many subsurface models and standards available, the Netherlands lacks an integrated approach linking subsurface information models with local climate adaptation design. It also lacks an example of the use of standards to exchange planning information containing climate adaptation design interventions.

This research explores how subsurface data models can enhance urban climate adaptation design. By assessing existing models, it identifies data requirements for effective interventions based on Dutch policy documents. The paper introduces CLIMACAT, an online tool integrating subsurface information models and other crucial data in one online catalogue following FAIR (findable, accessible, interoperable, and reusable) data principles, tested in four Utrecht neighborhoods.

The findings emphasize the importance of integrating subsurface information models into urban planning to achieve more effective and context-sensitive climate adaptation interventions. Significant barriers include data accessibility and standardization. New spatial plans were standardized using Land Administration Domain Model (LADM) Part 5 (ISO 19152-5), tailoring some attributes for climate adaptation design, facilitating cross-border information exchange. This approach addresses specific challenges in the Netherlands and provides a framework for international adoption, contributing to global urban climate adaptation efforts. The research highlights the need for accessible subsurface data and interdisciplinary collaboration, supported by continuous technological and policy advancements.

Bringing Subsurface Information Models and Climate Adaptation Design into LADM Part 5 Spatial Plan Information

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1. INTRODUCTION

The Delta Programme, a national initiative by the Dutch government, aims to protect the Netherlands from flooding and improve water management, requiring the country to achieve climate resilience and water robustness by 2050 (Ministry of Infrastructure and Water Management, 2023). This presents a significant challenge to spatial planning, necessitating an interdisciplinary approach. A key aspect is subsurface information, particularly since 'water and soil guiding' was established as a principle in Dutch spatial planning in 2022. Standardized information models are crucial for making informed design decisions, as many interventions related to flood and drought management, such as water storage, soil infiltration, and underground spatial management, require detailed knowledge of soil characteristics.

While the Netherlands has several subsurface data models at municipal and national levels, integrating these models into climate adaptation design remains challenging. Issues arise from differences in practices between designers and geodata engineers, as well as the historical development of Geographic Information Systems (GIS). Technological barriers, such as the evolution from data-poor to data-rich environments and the separate development of GIS technologies, also contribute to this challenge. Moreover, standardization issues in both geoinformatics and urban design further complicate integration. This paper examines how incorporating subsurface and design information into standardized models, such as Land Administration Domain Model (LADM) Part 5, or utilizing tools like online geoportals, can enhance climate adaptation efforts.

As highlighted by the Delta Programme, practical definitions of climate adaptation through standardization are essential (Ministerie van Infrastructuur en Waterstaat, 2022). This research focuses on climate adaptation guidelines and resources such as the *Leidraad Klimaatadaptief bouwen 2.0* (Bouw Adaptief), *Maatlat voor een klimaatadaptieve groene Gebouwde Omgeving* (Rijksoverheid), and *Klimaateffectatlas* (Klimaateffectatlas), and their integration with Dutch subsurface data models, including the Key Registry for the Subsurface (BRO) (Basisregistratie Ondergrond) and municipal models from Utrecht. Design proposals for four 500x500 meter areas in Utrecht, namely Kop Voordorp, Lunetten Zuid, Kanaleneiland Noord, and Voordorp, were developed to address local climate challenges, using existing subsurface models and a new online tool.

The paper introduces CLIMACAT, a tool that consolidates climate adaptation design information into a single online catalogue. Moreover, the paper exemplifies the storage and exchange of climate adaptation planning information using LADM Part 5. From this standard, it uses existing classes with new attributes tailored for climate adaptation. The goal is to develop a framework for integrating standardized subsurface information into climate adaptation efforts, addressing a global urban planning and land administration challenge. The presented LADM Part 5 Spatial Plan Information CLIMACAT specialization is rather generic and it is expected that it can also be used in other countries as climate adaption is a global challenge. Similar to other LADM parts, also for part 5 Spatial Plan Information, countries need to develop their own country profiles (customizing/ adding country specific information). If a country plans to address the climate adaption in its spatial plans, then it is recommended to start with the CLIMACAT profile of LADM part 5, and then add country specifics.

In short, this paper explores the integration of CLIMACAT and LADM Part 5, providing a comprehensive framework for addressing the challenges of incorporating subsurface information into climate adaptation design. It aims to demonstrate how these tools can overcome the institutional, technological, and semantic barriers that have historically hindered the effective use of subsurface data in urban planning. By examining the functionality and synergies between CLIMACAT, an online catalogue that consolidates vital information for climate adaptation, and LADM Part 5, which standardizes the documentation and sharing of urban plans, this research highlights a pathway towards more informed and effective climate adaptation strategies. This work contributes to realizing various Sustainable Development Goals (SDG's), especially relevant are the SDG's 11 (Sustainable cities and communities) and 13 (Climate action).

The paper is structured to first introduce the significance of integrating subsurface data into climate adaptation design. Section 2 delves into the relationship between subsurface information and climate adaptation design, emphasizing the importance of incorporating natural characteristics into adaptation strategies. This section also presents an overview of the existing subsurface models on a municipal and national level. Following this, Section 3 addresses the challenges in integrating subsurface information, highlighting the necessity of interdisciplinary approaches and standardization. Section 4 introduces CLIMACAT, detailing its role in facilitating the integration of climate adaptation data and design information. Section 5 explores the application of LADM Part 5 for storing and exchanging climate adaptation planning information. The subsequent Section 6 presents the results of design explorations in Utrecht, showcasing the use of subsurface models and CLIMACAT in selecting and implementing climate adaptation interventions. Section 7 evaluates the proposed designs through a survey, assessing the effectiveness and potential biases of the chosen interventions. Finally, Section 8 concludes this paper, emphasizing how the combined use of CLIMACAT and LADM Part 5 ensures that climate adaptation designs are well-informed, accessible, and standardized. This dual approach effectively addresses the challenges of integrating geoinformatics with urban design, ultimately enhancing climate resilience through improved integration of subsurface information into urban planning processes.

2. SUBSURFACE INFORMATION AND CLIMATE ADAPTATION

This section explores the role of subsurface information in the context of climate adaptation design, illustrating how the understanding of natural characteristics can enhance the effectiveness of adaptation strategies. In subsection 2.1, the necessity of integrating subsurface data, such as soil types, groundwater levels, and urban infrastructure, is discussed.

It emphasizes how these elements influence the selection and implementation of climate adaptation interventions and highlights the significance of localized data in addressing specific climate challenges. Subsection 2.2 reviews existing information models that capture various subsurface characteristics, namely soil type, subsurface congestion, geomechanics, and groundwater level, relevant to climate adaptation efforts. Collectively, this section underscores the importance of subsurface data to inform design choices that are both sustainable and context-specific, thereby facilitating effective climate adaptation in urban environments.

2.1 Subsurface and Climate Adaptation Design

Literature shows the necessity of integrating natural characteristics into climate adaptation strategies to ensure their sustainability (Deltares, 2020). Effective adaptation often involves nature-based solutions, which rely heavily on subsurface and water information, such as soil types and groundwater levels (Straatbeeld, 2020). For instance, soil types significantly impact the feasibility of rainwater infiltration to address flooding or waterlogging. High infiltration soils, like sandy types, are ideal for this purpose, while low infiltration soils, such as clay or peat, are less suitable (Deltares, 2020). Urban areas further complicate adaptation efforts due to man-made infrastructure that affects design decisions. Localized subsurface data, including soil maps, drilling profiles, and infrastructure details, are crucial for identifying viable climate adaptation interventions. Moreover, it's essential to assess the subsurface space available for adaptation, as obstructions like pipes are typically mapped only locally. Local climate adaptation design involves implementing interventions to address climate challenges, such as flooding or heat stress, and must account for the area's specific subsurface properties. These interventions, based on subsurface characteristics, can be categorized into four main groups (see Figure 1):

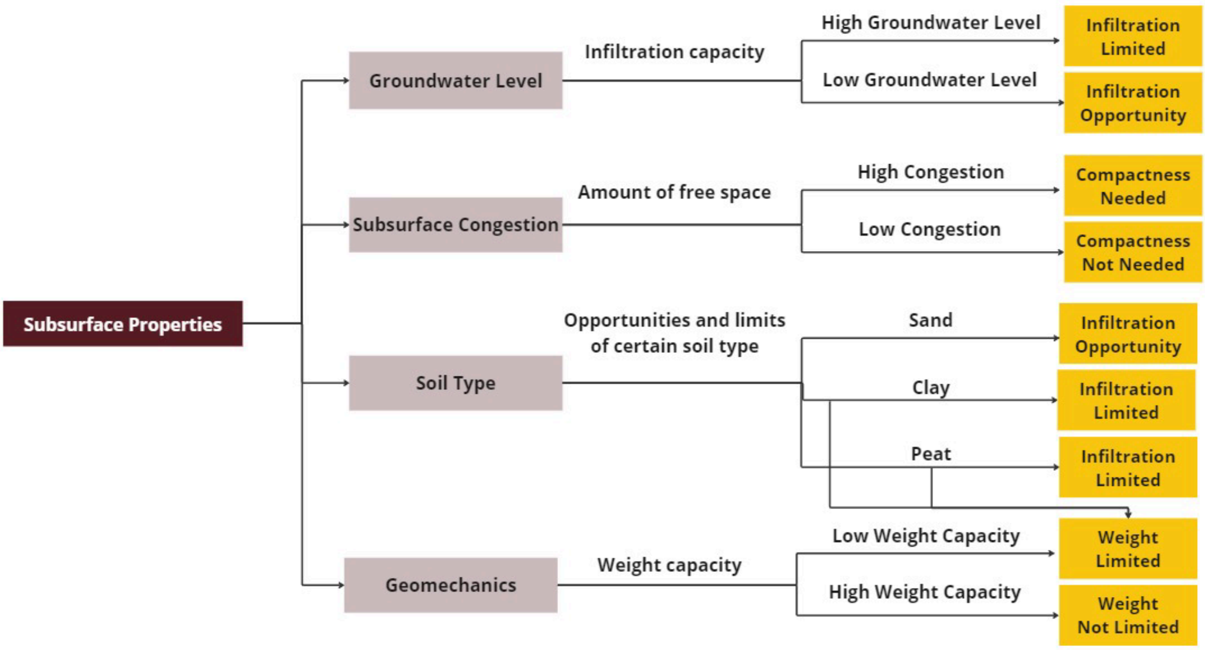

Figure 1. Decision tree for design interventions based on subsurface properties

– **Groundwater Level:** The highest groundwater level determines an area's infiltration capacity. Optimal infiltration occurs in the first 0.7 meters of the subsurface (Deltares, 2020).
– **Subsurface Congestion:** The presence or lack of subsurface congestion, e.g. the presence of cables/pipes, indicates the compactness level required for an intervention.
– **Soil Type:** Soil type influences both infiltration capacity and the suitability for construction. Sandy soil facilitates infiltration, while clay and peat limit it and may affect building stability.
– **Geomechanics:** This refers to the load-bearing capacity of the ground, which influences construction material and method choices.

Adaptation measures should be tailored to these subsurface properties. For example, sandy soils with low groundwater levels support rainwater infiltration through permeable pavements, while clay soils with high groundwater levels might be better suited for artificial water storage solutions.
In 2020, the Dutch Ministry of the Interior and Kingdom Relations compiled a summary of twenty-five prevalent climate adaptation interventions, including associated costs and maintenance requirements. This summary, applicable to both new and existing buildings, identifies which soil types are suited for each intervention (Rijksoverheid, 2020). However, it lacks detailed information on subsurface properties. To address this gap, this paper incorporates the twenty-five interventions with additional subsurface information requirements using guidelines from the *Leidraad Klimaatadaptief bouwen 2.0* (Bouw Adaptief). These guidelines, available through the interactive Bouwadaptief website, offer more detailed insights into subsurface requirements than the 2020 government document.

2.2 Subsurface Information Models

Several models are available for above-ground elements in the Netherlands, such as trees and buildings, but fewer exist for subsurface information. This section reviews standardized models relevant to subsurface properties for climate adaptation in Utrecht for the four categories identified as relevant to local climate adaptation design, namely soil type, subsurface congestion, geomechanics, and groundwater level (see Figure 1).
Regarding the first identified subsurface property, soil type, GeoTOP is a 3D model depicting subsurface layers up to 50 meters deep, represented in 100 x 100 x 0.5 meter voxel blocks. It provides insights into soil types and is useful for large-scale applications like infrastructure planning and groundwater research (Basisregistratie Ondergrond, 2023). Despite its utility, GeoTOP's resolution may be inadequate for specific local interventions, necessitating additional local data for precise applications.
It is important to notice that soil type models are probabilistic, based on interpolated data. GeoTOP, for instance, shows the likelihood of a soil type, related to its lithology and lithostratigraphy. This is indicated for example as 85% probability of sand. For accurate design or planning, local soil confirmation is often needed. The model is accessible via the 3D BRO webservices (Basisregistratie Ondergrond, 2023). This platform allows users to visualize and interpret soil voxels from selected locations using a provided legend. Additionally, users can create sections, rotate, and move the model.

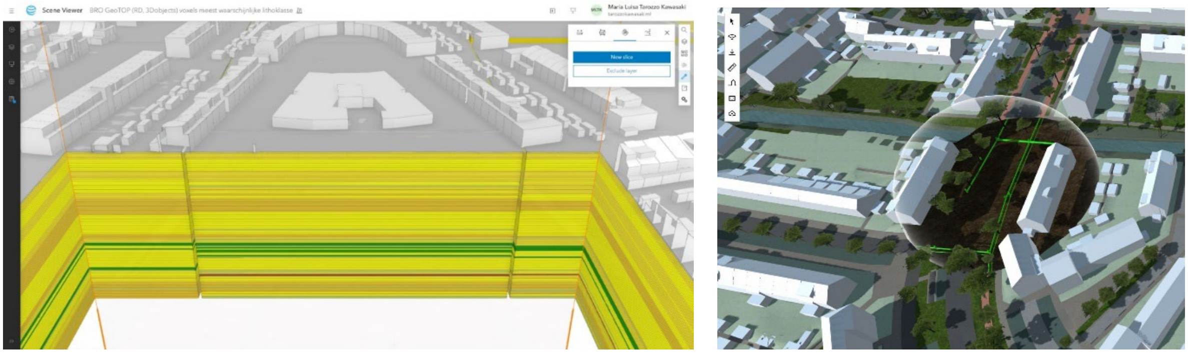

Figure 2. GeoTOP used to visualize soil types (left) and Utrecht3D used to visualize subsurface congestion (right)

Subsurface congestion is the second identified property, related to the available space underground for climate adaptation interventions. For this purpose, Utrecht's 3D digital twin can be used. This model includes subsurface elements such as cables and pipes, viewable through the municipality's web viewer (Gemeente Utrecht). This model supports local design needs by visualizing subsurface congestion.
The third property is geomechanics. In the context of urban design, geomechanics models assess subsurface load-bearing capacity. Utrecht provides a 2D map indicating suitability for traditional construction, considering factors like settlement sensitivity (Provincie Utrecht, 2011). While useful for regional design, it requires additional local data from Cone Penetration Tests (CPTs) for precise geotechnical assessments (Basisregistratie Ondergrond). In the BRO 3D webservice, CPTs are displayed in 3D as brown tubes without measurement values, offering immediate insight into their distribution and depth. Users can access detailed measurement data via a link in the pop-up, leading to the BROloket, where relevant graphs are provided (Basisregistratie Ondergrond). Interpreting these graphs often requires a geotechnical expert, so while the information is publicly accessible, expert assistance is necessary for its application in design.

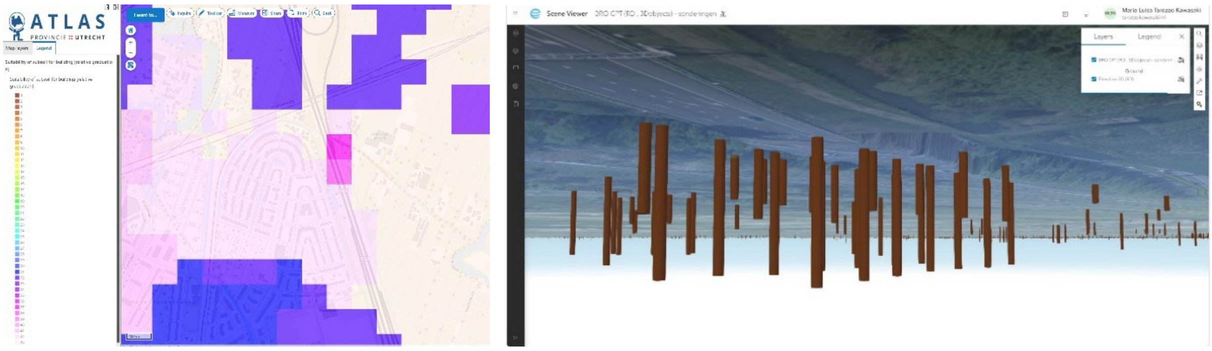

Figure 3. ATLAS used to visualize building suitability (left) and BRO 3D used to visualize CPTs (right)

Finally, the highest groundwater level, crucial for assessing subsurface suitability for water infiltration, is represented on a national 2D map of the Netherlands. This map shows the Average Highest Groundwater Level (GHG) under current conditions and is part of the Klimateffectatlas, which integrates national climate data to evaluate flood, waterlogging,

drought, and heat risks based on KNMI'14 climate scenarios. Provided by Esri Netherlands Content, this standardized ESRI map can be viewed via the ArcGIS web viewer or incorporated into ArcGIS software through the LivingAtlas (Kilmateffectatlas, 2022).
Groundwater monitoring wells are used to measure groundwater levels and quality. In the 3D BRO webservice viewer, the layer "Grondwatermonitoringputten" displays these wells as blue tubes, with measured levels in dark blue. Pop-ups provide details about the well, pipes, filters, and a link to BROloket for schematics and groundwater data (Basisregistratie Ondergrond). While this information is publicly available, expert consultation, typically with a hydrologist, is needed to effectively use it in urban planning.

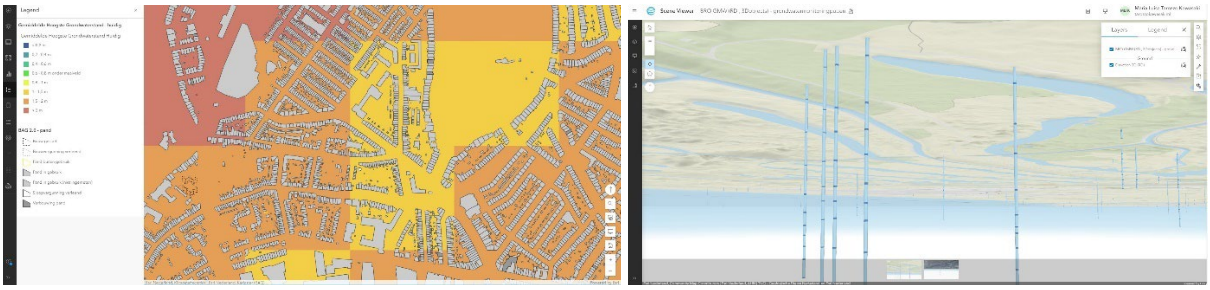

Figure 4. Highest groundwater level visualized with Klimateffectatlas (left) Monitoring wells visualized with BRO 3D (right)

3. CHALLENGES IN INTEGRATING SUBSURFACE INFORMATION

3.1 Barriers to the Interdisciplinary Integration of Information Models

Integrating expertise from various disciplines is essential to address complex issues like climate adaptation (Bhaskar, Frank, Høyer, Næss, & Parker, 2010). This requires T-shaped expertise (deep knowledge in one field and broad engagement across others) or interactional expertise, which involves understanding the language of another field without mastering all its details (Gorman, 2010) (Collins, Evans, & Gorman, 2007). However, it remains challenging to bridge Geoinformatics, Geology, and Urban Planning (Conley, Foley, & Gorman, 2017). This institutional challenge can partly be explained by the historical development of GIS removed from planning practices. GIS began in the 1960s within academia and became commercially available in the 1980s, but its integration into planning departments faced resistance due to its complexity (ESRI) (Zhu, 2016). GIS specialists often became technical support rather than decision-makers, a trend that persists today (Gorman, 2010). This has impeded an interdisciplinary approach, leaving planners and designers poorly trained in data creation and maintenance.
As cities become data-rich, sophisticated data models are increasingly needed. Integrating extensive data helps planners understand urban environments and identify intervention areas (Forgaci, 2020). Urban informatics is a field of research focused in combining geoinformatics and urban design, addressing urban challenges through data modelling (Goodchild, 2021). Digital tools and standards, such as those from the EU adaptation strategy, enhance climate impact understanding and urban planning (Climate-ADAPT). In the Netherlands, 3D subsurface data models have proven beneficial for energy transition, housing crises, and climate adaptation (Basisregistratie Ondergrond, 2022). However, the current models,

standardized and publicly available, are underused due to lack of integration with national design guidelines, appropriate tools, or standards (Zeiss, 2017)

3.2 Standardization as an Approach to Interdisciplinarity

Standards are essential for consistency and quality. In climate adaptation, they provide structured design, information and data models. However, an unified framework is missing, hindering effective well-informed climate adaptation design (ISO). Guidelines like the *Leidraad Klimaatadaptief bouwen 2.0* (Bouw Adaptief) and the *Klimaateffectatlas* (Klimaateffectatlas) offer design interventions, but integrating these with subsurface data models remains challenging.

The Basisregistratie Ondergrond (BRO) offers standardized subsurface data but is not fully integrated with design guidelines, limiting its use in climate adaptation (Zeiss, 2017) (Basisregistratie Ondergrond). Developing an integrated system to relate design interventions to subsurface data models would create an "information roadmap" for designers, geologists, and geo-informaticians. Moreover, standardizing 3D data models and web services, through collaborations between companies such as TNO, ESRI, and the Land Registry, can improve user interaction and integration into urban design (Basisregistratie Ondergrond). Standardization is also needed to share the results of designs including climate adaptation interventions. The Land Administration Domain Model (LADM) Part 5 (ISO 19152-5) supports standardized urban plans, crucial for sharing climate adaptation strategies globally (Kara, et al., 2024).

Therefore, the goal of this paper is to combine different crucial information for climate adaptation design in a single place and make use of standards for the exchange of climate adaptation information. For this purpose, an online catalogue, CLIMACAT, is created and described in section 4. This tool takes into consideration the different challenges presented in this paper and aims to be user friendly to designers, data providers and citizens. The tool was tested while designing climate adaptation urban plans for four different areas in Utrecht (see section 6.2). Moreover, in section 5, one of the urban plans and the described subsurface information models, is then stored using LADM Part 5 subclasses, assessing the suitability of this standard to share information regarding climate adaptation design, potentially globally.

4. COMBINING INFORMATION: CLIMACAT

The Open Geospatial Consortium (OGC) defines FAIR (findable, accessible, interoperable, and reusable) climate data services as crucial for effective climate information management (Hempelmann, 2022). This paper states that a FAIR climate catalogue, consolidating all relevant local climate adaptation data into a single online resource, is a key solution for integrating and accessing this information.

The digital Dutch climate design portal, named CLIMACAT, includes a climate design catalogue and different information sources necessary for climate adaptation urban design in one single place. Moreover, it introduces the user to climate themes topics and to the relationship between subsurface information, design standards, and climate adaptation design. The potential users for this website are urban designers, data providers, and citizens. Designers benefit from better understanding the information needed for their climate adaptation design, along with where to find relevant information. Data providers benefit from better understanding what are the data requirements for design, using it as basis to improve their own information and data models. Finally, citizens can use it to better understand climate adaptation needs in the Dutch context.

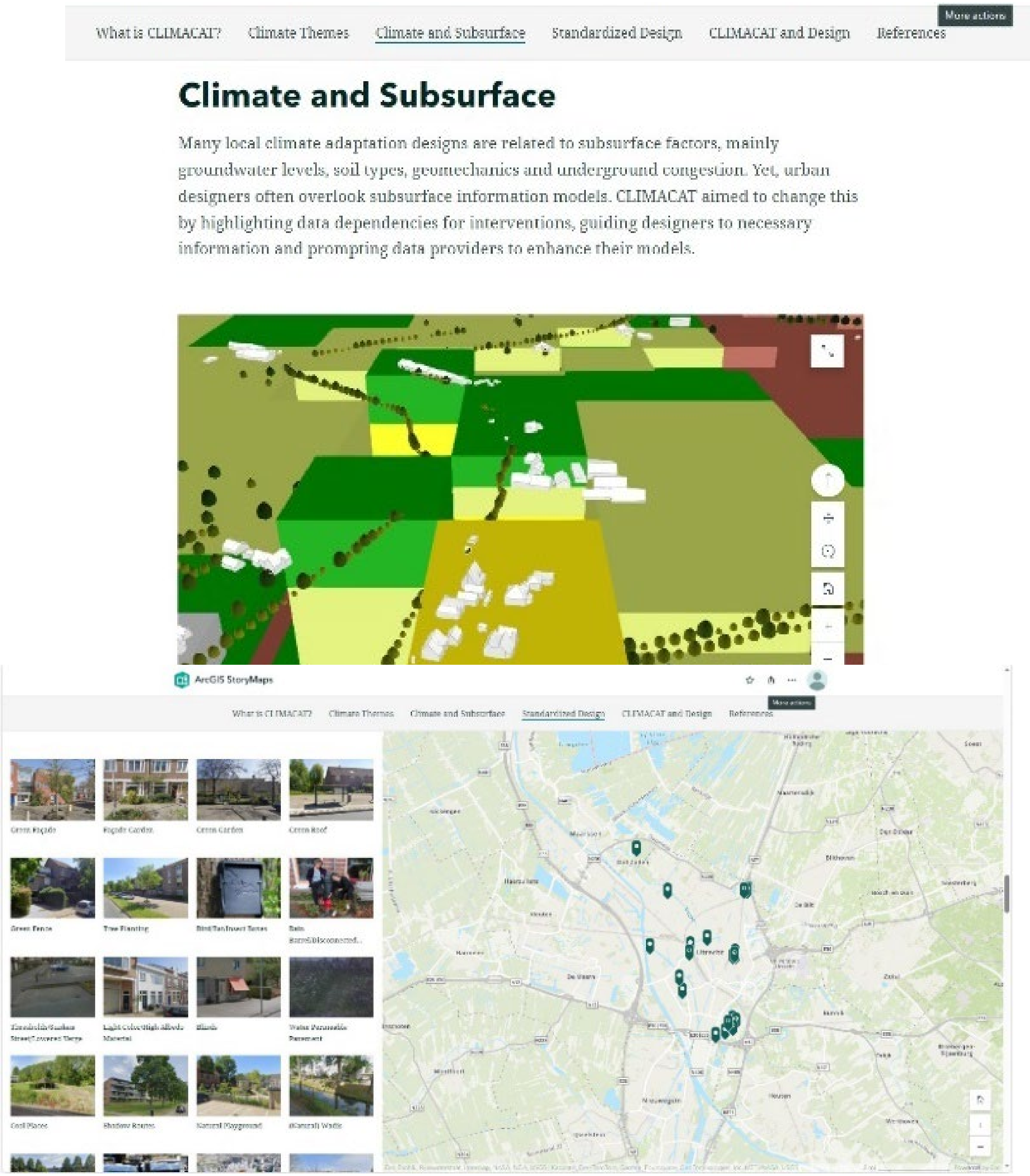

Figure 5. CLIMACAT showing subsurface models and the 25 standardized interventions

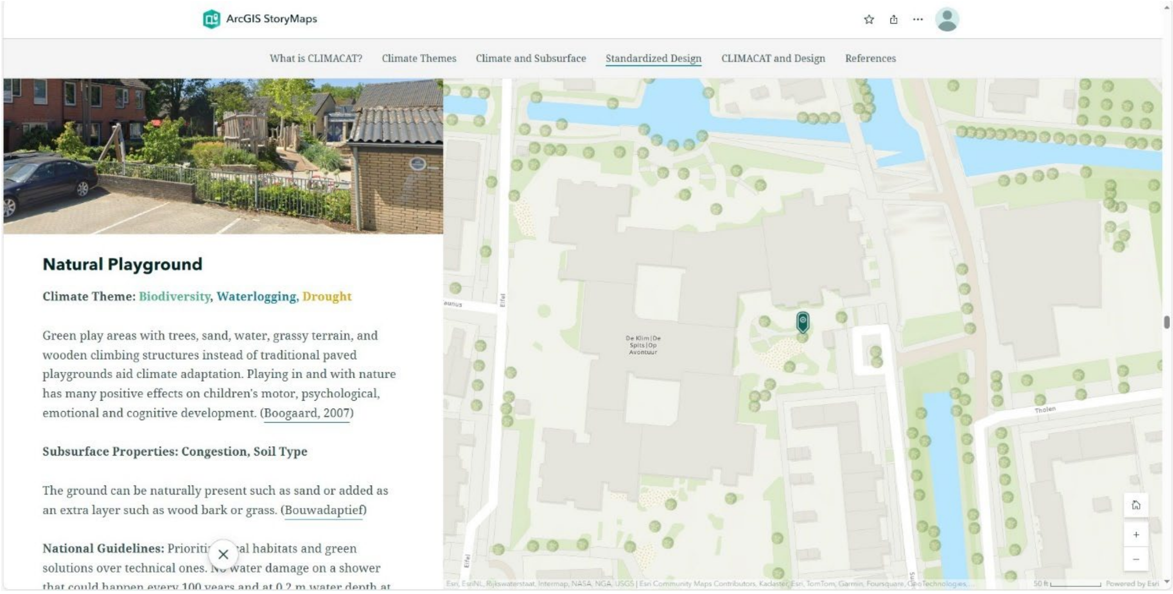

Figure 6. CLIMACAT showcasing one intervention along with its needed information and a geolocated example

CLIMACAT has a section on standardized climate adaptation design, where it indicates in a digital catalogue the twenty-five most used climate adaptation interventions in the Netherlands (Rijksoverheid, 2020), with a geolocated example in a map of the city of Utrecht, alongside with relevant information. For each intervention there is an explanation on how the intervention is an adaptation to the related climate theme (Rijksoverheid, 2020) (Bouwadaptief) (Klimaateffectatlas). This explanation often includes a link to technical drawings of the intervention. It then discusses the relevant subsurface properties, based on information from the *Leidraad Klimaatadaptief bouwen 2.0* (Bouwadaptief). The subsurface property name is a link to a web viewer or geoportal where this information can be found. It then indicates relevant national guidelines, taken from the Maatlat (Rijksoverheid) and local standards for the city of Utrecht, taken from the Leidraad (Bouwadaptief).
The online catalogue is concluded with an example use of this tool when designing. In the example, a neighbourhood in Utrecht, Voordorp, has its information requests and subsurface limitations and opportunities identified. It then exemplifies how a potential intervention, in this case infiltration crates, has all the identified information needs answered in one single place through the catalogue. This proved how a common ground can be found through a FAIR climate adaptation design portal. CLIMACAT is publicly available at https://arcg.is/4jPvG.

5. STANDARDIZING PLANS: LADM PART 5

Standardized urban plans enhance national and international knowledge exchange on diverse urban design and climate adaptation strategies. The LADM provides a unified framework for land administration, supporting spatial representations (Lemmen, Oosterom, Thompson, Hespanha, & Uitermark, 2010). The Spatial Plan Information Package (Indrajit, van Loenen, Ploeger, & van Oosterom, 2020) employs core LADM classes and add new ones to model plan group, block, unit and permit into spatial planning, using Party package classes from Part 2. Adopting a standard designed for sharing urban planning information can enhance the (inter)national exchange of climate adaptation plans and support the development of FAIR climate adaptation information systems. This paper introduces subclasses derived from the existing classes and properties in Land Administration Part 5, adding new attributes specifically for climate adaptation design in the Netherlands. These subclasses inherit the attributes of the original classes while integrating additional features relevant to climate adaptation. All classes and subclasses adhere to Part 5 of ISO 19152 LADM and are based on the LADM core, including Party, RRR, BAUnit, SpatialUnit, 2D/3D representations (from ISO 19107), and VersionedObject. The LADM Spatial Plan package comprises fundamental classes such as plan groups, plan blocks, plan units, and plan permits. The following subsections will detail these classes and outline how the climate adaptation subclasses were developed by extending existing attributes with new, relevant features.

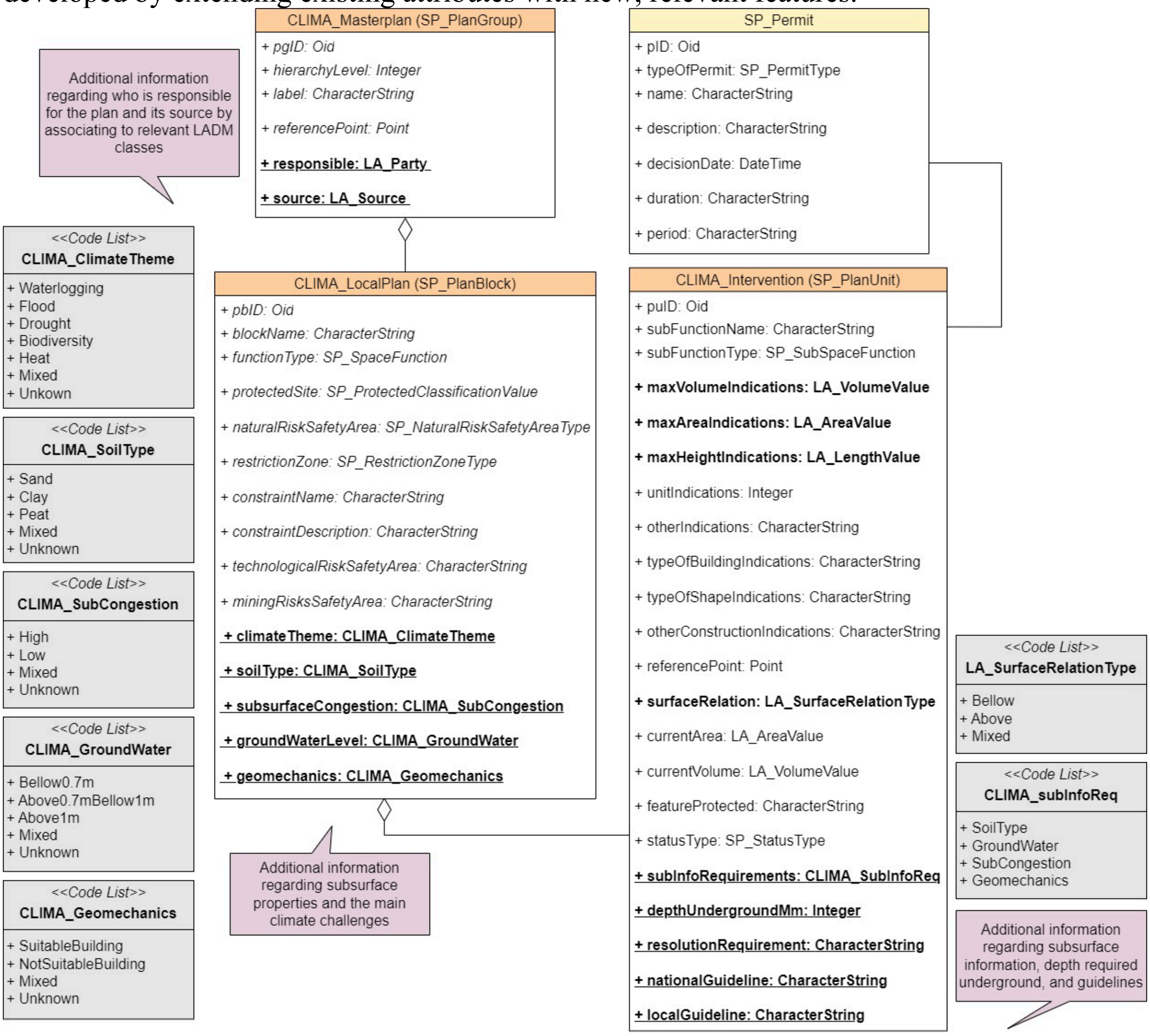

Figure 7. LADM Part 5 classes and new attributes (in bold) related to climate adaptation design

5.1 LADM Plan Group and CLIMA Plan Group

A Plan Group in the LADM represents an administrative hierarchy that organizes spatial plans. Higher-level plans, such as a national, regional or provincial masterplan, guide and encompass more detailed lower-level plans, like a neighborhood plan. For climate adaptation design, this hierarchy is crucial for aligning various planning levels and aspects. The attributes of the SP_PlanGroup class include: the plan group identifier (pgID), hierarchy level (hierarchyLevel), hierarchy name (label), and a reference point (referencePoint). The CLIMA_PlanGroup subclass inherits these attributes. The subclass also associates information to LA_Party and LA_Source to indicate the responsible party and the source of the plan.

5.2 LADM Plan Block and CLIMA Plan Block

An instance of the SP_PlanGroup class guides a collection of spatial planning blocks, with each block group linked to a single SP_PlanGroup instance. A SP_PlanBlock thus consists of a set of neighboring plan units decided or approved by authorities. This class includes attributes such as an identifier (pbID), block name (blockName), planned function type (functionType), protected zone type (protectedSite), and natural risk areas (naturalRiskSafetyArea). These attributes are vital for climate adaptation, detailing current and future uses and risks. For climate adaptation design, additional attributes are introduced to capture climate themes, soil types, subsurface conditions, groundwater levels, and geomechanics, based on a predefined code list.

5.3 LADM Plan Unit and CLIMA Plan Unit

The SP_PlanUnit class represents the smallest planning unit, relevant for local climate adaptation interventions. This class includes attributes like an identifier (puID), plan unit description (subFunctionType, subFunctionName), volume, area, height, status (statusType), and surface relationship (surfaceRelation). For climate adaptation, new attributes were added to capture subsurface requirements (subInfoRequirements), required depth (depthUndergroundMm), resolution needs, and relevant guidelines. The subInfoRequirements attribute includes a code list for key subsurface properties such as soil type, groundwater level, subsurface congestion, and geomechanics.

5.4 LADM Permit Registration

LADM Part 5 supports permit registration linked to plan units. The SP_Permit class handles permit-related information for zero or more plan units. Although this class is not central to this study, which focuses on design exploration rather than existing plans with permits, its inclusion is important for scenarios involving real plans where it would facilitate integrating permit information into climate adaptation designs.

6. RESULTS

The paper analyses the use of standardized information models, tools and standards in the context of climate adaptation design by proposing design explorations in four different neighbourhoods of Utrecht (see Figure 8). Each area's subsurface properties were carefully studied using relevant information models to address the main identified climate challenges. The interventions selected are based on the opportunities and challenges identified through these subsurface models. CLIMACAT facilitated the selection of interventions based on their subsurface properties, assessing the use of an online catalogue with different information models for design purposes. Finally, the plans were stored using the new and existing class attributes from LADM Part 5, evaluating the suitability of this standard for climate adaptation design.

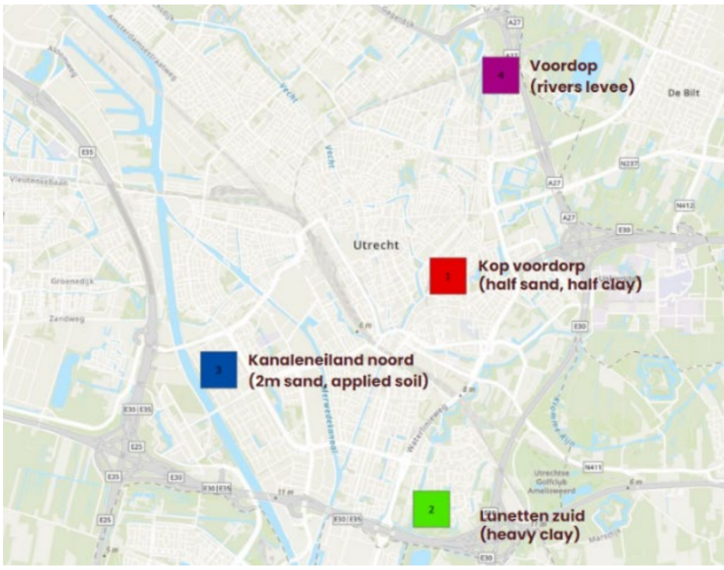

Figure 8. Design areas in Utrecht

6.1 Assessing Subsurface Information Models

For areas prone to waterlogging and flooding, GeoTOP was used to identify the soil type, assessing its suitability for rainwater infiltration. The first half meter is the most essential to assess direct rainwater infiltration of an area, therefore the resolution of GeoTOP layers (0.5 meter vertically) was adequate. Infiltration potential was further analysed using the Highest Groundwater Level model from Klimateffectatlas, which shows that a mean highest groundwater level above 0.7 meters below the surface reduces infiltration potential. Areas with clay or peat layers and high groundwater levels were considered unsuitable for natural infiltration and alternative interventions like artificial water storage were selected.

Utrecht3D's digital twin assessed subsurface congestion to determine if underground interventions needed size adjustments. This model was crucial for areas with high biodiversity and heat issues, helping to decide whether to use natural solutions like trees or alternatives like green roofs. The Atlas 2D map provided by the Utrecht geoportal was used to evaluate the geomechanical suitability for interventions involving significant weight.

Data resolution requirements varied: GeoTOP's 50 cm vertical resolution was adequate for small-scale interventions, but its 100 m horizontal resolution was less detailed. For larger interventions, this was less of a concern. Groundwater levels were useful, though a 3D model combining soil type and groundwater would provide better insights for natural infiltration. The ATLAS 2D building suitability map had limitations for smaller interventions due to its 100 x 100 meter cell size. The 3D on scale Utrecht3D model was very helpful for designing 3D subsurface elements such as infiltration crates or underground water storage.

6.2 Designing Using CLIMACAT

Once the climate challenges and subsurface properties of each area were studied using the existing models, three of the twenty-five standardized interventions were selected for each area. For this purpose, the decision tree presented in section 2.1 of this paper was used. An example of the use of this decision tree is shown in Figure 9.

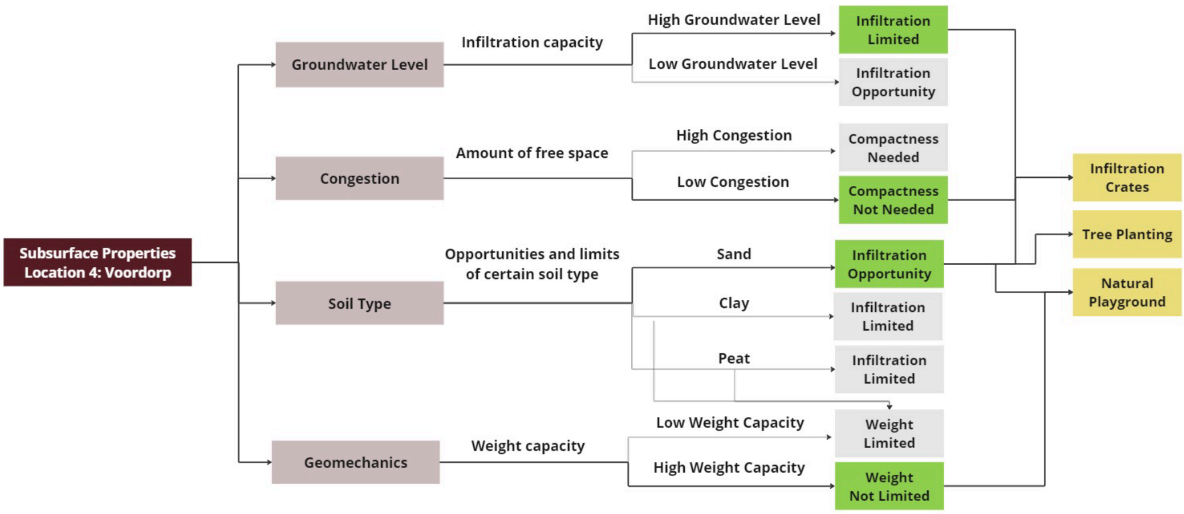

Figure 9. Decision tree used for design decisions

Based on subsurface characteristics from existing models, interventions were chosen using CLIMACAT, which efficiently matched interventions with suitable subsurface properties. For instance, in Voordorp, which faces heat stress and waterlogging, sandy soil and low congestion led to selecting infiltration crates and additional trees. The design also incorporated ecological and social factors. In Voordorp, features were added to a playground and public school area, combining underground water storage with infiltrating soil and greenery. The subsurface properties and standardized design interventions selected for each area are shown in Table 1. For detailed design insights, refer to the thesis (Tarozzo Kawasaki, 2024).

Table 1. Subsurface characteristics and choice for design interventions

Neighborhood	Koop Voordop	Lunetten Zuid	Kanaleneiland	Voordorp
Soil type first 0.5 m	Clay	Clay	Clay	Sand
Groundwater level	High	High	High	High
Subsurf. congestion	Low	Low	High AND Low	Low
Weight limitation	Not limited	Limited AND Not	Not limited	Not limited
Intervention 1	**Bat/insect box**	**Surface water**	**Water storage paved surface**	**Infiltration crates**
Intervention 2	**Tree planting**	**Water square**	**Green garden**	**Natural playground**
Intervention 3	**Green roof**	**Water roof**	**Rain barrel**	**Tree planting**

6.3 Storing Climate Adaptation Planning Information with LADM Part 5 Classes

LADM Part 5 includes classes essential for standardizing urban planning and design information. These basic classes—plan groups, plan blocks, plan units, and plan permits—are detailed in Chapter 5, where new attributes for climate adaptation were added. The Voordorp design proposal illustrates this process. By using adapted subclasses from LADM Part 5, the interventions and plans were stored in a database with both existing and newly defined attributes, demonstrating LADM Part 5's applicability to climate adaptation in urban planning.

```
INSERt INTO clima_planblock (pbid,blockname,functiontype,protectedsite,
   naturalrisksafetyarea,restrictionzone,constraintname,constraintdescription,
   technologicalrisksafetyarea,miningriskssafetyarea,climatetheme,soiltype,
   subsurfacecongestion,groundwaterlevel,geomechanics,plangroup_id) VALUES (
  'UVoord001',
  'VoordorpPlan001',
  'cultivationPublicFacility',
  '',
  'stormRiskZone',
  '',
  '',
  '',
  '',
  '',
  'Waterlogging␣Heat',
  'Sand',
  'Low',
  'Above1m',
  'SuitableBuilding',
  'MU2040'
);
```

Figure 10. Storing information using CLIMA_PlanBlock

A new table was created using the CLIMA_PlanGroup subclass, which builds on the SP_PlanGroup attributes by adding fields for the plan's responsible entity and source. Information about Utrecht’s 2040 masterplan was stored here, with the municipality of Utrecht designated as the responsible party. Another table was created using the CLIMA_PlanBlock subclass for local plans, linking them to the masterplan and using the PlanGroup and PlanBlock classes to manage hierarchical relationships. This table incorporated attributes from the Spatial Planning LADM package for local plan functions and natural risks. The CLIMA_PlanBlock subclass added attributes for climate challenges, soil type, subsurface congestion, groundwater level, and geomechanics, storing details for the Voordorp design.

A third table catalogued the specific interventions within the Voordorp local plan, with each row representing one intervention. This table linked to the Voordorp plan and used the PlanUnit subclass to detail attributes like subfunction, area, volume, height, status, and surface relation. The CLIMA_PlanUnit subclass expanded on these with attributes for resolution requirements and guidelines. Though CAD or 3D files could be used with tools like FME, the preliminary nature of the Voordorp designs meant this was not done. Instead, plan information was stored in tables, as shown in this paper.

```sql

INSERT INTO clima_planunit (puid,subfunctionname,subfunctiontype,
    maxvolumeindications,maxareaindications,maxheightindications,unitindications
    ,otherindications,typeofbuildingindications,typeofshapeindications,
    otherconstructionindications,referencepoint,surfacerelation,currentarea,
    currentvolume,featureprotected,statustype,subinforequirements,
    depthundergroundmm,resolutionrequirement,nationalguideline,localguideline,
    planblock_id) VALUES (
  'InfiltrationCrates',
  'underPlayground',
  'education',
  '190',
  '159',
  '1',
  '',
  '',
  '',
  '',
  '',
  '',
  'Bellow',
  '159',
  '0',
  '',
  '',
  'GroundWater␣SoilType␣SubCongestion',
  '1000',
  '0,5x0.5x0.5',
  'Maatlat',
  'N1␣N2␣N3␣D1␣D2',
  '001'
);
```
Figure 11. Storing information using CLIMA_PlanUnit

7. DESIGN EVALUATION SURVEY

The design choices demonstrate the value of integrating standardized climate adaptation interventions with subsurface information models and tools. However, as the interventions were selected by a single author, a method for evaluating potential biases is proposed. For this, two design areas from this study were compared with proposals from sixteen designers, of which ten were students of architecture, landscape architecture, or urbanism, and six were professional urban designers. An online survey was employed to gather responses on the climate challenges of Lunetten Zuid and Kanaleneiland Noord. Participants were provided with climate-themed maps and chose from twenty-five standardized interventions, each illustrated with a small image. Following their intervention selections, participants explained their choices and identified potentially useful datasets. While they were aware that the survey was for research purposes, they were not informed about all details.

For Lunetten Zuid, which is prone to heat stress and flooding, designers predominantly selected green gardens, tree planting, natural routes, and natural wadis to increase water infiltration and provide shade. However, due to the area's clay soil and high groundwater levels, the infiltration capacity is limited. With subsurface data, designers might have opted for more suitable interventions such as water squares or green roofs. In Kanaleneiland Noord, which faces biodiversity and waterlogging issues, designers favored green gardens, natural playgrounds, natural wadis, and soil structure improvements to enhance biodiversity and rainwater infiltration. Despite the absence of soil knowledge, many chose soil structure improvements, but given the area's clay soil and high groundwater levels, interventions like artificial water storage and rain barrels would be more appropriate.

When queried about additional helpful information, most designers mentioned demographic data, with only 12.5% highlighting the need for subsurface information, and half of those specifying soil type. This survey underscores how the lack of subsurface information can result in less effective climate adaptation interventions. A comprehensive understanding of soil type, subsurface congestion, groundwater levels, and geomechanical properties is essential for context-sensitive and effective design decisions. Nevertheless, a small proportion of designers recognize the relevance of subsurface data in preliminary climate adaptation design. The approach proposed in this paper, with the use of tools and standards such as CLIMACAT and LADM Part 5, aims to increase this number.

8. CONCLUSION

8.1 Main Results

The integration of CLIMACAT and LADM Part 5 represents a comprehensive approach to addressing the challenges associated with integrating subsurface information into climate adaptation design using information models and standards. Both tools are essential in overcoming institutional, technological, and semantic barriers that have historically impeded the effective utilization of subsurface data in urban planning.

CLIMACAT, an online catalogue, consolidates various types of information crucial for climate adaptation design. It provides a user-friendly platform for urban designers, data providers, and citizens, thereby fostering interdisciplinary collaboration. By bringing together information on climate themes, subsurface properties, and national and local guidelines, CLIMACAT addresses the need for a comprehensive and accessible data repository. This approach aligns with the FAIR data principles, ensuring that climate adaptation interventions are well-informed and context specific. On the other hand, LADM Part 5 offers a standardized framework for documenting and sharing urban plans that incorporate climate adaptation strategies. The use of LADM Part 5 facilitates the integration of spatial planning information within a unified model. This standardization is crucial for the international sharing of urban plans, thereby enhancing global knowledge exchange and collaboration on climate adaptation practices. Moreover, the creation of class attributes tailored for climate adaptation design ensures that specific requirements, such as subsurface properties and intervention suitability, are adequately captured and documented.

The combined use of CLIMACAT and LADM Part 5 ensures that climate adaptation designs are both well-informed and standardized. CLIMACAT enhances the accessibility and usability of critical data, while LADM Part 5 ensures that the resulting plans are documented in a manner that facilitates sharing and interoperability. This dual approach addresses the institutional challenges of integrating geoinformatics with urban design by providing both a practical tool for design and a standardized framework for documentation and dissemination. Thus, the synergy between CLIMACAT and LADM Part 5 represents a comprehensive solution for advancing climate adaptation efforts through improved integration of subsurface information into urban planning processes.

8.2 Future work

This paper discusses the combined use of an online portal and standardized information models for the exchange of information related to climate adaptation in the context of the Netherlands, and particularly the city of Utrecht. Future work potentially could include the assessment of this method in different cities and countries. Utrecht benefits from a wide range of information models that make it possible to combine different information into a singular portal. Future work could include the assessment of this approach in smaller municipalities with scarcer data availability. Moreover, this approach is believed to be useful on an international level, but this could be further investigated in new research. Further work could include the use of LADM Part 5 subclasses tailored to climate adaptation in different countries, for example.

In this paper, the LADM Part 5 classes and subclasses were used to store information regarding urban plans created by the authors based on subsurface characteristics. These plans did not contain the detailed planning information that a spatial plan approved by authorities usually does, such as geometry and other detailed attributes. Therefore, future work could include the use of the proposed new attributes for approved urban plans. This would allow, for example, the use of tools such as FME to load planning information, such as (3D) geometry.

Finally, CLIMACAT was created based on the research and experience from the authors. Feedback from users will allow it to improve, leading to further work and a better tool for the purpose of integrating standardized information into climate adaptation design practices.

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BIOGRAPHICAL NOTES

Maria Luisa Tarozzo Kawasaki holds two Master of Science degrees in Geomatics and Urban Design from Delft University of Technology. This paper is partly based on her thesis, "Common Ground: Bridging Subsurface Information Models and Climate Adaptation Design." Her research emphasizes interdisciplinary approaches to societal challenges, particularly integrating geoinformatics and design. An example is her article "Digital Surveys to Access Marginalized Views in Favela Communities," published by Urbanet. She currently works as an information analyst at TNO in Utrecht.

Rob van der Krogt is a Senior Project Manager at TNO - Geological Survey of the Netherlands. Throughout his 30-year career, he conducted many interdisciplinary projects involving geoscience data and information, spatial planning, and infrastructure. His main clients are public boards at national, regional, and local levels and European research programs. He has a key role in the national database for the subsurface, which Dutch government bodies are legally obliged to use for certain policies and decisions, and he is project lead for the 3D transformation of this system.

Wilfred Visser is a Senior Researcher at TNO - Geological Survey of the Netherlands. He has a background in computer science and software development. Working at TNO for over 25 years in the field of acquisition and processing of geoscientific data and information. His knowledge lies in handling large amounts of data, such as seismic sensors but also Distributed Acoustic Sensing (DAS) and InSAR. Also involved in developing subsurface models, such as GeoTOP 3D a detailed three-dimensional model of the upper 30 to 50 meters of the subsurface of the Netherlands and REGIS II 3D a hydrogeological subsurface model of the Netherlands. His main clients are other TNO research institutes, universities and the government in advising on the application of Geo Data and information.

Ulf Hackauf graduated as Diplom-Ingenieur (MSc) architecture at Technische Universität Braunschweig in 1999. He worked as architect for Erick van Egeraat and for Neutelings Riedijk architecten, both in Rotterdam, on large projects in Germany, Great Britain, Denmark and the Netherlands. From 2007 to 2014, he collaborated with Winy Maas at The Why Factory, TU Delft, using spatial design to imagine consequences of global dynamics and challenges. He co-authored several books of The Why Factory’s book series and taught related studios at TU Delft, ETH Zürich and IIT Chicago. Since 2015, Ulf Hackauf is teacher and senior researcher at the section Environmental Technology and Design, department of urbanism. He teaches in Urbanism and Industrial Ecology. His research focusses on multi-scale relations between urban space and sustainable transitions.

Alexander Wandl is an urbanist and associate professor at the chair of Environmental Technology and Design, at the Faculty of Architecture and the Built Environment. His research focuses on developing sustainable urbanisation, using an extended territorial metabolism approach and integrating (GIS-supported) methods and tools from different disciplines. As scientific coordinator of the Horizon 2020 financed research project REPAiR – Resource Management in peri-urban areas– he is at the forefront of developing spatial strategies, which support the transition towards a circular economy. He specifically focuses on the challenges related to the sustainable development of dispersed urban areas and peri-urbanisation processes in Europe.

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 Physics and Electronics 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 database. Since 2000, he is Professor at Delft University of Technology, and chair GIS Technology, Digital Technologies Section, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands. He is the current chair of the FIG Working Group on 'LADM and 3D Land Administration' and co-editor of the International Standard for Land Administration Domain, ISO 19152.

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Development of 4D Marine Cadastre Data Model – A Case Study of Terengganu Shoreline

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Key words: Temporal Dimension, 4D (3D + T) Cadastral system, Marine Cadastre, LADM.

SUMMARY

In this paper, a 4D (3D + time) marine cadastral data model (MCDM) based on LADM is presented to improve the management of 3D marine properties considering the temporal elements, especially on the coast of Terengganu, Kuala Nerus. The model integrates temporal components and introduces a new bitemporal transaction class, the archived historical record class, which is structured to document two types of time-related information: valid time and transaction time. This dual-time perspective is critical for accurately recording data changes over time. Suffice it to say that the LADM version object in its current form may need to be included or redesigned to accommodate bitemporal data. This paper will first examine current practices in marine management, identify and establish temporal elements for implementation, identify LADM and existing 3D classes for adoption along with their attributes, relationships, associations, and code lists, and develop a conceptual data model that describes the modeling technique and requirements for coastal data, leading to a 4D MCDM. The output result is expected to provide visualization of the position and boundaries for each component of the marine and land cadastre in the area and, by extension, present a practical country utilization of 3D LADM provisions in the marine and land cadastre context, which can serve as a model for many aspects of modern urban planning.

Development of 4D Marine Cadastre Data Model – A Case Study of Terengganu Shoreline

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1. INTRODUCTION

Human activities and natural occurrences such as erosion have led to geometrical alterations in spatial and non-spatial property attributes (Celliers, 2016; Morar et al., 2022). Land status changes have great consequences for both the government and the people, particularly property ownership, which affects the entire land allocation, possession, and ownership process. Changes in questions could be when the land cover changes take place from land to marine (as noticed along most Malaysian beaches and coastal areas, especially in Terengganu, and others), marine to land (reclamation like in the case of Forest City in Johor Malaysia), and marine to marine situations. Other Malaysian beaches affected include, Kuala Maras near Batu Rakit, and Kuala Besut.

Changes in the physical characteristics of spatial objects both terrestrial and marine with their geometries and locations will continue to occur if the Earth's surface temperature is trending toward record highs, which will raise sea levels and generally degrade land surface area (Abdul Rahman et al., 2024). These changes are critically on the increase despite government mitigation and intervention plans saw owners of properties continuously losing them which invariably affects cadastral documentation (Rashidi et al., 2021). Furthermore, these changes are monumental and affect the entire cadastre situation in both the land and marine cadastres including but not limited to the destruction of coastal properties submerging and complete loss of properties affecting cadastral property ownerships. The affected land and property become marine and now government property while the original owner is still in the custody of the legal instrument (RRR) of ownership which is valid for historical and legal purposes. Cadastral changes are equally recorded over time from the initial cadastral model or platform used in the allocation has undergone transitions from 2D, 2.5D, or 3D to the present LADM 1 to LADM II. Changes in jurisdictions from land cadastre jurisdictions to marine cadastre jurisdictions require necessary compliance, and regulations, based on the new development (Trice et al., 2021). Equally, equipment and software used in the initial data collection, processing, and analysis methods employed in cadastres have changed over time from analog to digital, and software changes have occurred over time with the use of AutoCAD, Ilwis, and now Enterprise Architect, PostgreSQL. Database creation and archiving, from manual data archiving to digital archiving, be it conventional or blockchain databases, are part of the transitional temporal changes. Seamless transition or transfer of the record to the appropriate cadastre from land to marine cadastres or marine to land cadastres for appropriate jurisdiction and documentation. For a credible cadastre devoid of litigation, settlement, and resettlement plans, compensations to avoid litigation as witnessed in Terengganu, Malaysia, as reported by

V Anbalagan of FMT Media Sdn on February 12, 2022, faced a conflict with landowners who claimed RM5.5 million in damages for breach of contract and statutory duties. If we must address these issues particularly property loss and others and avoid any form of litigation, the time (t) element must be incorporated to account for the shifting shoreline border over time for a real 3D situation, and presentation of attributes and properties. Moreover, the historical data of transactions over time must be obtained, analyzed, and processed using the 4th dimension capability (documenting the temporal changes), particularly for marine environments as presentation and visualization of properties in 3D land cadastre is static visualization, so cadastral property presentation and visualization in marine cadastre environment requires temporal integration for proper visualization which can be achievable only in 4D (3D + Time). This paper attempts to develop a 4D marine cadastral data model for land administration. It involves the integration of temporal elements of shoreline changes and property ownership loss, accounting for these temporal truncations, documenting, and archiving based on LADM.

This paper will cover several sections. Section 2 discusses the Related works, Section 3, the Conceptual Model Development, Section 4, the Conclusion, and future works.

2. RELATED WORKS

The utilization of 3D land and marine cadastral representations of properties showcases their application in various fields (Abdul Rahman et al., 2012). A 3D land cadastre are advanced land registration systems that provide a comprehensive volumetric delimitation of property rights, enabling a more detailed spatial representation of property boundaries compared to conventional 2D cadastres (Drobež et al., 2017); (Semlali et al., 2015). 3D land cadastre is critical for urban development since it requires precise property rights delineation for efficient use of urban space, especially in high-rise buildings and subsurface infrastructures. The three-dimensional land cadastre promotes legal and administrative clarity, eliminating conflicts over land and property rights by providing precise boundaries in three dimensions (Levin et al., 2018). It is used to develop and manage complicated property arrangements, such as multilevel commercial complexes. Equally, the technology improves asset and real estate management by providing a comprehensive geographical context, enriching transactions with detailed 3D property descriptions, and assisting with valuation and development planning (Gkeli et al., 2020a). A 3D marine cadastre, maps and manages marine boundaries and property rights in three dimensions, covering the surface water, water column, and seabed (Kurniawan et al., 2023) (N. A. A. Zamzuri & Hassan, 2021), (Gkeli et al., 2020b),(Pouliot et al., 2018) &(Binns et al., 2004). It aids in maritime spatial planning, facilitating the management and planning of marine resources and activities like fishing, shipping lanes, and offshore energy production (Ehler, 2021), (Longhorn, 2016). Also, it helps in conflict resolution among competing users of marine spaces by providing clear boundaries. It ensures environmental protection and facilitates the conservation of Marine ecosystems by delineating protected areas in three dimensions. Also, it accounts for different habitats and species at various depths, assisting in monitoring and enforcing environmental regulations on infrastructure development, critical for the planning and management of underwater infrastructure like cables, pipelines, and tunnels (Karabin et al., 2020). The system ensures the safe and efficient placement of offshore installations like wind farms and oil rigs by accurately mapping the seafloor and water column.

In spatial representation, both 3D lands and marine cadastres represent significant advancements in the field of spatial information management, addressing the complexities of modern property and resource management (Polat & Alkan, 2018);(Aien et al., 2017). While they offer substantial benefits in terms of detailed and precise spatial data, their implementation requires overcoming significant technical, legal, and administrative challenges (Gürsoy Sürmeneli, Koeva, et al., 2022); (Paasch & Paulsson, 2021). The development of robust 3D cadastral systems is essential for sustainable development, efficient resource management, and effective governance in both terrestrial and marine environments.

The geometric aspects of 3D land and marine cadastres differ significantly due to the nature of their environments. The 3D land cadastre deals with relatively static, well-defined boundaries and complex urban structures, relying on precise volumetric representations. In contrast, the 3D marine cadastre must handle dynamic, multi-layered environments with fluid boundaries, requiring constant updates and integration of temporal data (Karki et al., 2010)(Griffith-charles et al., 2014). Both systems employ advanced technologies and tools to capture, integrate, and visualize their respective geometries, but they face unique challenges due to the inherent differences in their physical contexts (Rosdi, 2016)(Fraser et al., 2003).

The integration of temporal data in 3D land and marine cadastres varies significantly due to the different nature and dynamics of their environments (Atulukwu & Rahman, 2023); (Rakuša et al., 2021)(Polat et al., 2020). The dynamic boundaries of ownership transactions and legal instruments like RRR require a comprehensive consideration of time components. Failure to do so may lead to embarrassment for the government and stakeholders. The current effort to resolve this issue includes the integration of 3D cadastral object registration with time attributes (3D + t) within the Turkish LADM framework, focusing on land cadastres and no representation in marine cadastral environments (Gürsoy Sürmeneli, Alkan, et al., 2022). Also, the application of the ADE 4D cadastral data model for 3D cadastral item registration in Turkey demonstrates the legal and physical boundaries of multi-story addressing knowledge deficits in land-based cadastres but deficient in marine environments ((Alkan & Gursoy Surmeneli, 2020); (Gürsoy Sürmeneli, Koeva, et al., 2022). Efforts to increase cadastral capacity were witnessed to effectively manage the temporal dimension of modern land use in Turkey, the Netherlands, and Queensland, Australia. Still, this initiative was only for Land cadastre and not deployed to the dynamic marine environment ((Döner et al., 2010); (Ho & Hong, 2021) focused on temporal modeling in cadastral systems, specifically valid time, and the semantics of temporal information for Taiwan's cadastral data system. However, the temporal integration here was limited to land cadastre and was not extended to the dynamic marine environment. In Argentina, a conceptual model for water bodies, like LLO, with dynamic limits based on Argentine law's riparian boundaries (Riparian water rights is a system for allocating water among those who possess land along its path) was proposed, but they did not consider temporal transactions and property representation but limited to water right (Alberdi & Erba, 2020). Turkey developed a Temporal Cadastral Information System for land use, focusing on easement rights and national cadastral data management standards, but the focus of the study was limited to land cadastre and not extended to cover marine cadastre and its environments (Polat et al., 2020).

According to (Oosterom et al., 2019), existing models often overlook the spatial representation of property boundaries, morphology, and temporal dynamics and lack valid transaction time forms, limiting validity in uni-temporal and bitemporal models, and overlook property boundaries, causing inaccurate appraisals and financial losses. According to (Atulukwu et al., 2024), the absence of effective procedures for monitoring and documenting changes in property ownership over time can result in disputes, conflicts, and legal ambiguities in land management and legal actions. (Oosterom et al., 2019); (Kvet & Matiaško, 2013) argue that temporal truncation events in property ownership, including subdivisions at different transaction times, pose challenges in marine and land cadastres. Historical documentation is crucial for understanding past, present, and future records and tracing subdivision and land use patterns. (Kara et al., 2024); (Lemmen et al., 2021); (Thompson & van Oosterom, 2021), the Land Administration Domain Model (LADM-ISO 19152) offers bi-temporal support but lacks a valid time interval or life span, affecting spatial unit and party relationships.

Land title and cadastral data are dynamic and crucial for property applications like taxation, valuation, and mortgage. This paper discusses the modeling of Rights, Restrictions, and Responsibilities (RRR) in Turkey, focusing on easement rights. A prototype model was built using the Land Administration Domain Model (LADM) RRR classes and national cadastral data management standards. The model includes temporal cadastral attributes related to easements, providing significant advantages to land administrators, governments, and users in Turkey (Polat et al., 2020). This paper explores the conversion of 2D analog cadastral boundary plans into 3D digital information, focusing on a research project in Stockholm. The study highlights legal issues and the need for detailed interpretation of existing legislation to incorporate 3D models into cadastral decisions. It also analyzes the current cadastral process and suggests further development, highlighting the need for further investigation and interpretation of 2D cadastral data (Larsson et al., 2020). Turkey's land register and cadastre (LRC) data is widely used by both public and private organizations. However, traditional LRC systems have manual archiving, making it difficult for users to perform temporal analyses quickly and reliably. This research aimed to design and developed a Temporal Geographic Information System (TGIS) for Turkey, evaluating agencies' needs and testing the system (Polat et al., 2020).

Atulukwu et al. (2024). positioned the development of a 4D Malaysian marine cadastre data model based on the Land Administration Domain Model (LADM) to address the challenges of effective land management in coastal and marine settings, integrating temporal dimensions with existing 3D marine models which will enhance land administration methodologies in dynamic marine settings and promote sustainable marine development. Siejka et al., (2014) discusses the introduction of a 3D+time system transition from a 2D cadastre to a 3D+time system using official spatial data registers in Poland aiming to enhance property rights, database efficiency, data quality, planning, and land management with advanced technologies like CAD, GIS, and DBMS enable 3D visualization and reconstruction of real estate state.

The 3D cadastre, a key component of the Land Administration System, provides a 3D view of legal and physical boundaries in multi-story properties. Also, that most 3D integrated data models are conceptual, leading to a knowledge gap in logical data model relationships was the canvassed in the study proposing an innovative ADE 4D Cadastral Data Model for 3D cadastral object registration with time attributes using LADM and CityGML, managed in an open-source database for the Turkish cadastral system (Gürsoy Sürmeneli, Koeva, et al., 2022). According to (Aien et al., 2017) the authors repoerted the theories and concepts of the common existing cadastral data models and their management of 3D legal and physical data

as none of the existing models can fully support the requirements of 3D cadastres or develop new models.
Temporal integration of marine properties ensures accurate records, addresses issues in dynamic ecosystems, and improves monitoring, sustainability evaluations, human impact assessments, dispute settlement, and legal representation by considering temporal dynamics like jurisdictional control and resource availability. The inability to integrate legal and physical data leads to inconsistent descriptions, complicating enforcement and increasing the likelihood of legal disputes (Flego et al., 2021), (Radjai & Rassoul, 2016) and (Van Oosterom & Stoter, 2010), and. Cadastral integration can be achieved by adding legal data to physical information models or combining both. Combining Enterprise Architect (EA) or CityGML and LADM ideas involves designing a profile of LADM for a country and creating an ADE for the EA or CityGML standard (Gürsoy Sürmeneli, Koeva, et al., 2022), (Rajabifard et al., 2021), (Spijkerboer, 2021), and (Sun et al., 2019). The study explores the integration of marine cadastral units with land administration, aiming to improve marine resource management opportunities within existing land administration frameworks (N. A. A. Zamzuri & Hassan, 2021). The paper highlights how the integration of marine cadastre with land administration can enhance the coordination of marine and terrestrial spatial data, as studied in projects like the Dutch North Sea Dialogues and Agreement (Spijkerboer, 2021). The integration of maritime settings is crucial for sustainable marine resource management and decision-making, as studies show temporal and local impacts on coastal areas and the scalability of water property measurements ((Nylén et al., 2021). Marine spatial planning integration practice is viewed from multiple perspectives and addresses challenges and problems in diverse settings, highlighting its importance for efficiency, participation, and sustainability (Saunders et al., 2019). Also, temporal truncation events in property ownership, including subdivisions at different transaction times, pose significant challenges in marine and land cadastres. Historical documentation of these events in spatial models is crucial for understanding past, present, and future records, which are not currently implemented (Oosterom et al., 2019) (Kvet & Matiaško, 2013). The transaction time in cadastre records is crucial for tracing subdivision and land use patterns, planning future activities, and maintaining the database's knowledge. Existing models lack the "valid time" and "transaction time" forms of time stamping (Oosterom et al., 2019). The temporal and transaction models are crucial for data processing, storing both current and future data. Uni-temporal models limit data validity, while bitemporal models consider both validity and transaction time, allowing for updates without user input (Kvet & Matiaško, 2013). The Land Administration Domain Model (LADM-ISO 19152; ISO-TC211, 2012) partially provides bi-temporal support (beginLifespanVersion and endLifespanVersion) but lacks a valid time interval or life span. The LADM VersionedObject only covers TransactionTime concepts, not focusing on recording interval events or recurring patterns, thereby affecting the relationship between spatial units and parties, which is one of our focus areas in this current research work (Kara et al., 2024); (Lemmen et al., 2021); (Thompson & van Oosterom, 2021).

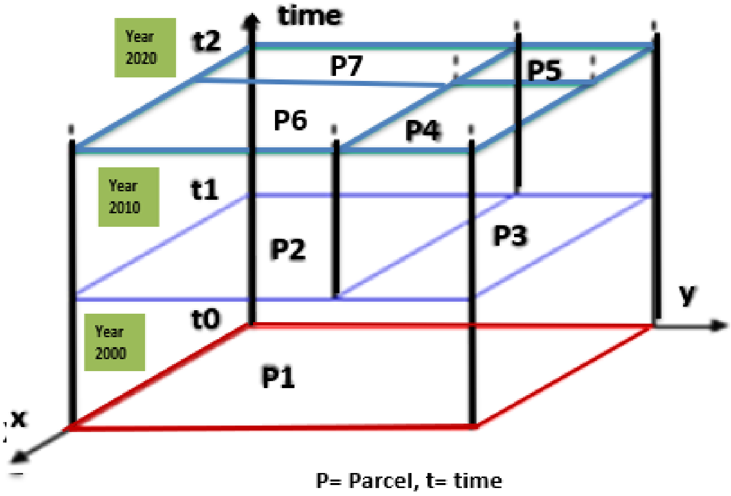


Figure 1. Land cadastral property representation, modified after (Pouliot et al., 2018)

Figure 1 illustrate 3D land cadastres record changes in land records based on schedule updates. Regulated modifications such as division, subdivision, alteration, and amalgamation are manifested here. The boundary here is static, and there is no change in geometric attributes or spatial units as the boundary remains static, showing that cadastral property representations here can be declared true in 3D representations of properties. Also, the diagram shows that the initial one parcel (P1) in year 2000 and time (t0) was then subdivided into two parcels (P2 and P3) at time (t1) in year 2010 after ten years, and at another ten-year interval, parcel P2 and parcel P3 at time (t2) were further subdivided into parcels P4, P5, P6, and P7, respectively, and can be amalgamated into a larger parcel with new land use depending on needs. The emphasis here is that the spatial unit remains unchanged and does not affect the geometric attributes except for the unit changes in the subdivisions.

The followiing reports by Gürsoy Sürmeneli, Koeva, et al. (2022), Thompson & van Oosterom (2021), Ho & Hong (2021), Pribadi et al. (2021), and Cole & Wilson (2016) summarized the need to consider the time aspect of land ownership and transactions, highlighting the drawbacks of current models.

The overall aim of this research is to attempts to develop a 4D marine cadastral data model for land administration. It involves the integration of temporal elements of shoreline changes and property ownership loss, accounting for these temporal truncations, documenting, and archiving based on LADM and to improve the 3D situation, and presentation of attributes considering the temporal elements, particularly in the Terengganu shoreline. The model would integrate temporal components and introduces a new bitemporal transaction class, the archive Historical Record class, which is structured to track two types of time-related information: valid time and transaction time. This dual-time perspective is crucial for maintaining a comprehensive and accurate record of changes in data over time. This research work would follow a workflow divided into preliminary research phase, conceptual and data model development phase, and data model validation phase respectively. This work took cognizance of past research efforts in Malaysia, Turkey, and some other nations but their outcome were limited to land cadastral administration; however, Malaysia has developed a marine cadastral data model based on LADM at a 3D level, which is short by lack of integration of the temporal component, thereby necessitating the current integration of the temporal component for the 4D (3D + T) Marine cadastral data model to ensure sustainable marine cadastral administration. The expected model will on the LA_SpatialUnit receive an additional object class, bringing to a total of six (6) classes, while the LA_Party Unit and the LA_BAUnit inherit the transaction class, respectively and is expected to provide visualization of features and boundaries for each component for the marine cadastre in the area, and, by extension, present a practical country utilization of 3D LADM provisions in the marine context, which can serve as a model for many aspects of modern urban planning. However, this paper focuses on the development of the 4D marine cadastre conceptual data model for the integration of temporal elements of changes for the management of 3D situation of cadastre properties in Terengganu shoreline based on LADM (Gürsoy Sürmeneli, Alkan, et al., 2022; Gürsoy Sürmeneli, Koeva, et al., 2022; A. Zamzuri et al., 2022; Drobež et al., 2017; Ashraf Abdullah et al., 2014).

3. THE CONCEPTUAL MODEL DEVELOPMENT

Marine boundaries are dynamic due to natural processes, tides, currents, and human activity, causing changing shoreline, overlapping claims and disagreements. This makes it difficult to establish stable legal boundaries and maintain consistent legal descriptions in the marine cadastre. The lack of integration between legal and physical data also complicates matters. Malaysia's 3D marine cadastre model and current data models have limitations in representing temporal dynamics of maritime environments, necessitating the development of a 4D marine cadastre model. A 4D marine cadastre model is needed to improve resource management and address these limitations. The cadastral situations of 3D properties on the Terengganu shoreline (Figures 2, 3, 4, and 5) illustrate property presentations, highlighting the challenges associated with temporal changes, modeling, presentation, and updating the documentation of cadastral properties in marine environments. The situations illustrated in the following figures 2, 3, 4 and 5 serve as a research gap in this paper; thus, all the related modeling processes or tasks will be elaborated on in sections 3.1–3.3, respectively.

Figure 2. Coastal situation of Kuala Besut coast north of Terengganu as of 2024

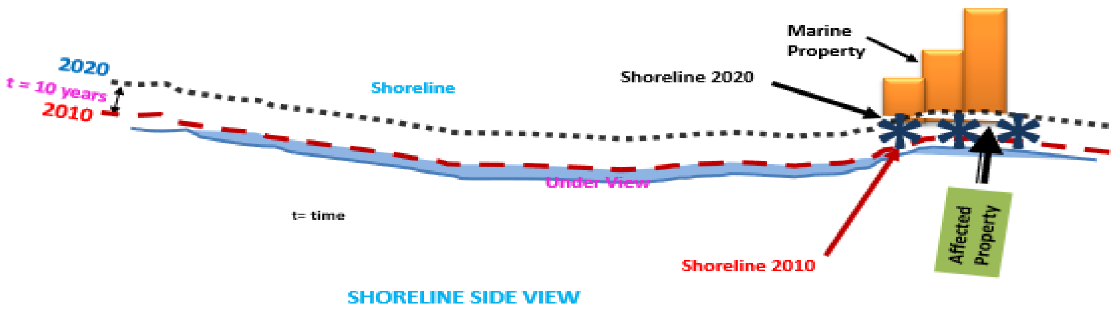


Figure 3. 3D Situation of marine cadastral property representation

Figure 3 illustrates a 3D Situation of marine cadastre presentation of attributes and properties showing natural changes. 3D marine cadastres need constant updates to manage the dynamic maritime environment with constantly shifting boundaries over time. The representation here is by 3D + T to account for the temporal (t) change over time. In the transactional process, time is of the essence, and the intricate integration of temporal (t) for marine cadastral 3D property representation is a necessity.

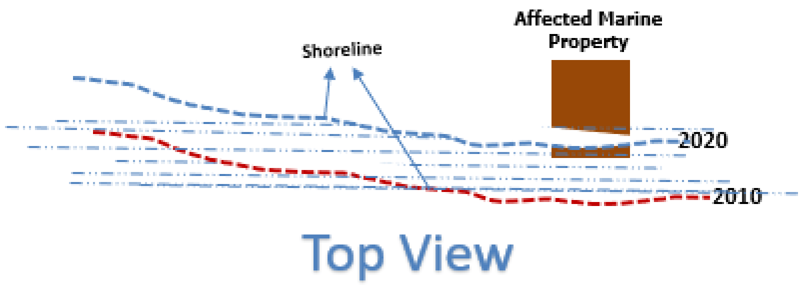


Figure 4. 3D Situation of shoreline changes and property loss (Land-Marine)

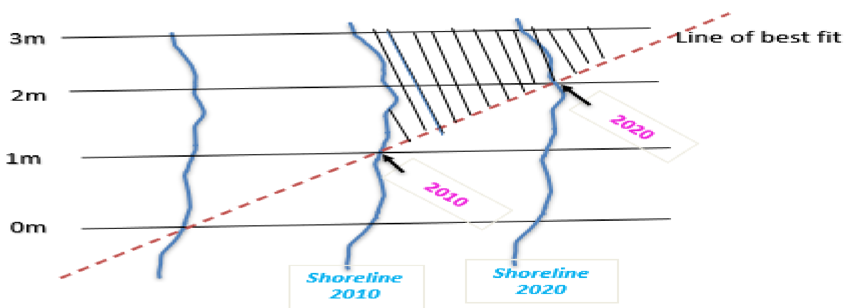


Figure 5. Cross-section of shoreline changes (Land-Marine)

Figure 5 illustrates the cross-sectional view of shoreline changes with time, particularly for status changes from land to marine of affected property area in a pattern using 1meter interval.

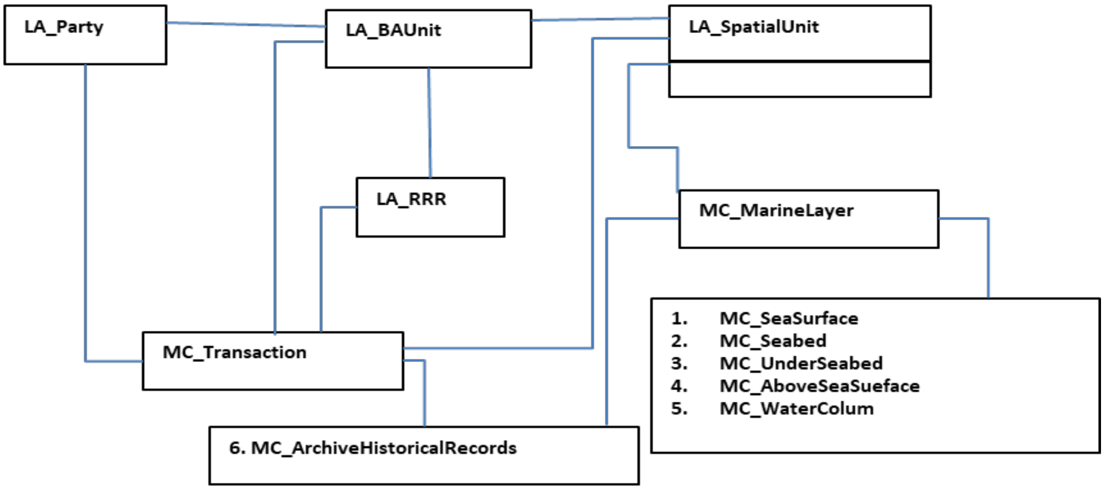


Figure 6. Object modeling process based on LADM classes

Figure 6 illustrates the modeling process of marine property object classes and their relationships based on LADM classes and standards.

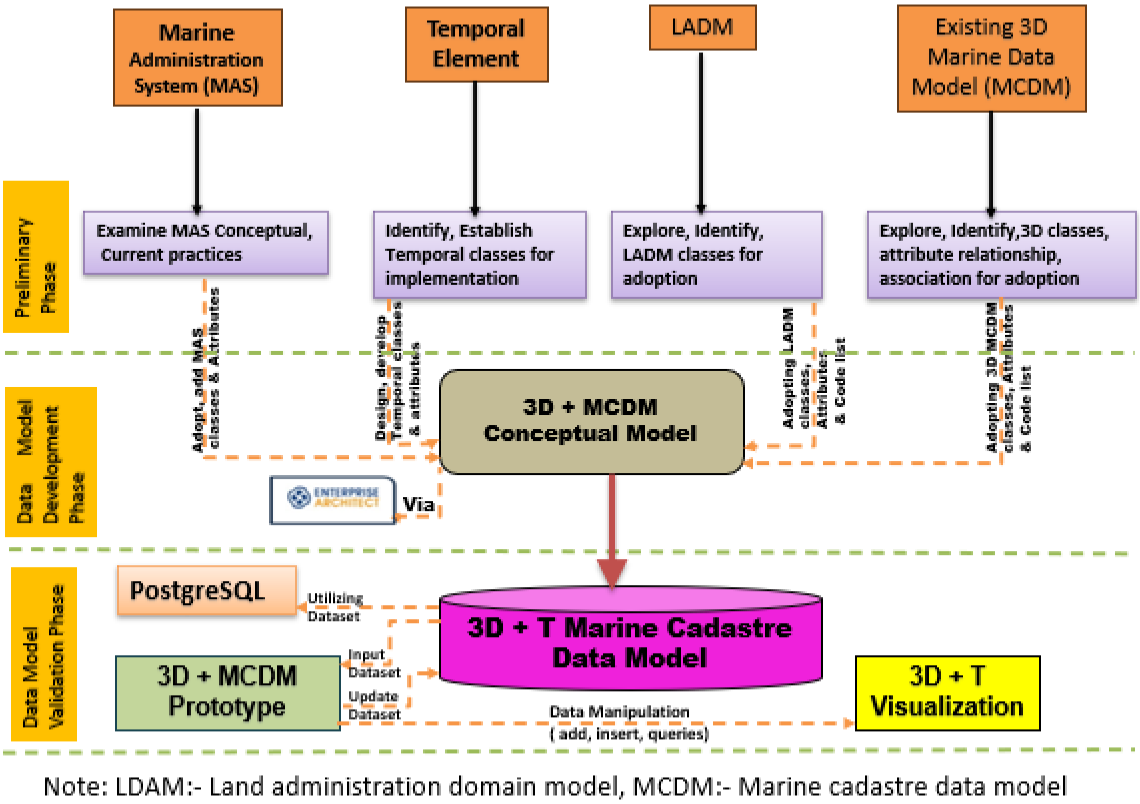


Figure 7. Research framework for 4D marine cadastre data model development

Figure 7 describes the research framework for the development of the 4D MCDM based on LADM and consists of the preliminary, data modeling, and data validation phases.

3.1 Preliminary Research Phase

The preliminary research phase discusses the 4D marine data model developmental phase, which examines current practices in marine management, identifies and establishes temporal elements for implementation, identifies LADM and existing 3D classes for adoption along with their attributes, relationships, associations, and code lists, and develops a conceptual data model that describes the modeling technique and requirements for coastal data, leading to a 4D MCDM.

The next phase is the data model validation phase, which is the translation of the developed conceptual model into a logical database, converting the classes into schemas, prototype model development, and finally developing the 4D marine cadastre data model, followed by validation, respectively.

3.2 Data Model Development Phase

Data modeling consists of developing a conceptual representation of object classes and their relationships, which incorporates implementing constraints, code list classes, object identity, association cardinality, inheritance, and an appropriate data format. As a result, the UML diagram tool of Enterprise Architect will be used to define classes and attributes, establish relationships between the classes, and create a model that better represents the data in a way that organizations, database administrators, and other stakeholders can understand. The data model creation phase specifies how the information retrieved and adopted from preliminary

3.3 Potential Classes

The potential classes in Table 1 for the development of the conceptual model based on the LADM standard were identified and classified along the LADM structure of the party unit, the administrative unit, and the spatial unit, respectively. The newly proposed classes are covered with red boxes, and their grouping was generated based on Malaysia's LADM country profile. The generated possible classes were expanded and translated into the 4D marine conceptual model (Figure 8).

Table 1. Potential classes

Group/Package	Subclasses
Party	MC_Party MC_PartyMember
Administrative	MC_RRR MC_Right MC_Responsibility MC_Restriction MC_BAUnit MC_AdministrativeSource MC Transaction
Spatial Unit	MC_MarineSpatialUnit MC_MarineLayer MC_Source MC_SeaSurface MC_AboveSeaSurface MC_WaterColum MC_Seabed MC_UnderSeabed MC ArchiveHistoricalRecord

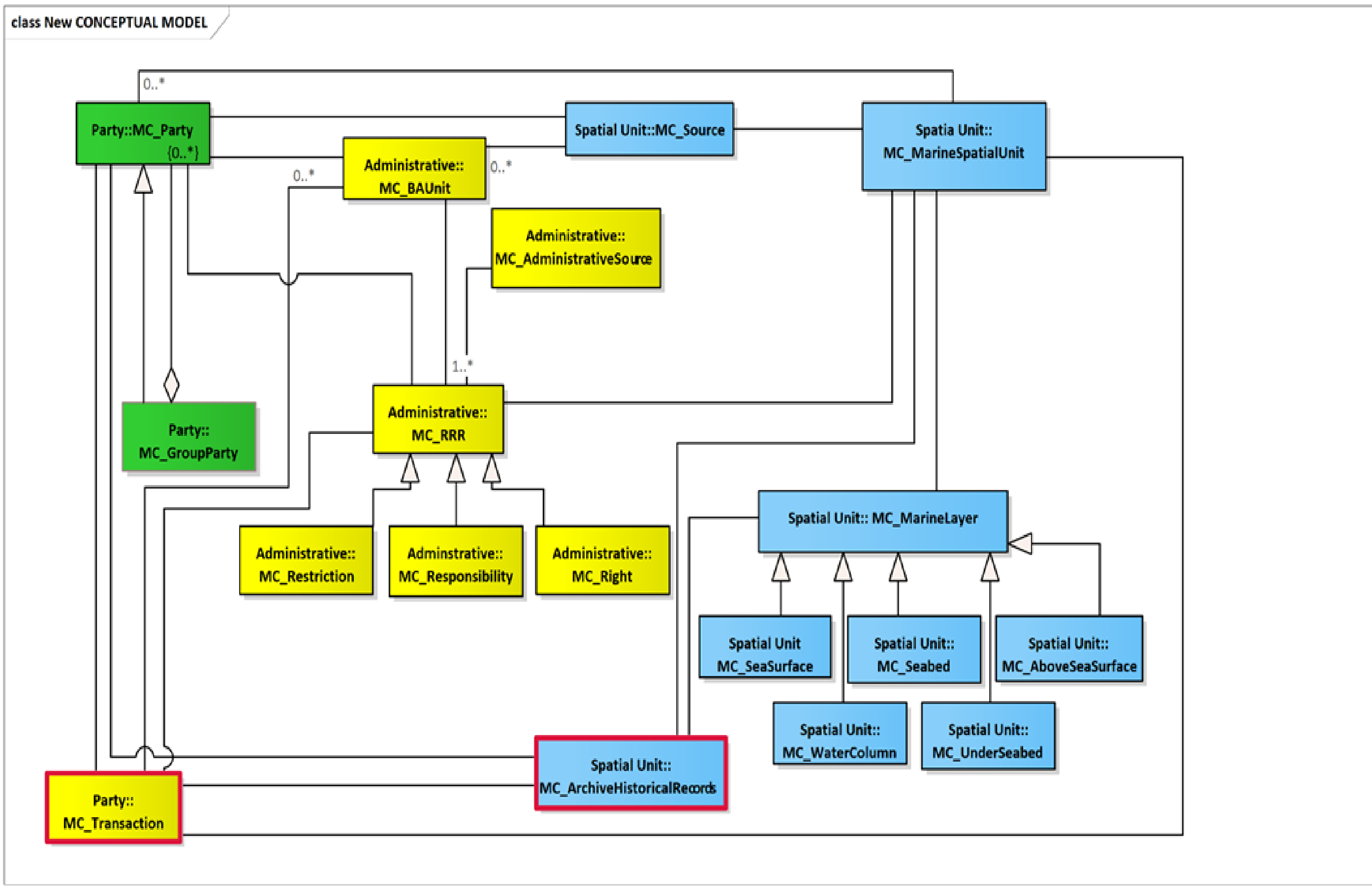


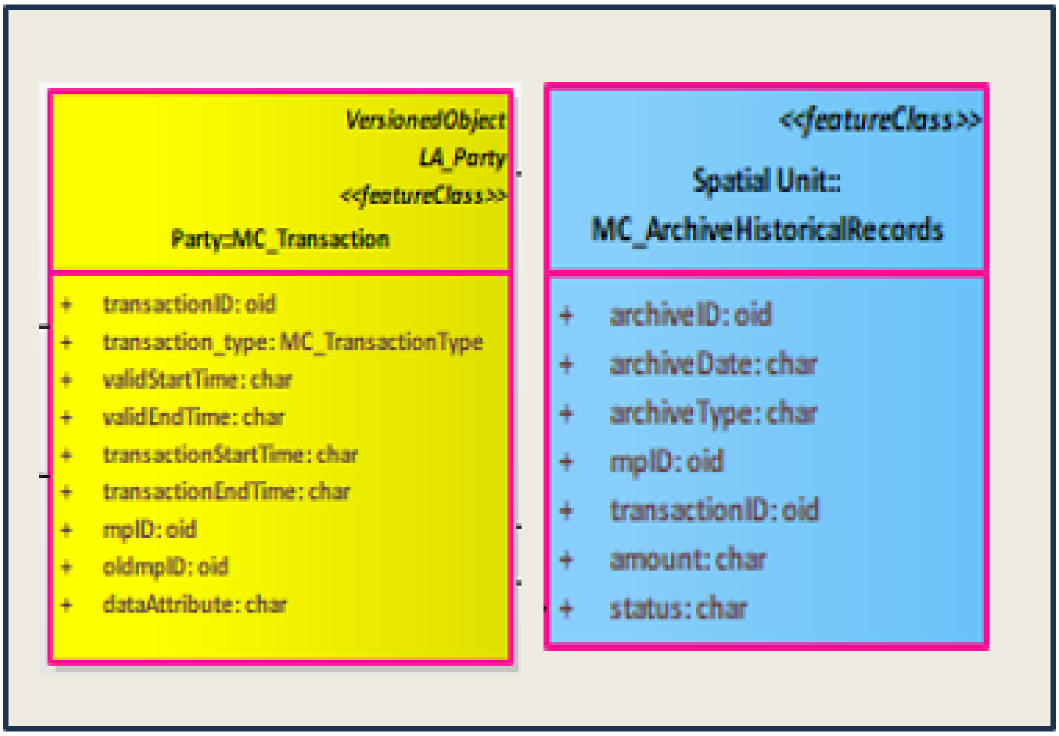
Figure 8. The 4D Marine cadastre conceptual data model

Figure 8 shows the developed 4D marine cadastre conceptual data model 4D (3D+T) (MCDM) with the introduced classes. The model comprises of party, administration, and spatial unit packages, but surveying and representation were excluded due to 'no-mark boundary quality' enabled by maritime space georegulation technology. The parties participating in a marine environment can include a state, a stakeholder, a company, or a group. Based on administrative interests, the party package in this work acquired the MC_Transaction class, which specifies who has superior jurisdiction over maritime operations or marine parcels and is introduced to the MC_Party unit. In this research work, the prefix 'MC_' designates the Marine Cadastre and is utilized. MC_Party is organized in green and subdivided into MC_Party and MC_GroupParty. MC_Administrative in yellow is expanded into MC_RRR, MC_Right, MC_Responsibility, MC_Restriction, MC_BAUnit, MC_AdministrativeSource, and MC_Transaction. The spatial unit in blue and enlarged to include MC_MarineSpatialUnit, MC_MarineLayer, MC_Source, MC_SeaSurface, AboveSeaSurface, MC_WaterColum, MC_Seabed, and MC_UnderSeabed is inherited from the current 3D Malaysian marine cadastre data model. At the same time, the MC_ArchiveHistoricalRecords class is introduced to the spatial unit, enhancing the marine administration. The transaction class is related by associations with MC_Party, MC_RRR, MC_BAUnit, MC_SpatialUnit, and MC_ArchiveHistoricalRecords, respectively. MC_AchiveHistoricalRecords is equally related by association to MC_Transaction, MC_Party, MC_Spatial Unit, and MC_MarineLayer, respectively. The proposed classes of transaction (bitemporal) and archive historical records have data structure and as in table 2.

MC_Transaction (Bitemporal)
+ transactionID: oid a unique identifier for the record.
+ Transaction_type: MC_TransactionType Relevant data attributes (e.g., owner name, land parcel ID).
+ validStartTime: char (The beginning of the valid time)
+ validEndTime: char (The end of the valid time)
+ transactionStartTime: char (The beginning of the transaction time).
+ transactionEndTime: char (The end of the transaction time)
+ mpID: oid
+ oldmpID: oid
+ dataAttribute: char

MC_ArchiveHistoricalRecords
+ archiveID: oid (a unique identifier for the record)
+ archiveDate: char
+ archiveType: char
+ mpID: oid (Marine property ID)
+ amount: char
+ status: char

Table 2. Proposed new classes and its data structure



4. CONCLUSION AND FUTURE WORK

In conclusion, this study presents a practical implementation of 3D LADM provisions within the marine and land context, offering a model for essential aspects of modern urban planning. The 4D (3D + Time) Marine Cadastre Conceptual Data Model (MCDM), based on LADM Edition II, aims to enhance marine property management by integrating temporal elements, particularly along the Terengganu shoreline. The model introduces a bitemporal transaction class, the archive historical record class, which tracks both valid time and transaction time. This dual-time perspective ensures a comprehensive and accurate record of data changes over time, preserving historical data and transaction records. To accommodate bitemporal data specific to marine environments, modifications to the current LADM version object may be necessary. Such adjustments are critical for thorough analysis and maintaining continuous data updates, which are essential for effective marine property management. Importantly, this research aligns with global and national priorities, contributing to the United Nations Sustainable Development Goals (SDGs) 11, 14, and 15, and supporting Malaysia's National Agendas 4 and 5. Despite its potential, this study has limitations, as it does not cover the provision of unique parcel identifiers for Malaysian maritime parcels, user training, or data auditing. Future work would be on the data model development, visualization, and validation to fully realize its potential and broader applicability.

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BIOGRAPHICAL NOTES

Yusuf Hussaini Atuklukwu obtained his MGIS in 2012 from the University of Ilorin, Nigeria. He has been a chief lecturer since 2015, teaching GIS and cartographic courses at the Federal Polytechnic in Bida, Niger State, Nigeria. He has been a PhD student since 2022 and has published in 2024: Developing a 4D Malaysian Marine Cadastre Data Model Based on LADM: Preliminary Works, Xlviii (January), 11–12. The International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences, Volume XLVIII-4/W9-2024, and in 2023, Marine Cadastre Data Models With Temporal Aspect: Review. International Archives of the Photogrammetry, Remote Sensing, and Spatial Information Sciences—ISPRS Archives, 48(4/W6-2022), 159–166. https://doi.org/10.5194/isprs-archives-XLVIII-4-W6-2022-159-2023 and have publications to his credit. He belongs to several professional bodies, including the Geoinformation Society of Nigeria, the Nigerian Cartographic Association, and the and the Nigerian Institution of Surveyors.

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Developing a LADM Part 5 –
Spatial Plan Information country profile for Greece

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Key words: Spatial planning, LADM Edition II, ISO19152-5, LADM Country Profile, Greece

SUMMARY

Spatial planning is a critical element of Land Administration (LA), involving the assessment and management of land use, development, environmental protection, and the optimal utilization of land resources. Recognizing the significance of integrating spatial planning information into the Land Administration Domain Model (LADM) framework, LADM Edition II introduces a dedicated part for spatial plan information -Part 5. This paper delves into the conceptualization and development of the LADM Part 5 – Spatial Plan Information country profile for Greece (GR_SP_LADM). The development of this profile aims to enhance the applicability of LADM Edition II Part 5 and to support better planning, monitoring, and management of spatial data in alignment with Greek regulations.

Spatial planning in Greece operates on multiple levels—national, regional, and local/municipal—each corresponding to different scales of implementation. The national level offers broad spatial guidelines, while the local level focuses on community-specific planning, which may encompass one or more municipalities or even regional or hyper-local areas. Given the complexity of spatial planning processes in Greece, standardization is vital for ensuring interoperability across the different hierarchical levels of government and stakeholders. This paper aims to make the organization of spatial planning-related information in Greece more efficient and transparent, thereby promoting sustainable growth and urban development using consistent spatial data structures and clear legal and administrative procedures.

Therefore, the paper examines the country profiles of LADM Part 5 that have been developed (as in the case of Indonesia, Turkey and others), with a focus on the current state and evolution of spatial planning in Greece. It maps the existing spatial planning framework against the concepts and classes of LADM Part 5, resulting in the development of a tailored country profile for Greece. This profile is illustrated through UML diagrams and at the next step of this research, it will be implemented in a database and validated through instance-level diagrams and practical implementation using 2 case studies. Future work includes the comparison of the country profile for LADM Part 5 for Greece, with the profile developed for Turkey using corresponding use cases.

Developing a LADM Part 5 – Spatial Plan Information country profile for Greece

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1. INTRODUCTION

Land Administration (LA) has emerged as a critical concern in the modern world, with effective land management playing a vital role in ensuring sustainable land use and safeguarding the interests of both present and future generations. Spatial planning, a key component of LA, involves the systematic organization of land use across various scales and planning levels. To enhance the effectiveness of Spatial Planning, it is essential to standardize these processes, thereby ensuring consistent and sustainable development outcomes.
The international standard LADM (ISO 19152), particularly through its revised edition, provides a comprehensive framework for standardizing spatial planning. LADM supports interoperability in representing Rights, Restrictions, and Responsibilities, including the representation of spatial plans in four dimensions—3D space and time (ISO/ DIS, 2023).
The decision to publish LADM Edition II as a multi-part series has resulted in the development of six standards that are backward compatible with Edition I and together they form LADM Edition II. LADM Part 5 - Spatial Plan information includes a conceptual model that encompasses packages related to plan units, plan blocks, plan groups, and permits.
Defining the role and scope of spatial planning within the broader context of LA is crucial. As highlighted, spatial planning significantly contributes to the core objectives of LA, including the registration of property information, valuation, and land use management (UNECE, 1996).
This paper aims to develop a country profile for Greece based on LADM Part 5. In developing this profile, legal, institutional, and technical considerations have been carefully examined (Kalogianni et al., 2021), with particular attention to Greece's three planning levels: national, regional, and local.
The rest of the paper is structured as follows: Section 2 discusses the hierarchy of planning levels in selected countries, chosen for their design similarities to Greece. Section 3 presents the development of country profiles based on LADM Part 5 (ISO 19152-5). Moreover, Section 4 outlines the methodology and process for creating the country profile for Greece, while Section 5 provides conclusions and discusses potential future work.

2. SPATIAL PLANNING IN SELECTED COUNTRIES

Spatial planning can be regarded "the soul of space optimization" (Liu & Zhou, 2021), given its role in guiding strategic interventions in spatial development (Giannakourou, 2022; Economou, 2008). The objectives set within spatial planning vary by country and are influenced by international and European policies (Wassenhoven, 2004 in Seitanidis, 2023;

Asprogerakas & Zachari, 2019; Asprogerakas, 2016) as well as by challenges that manifest on both global and local scales (Wassenhoven, 2009 in Wassenhoven, 2022). Additionally, local traditions, significantly impact these objectives (Vassi et al., 2022a), contributing to the diversity of spatial planning systems across Europe and globally (Wassenhoven, 2023; Vassi et al., 2022). Giaoutzi and Stratigea (2011) argue that spatial planning must address problems by considering their spatial context and impact, which requires identifying a cohesive spatial (residential) system. Furthermore, Vassi et al. (2022a) highlight that legal initiatives for spatial management differ across countries due to varying legal traditions. In Europe, these traditions are generally categorized into four "legal families" (Germanic, Scandinavian, British, and Napoleonic - with Greece falling under the latter) that correspond to five planning traditions: Germanic, Scandinavian, British, East European, and Napoleonic (Newman and Thornley, 1996).

It is important to note that a planning system encompasses all tools (plans, frameworks, or directives) applied across different spatial scales (Economou in Wassenhoven, 2022). Giannakourou (2022) suggests that a planning system primarily revolves around spatial plans, which can be categorized into four categories based on criteria such as objectives, content, spatial scale, and legal implications resulting from their institutionalization (Giannakourou, 2022; Silva & Acheampong, 2015):

- **Perspectives – Visionary Plans:** These plans include policy statements and long- or medium-term goals and visions for spatial development across various scales. They are typically indicative, programmatic in nature, and provide direction to administrative bodies, resulting in loose binding. An example is the Structuurvisies in the Netherlands. Countries like Australia, the USA, Canada, Spain, and Sweden do not have national policy and perspectives of this type.
- **Strategic Plans:** These plans provide integrated frameworks that coordinate the spatial impacts of various planning activities implemented by public bodies, ensuring vertical and horizontal coordination. Examples of such plans include regional plans in Japan, Korea, Turkey, Denmark, Estonia, and Slovenia.
- **Framework Plans:** These plans are further divided into structure plans and master plans, which are tools for socio-economic policy development and location-specific land use planning. They operate at either the municipal level or higher/lower levels (clusters of municipalities or municipal units). Municipal Structure Plans in Belgium and District Outline Plans in Israel are typical examples.
- **Regulatory Plans:** These plans regulate development and protect individual parcels of land, usually through detailed planning. Examples include planning permission in the UK and Ireland, Byggetilladelse in Denmark, Permis de construire in France, Baugenehmigung in Germany, and Licenciamento Municipal de Obras Particulares in Portugal. Similar tools exist in the USA, where land-use zones are defined.

Given this global categorization, studying Greek spatial planning is crucial to understanding its distinctive approach within this broader context. Exploring the Greek spatial planning framework provides valuable insights into how national legal, cultural, and administrative traditions influence the formulation and implementation of spatial plans, thereby building the foundations for the development of country profile for LADM Part 5, as presented in Section 4.

3. LADM PART 5 - ISO 19152-5: SPATIAL PLAN INFORMATION AND ITS IMPLEMENTATIONS

This section provides an overview of the recent advancements in the implementations of LADM Part 5- Spatial Plan Information. Although Part 5 has not yet been voted as ISO standard, several countries have developed country profiles for their spatial planning systems based on its structure and concepts.

LADM Part 5 supports planning hierarchies, plan units are organized through plan blocks, while spatial functions and spatial planning permit registrations are supported. This ensures a comprehensive approach to land management by linking land tenure with spatial information (Indrajit et al., 2020). The primary goal is to document the RRRs associated with spatial plans, ensuring compatibility with data from land tenure, value, and development activities (Indrajit et al., 2021).

The spatial planning package in LADM Part 5 includes five key classes, each with distinct attributes designed to represent different aspects of spatial planning. These classes are: SP_PlanGroup, SP_PlanUnitGroup, SP_PlanBlock, SP_PlanUnit, and SP_Permit. The SP_PlanGroup class plays a hierarchical role, representing different spatial planning levels, thereby facilitating the classification and distinction of planning levels, while the SP_PlanUnitGroup corresponds to areas associated with higher planning levels, representing larger planning areas. The SP_PlanBlock class is an integral part of LADM Part 5, composed geometrically of one or more SP_PlanUnits. The SP_PlanUnit class represents the smallest homogeneous area at the highest scale, offering the greatest level of detail among the classes. Finally, the SP_Permit class addresses various permits relevant to spatial planning processes (ISO/ DIS, 2023).

Indonesia was the first country to pioneer the adoption of LADM Part 5 at a conceptual level (Indrajit et al., 2019), aiming to effectively integrate RRR-related information from LA into existing LAS while embracing a participatory approach. This initiative led to the development and iterative enhancement of Indonesia's country profile, including the creation of a 3D planning data model for cities like Jakarta. The improvement of the LADM country profile was guided by the examination of three key aspects related to the incorporation of spatial planning information: additional data for land-use planning, the inclusion of parties related to land possession and spatial planning and RRR information. Furthermore, another notable application of LADM in Indonesia is the implementation by BPN (Badan Pertanahan Nasional), the national land agency, of a computerized land office system that leverages an interest-based system (Computerized Land Office) grounded in LADM principles.

Apart from Indonesia, several other countries have also applied the Draft International Standard (DIS) LADM Part 5 to meet their specific spatial planning needs. In Turkey, Yilmaz et al. (2024) analyzed the requirements of the Turkish spatial planning system and developed a corresponding country profile (Figure 1). The conceptual profile was validated through instance-level diagrams and technically implemented using Netcad. Additionally, Gruler (2023) extended the CityJSON schema based on the conceptual model of LADM Part 5 and tested it with real-world use cases for approved zoning plans in Turkey.

Furthermore, for the Netherlands, van Aalst (2023) based on the LADM edition I country profile that was already in place, followed the methodology of making a country profile (Kalogianni et al., 2021) and developed a country profile for LADM part 5. The Netherlands has a comprehensive spatial planning system that divides land into various uses, including residential, industrial, agricultural, and natural areas. There are five different geoportals providing open data for them from different spatial plans, tailored to the needs of each managing institution, leading to ambiguities and interoperability issues when it comes to use them together for the LADM country profile.

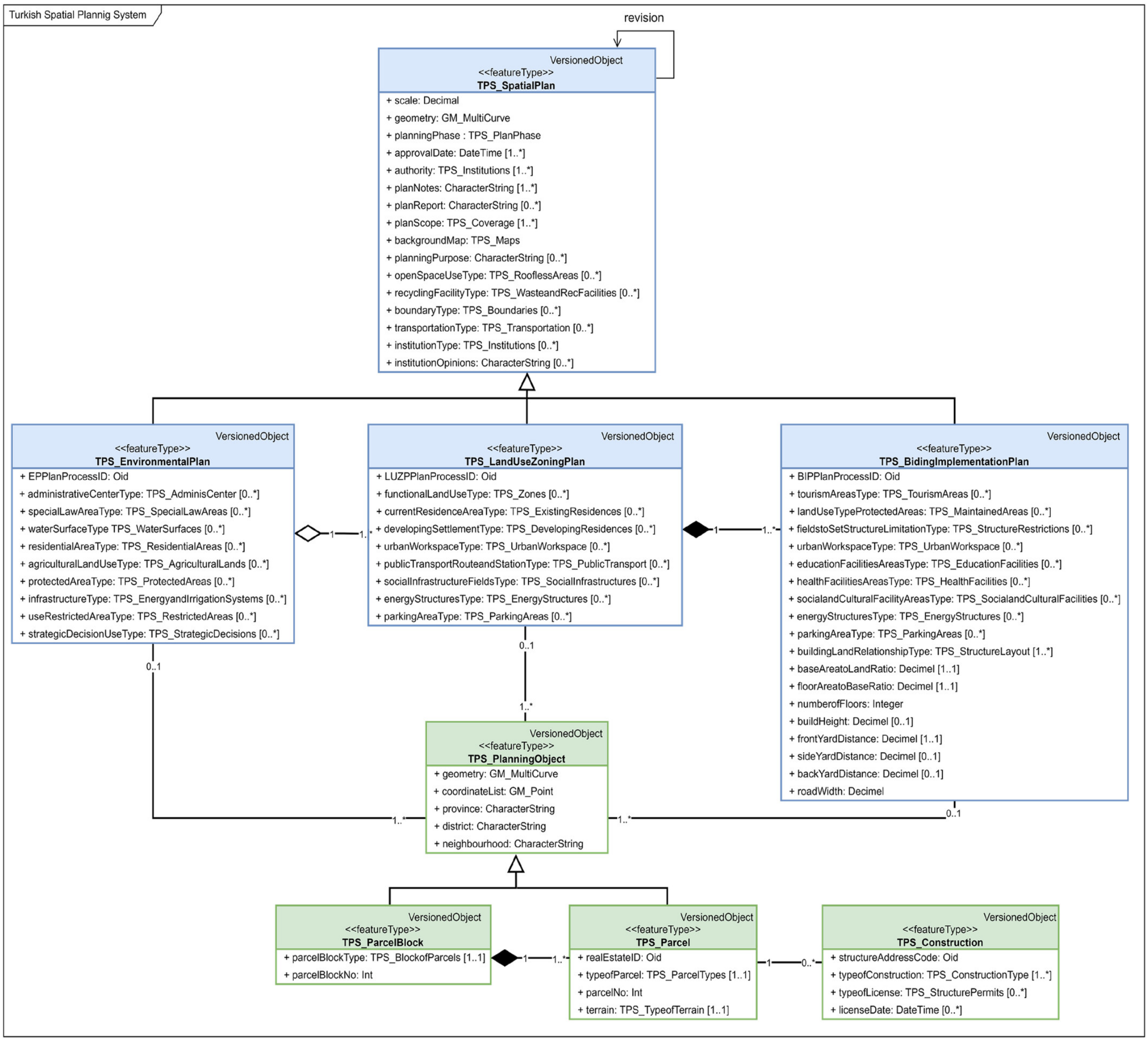

Figure 1. UML class diagrams of the Turkish LADM Part 5 country profile (Yilmaz et al., 2024)

Finally, Batum et al. (2024) proposed the integration of IFC with LADM Part 5 to standardize BIM-based permit checking processes, focusing on a case study from Estonia. An LADM Part 5 country profile for Estonia, integrated with the Estonian spatial planning database has been developed alongside a prototype solution for compliance checks among Estonian spatial plans, implemented with the software solution provided by Future Insight B.V. The Estonian LADM profile achieved Level 2 conformance according to the abstract test suite of ISO 19152:2012(E), demonstrating its ability to address both national requirements and international standards effectively.

4. DEVELOPING AN ISO 19152-5 PROFILE FOR GREECE

The intricate nature of spatial planning in Greece necessitates the creation of a country profile based on LADM Part 5. The LADM can effectively support this complex system, which is subject to frequent updates and changes, by offering a unified framework for LA, consistent spatial data structures, and clear legal and administrative processes. A well-developed profile will introduce the necessary legal and institutional data to govern the RRRs within Greece's Land Administration Systems (Kalogianni et al., 2021).
The development of the Greek country profile followed the methodology proposed by Kalogianni et al. (2021) for creating LADM-based country profiles. This process involved completing 'Phase I: Scope definition' and 'Phase II: Profile creation (modelling)'. The final phase, 'Phase III: Profile testing (implementation)', will be addressed as part of the future work in this research.

4.1 Phase I - Scope definition of the LADM Part 5 country profile for Greece

To establish a comprehensive and future-proof profile, it was essential to first define the scope to cover, not only the current situation of spatial planning in Greece, but also the anticipated changes stemming from recent legislative updates. The current and evolving legal framework introduces flexibility into the Greek spatial planning system, highlighting the need for standardization to facilitate a more adaptive approach to spatial planning. The structure and interrelations within the Greek spatial planning system are illustrated in Figure 2.
The Greek spatial planning system has undergone significant transformation, primarily due to Law 2742/2020, which amended Law 4447/2016. The revised framework introduces a three-tiered, top-down hierarchical system that is more adaptable than its predecessor. The first two levels—national and regional—focus on strategic plans coordinated by a visionary national strategy, known as the National Spatial Planning Policy (Nowak et al., 2023). This strategy also includes a guiding document addressing maritime space, although it is not classified as a formalized plan. However, due to delays in finalizing this strategy, the previously established General Framework for Spatial Planning and Regional Development (GFSPRP) continues to play a crucial role. Papageorgiou (2017) notes that this political decision effectively downgraded the GFSPRP, while elevating the status and thematic scope of Special Spatial Plans.
At the national level, Special Spatial Plans (SSPs) were first introduced by Law 2742/1999, to provide sector-specific directions in areas of critical importance (Gourgiotis et al., 2022), such as penal institutions (prisons), renewable energy sources, industry, aquaculture, tourism (this plan has been canceled by the Council of State) (Kyriakidis et al., 2022), and mineral raw materials (currently under implementation) (Gourgiotis & Tsilimigkas, 2021).
Alongside these, Regional Spatial Plans (RSPs) hold equivalent importance, with both being binding on each other. Since the reforms introduced by the Law 4447/2016, RSPs have been elevated in significance, allowing them to complement, specify, or modify SSP directions when permitted (Giannakourou, 2022; Stefani, 2021). Furthermore, Maritime Spatial Plans (MSPs) have been integrated at the regional level to manage marine spatial units, operating under guidelines set by the National Spatial Planning Policy for Maritime Space. These plans focus exclusively on marine spaces, avoiding conflicts with terrestrial plans (Gourgiotis & Tsilimigkas, 2021; Gourgiotis et al., 2023; Papageorgiou & Kyvelou, 2021).

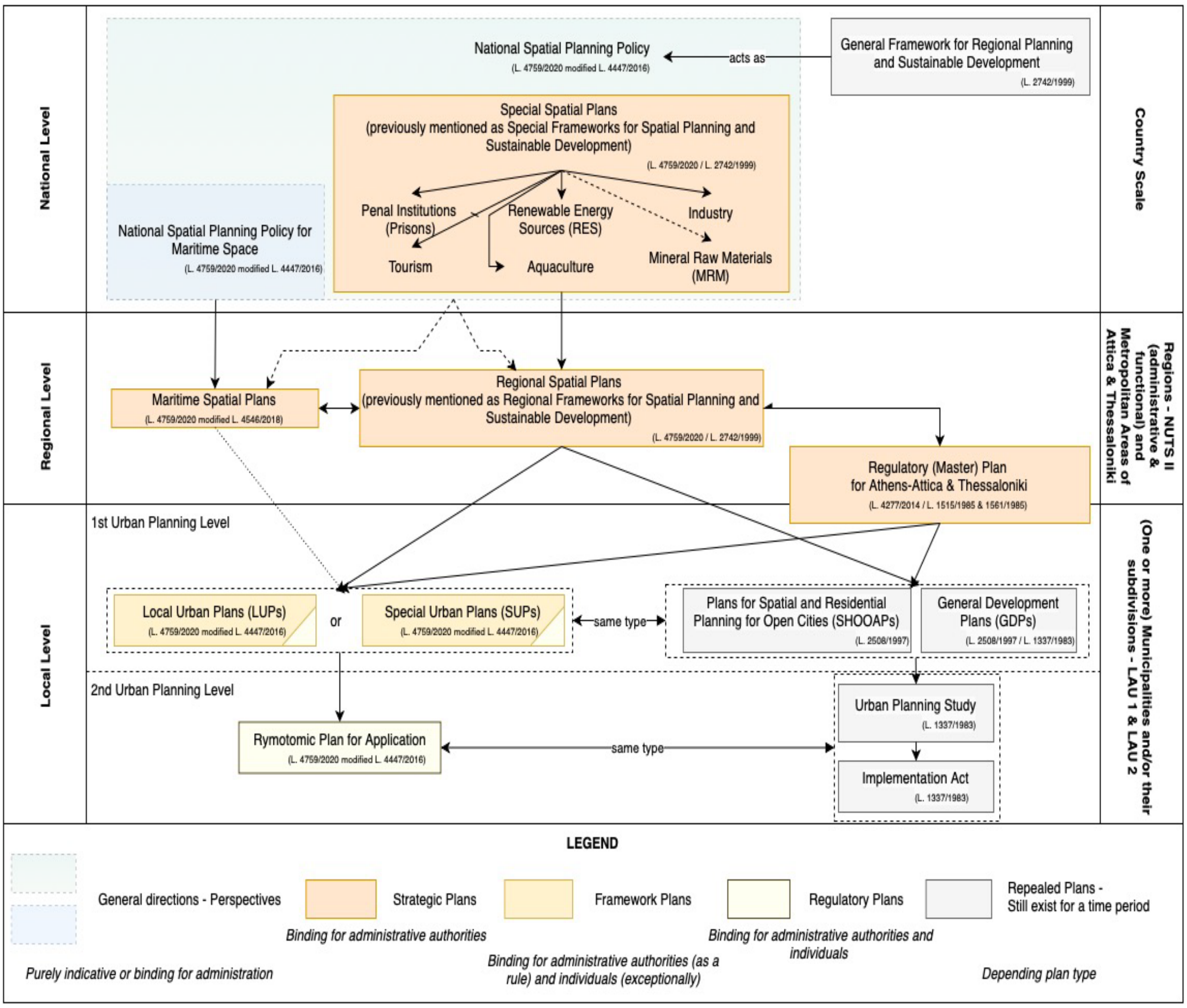

Figure 2. Structure and relationships of the Greek spatial planning system

Between the regional and local levels, a distinct category of plans addresses metropolitan areas, reflecting their strategic developmental role (Bakogiannis, et al., 2024). Regulatory (Master) Plans for the major metropolitan regions of Attica and Thessaloniki remain in effect, with those for other metropolitan areas repealed. These plans that have been institutionalized through ad hoc laws (Economou, 2007 in Siolas, et al., 2015), differ in their geographic scope: the Attica plan covers the entire region, effectively acting as a RSP, while the Thessaloniki plan covering selected parts, serves as an intermediary between regional and local spatial planning (Bakogiannis et al., 2024).
At the local level, the planning system adopts directions from the higher levels (Gourgiotis et al., 2022; Bakogiannis et al., 2021). This third level includes framework and regulatory plans structured into two categories: Local Urban Plans (LUPs) and Special Urban Plans (SUPs), which are intended to replace the older General Development Plans (GDPs) and Plans for Spatial and Residential Planning for Open Cities (SHOOAPs) that were institutionalized since 80s and 90s, respectively, for planning system to be more flexible (Asprogerakas, 2016). While LUPs and SUPs serve as flexible updates to the planning framework, GDPs and SHOOAPs remain valid until fully replaced. It is important to note that LUPs and SUPs are

not concurrent; each is designed to be implemented under specific circumstances. These plans, although primarily framework-oriented, also incorporate regulatory elements (Giannakourou, 2022). The approval process for LUPs and SUPs has been upgraded under Law 2742/2020, requiring a Presidential Decree, which contrasts with the past approval process through centralized or decentralized administrative bodies. This change makes the provisions more binding and directly enforceable.
Under the previous system, local planning was further detailed through Urban Planning Studies and Implementing Acts. These have now been replaced by Regulatory Plans for Application, which are explicitly regulatory in nature.
In Greece, spatial planning data availability is currently undergoing significant improvement, particularly through the development of geoportals at the local level. Given that much of the spatial planning information exists in non-digital formats, numerous local and regional authorities have taken initiatives to digitize their data and provide open access to spatial planning elements within their jurisdictions. However, the access rights, accuracy, and reliability of these open data services differ considerably across platforms. Additionally, it is common for similar or overlapping thematic categories to be represented across different sources, leading to inconsistencies in data presentation and usability.

4.2 Phase II - Profile creation

Phase II of the methodology for creating LADM-based country profiles, involves the conceptual standardization using UML, specifically focusing on aligning the existing spatial framework of Greece with the LADM Part 5 concept and classes. This phase is particularly challenging due to the difficulties in finding direct correlations between existing national spatial data and the LADM classes. In many cases, not all LADM Part 5 classes are applicable, and sometimes the classes provided by the international standard do not fully capture the specific characteristics needed for the Greek context. Therefore, this phase requires multiple revisions to refine the model and ensure it meets the intended objectives.
The primary goal during this phase, is to develop a conceptual model that includes as many relevant LADM classes as possible to achieve high level of conformance with the standard, while also simplifying the profile under development. This approach is aimed to optimize the profile's applicability by aligning it with the international standard and the needs and requirements of spatial planning in Greece.
To develop the Greek country profile, key design decisions were made. Notably, the LADM Part 5 did not explicitly model strategic framework documents like the General Framework for Regional Planning and the National Spatial Planning Policy for Maritime Space, as these provide high-level directions without detailed provisions suitable for standardization. Figure 3 presents the mapping between the core LADM Part 5 classes and the main classes that reflect the Greek spatial planning reality.
Based on the strategic hierarchy of spatial planning in Greece, as outlined by legislation, it appears that the Special Spatial Plans occupy the highest national level, followed by the Regional Spatial Plans and the Maritime Spatial Plans at the regional level. While these plans operate at different levels, in the context of planning and standardization, they are considered to be on the same hierarchical level. This is because Regional Spatial Plans are related to, but not subordinate to, the Special Spatial Plans and Maritime Spatial Plans; instead, they are developed in parallel.

Current Spatial Planning in Greece	ISO 19152-5 Spatial plan information
Special Spatial Plan for Tourism	SP_PlanBlock
Special Spatial Plan for Industry	SP_PlanBlock
Special Spatial Plan for Renewable Energy Sources (RES)	SP_PlanBlock
Special Spatial Plan for Aquacultures	SP_PlanBlock
Special Spatial Plan for Penal Institutions (Prisons)	SP_PlanBlock
Special Spatial Plan for Mineral Raw Materials (MRM)	SP_PlanBlock
Regional Spatial Plans	SP_PlanGroup
Maritime Spatial Plans	SP_PlanGroup
Regulatory (Master) Plan for Thessaloniki	SP_PlanGroup
Local Urban Plans (LUPs)	SP_PlanGroup
Special Urban Plans (SUPs)	SP_PlanGroup
Rymotomic Plan for Application	SP_PlanBlock
Implementation Act	SP_PlanBlock
General Development Plans (GDPs) & Plans for Spatial and Residential Planning for Open Cities (SHOOAPs)	SP_PlanGroup
Urban Planning Study	SP_PlanBlock

Figure 3. The use of LADM classes in the standardization of the project for Greece

The Regional Spatial Plans in Greece were established first, followed by the Special Spatial Plans, indicating their parallel development. To reflect this hierarchy and relationship in the country profile, the SP_PlanGroup class was used to represent the Regional Spatial Plans and Maritime Spatial Plans, capturing their hierarchical nature. On the other hand, the Special Spatial Plans were modeled using the SP_PlanBlock class, as these plans function independently and operate alongside the other two types of plans.

At the next planning level, LUPs, SUPs, GDPs, and SHOOAPs, along with the Regulatory (Master) Plan for Thessaloniki, were standardized using the SP_PlanGroup class to reflect their hierarchical position. These plans are directly related to the Regional Spatial Plans, inheriting regional directions and depending on them for their implementation. While the Regulatory (Master) Plan for Athens-Attica aligns with Regional Planning and is grouped with Regional Spatial Plans, the Regulatory (Master) Plan for Thessaloniki, due to its sub-regional nature, is categorized differently.

At the subsequent level, the Rymotomic Plan for Application and the Urban Planning Study are modeled with the SP_PlanBlock class and are associated with LUPs, SUPs, and GDPs/SHOOAPs. This relationship is one of aggregation, where a Rymotomic Plan for Application cannot exist without the associated Local Urban Plans or Special Urban Plans.

Similarly, the Urban Planning Study is dependent on the General Development Plans/SHOOAPs.
Finally, the Implementation Act is linked to the Urban Planning Study through aggregation, meaning that without the Urban Planning Study, the Implementation Act cannot exist. However, the Implementation Act is considered part of the Rymotomic Plan for Application, and in cases where the Rymotomic Plan for Application is applied, the Implementation Act is not separate and thus has no independent correlation.
The UML diagrams of the LADM country profile for Greece, as shown in Figures 5 and 6, illustrate how these various spatial planning tools and plans are standardized within this framework.
Additional analysis was carried out for the LUPs and the SUPs to further refine their representation within the LADM framework. This analysis was particularly necessary given that these two plan categories form the foundation of a streamlined system designed to address long-standing urban and spatial planning challenges in Greece. These plans are part of a broader initiative currently funded by the Hellenic Recovery and Resilience Facility, set to be implemented between 2022 and 2026 under the supervision of the Hellenic Ministry of Environment and Energy (Vassi et al., 2022a; Vassi et al., 2022b).
The key components for both plan types include the classes: Xoriki_Organwsi_TPS, Oikismos, Tomeas_Poleodomikou_Kanonismou, Poleodomiki_Enotita, and Genikes_Xriseis_Gis.
These components are critical in the spatial planning process as they define the core spatial planning elements. Therefore, further modelling of them in their corresponding LADM classes was undertaken, as illustrated in Figure 6. This modelling effort ensures that the LADM-based profile accurately represents the current and future needs of spatial planning in Greece, allowing for better alignment with international standards and improved interoperability across different levels of government and planning authorities.

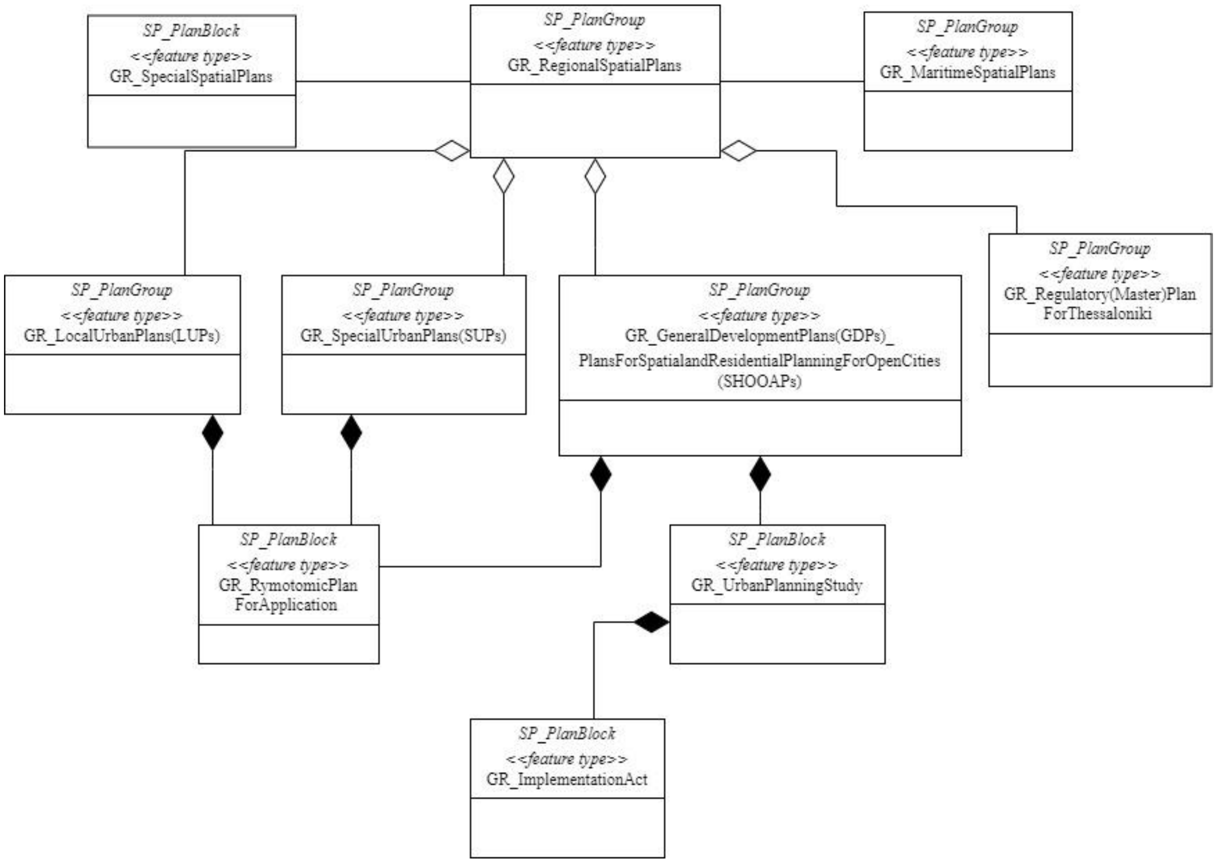

Figure 5. UML country profile of Greece -1

Upon closer examination, it was noted that Tomeas_Poleodomikou_Kanonismou is autonomous and independent of the other components. This element defines the limitations and building regulations within specific areas, making it appropriate to model it as an SP_PlanBlock in the LADM framework. On the other hand, Xoriki_Organwsi_TPS, Oikismos, Poleodomiki_Enotita, and Genikes_Xriseis_Gis are all represented as SP_PlanUnitGroup classes. These classes collectively capture the hierarchical organization of spatial units and land use designations as dictated by the LUPs and SUPs, ensuring that the framework accurately reflects the complexities of spatial planning in Greece.

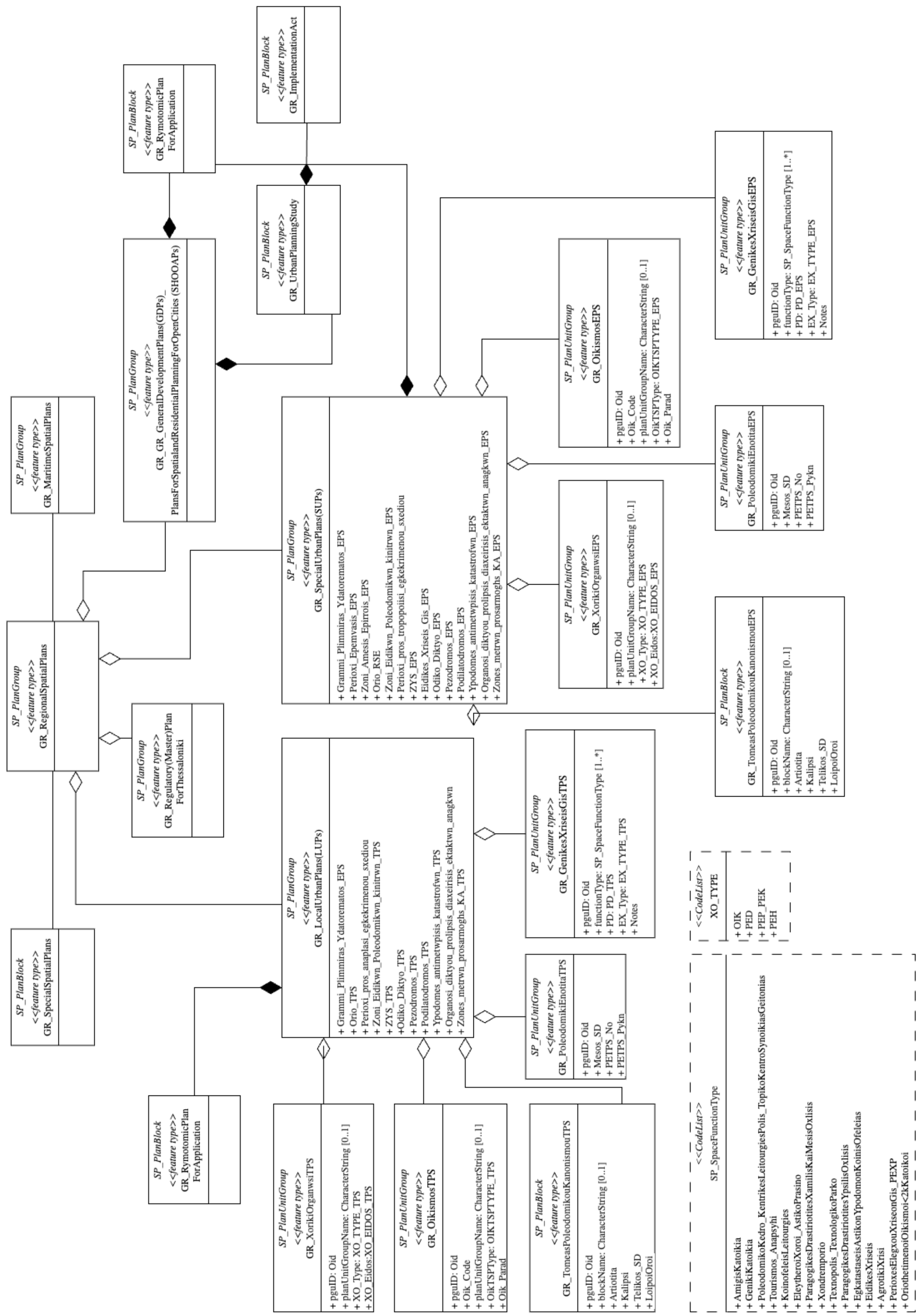

Figure 6. UML country profile of Greece -2

5. CONCLUSION AND FUTURE WORK

This study has developed an LADM-based country profile for Greece, focusing on Part 5, which deals with spatial planning information. This involved a thorough examination of Greece’s spatial planning system, encompassing both the existing framework and anticipated changes driven by evolving legislation. The profile was designed to address the complex nature of Greek spatial planning, which operates across multiple levels—national, regional, and local—each with its own specific plans and tools. Given this complexity, standardization was essential to create a more flexible and efficient spatial planning system, while ensuring consistent spatial data structures and transparent legal and administrative processes. By standardizing spatial information, which is very important for a complex system like Greece’s, the development of this model ultimately enhances the flexibility of the Land Administration System (LAS).

The next stage of the methodology, following the study of the Greek spatial situation and its challenges, involved correlating the standard LADM with its specific classes. The Greek plans/tools which were standardized based on the LADM classes were those containing objects for standardization, rather than general frameworks with broad directions. These plans and tools, which operate at national, regional and local spatial planning level, were standardized using basic classes of LADM-part 5, such as SP_PlanGroup, SP_PlanBlock, SP_PlanUnit and SP_PlanUnitGroup, depending on the requirements and content of each standardized element.

It is important to note that an additional phase should be incorporated into the existing methodology, to ensure the proper validation of the new model. Specifically, this phase III involves testing the developed country profile for Greece (Kalogianni et al., 2021). To advance to this phase, a repeated process must be followed, aiming to refine and improve the model through a pilot application. This approach will facilitate the transition from a conceptual model to standardized one, resulting in a well-defined final model. So, this phase III will involve examining two case studies to validate the model. The first case study is in the Attica region, focusing on an Implementation Act related to an Urban Planning Study. Relevant data will be provided by the Hellenic Cadastre, in compliance with GDPR regulations. The Implementation Act refers to the legislative and procedural framework that governs the detailed planning and execution of urban development projects, translating urban plans into actionable steps and ensuring adherence to regulations. The second case study concerns a municipal-scale project in the historic city of Chania, Crete. This study will assess municipal (local) plans and utilize the municipal WebGIS for spatial planning as the primary data source. Additionally, data captured through laser scanning will be used to create a 3D city model of the area. Both case studies will provide real-world data to validate and refine the model effectively. Further studies could explore the impact of the model on various stakeholders and assess its effectiveness in different contexts.

Finally, future work includes the comparison of the country profile for LADM Part 5 for Greece, with the profile developed for Turkey using corresponding use cases.

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Leveraging BIM/IFC for the Registration of Spatial Plans and Compliance Checks and Permitting in Estonia based on LADM Part 5 - Spatial Plan Information

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Key words: Land Administration, Spatial Plans, Digital Permitting, LADM, IFC, BIM

SUMMARY

This research explores the integration of IFC with LADM Part 5 Spatial Plan Information (ISO DIS 19152-5) to standardize BIM-based permit checking processes, focusing on a case study from Estonia. Land Administration Systems (LAS) are crucial in spatial development, managing land-related information. Rapid urbanization necessitates efficient space management, promoting the adoption of digital technologies in the Architectural, Engineering, and Construction (AEC) sector. The integration of Geographic Information Systems (GIS) and Building Information Modelling (BIM) presents opportunities for enhanced collaboration and data management. The main aim is to enhance efficiency, interoperability, and standardization in the compliance checks between different plan levels (e.g., Detailed Plan vs Mater Plan) by incorporating LADM Part 5 into digital frameworks. Traditional permit processes are often manual, time-consuming, and prone to errors. By integrating LADM Part 5 with IFC data, this research aims to create a standardized approach that not only improves data management and facilitates seamless information exchange but also maximizes industry and technical support to ensure compliance with international standards.

The methodology involves several key steps. First, a country profile for Estonia using LADM Part 5 is developed, tailored to the specific needs of the Estonian LAS. This profile integrates with PLANK, the Estonian spatial plan database, incorporating how Estonia acquires, stores, and requires data in their spatial plans. Next, a PostgreSQL database is created to store this profile. Pilot Detailed Plan datasets encoded in IFC format are then imported into the database using FME scripts, mapping the data to relevant sections. This integrated database supports digital permitting processes, specifically plan compliance checks between different levels of spatial plans. Throughout the research, the country profile is refined based on the optimizations of the database, driven by the specific requirements of the input data processed through FME scripts. Given that LADM is a standardized model, the database enforces specific data structures, ensuring processed data is valuable and relevant. The FME scripts facilitate this process, ensuring the data extracted from the database is standardized and user-friendly. Constraints such as maximum building height restrictions are pre-processed and stored within the database, enabling users to access this information without manually reviewing raw plan data. Later, the database was sampled using pilot datasets, with the tools

and scripts made available on the research's GitHub repository. After storing the spatial plan data in the database, data can be directly accessed by scripts designed to execute compliance checks between Detailed Plans and Master Plans, as shown in the Estonia case study. Although developing these specific checks is beyond this research's scope, the work was structured to integrate smoothly with the processes used in the Estonia case study.
Preliminary findings show that combining LADM with IFC improves data representation, enhances interoperability, and establishes a consistent standard for compliance checks between Master and Detailed Plans. This research contributes to developing standardized, reliable, and efficient permit checking systems, with important implications for urban planning and land management.

Leveraging BIM/IFC for the Registration of Spatial Plans and Compliance Checks and Permitting in Estonia based on LADM Part 5 - Spatial Plan Information

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1. INTRODUCTION

Spatial development and rapid urbanization necessitate efficient Land Administration Systems (LAS) to manage and govern land-related information. The integration of Geographic Information Systems (GIS) and Building Information Modelling (BIM) presents new opportunities for enhanced collaboration and data management in the Architectural, Engineering, and Construction (AEC) sector. Traditional permit processes are often manual, time-consuming, and prone to errors. Utilizing digital technologies and standards can enhance the efficiency, transparency, and reliability of these processes. This research aims to improve the compliance checking and permitting process by incorporating the Land Administration Domain Model (LADM) Part 5: Spatial Plan Information with IFC.

Despite the potential benefits, translating complex urban regulations into a machine-readable format for automated permit checks remains a challenge. This research addresses this challenge by integrating LADM Part 5 with IFC to create a standardized approach for BIM-based permit checking. The research focuses on developing a country profile for Estonia using LADM Part 5, creating a PostgreSQL country profile database, and importing Detailed Plans encoded in IFC formats to the database. The Estonia case study serves as a reference point for developing and assessing the implementation.

The study follows a Design Science Research approach (Hevner & Chatterjee, 2010), involving three main stages: reviewing existing literature and standards to define the problem and gather knowledge; developing a conceptual model for integrating LADM and BIM, and mapping relevant data for the Estonia case study; implementing the model, creating an FME script and a PostgreSQL database, and continuously refining the model based on feedback and assessment results. This methodology ensures a structured approach to addressing the research questions and developing a practical solution for automated permit checking.

The paper is structured as follows: Section 2 presents the related research on LADM Part 5 and BIM-based permits. Section 3 details the case study of Estonia, including the development of the country profile and the database implementation. Section 4 discusses the integration process and the results of applying the model to the case study. Section 6 evaluates the system's effectiveness and compliance with international standards, while Section 7 concludes the research and outlines potential directions for future work.

2. RELATED RESEARCH

2.1 LADM Part 5 and its Implementations

The Land Administration Domain Model (LADM), provides a comprehensive framework for land administration, systematically recording and disseminating information about land ownership, value, use, and the relationship between people and land(Simon Hull et al., 2024; UNECE, 1996). In its latest revision, LADM has evolved into a multi-part standard known as LADM Edition 2. Among its various parts, Part 5 focuses on integrating land registry and planned land use information into a single conceptual model (Lemmen et al., 2023).

LADM Part 5 supports planning hierarchies, organizes plan units in a plan block, provides extensible code lists for spatial functions, supports permit registration related to relevant plan units, and allows open dissemination and clear 2D and 3D visualization of plan information. This integration ensures a comprehensive approach to land management by linking land tenure with spatial information (Indrajit et al., 2020). The primary goal is to document the rights, restrictions, and responsibilities (RRRs) associated with spatial plans, ensuring compatibility with data from land tenure, value, and development activities (Indrajit et al., 2021).

LADM country profiles are tailored versions of the standard that align with specific local land administration needs and systems. For instance, the Indonesian country profile integrates spatial planning information with land administration, addressing dynamic land use and urban planning needs (Indrajit et al., 2020). The Malaysian profile integrates 2D and 3D cadastral registration systems, enhancing information interoperability and supporting the National Spatial Data Infrastructure (SDI) (Zulkifli et al., 2014). These country profiles demonstrate the flexibility and adaptability of LADM to different national contexts, facilitating efficient land administration adapted to their specific requirements.

2.2 BIM-based Permit Checks

Building Information Modelling (BIM) creates a 3D representation of an asset with both physical and functional information. BIM serves as a shared knowledge resource for decisions throughout a facility's life cycle, from conception to demolition (Kubba, 2012). It incorporates various dimensions, such as 4D (time), 5D (costs), and 6D (asset management), and uses an object-oriented and information model to distinguish between elements like walls, doors, and windows.

BIM-based Model Checking (BMC) automates the building permit process by using algorithms to process BIM data and verify compliance with relevant building regulations. This approach increases the speed and accuracy of permit verification by supporting human decision-making and automating time-consuming and error-prone tasks (Beach et al., 2020; Gade et al., 2018). Traditional permit processes involve manually checking plans for compliance, which is time-consuming and prone to errors. BMC replaces this manual process with automated checks, ensuring that BIM models comply with regulations and standards. The use of BIM for building permits offers several advantages, including enhanced data representation, interoperability, and standardization. Combining BIM data with LADM Part 5 aims to create a standardized approach for permit checking. BIM data, encoded in the Industry Foundation Classes (IFC) file format, serves as a universal language for exchanging information across different software applications (Industry Foundation Classes (IFC), n.d.).

IFC data can be mapped to LADM Part 5 classes, ensuring a comprehensive approach to spatial planning and permit checking. Combining various data models can enhance the functionality and interoperability of digital permitting systems.

It should be noted that, the IFC files used in the Estonia case study, representing Detailed Plans, were specifically created for this research in collaboration with Future Insight and Estonia. Currently, Estonia primarily uses 2D data such as CAD for spatial plans. Despite this, IFC, being a widely adopted standard in the AEC industry, provides a robust framework for representing and exchanging building information. This makes it a suitable choice for this research, allowing for the seamless integration of Detailed Plans and spatial data into the LADM database. The integration of IFC in this pilot project was aimed at investigating the potential future use of 3D data in urban planning and permit checks, even though it is not yet the standard practice in Estonia. This exploration serves as a theoretical step towards possibly combining IFC data with existing 2D practices, paving the way for the future development in Estonia.

In summary, combining LADM with IFC enhances data representation, promotes interoperability, and facilitates the creation of standardized permit checking systems.

3. CASE STUDY: ESTONIA

This research is conducted in collaboration with Future Insight B.V. and the case study examined in this context is based on a project of the company in collaboration with the Ministry of Climate (Kliimaministeerium) of Estonia. This project is a follow-up project of Future Insight for automated BIM-based building permit checks, which laid the foundation for automated BIM-based permit checks in Estonia. The primary objective is to develop a prototype for plan compliance checks between Detailed Plans and Master Plans using IFC models and integrating with the Estonian e-construction platform. The project aims to address the need that Detailed Plans align with higher-level zoning regulations before the building permit issuance phase. This process occurs early in the planning lifecycle in Estonia and is designed to tackle any inconsistencies or non-compliance with zoning regulations before any construction begins. This helps ensure that the initial plan is compliant, reducing potential issues in later stages of the construction and registration processes.

The digitization of the planning process in Estonia advanced significantly with the introduction of PLANK in 2022, a centralized database mandated by the Spatial Planning Act. This regulation ensures that all established spatial plans from the 79 municipalities are accessible in digital form, containing the necessary digital information and meeting spatial data quality standards. PLANK's main goals include reducing the burden on municipalities, ensuring up-to-date plans, dissemination with stakeholders (including citizens) and facilitating the collaborative use of planning data with other information systems. The database features automatic validation checks that verify the validity and integrity of plans, allowing only validated plans to be shared and displayed. However, these checks are limited to 2D data and do not include compliance checks between different plan levels (e.g., Master Plan vs. Detailed Plan). Additionally, plans are only registered in PLANK after the planning procedure, whereas having plan data available throughout the planning process would be more beneficial.

This highlights the need for a mechanism capable of handling both 2D and 3D data to ensure adherence to regulations throughout the planning process.

The project began with desk research and interviews with key stakeholders to understand the challenges in Estonia's planning processes. The findings highlighted the need for better standardization, collaboration, and the adoption of 3D planning, as most of the existing planning data were in 2D formats, lacking interoperability. To address these issues, the project focused on integrating IFC as a standardized format for spatial plans, ensuring compatibility with Estonia's e-construction platform. Furthermore, the prototype developed utilized Clearly.HUB for data management and FME Flow for orchestrating checks, integrating Master Plan and object data from the city of Tallinn and the Land Board of Estonia.

Additionally, the project identified and implemented seven key compliance checks using IFC-based Detailed Plan data and other spatial datasets. Afterwards, these automated checks enabled assessing the compliance between Master and Detailed Plans specifically, with the results visualized through Clearly.HUB.

4. IMPLEMENTING ISO19152:5 – SPATIAL PLAN INFORMATION IN ESTONIA

The methodology for creating the LADM country profile follows a three-step process: first, establishing an initial mapping based on LADM Part 5 classes; second, iteratively refining the profile through expert feedback and integration with national databases like PLANK; and finally, validating and optimizing the profile with real-world data to ensure its practical applicability and conformance to international standards.

4.1 Current situation in Estonia

Estonia's land administration and spatial planning system is governed by the Planning Act, adopted on January 28, 2015, and came into force on July 1, 2015[1]. This Act redefined the principles, procedures, and responsibilities related to spatial planning, establishing a legal basis for all planning activities. It focuses on creating preconditions for sustainable development, encompassing environmental, economic, cultural, and social aspects. Additionally, spatial planning, initially organized under the Ministry of Finance, was transferred to the Ministry of Regional Affairs as of July 2023.

The Estonian spatial planning system is structured into a hierarchical framework involving various levels of spatial plans, seen in Figure 1.. At the top of this hierarchy are national spatial plans, which provide key guidelines and strategies for the country's development. National Plans, including the National Spatial Plan (NSP) and National

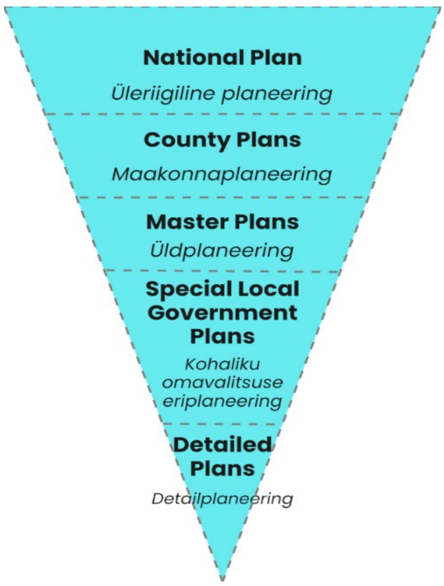

Figure 1. Spatial plan hierarchy of Estonia.

[1] https://www.riigiteataja.ee/akt/111062024012

Designated Spatial Plans (NDSPs), set guidelines to help regional and local plans develop in a coordinated manner, ensuring that all plans support national priorities. The NSP, currently "*Estonia 2030+*"[2], outlines country-wide development principles and is managed by the Ministry of Regional Affairs and Agriculture.
At the local level, spatial planning involves County-wide Plans, Master Plans (also referred to as Comprehensive Plans in the Estonian context), and Detailed Plans. The Ministry of Regional Affairs manages County-wide Plans, while municipalities handle Master and Detailed Plans. Additionally, all local plans are reviewed by the Ministry to ensure alignment with national guidelines.
The **National Plan** provides a broad, long-term vision for the spatial development of Estonia. "*Estonia 2050*,"[3] initiated on January 5, 2023, aims to define Estonia’s spatial structure and development principles up to 2050. It integrates regional characteristics and national objectives and is administered by the Ministry of Rural Affairs, with initiation and approval by the Government of the Republic .
The **County Plan** focuses on regional spatial development, balancing local and national needs, and provides guidelines for municipal planning. These plans integrate various sectoral interests and regional characteristics, influencing the preparation of municipal Master Plans. For example, the *Jõgeva County Plan*[4] outlines spatial development according to the vision and development trends agreed upon during the creation of the national plan "Estonia 2030+".

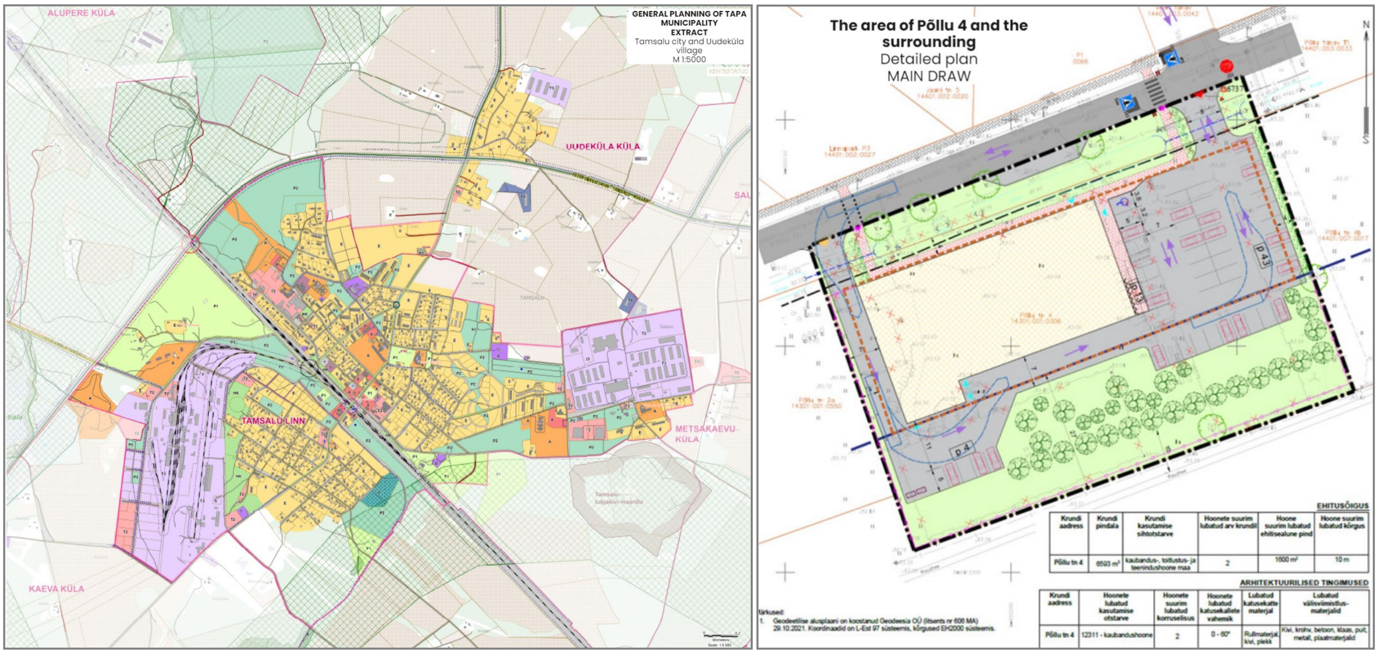

Figure 2. Tapa Parish Master Plan (left) showing Tamsalu town and Uudeküla village (scale 1:5000), and Põllu tn 4 Area and Surroundings Detailed Plan (right), illustrating land use and development specifics (scale 1:500). Figures by Kerttu Kõll, Janne Tekku, and Piret Põllendik with Entec Eesti OÜ, and Laura Andla

[2] https://eesti2030.files.wordpress.com/2014/02/estonia-2030.pdf
[3] https://riigiplaneering.ee/en/national-spatial-plan/national-spatial-plan-2050/national-spatial-plan-2050
[4] https://planeeringud.ee/plank-web/#/planning/detail/10100015

Master Plans are comprehensive plans that guide the development and use of land within specific areas. They provide a framework for land use, infrastructure, and community development. Municipalities are responsible for creating Master Plans, which align with County and National Plans and address local development needs. These plans set out general land use principles and development guidelines, providing a basis for more detailed planning activities[5]. An example of a Master Plan is the *Tapa Parish Master Plan*[6] (seen in left side of Figure 2), which outlines spatial development principles for *Tamsalu* town and *Uudeküla* village.

Detailed Plans are the most specific level of planning, focusing on individual sites or projects. They provide precise instructions for land use, infrastructure, and construction. Prepared by local authorities or private developers, Detailed Plans ensure compliance with broader Master Plans and County Plans. These plans include detailed information on land use, building design, infrastructure, and other specifics necessary for implementation. An example is the *Põllu tn 4 Area and Surroundings Detailed Plan*[7] (seen in right side of Figure 2), which specifies construction rights and land use changes for a commercial building.

Special Local Government Plans (SLGP) address specific spatial needs at the municipal level, focusing on particular projects or areas of interest. Local governments develop these plans to meet unique local requirements not covered by general plans. SLGPs provide detailed guidance for specific projects, complementing broader County and National Plans. These plans ensure significant projects are planned in suitable locations without hindering other activities. Established by the planning law effective from July 1, 2015, SLGPs expire if not implemented within five years, making them suitable for near-term development rather than long-term strategic planning.

Each level of planning in Estonia is designed to address different aspects of spatial development, and it is crucial to assess the potential impacts of these plans on the environment. This is where ***Strategic Environmental Assessment*** (SEA)[8] becomes important. As it ensures that the potential environmental impacts of various plans are thoroughly evaluated and addressed.

In Estonia, the SEA process applies differently depending on the type of plan. For National Plans, SEA is a mandatory procedure, focusing on strategic assessments of long-term and large-scale impacts on the environment, while County Plans are also important in regional development, they typically do not require a separate SEA process. Master Plans, being more localized, often require a specific SEA to address the direct and indirect impacts of proposed developments. Detailed Plans generally do not require an independent SEA but must comply with the SEA findings and recommendations from Master Plans.

4.2 LADM Part 5 Country Profile Development at a Conceptual Level

The By developing a country profile, the specific needs of Estonia's LAS can be addressed, allowing spatial plans and permit checks to be effectively integrated into the broader national infrastructure.

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[5] https://planeerimine.ee/ruumiline-planeerimine-2/kov-planeeringud/
[6] https://planeeringud.ee/plank-web/#/planning/detail/20100048
[7] https://planeeringud.ee/plank-web/#/planning/detail/30100010
[8] https://environment.ec.europa.eu/law-and-governance/environmental-assessments/strategic-environmental-assessment_en

The general layout of LADM classes and attributes might not always completely meet the needs of a country planning to utilize LADM. The country profile development involves creating or omitting classes, attributes and relationships if necessary to represent the specific needs of the country. There are two main approaches when developing an LADM country profile: a holistic view mapping all cadastral information, or a targeted approach focusing on specific parts based on the country's needs (Kalogianni et al., 2019). This research focuses on spatial data and permitting, making LADM's Part 5: Spatial Plan Information package the basis for the new Estonia country profile.

Furthermore, the final country profile will be assessed according the abstract test suite (ATS) of *ISO 19152:5* in Section 5: Evaluation and Discussion. Major sources that affected each country profile version are the following:

- **Version 1:** Data layer requirements
- **Version 2:** Data layer requirements + PLANK requirements and metadata
- **Version 3:** Data layer requirements + PLANK requirements and metadata + real data

The development of the Estonia-specific LADM profile evolved through three major iterations. The first version introduced new Estonian-specific classes ("EST") to represent different plan types, with attributes based on existing Estonian Plan data layer requirements (details are available with the authors).

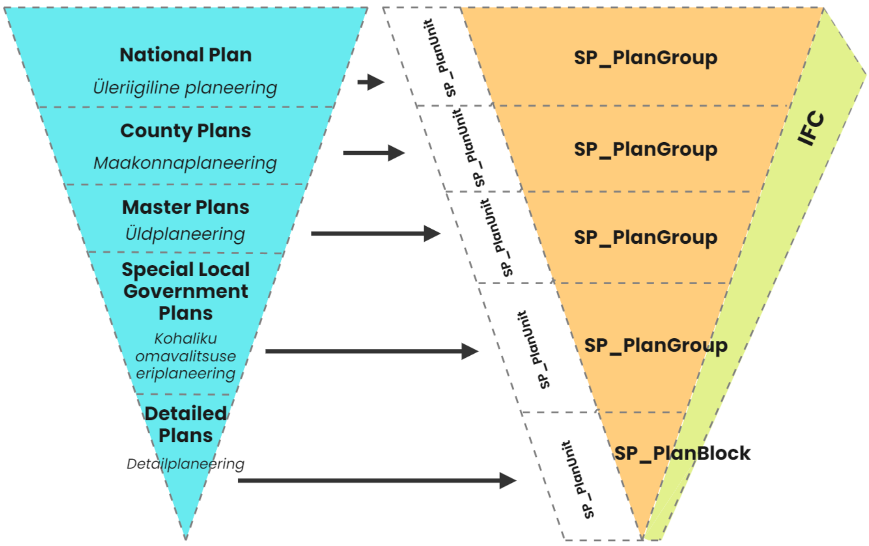


Figure 3. Mapping of Estonian spatial planning levels to LADM Part 5 classes.

The initial approach focused on translating Estonian attribute names and creating separate classes to explore the overlap with LADM Part 5 concepts. As the profile progressed, redundant attributes were eliminated, and LADM attributes were mapped to Estonian data.

The second version integrated feedback from Estonian Ministry experts and incorporated the database model from PLANK, Estonia's spatial plan database. This update significantly impacted the profile by reducing attribute redundancy, integrating metadata from PLANK, and creating code list classes for attributes specific to Estonia.

The final version of the profile (full UML diagram seen in Figure 19) introduced real data representations and optimized the model for practical use. This included incorporating real-life data, technical adjustments encountered while building the PostgreSQL database, and loading spatial data via FME. The final result is a comprehensive profile that accurately reflects the management of Estonian spatial planning data, aligning both technical and conceptual requirements.

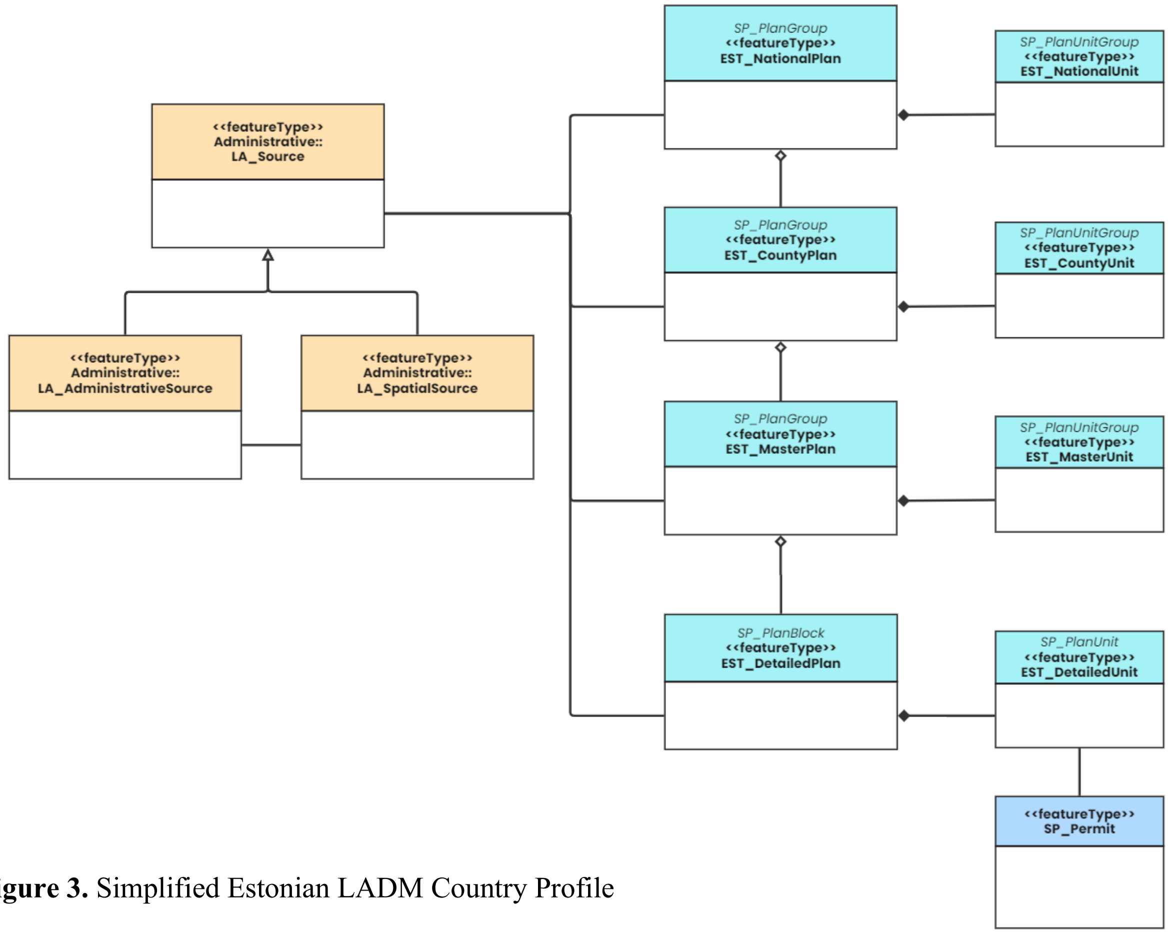


Figure 3. Simplified Estonian LADM Country Profile

The general model is presented in Figure 4. Details in the left part (seen in orange classes, detailed in Figure 5) focused on representing and storing information about the source data and metadata of the uploaded plan. The right part of the model (seen in blue, detailed in Figure 6) represents the different country profile classes, their units and relationships with each other. Part 5 classes as super classes for country profile classes, such as allowing *EST_DetailedPlan* to inherit attributes from *SP_PlanBlock* and the *VersionedObject* class in addition to its own specific attributes. Main plan classes (*EST_NationalPlan, EST_CountyPlan, EST_MasterPlan, EST_DetailedPlan*) have an "aggregation" relationship vertically with each other, representing conceptual geometry aggregation rather than strict composition. This allows for flexibility in spatial plan representation as in reality multiple smaller scale plans are not always represented by one higher scale geometry. Additionally, each plan class is associated with a unit class (e.g., *EST_DetailedPlan with EST_DetailedUnit*) to represent detailed elements with specific functions like a building or a park area, facilitating detailed information storage and easy retrieval. This hierarchical and granular approach ensures each unit within a plan can be individually addressed for comprehensive planning and management. Finally, Part 5's *SP_Permit* class is linked to *EST_DetailedUnit*, representing the most granular level of information in the model, building scale data.

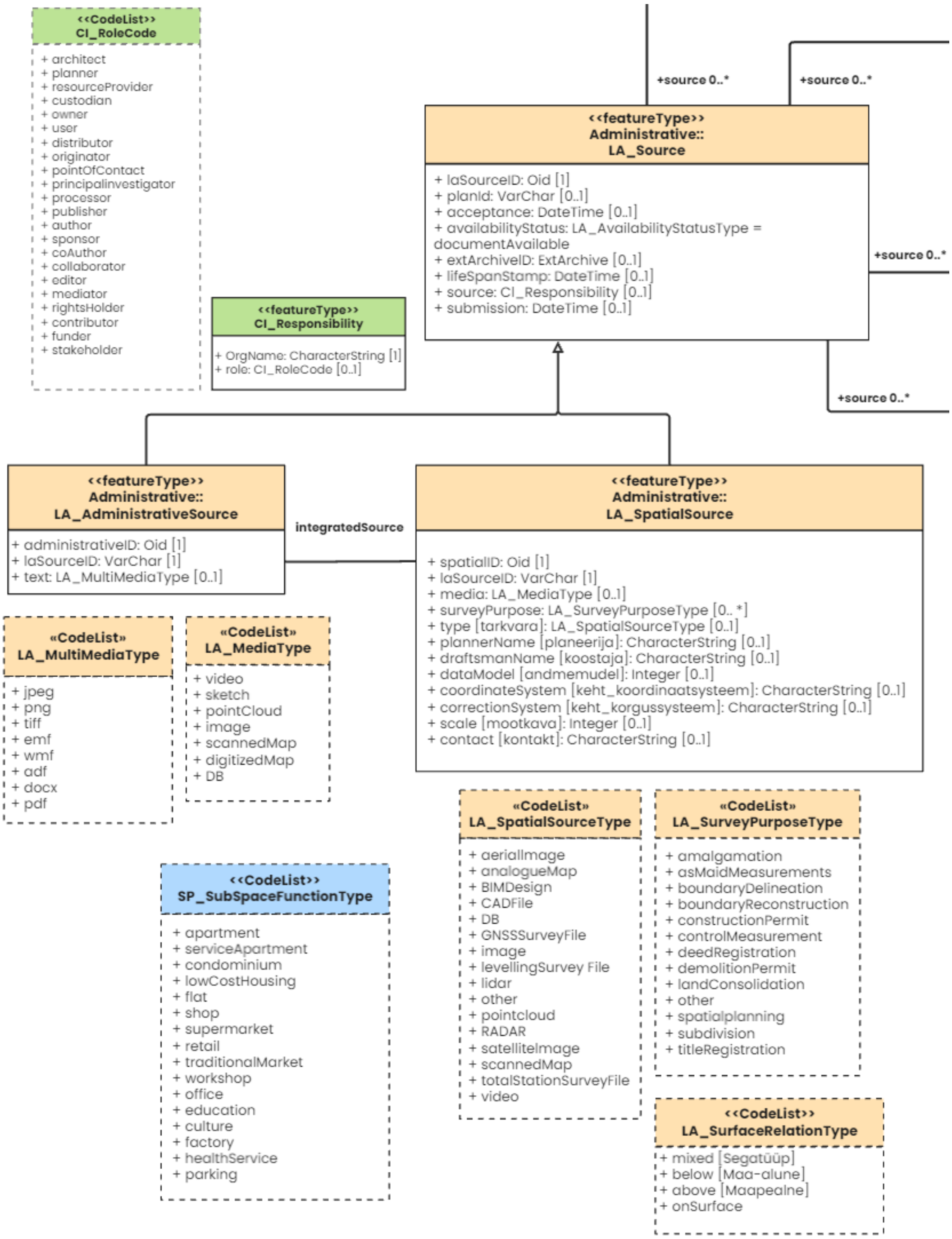


Figure 4. Representing and storing information about the source data and metadata

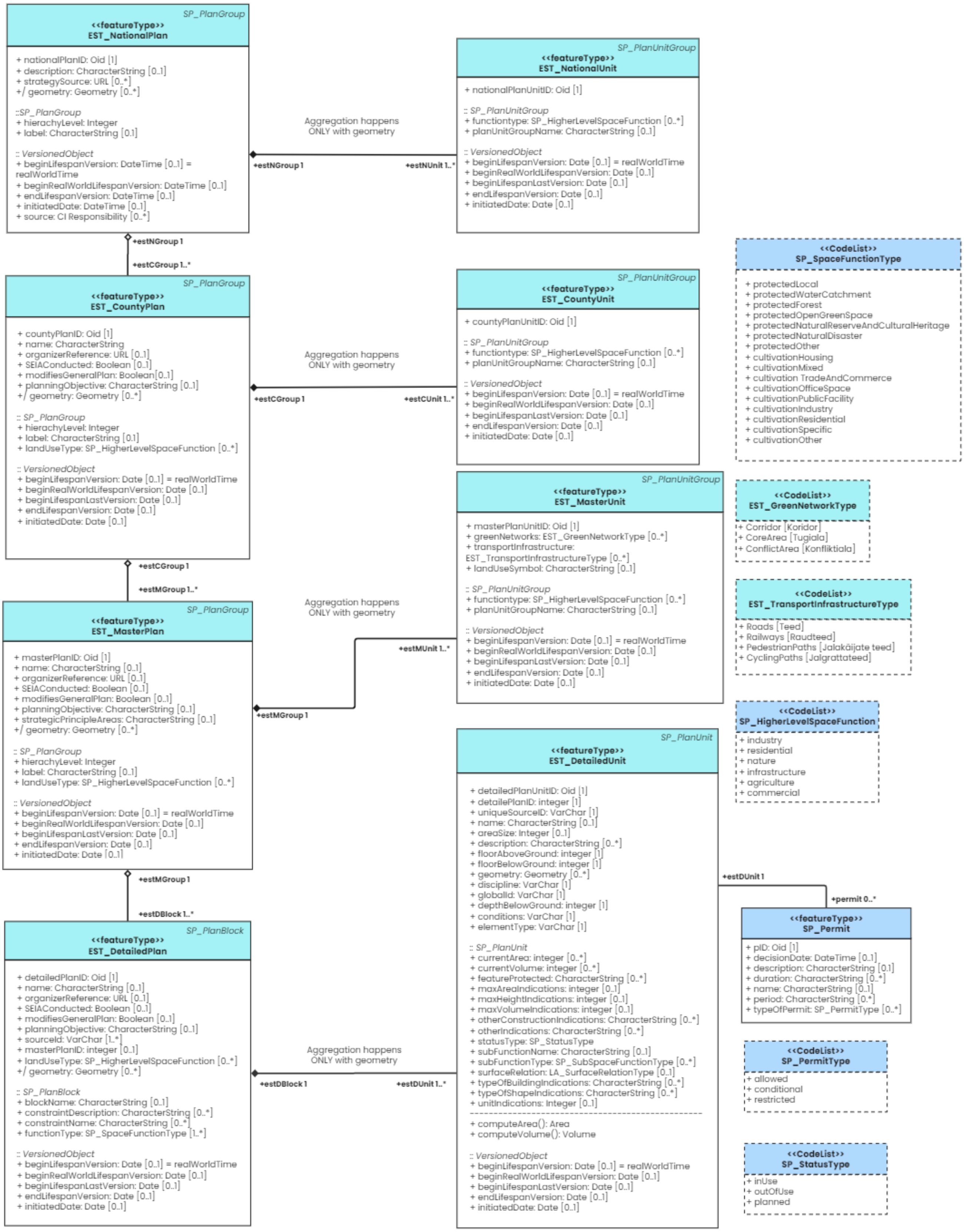


Figure 5. Plan classes and their units.

5. LADM PART 5 COUNTRY PROFILE IMPLEMENTATION IN DATABASE

The The implementation of the LADM database began by selecting PostgreSQL with the PostGIS extension as the database software due to its robustness and support for spatial data types. The initial step in developing the database involved creating the feature classes' of the country profile as separate tables. These tables serve as the primary repositories for all imported data. Key feature classes include *EST_NationalPlan, EST_CountyPlan, EST_MasterPlan, EST_DetailedPlan, EST_NationalUnit, EST_CountyUnit, EST_MasterUnit, EST_DetailedUnit,* as well as original LADM classes, such as *SP_Permit, LA_Source, LA_AdministrativeSource,* and *LA_SpatialSource*, where no changes were needed.
To establish relationships between the plan tables (i.e., *est_national_plan, est_county_plan, est_master_plan* and *est_detailed_plan)* and their corresponding unit tables additional foreign key attributes were added to the unit tables. Figure 7 illustrates an example of this. In the figure, **county_plan_id** is the primary key of the *est_county_plan* table and a foreign key in the *est_county_unit* table. This configuration allows direct access and visibility of which unit (identified by **county_plan_unit_id**) belongs to which version of a specific plan.

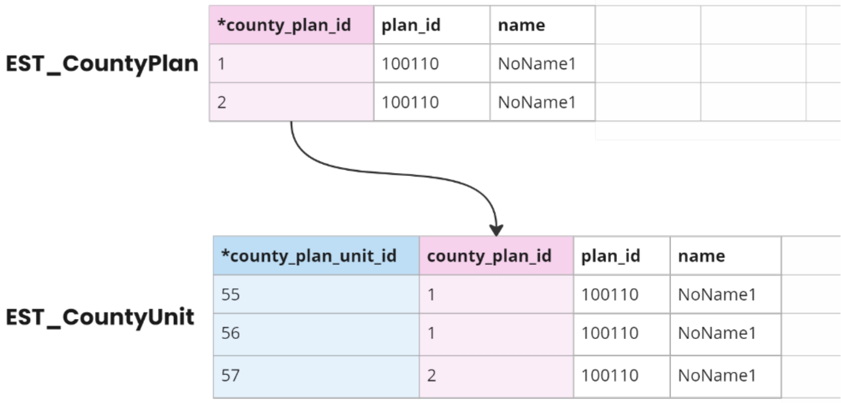


Figure 6. EST_CountyPlan and EST_CountyUnit relationship in the database

Another design decision was the creation of intermediate tables to handle many-to-many relationships in the model. One important example is the relationship between plan classes and *la_source*. Figure 8 shows an example of how the primary and foreign keys work in this situation through the example of *master_plan_la_source* table. The *master_plan_la_source* table has two primary keys: **master_plan_id** and **la_source_id**. Each **master_plan_id** is a foreign key that references the *est_master_plan* table, and each **la_source_id** is a foreign key that references the *la_source* table. The codelist tables are essential to maintaining the integrity of the country profile. These tables contain predefined codelist values that are either newly created for Estonia or derived from LADM standards.
Furthermore, to optimize the database, some sequences, triggers, views, and functions were implemented.

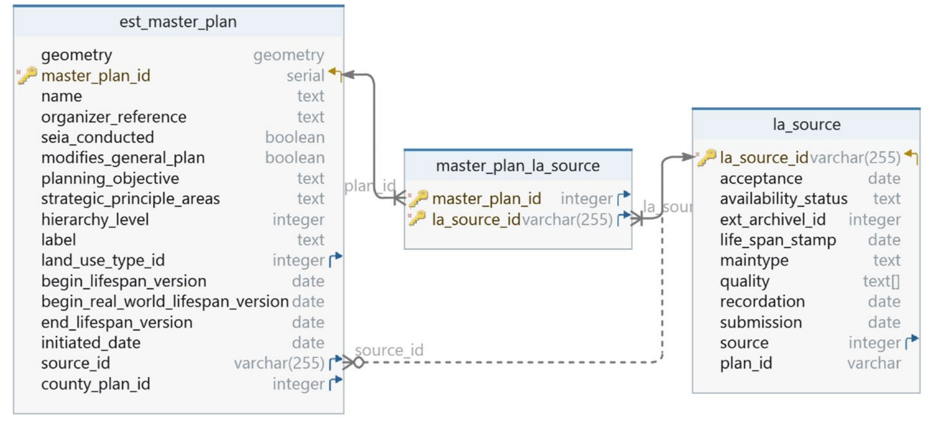


Figure 8. Example of primary and foreign key relationships in the master_plan_la_source table

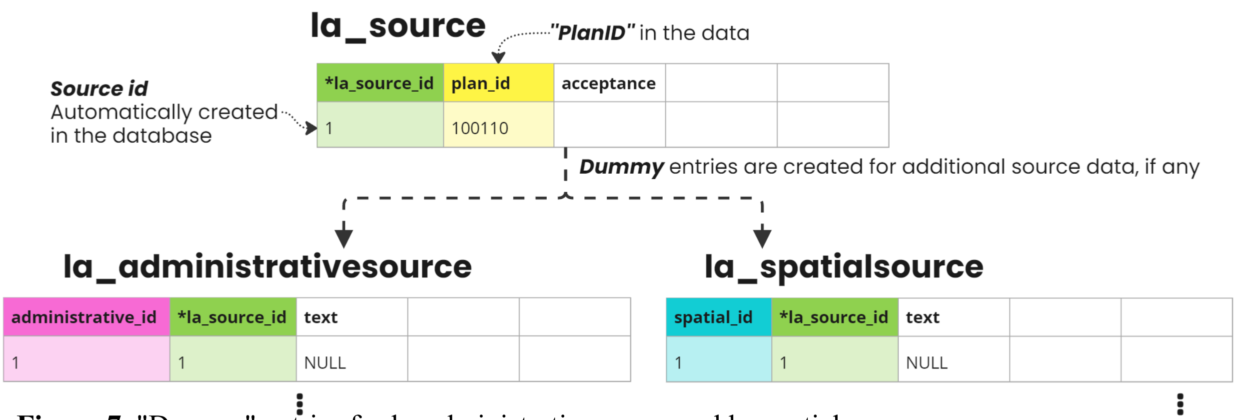


Figure 7. "Dummy" entries for la_administrativesource and la_spatialsource

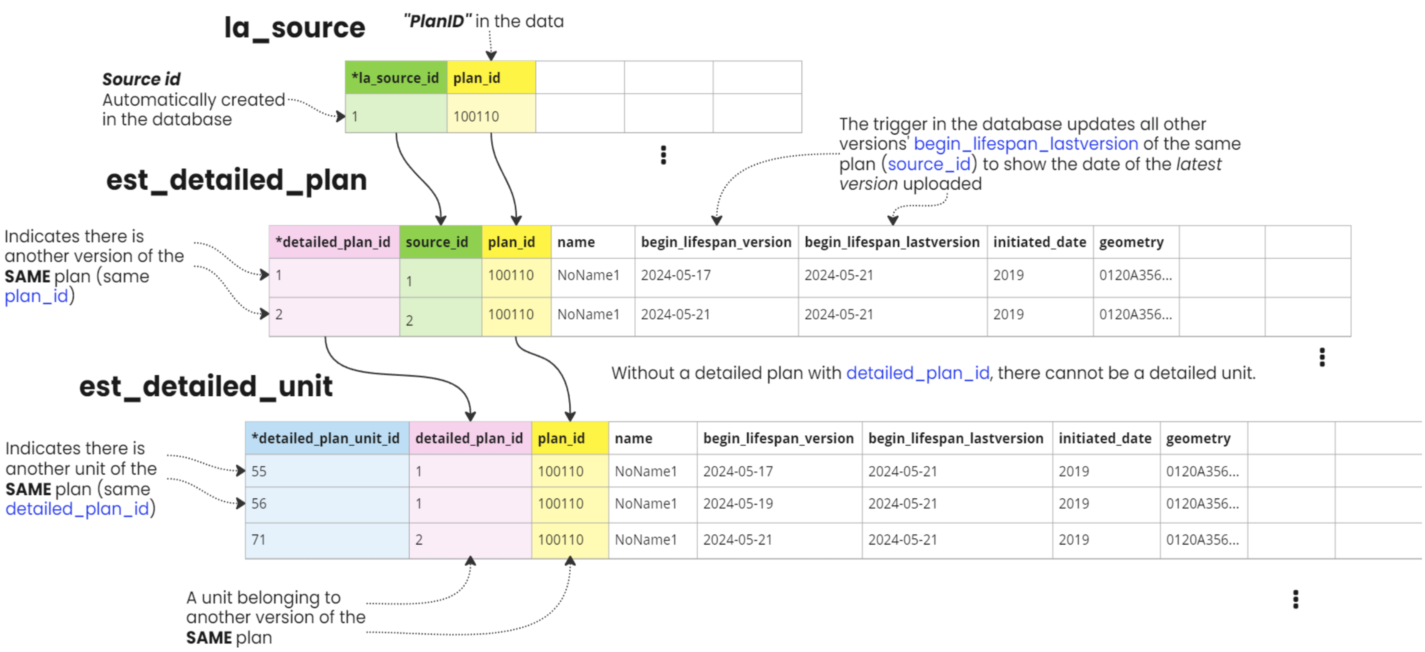


Figure 10. Example of how the versioning in the database works

Sequences are mainly used to generate unique identifiers for records in various tables, ensuring that each entry has a distinct and traceable ID. For instance, sequences *like ci_responsibility_id_seq, ci_rolecode_id_seq, detailed_plan_id_seq*, and many others are created to automatically increment IDs, starting from 1, whenever a new record is inserted. This guarantees the uniqueness of each plan record's identifier.
The database also contains several trigger functions to enhance efficiency and maintain data integrity. For example, the *insert_default_administrative_source* and *insert_default_spatial_source* trigger functions run after a new entry is inserted into the *la_source* table through FME. These triggers call the *insert_default_administrative_source* and *insert_default_spatial_source* functions to insert corresponding "dummy" entries in the *la_administrativesource* and *la_spatialsource* tables. This mechanism can be seen in Figure 9.
For versioning, both the database and FME script were utilized. The upload date (**begin_lifespan_version**) is added through the FME script before uploading to the database. An attribute for the last version (**begin_lifespan_lastversion**) was added to every plan and unit table to manage different versions. Functions named with the plan levels (e.g., *update_d_plan_beginlifespanlastversion*) update the begin_lifespan_lastversion field, ensuring all records with the same plan_id reflect the most recent date. During the import process, **begin_lifespan_version** and **begin_lifespan_lastversion** are set to the current date to mark records as the latest version. Initially, complex logic caused infinite loops and errors, but refining the logic solved this. The trigger *trg_update_d_unit_lifespan* activates after an insert or update, ensuring accurate versioning without errors. The same logic applies to other plan and unit tables. Figure 10 illustrates an example scenario demonstrating how the versioning works in the database.
To further enhance the database's legibility further, several views were implemented. For instance, the *est_detailed_plan_unit_count* view was created to aggregate detailed plans and their corresponding unit counts. This view provides a summarized count of units associated with each Detailed Plan, making it easier for users to get an overview of the data without needing to perform complex joins or queries themselves.
Most functions and triggers were created during the testing phase using FME to import data, allowing realistic optimization for Estonian data requirements. This iterative process was crucial for finalizing the database setup. A database dump script for deploying the database from scratch and a reset script to clear all records except codelist values are available on GitHub[9]. These scripts ensure the database's integrity during testing and development.
Figure 11 illustrates the overall system architecture for both the database and the import process. The steps with a white background indicate the procedures followed for the project by Future Insight. The figure also shows that the initial starting point remains consistent to facilitate better integration with the actual project pipeline. Once the database was established, FME scripts were developed to handle the importation of spatial data.

[9] https://github.com/simaybtm/LADM-4-Estonia

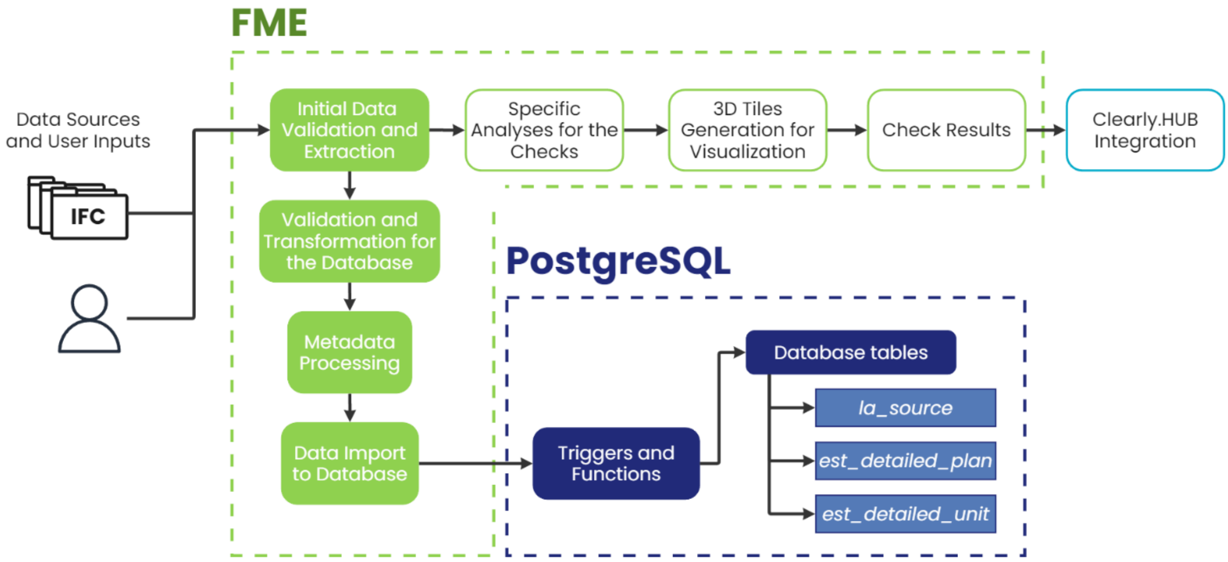


Figure 8. Overall system architecture of the process

The import process begins with the preparation of IFC data, ensuring that the data conforms to the required standards and formats. FME is used to manipulate and transform Estonian IFC data into a format compatible with the developed LADM database. The basis for the FME script is derived from the case study project, utilizing the scripts created by the company for permit checks. These scripts automate the extraction, transformation, and loading of data for the checks.

The process can be divided into two main parts. The first part involves general data extraction and initial validation methods for the IFC data. This includes verifying the completeness of metadata, ensuring spatial data integrity, and validating object properties and layer naming conventions, all according to the Estonian layer requirements. The second part of the process handles the necessary data transformations and additional data extraction mechanisms needed to comprehensively represent the data in the LADM profile. This phase includes transforming the data to meet specific schema requirements and finally importing the transformed data into the new PostgreSQL database.

Additionally, various *User Parameters* were created to make the FME workflow more generic and flexible for various input data. Key parameters include database connections, source dataset paths, and domain-specific (also reffered as *discipline* in the research and case study) property sets and their syntax.

Figure 12 shows detailed explanation of the general FME workflow. After the IFC files are read, the data's *IfcPropertySet* and *IfcAnnotation* are compared against each other. The aim is to only keep the matched discipline records with a property set and exclude everything else. A "*discipline*" represents specific thematic categories (i.e. layering) within the Estonian IFC data, such as public spaces, landscaping, building zones, access routes, utility conditions, plot areas, land use types, and transportation networks. Next, the script checks if the *plan_ala* or *dp_krunt* is in the kept disciplines. These layers represent the planning area and the plot area, respectively and according to Estonian layer requirement, it is mandatory that every plan data must have both layers.

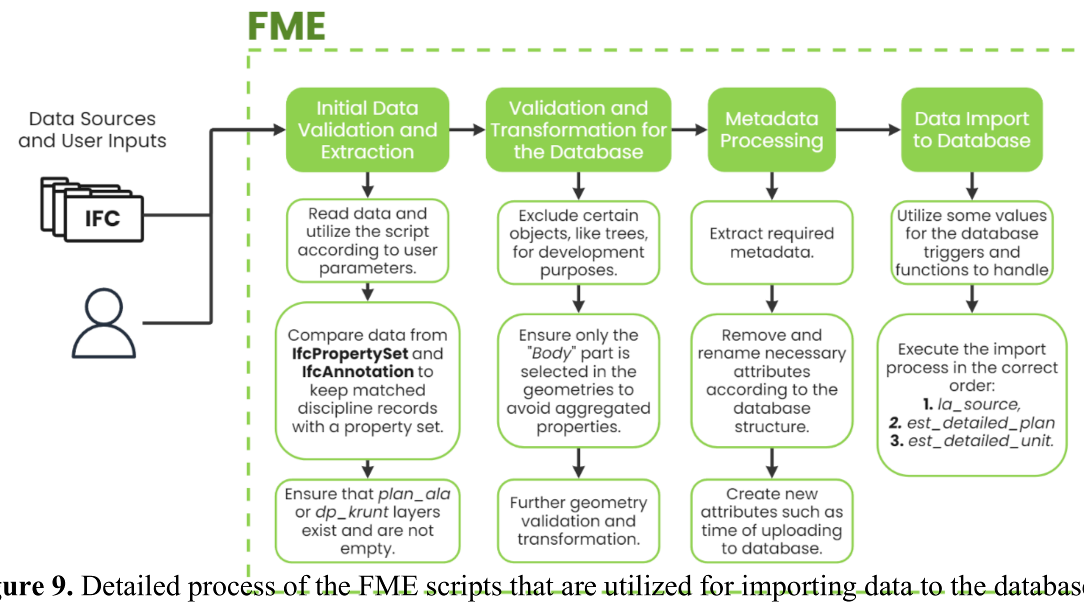


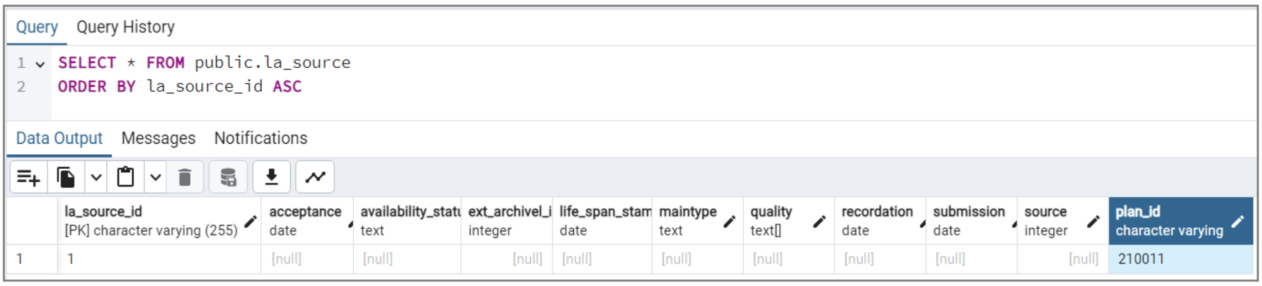
Figure 9. Detailed process of the FME scripts that are utilized for importing data to the database

After the initial data extraction and validation, the second stage (i.e., "Validation and Transformation for the Database" in Figure 12) of the script begins with excluding some objects from the records for development purposes, like trees. To avoid any relevant data loss during the import, these objects will be included again in the end, right before importing the data into the database.

Following the exclusion of some elements, the final data extraction and transformation before the LADM part focuses on geometries. When reading IFC files in FME, the "*Body*" geometry often includes aggregated property information. To ensure predictable and clean geometry data for the database storage, it is important to avoid these aggregates and extract only the "*Body*" part of the geometry. This ensures that the extracted geometries are consistent and free from unwanted aggregation. After the geometry validation, the workflow focuses on specific layers, such as the planning area (i.e., *plan_ala*) and plot area (i.e., *dp_krunt*) layers, applying some checks and transformations. steps include validating layer presence, converting geometries to 2D representations, and ensuring that lines are closed to form valid polygons. For other disciplines, similar validation and transformation processes are applied to ensure all geometries are correctly formatted and meet the required standards before continuing with the LADM part of the FME script. This guarantees that the spatial data is accurately represented, is consistent, and ready for the next steps.

The first table in the database to import information into is the *la_source* table. As previously explained, the database has been developed with sophisticated constraints such that every plan uploaded must first have source data uploaded to the *la_source* table. This is crucial to maintain the integrity and traceability of the spatial data within the database.

Since the *la_source* table primarily stores metadata about the source rather than the spatial information itself, the geometry is removed from this table. Figure 13 illustrates an example of pilot data, "*Põhi*," in the *la_source* table. Notice that there is one entry to represent one source data, which in this case refers to the combined IFC files representing the *Põhi* Detailed Plan. Another important column is the *plan_id*. It allows the data to be correctly uploaded to the Detailed Plan and Unit tables, as the database can now recognize the plan id and connect it to the source file.


Query Query History

```
SELECT * FROM public.la_source
ORDER BY la_source_id ASC
```

Data Output Messages Notifications

	la_source_id [PK] character varying (255)	acceptance date	availability_statu text	ext_archivel_i integer	life_span_stam date	maintype text	quality text[]	recordation date	submission date	source integer	plan_id character varying
1	1	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]	[null]	210011

Figure 10. Example entry to the la_source table using the pilot data, Põhi.

The order of the script's import to the database is crucial, even after the *la_source* table. The correct import sequence for a spatial plan should be *la_source, est_detailed_plan*, and *est_detailed_unit* (for Detailed Plans). For example, for a county plan, the order would be *la_source, est_county_plan,* and *est_county_unit*. This approach aligns with the constraints established during the database creation, which state that one or more plan units cannot exist without the plan existing first. Additionally, there are technical constraints in the database to enforce this rule. Therefore, the script's execution order meticulously conforms to these constraints.

After the data is imported into the *la_source* table, the script continues with the transformation of the geometries. A significant design choice involved selecting the geometry to be imported into the *est_detailed_plan* table. Since the unit table was developed to store every geometry element as a unit (e.g., a building, a tree, a street, etc.), the plan table was designed to show one entry representing the data and metadata of the entire plan. This led to the decision to merge the geometries into one mesh to represent the plan as a single geometrical entry. This approach was also considered more practical for simple visualization purposes of the plan in the database or as 3D Tiles.

The IFC data, originally represented as unit elements in terms of geometry, required necessary transformations to merge these units into one geometry. To accurately represent the plan area (*plan_ala*, represented as a 2D line in the Estonian data), additional manipulations, such as creating a 3D platform of the plan area, were performed. These steps ensured that the final

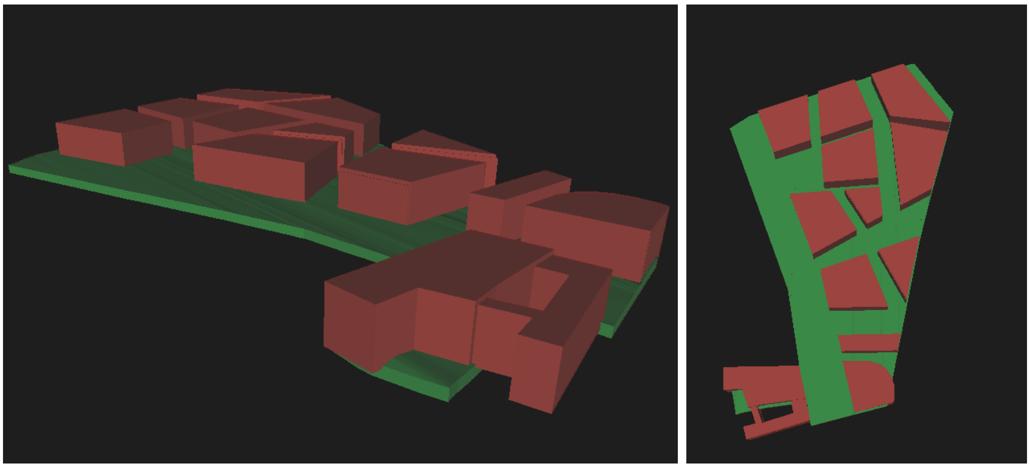
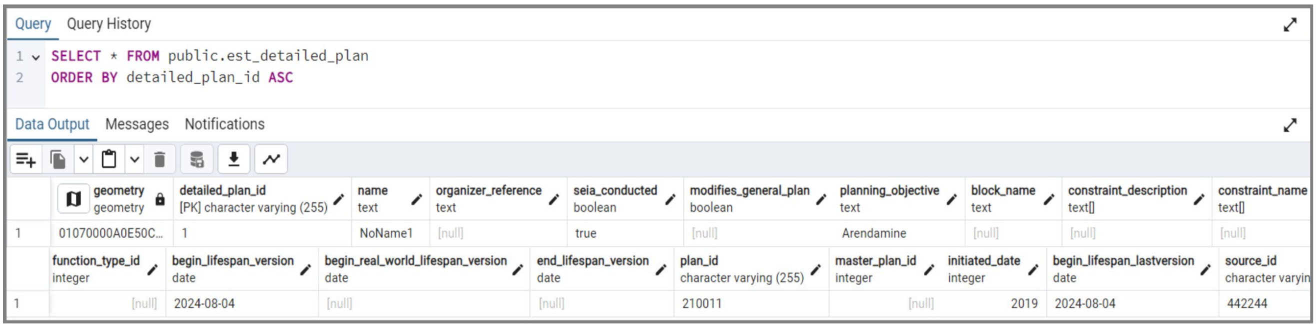


Figure 11. Final Geometry Product for est_detailed_plan table

mesh visually reflected the entire plan area in 3D. Figure 14 shows an example of the final geometry product that is to be uploaded to the *est_detailed_plan* table.

After forming the plan geometry, the current date and time are added as an attribute, representing the *begin_lifespan_version* in the plan tables to indicate the upload time. Finally, after renaming attributes, cleaning unnecessary data, and merging with the geometry to represent a single record, the data is imported into the *est_detailed_plan* table in the database. Figure 15 shows an example representation in the database for the Põhi dataset. For better legibility, the continuation of the first row is pasted below, ensuring the complete information of the single entry is clearly visible and understandable. It should be noted that most of the null fields in the database come from the lack of the necessary data in the pilot dataset.

After importing the necessary information into *est_detailed_plan*, the script prepares and transforms data for the *est_detailed_unit* table. An SQL query executed in the FME script ensures that the later imported data is recognized as units of the same plan by retrieving the most recently imported Detailed Plan's ID from the *est_detailed_plan* table from the database. This allows the corresponding units to be linked to the specific plan with a foreign key. Therefore, the source, plan, and its units should be uploaded together to maintain data integrity, although this constraint can be optimized for more flexibility in the future development of the research.


Query Query History

```
SELECT * FROM public.est_detailed_plan
ORDER BY detailed_plan_id ASC
```

Data Output Messages Notifications

	geometry geometry	detailed_plan_id [PK] character varying (255)	name text	organizer_reference text	seia_conducted boolean	modifies_general_plan boolean	planning_objective text	block_name text	constraint_description text[]	constraint_name text[]
1	01070000A0E50C...	1	NoName1	[null]	true	[null]	Arendamine	[null]	[null]	[null]

	function_type_id integer	begin_lifespan_version date	begin_real_world_lifespan_version date	end_lifespan_version date	plan_id character varying (255)	master_plan_id integer	initiated_date integer	begin_lifespan_lastversion date	source_id character varyin
1	[null]	2024-08-04	[null]	[null]	210011	[null]	2019	2024-08-04	442244

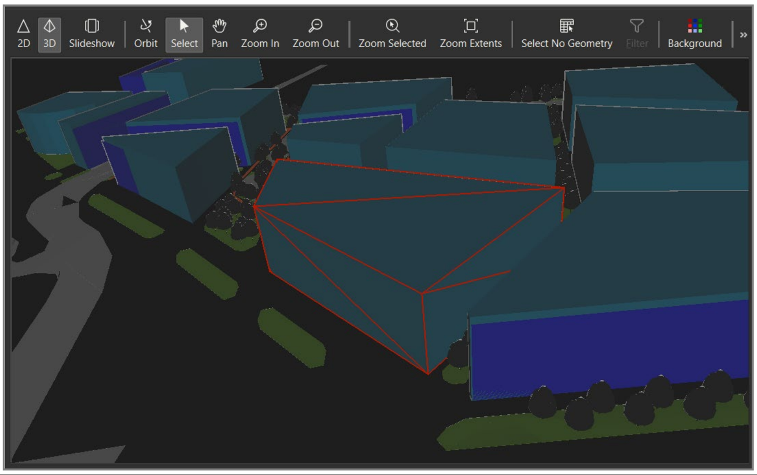
Figure 12. Example entry to the est_detailed_plan table using the pilot data, Põhi

Moreover, testing mechanisms were implemented to categorize codelist values. For example, the *la_surface_relation* codelist table, illustrates a mechanism for categorizing incoming data. This was tested with flexible methods, such as automatically recognizing and labeling vegetation elements as "on surface" or comparing the depth below a building with the floors above and below it. For instance, if an element is below ground, it is assigned a value of code id "2," which the codelist table maps as code label "below." This ensures that the incoming data matches the predefined codelist values set by the country profile and the database.

Finally, after all the extraction, transformation, and manipulation of the data, the resulting unit records are imported into the *est_detailed_unit* table in the database. Figure 16 shows an example of how different units are stored with their own metadata. The building geometry highlighted in red represents the sixteenth unit, which is highlighted in blue below.

To test the accuracy of the imported results compared to the raw input IFCs, another FME script was created to read the recently imported data from the database. Specifically, for the units in the *est_detailed_unit* table, the only requirement is to input the *detailed_plan_id* into the reader, so it only reads the plan units of the specific plan requested. For versioning, this

query can be made more specific to isolate the requested plan and the version available in the database.
The results, seen in Figure 17, showed that the geometries accurately reflected the original pilot dataset, and the metadata was stored correctly without any errors. The only shortcoming encountered was PostGIS's inability to store geometry appearance/style, such as the color of the elements. This limitation stems from a technical issue with PostGIS. While there wasn't a solution to overcome this limitation during the research, future optimization efforts could explore alternative options. For example, using a database that supports styling features like MongoDB with GeoJSON for rendering styled geometries could be considered. Additionally, developing custom scripts to store and apply styles separately from the geometry data could also be a potential solution, although it would make the process more complex.
Referring to the initial system architecture in Figure 11, the updated system architecture in Figure 18 demonstrates how the process of reading the Estonian spatial data previously uploaded to the database can be implemented into the case study project with Future Insight for the prototype of seven compliance checks. In this updated system, Estonian plan data can be directly read from the database, transformed into 3D Tiles, and then used to develop and execute the checks, with the results visualized in Clearly.HUB. This approach enhances scalability, as the database (and country profile) is designed to handle and store comprehensive plan data from various levels.



	current_area	current_volume	floor_above_ground	floor_below_ground	max_height_indications	ifc_unique_id
7	3825.435294091...	63451.18653629036	5	1	24	2n4tysWu3ZY000...
8	1334.245009290...	29353.390204384643	5	1	24	2n4tysWu3ZY000...
9	2638.274029955...	46510.990954235196	5	1	24	2n4tysWu3ZY000...
10	877.1721401932...	19297.787084251762	5	1	24	2n4tysWu3ZY000...
11	1062.882424950...	23383.413348913193	5	1	24	2n4tysWu3ZY000...
12	3574.453215939...	53217.0964902878	5	1	24	2n4tysWu3ZY000...
13	3614.229775483...	86741.51461159858	<missing>	<missing>	0	2n4tysWu3ZY000...
14	2919.119912232...	70058.87789357157	<missing>	<missing>	0	2n4tysWu3ZY000...
15	3133.738321008...	75209.71970420341	<missing>	<missing>	0	2n4tysWu3ZY000...
16	4144.975745226...	99479.4178854475	<missing>	<missing>	0	2n4tysWu3ZY000...
17	2718.710644916...	65249.055477986774	<missing>	<missing>	0	2n4tysWu3ZY000...
18	1374.112807205...	32978.707372933335	<missing>	<missing>	0	2n4tysWu3ZY000...
19	963.1652064284...	23115.964954283078	<missing>	<missing>	0	2n4tysWu3ZY000...

Figure 13. Example unit geometries stored as individual records with specific metadata

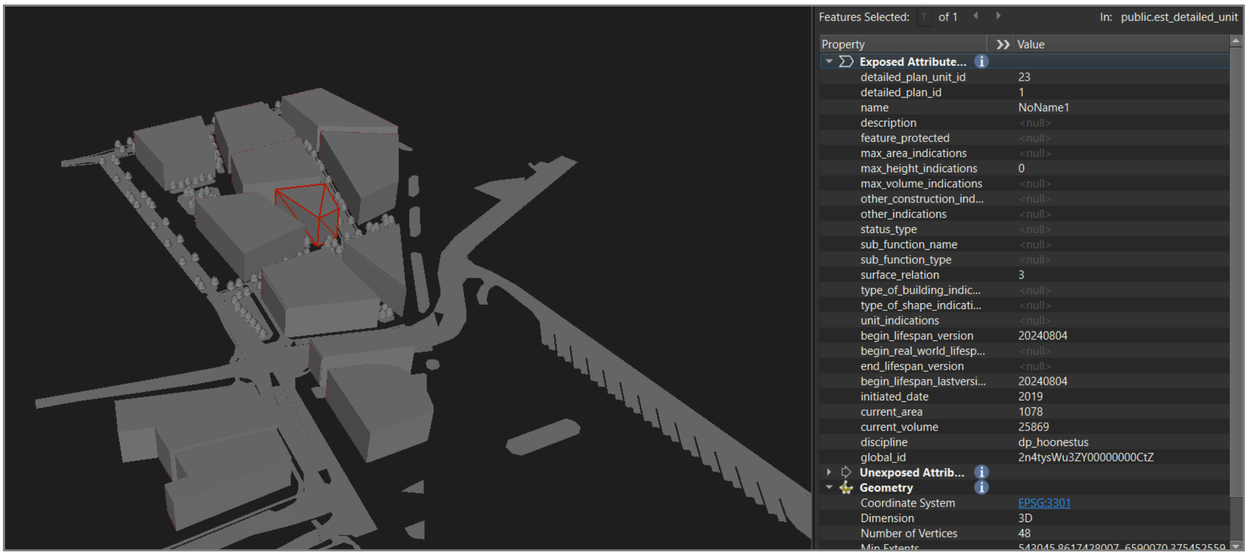


Figure 15. Read geometries and metadata from the database

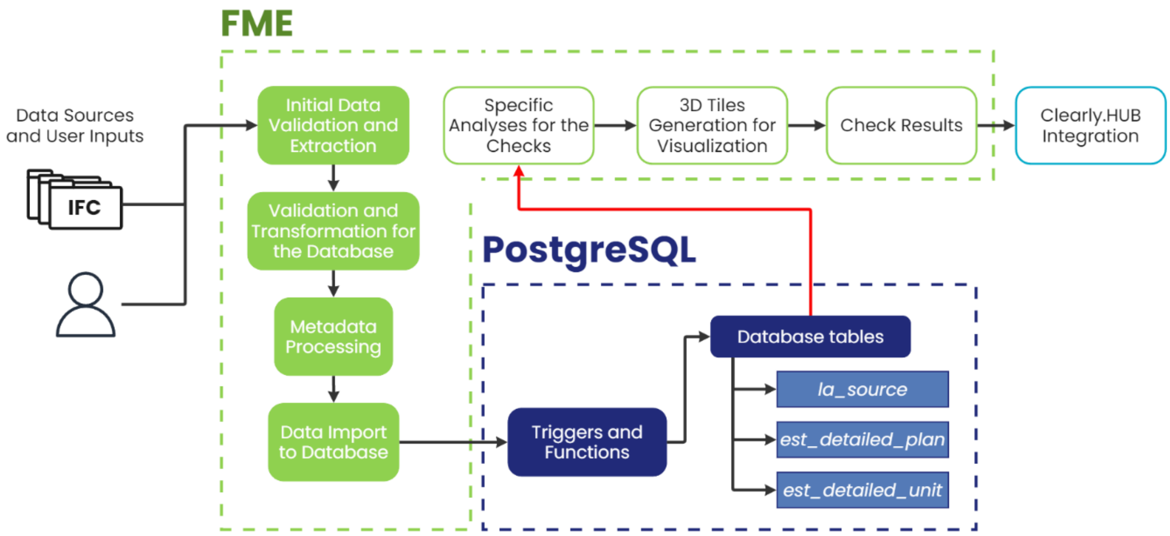


Figure 14. Updated system architecture diagram representing how to implement the LADM database process into the case study project with Future Insight

The FME scripts developed for extracting and loading plan information also extract metadata (not currently needed for the seven checks) to fully represent the plan in the database. By reading previously uploaded plan data from the database, the compliance check process becomes simpler and shorter. Specifically, this would eliminate the need for the hefty extraction and transformation processes, developed specifically for the required information for the checks. Since the database is designed to represent the plan data comprehensively, the required information for the checks and more is directly accessible from the database, provided the plan data contains it.

Additionally, users can access different versions of the uploaded plans directly from the database and easily compare the compliance check results for each version. Further optimizations with larger datasets will enhance both the FME scripts and the database, making the process more scalable and efficient for Estonia. This would also simplify the development of additional compliance checks in the future. The implications, benefits and constraints of this approach are all summarized in Section 6: *Evaluation and Discussion.*

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5. EVALUATION AND DISCUSSION

It is crucial to assess of the Estonia-specific LADM profile, along with the developed database and FME scripts' effectiveness, limits and compliance with international standards. This section first assesses the LADM implementation using the ATS provided in Annex A of *ISO 19152:2012(E)*. It then discusses the practical implications, benefits, and constraints of the developed system.

The ATS is a standardized set of tests provided by *ISO 19152:2012(E)* to ensure that implementations of the LADM conform to specified conformance levels.

The Estonia profile has been developed to comply with level 2 conformance of ISO 19152:2012(E). According to the ATS, level 2 conformance requires the implementation of basic and common classes, which include core classes in Part 5. These classes have been inherited by the new Estonian plan and unit classes to include attributes specific to Estonian requirements, such as "*landUseType*" for *EST_DetailedPlan* and "*strategicPrincipleAreas*" for *EST_MasterPlan*, ensuring that national requirements are addressed while maintaining the LADM's integrity. The profile also includes comprehensive metadata attributes and predefined codelist values to maintain data integrity with PLANK. Overall, in the scope of the research, the Estonia-specific LADM profile achieves level 2 conformance, meeting the necessary requirements and providing a robust framework for managing spatial plan data in Estonia.

6. CONCLUSIONS AND FUTURE WORK

This research has successfully developed a country-specific LADM profile for Estonia, integrated with the PLANK database, and demonstrated the potential of using IFC within the prototype solution for compliance checks among Estonian spatial plans. By achieving Level 2 conformance with the ATS of ISO 19152:2012(E), the Estonia's LADM profile has proven effective in addressing both the national requirements while adhering to international standards. Additionally, the case study involving the company Future Insight and organizations from Estonia highlighted the practical benefits of this integration, including the ability to directly read and process spatial data for compliance checks, reducing manual intervention and potential errors. However, certain assumptions made during the development of the FME scripts and database shall be revised in future work to enhance scalability and flexibility.

One assumption involves the order of data imports in the FME script. Currently, after importing Detailed Plan data into the *EST_DetailedPlan* table, an SQL query is made within FME to retrieve the unique plan ID from the PostgreSQL database. This ID is then used to establish a foreign key relationship for uploading the corresponding unit data to the

EST_DetailedUnit table. However, if two different plans are imported into the *EST_DetailedPlan* table one after another, the units of the first plan cannot be imported from the FME script without manually retrieving and using the plan ID from the database. Additionally, the script's reliance on predefined discipline names for filtering IFC data is based on a limited set of pilot datasets used within the case study. In a broader context, variations in discipline naming conventions could create challenges. Thus, for scalability reasons, the script should be tested and optimized with a wider range of Estonian datasets to ensure accurate operation.

Future work could focus on refining these assumptions and enhancing the system's scalability. Another point to consider is performance optimization. Performance testing with larger datasets will be crucial to ensuring efficiency and identifying any further areas for optimization. Addressing these factors will improve the overall model and tools developed, making the system more scalable and robust for compliance checking.

As digitized permit checks are an emerging domain, and the case study with Future Insight demonstrates a state-of-art prototype, the ongoing development of these checks will likely influence the evolution of the LADM model used. While this research concentrated on integrating IFC data due to its prevalent use in the AEC industry and the specific pilot dataset employed in the case study, future work should also explore additional data formats such as CityGML. CityGML's potential for representing urban features and integrating spatial plan information could be particularly beneficial for smaller-scale spatial plans, making it a valuable consideration for further development.

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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 Physics and Electronics 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 database. Since 2000, he is Professor at

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APPENDIX

Figure 19. Final Estonia LADM Part 5 Country Profile's UML model

Developments of 3D Land administration in China – advancements and challenges

Walter Timo DE VRIES and Yiming ZHONG, Germany

Key words: 3D Cadastre, land register, integrated land policy, legal aspects of cadastre, China

SUMMARY

Rationale– The development of 3D information models and systems in China has progressed rapidly. Nevertheless, there is no standard 3D land administration model yet, which is applied throughout the country, and there is no legal framework supporting and advancing the developments yet. The consequence is that research and practice of 3D cadastre concepts and models remains scattered and fragmented.
Research objective– This study aims at reviewing and categorizing the developments in 3D land administration models and systems in China of the past years to analyze which developments and practices are spearheading and which possibilities exist to formulate a more general policy for 3D cadastre development.
Theoretical framework– We review the current 3D land administration conceptualizations from an international perspective and compare these to how 3D land administration is currently understood in the Chinese context of practice and academia. From this analysis we derive a set of key unknowns on 3D land administration developments in China with respect to basic understanding of the definitions, the technical aspects related to 3D models, the legal embedding of 3D land administration and the organizational requirements to make 3D land administration systems functional and operational.
Methodology – The key unknowns derived from the theoretical review are the basis for a keyword co-occurrence analysis of academic literature in Chinese and in English, and the basis for a survey design, which was distributed among a selection of key experts and practitioners in China. In addition, several expert interviews were held with prominent scientific researchers in this field to validate both the literature review and the survey results.
Results – The results from the keyword co-occurrence analysis reveal how, when and where the terms cadastre and land registration are being used and applied, and with which (other) terms 3D models are being associated. It is important to understand the Chinese connections to cadastre and hence the implications of these to the term 3D cadastre. Nowadays, the cadastre has a completely independent status. China's real estate registration is moving towards a unified rights registration of natural resources, which also has 3D implications, as many of these resources as well as rights exist in a 3D environment. Institutional integration influences what is a valid 3D land administration. The results of the survey and interviews demonstrated and confirmed that indeed the developments in both the technical and legal aspects are scattered, but that at the same time several other developments – which may not directly be associated with 3D land administration – have emerged, which influence and possibly shape the ideas of a de facto system of 3D records of properties in China. From a

technical perspective, developments in GIS, remote sensing, BIM and digital twin technologies have generated new ideas and practices in how to shape and manage technical information. Whilst these have resulted in many types and applications of 3D models, the main purpose of these developments was not necessarily to design and innovate 3D cadastres, but to manage and support applications in for example housing, construction and environmental protection which require 3D models to generate useful outcomes. Examples include the use of key technologies for three-dimensional rights registration of natural resources, and the construction of a three-dimensional "one map" of all natural resources and unify management and application of the data of the 3D "one map" of natural resources by means of the land spatial basic information platform. These developments have generated as a side-effect the development of models which carry 3D information on legal properties, and therefore mirror the original paradigms of 3D cadastres.
Conclusions– the shape and conceptualisation of 3D land administration in China follows an emergent and operant path rather than a pre-designed policy. This process is largely driven by societal and political demands and by autonomous technological advancements in industry and in scientific research. Whilst the application of 3D models in multiple sectors has significantly increased, constructing a legal framework remains a sizable challenge. This raises the question whether such a standard framework is required in the short term, or whether the development of such a framework should no longer focus on 3D cadastres, or land administration in a narrow sense, but on an integrated approach regulating 3D-related, digital twin and AI related technologies in a broader sense. It is more about supporting a logical and responsible design public information infrastructure and its maintenance than about harmonizing heterogeneous (legal/institutional) models and systems.

Developments of 3D Land administration in China – advancements and challenges

Walter Timo DE VRIES and Yiming ZHONG, Germany

1. INTRODUCTION

Conventional land administration systems rely on two-dimensional cadastres, which implies there is no ability to administer and/or manage parcels in the vertical dimension. Traditional 2D cadastral information systems, based on 2D representation and visualisation technologies, however no longer meet the changing needs of modern (digital) societies. Still, constructing and relying on technologies and models which represent 3D spaces and legalities accurately and reliably is not a given in most countries. It is not so much a problem of technologies, but a complex problem of technological possibilities, legal reliabilities and accountabilities and process oriented data acquisition and maintenance. Part of this problem furthermore lies in standard agreements on technical definitions and legal regulations (Tang et al., 2022). For China, this problem is similar as in other countries, yet this does not mean that there hasn't been any development. Over the years of 3D cadastre research in China, there have been several changes in the form of land and house registration, yet what kind of requirements have been put forward by these changes to the cadastre? This remains unknown. At the technical level, many 3D data models and 3D spatial information models have been proposed, but since a cadastre, especially the 3D cadastre, is largely influenced by the development situation and legal system of the country or region, there is no model with high applicability or universal application. Especially for China the establishment of a three-dimensional cadastre is even more special due to the uniqueness of its land tenure system (dualistic system). Despite the rapid development of 3D information models and systems in China, there does not yet exist a standard 3D cadastral (data/information) model, which is applied throughout the country, neither is there a commonly accepted legal framework for 3D cadastres throughout the country. In fact, the research and practice of 3D cadastre concepts and models in China remains scattered and fragmented. Nevertheless, China has been conducting research on 3D cadastre for a long time. Yet, there is no precise definition of what a 3D cadastre is in China, and there are fewer studies on how to construct a 3D cadastre law. Consequently, there is no clear and complete compilation of what the most appropriate legal system for China would be, and there is a disconnect between the legal research on three-dimensional cadastres and the technical research.

The main objective of this paper is to describe and explain how, where and why 3D cadastre development occurred in China, and to explore which problems, challenges and opportunities 3D cadastre developments faces in different aspects in the context of China's unique property rights and changes in policy regimes. The paper starts by providing an introduction into the history and current status of land and property laws in China, and describing how these could impact the description and maintenance of 3D properties. The subsequent section describes some of the core definition and current insights into what constitutes 3D land administration and §D cadastres and which technical models are currently available. and 3D cadastre from a global perspective. The next section describes the methodology of further data collection and analysis of the developments on 3D land administration in China, followed a results section. We end the paper by deriving a set of conclusions in view of the main research question.

2. REVIEW OF LAND ADMINISTRATION IN CHINA

In 2007, the Property Law of the People's Republic of China was enacted. Article 136 states: "*The right to use land for construction may be separately established on the surface of the land, above the land or under the land. The newly established right to use land for construction shall not affect the previously established right of use*". The implementation of the Property Law secures and promotes the development of the vertical space on the land and provides a certain legal basis for a three-dimensional cadastre. How to accurately describe and express the three-dimensional characteristics of spatial and property rights of real estate and how to establish a three-dimensional cadastral information model that integrates the cadastre of real estate has become an urgent and fundamental task for the management of real estate in China (Tang et al., 2022). Although the right to develop and utilise vertical space is legally guaranteed, in practice, China's laws and regulations related to the 3D cadastre are still lacking, both at the technical level and the management level. Moving from a two-dimensional cadastre to a three-dimensional cadastre is not simply a matter of adding textual records or schematic diagrams, but it is also a fundamental transformation of the entire operational, organisational, regulatory and legal system supporting and securing the validity of the 3D cadastral information (products and services). As the latter is not yet in place, there is still a long way to go before a three-dimensional cadastre can be realised.

Article 9 of the *Land Administration Law of the People's Republic of China* (2019 Amendment) states that land in urban areas is owned by State. Land in rural areas and urban suburbs is owned by peasants' collectives, except for land that is State-owned as stipulated by law; homesteads and self-reserved land and hills are owned by peasants' collectives. Article 10 specifies that state-owned land and collective land may be legally determined for the use of units or individuals. Land in China is classified into agricultural land, built-up land, and unutilised land. According to the *Interim Regulations of the People's Republic of China Concerning the Assignment and Transfer of the Right to the Use of the State-owned Land in the Urban Areas* (2020 Amendment), Land use right concession refers to the act of the State, as the landowner, ceding the land use right to the land user for a certain number of years, and the land user pays the land use right concession premium to the State. The granting of land use rights is subject to a grant contract. The maximum number of years for land use rights concession is stipulated as follows:

- 70 years for residential land.
- 50 years for industrial land.
- 50 years for land for education, science and technology, culture, health, and sports.
- 40 years for land for commerce, tourism, and recreation.
- 50 years for integrated or other land use.

When the land use right expires, the land use right is terminated, but the land user can apply for renewal. Article 359 of the *Civil Code of the People's Republic of China* enacted in 2020 has a detailed description of the renewal of land use right, when the term of the right to use land for residential expires, it shall be automatically renewed. The renewal of the right to use

land for non-residential construction after the expiration of the term shall be handled in accordance with the provisions of law.
Land users may also acquire use rights through land use rights allocation. Article 23 of the *Urban Real Estate Administration Law of the People's Republic of China* (2019 Amendment) defines the allocation of land use right as the act of the people's government at or above the county level approving in accordance with the law to deliver the land to the land user for use after the land user pays the compensation, resettlement and other fees, or delivering the land use right to the land user for use without compensation. Land use rights acquired by way of concession can be transferred, leased and mortgaged. However, there are severe restrictions on the transfer, leasing and mortgaging of allocated land use rights.
The management of land use rights in rural areas of China under the dual urban-rural structure is different from that in urban areas. Regarding construction land, Article 62 of the *Land Administration Law of the PRC* stipulates that each rural household can have only one homestead. The right to use the homestead can only be transferred between members of the local collective economic organisation. The marketing of rural collective construction land for development purposes (transferring and leasing etc.) was completely liberalized with the implementation of the new Land Administration law in 2020.
Land registration in China is a combination of title registration and Torres registration. The development of real estate registration in China can be roughly divided into two stages. In the first stage, the land registration is separate from the building registration. The second stage is the unified registration. The *Measures for Land Registration* (Ministry of Land and Resources Decree No. 40) which were implemented in 2008 and repealed in 2017 (Ministry of Land and Resources Decree No. 78) used to be the basis for land registration in China. It stipulates the land needs to be registered on a parcel basis. A parcel is a plot or space enclosed by the boundaries of land ownership. And it indicates that land registration is conducted according to the principle of territorial registration. The *Building Registration Measures* and *Urban Real Estate Administration Law of the People's Republic of China* (2019 Amendment) regulate the building registration process in China. Building registration is the act of building registration authority in recording the rights of building and other matters that should be recorded in the building register in accordance with the law. The buildings refer to houses and other structures on the land. Building shall be registered according to the basic unit which means a building or a specific space such as blocks, floors, suites, rooms that have fixed boundaries, can be used separately, and has a clear and unique number (block number, room number, etc.). Table 1 illustrates the objects and types of building registration.

Table 1. Objects and types of registration in China

Purpose of registration	Objects of registration	Types of registration
Registration of buildings on State-owned land	Building ownership Mortgages Easements	Initial registration Transfer registration Modification registration Cancellation registration Advanced-notice registration Other types (correction, dissenting)
Registration of buildings on collective-owned land	Building ownership Easements	Initial registration Transfer registration

Purpose of registration	Objects of registration	Types of registration
(Buildings on homesteads and Buildings on other collectively owned construction land)		Modification registration Cancellation registration Advanced-notice registration Other types (correction, dissenting)

3. REVIEW OF 3D LAND ADMINISTRATION FROM LITERATURE

How a 3D land administration can contribute to solutions of local or national is strongly dependent on local situations and user needs, including the land market dynamics, existing legal frameworks and the technical capabilities of those working with the data (Van Oosterom, 2013). Paasch & Paulsson (Paasch & Paulsson, 2023) differentiate 4 components of 3D land administration and 3D cadastres: legal, technical, registration and organisation. The legal boundaries or boundary descriptions of the rights, restrictions and/or responsibilities of land and property may not necessarily align with physical ones, even though in legal terms the rights to apartments, condominiums or shared spaces are clearly defined (Paasch & Paulsson, 2021). More complicated is however recording or recognizing the de facto yet unrecorded 3D claims which exist in many developing countries, countries where registration is not complete or countries where the legal system only covers one type of legal right. One could argue in these cases that the types of rights can be extended to formal and informal (on a continuum), legal or legitimate (socially or societally), or rights which vary and/or come in bundles. Consequently, the legal framework of a continuum or set of bundles poses a great challenge for the implementation of 3D cadastre in different countries. This makes legislation, adjudication and interpretation of rights, recording and maintaining cadastral information unique in different countries, let alone their translation or expansion to 3D properties of such rights (Atazadeh et al., 2023; Ding et al., 2017; Kitsakis et al., 2019; Radulović et al., 2017; Soon et al., 2016; Zhang et al., 2023).
Despite this legal heterogeneity, there has been progress in the technical standardization. The Land Administration Domain Model (LADM) is currently commonly accepted (Paasch & Paulsson, 2021; van Oosterom & Lemmen, 2015) and adapted to local or national contexts. Researchers have adapted and modified the LADM to address the land and real estate management situation in different countries, resulting in a cadastral model that is more applicable to their country context (Ahsan et al., 2024; Felus et al., 2014; Gürsoy Sürmeneli et al., 2021; Janečka & Souček, 2017; Lee et al., 2015; Velastegui-Cáceres et al., 2020). The technical challenges often remain integration and connection with other technical systems. To overcome these integration problems, open data models have been developed for storing and exchanging three-dimensional spatial information, including IFC, CityGML IndoorGML. Adoption and adaptation of these models affect and influence the way 3D property information is de facto stored and will thus influence the way one 3D cadastres and land administration is de facto developing. Many agencies current use the combination of BIM and GIS as de facto 3D standards. BIM is an object-oriented model, it focuses on the building elements of building, while GIS can collect, store, manage, calculate, analyse, display and describe spatial information about Earth surface. In recent years, many researchers have been exploring how to convert data sources such as BIM, CityGML and IFC, to 3D cadastral

modelling (Andrianesi & Dimopoulou, 2020; Gkeli & Potsiou, 2023; Sun et al., 2023). Regarding the work flows and organisation of 3D information, it is argued that there will still be a key role for surveyors and geodetic and/or geomatic engineers. Within the respective institutional and regulatory frameworks they need to migrate their workflows to 3D submissions (Stoter et al., 2019). This implies however that cadastral and /or land administration organisations will have to be reactive which means they cannot carry out their own cadastral registration in the absence of a legal requirement to do so.

4. METHODOLOGY OF DATA COLLECTION AND ANALYSIS

The review of the status and developments relied on an extensive literature review in both English and Chinese language publications. For the literature review we used several keyword-based strategies and different scientific repositories, such as the keywords '3d cadastre', '3D spatial information', 'China', 'natural resources unified registration', and the platforms Web of Science, Google Scholar, CNKI. This resulted in 110 relevant publications. From these the analysis drew on keyword co-occurrence analysis and topic classification to interpret these documents. The keywords co-occurrence analysis is a text-mining technique that analyses the 'co-occurrence' of pairs of keywords in the review documents to visualize the relationships of keywords or topics to one another (Narong & Hallinger, 2023). The key unknowns derived from the theoretical review are the basis for a keyword co-occurrence analysis of academic literature in Chinese and in English, and the basis for a survey design, which was distributed among a selection of key experts and practitioners in China. In addition, several expert interviews were held with prominent scientific researchers in this field to validate both the literature review and the survey results.

5. RESULTS

The literature study reveals that authors in China refer to the 3D land administration or 3D cadastres in different ways. The keyword analysis generated two figures displaying clusters of keywords: Figures 1 and 2 show the high-frequency keywords that appeared alongside 3D cadastre in 3D cadastral researches in China over the past few years. The difference is that the two graphs have different data sources. The data in Figure 2 were obtained from the selected Chinese and English literature, totalling 108 articles. The data source for Figure 2 is from a total of 26 papers after a 3D cadastral related search in web of Science.
The results from the keyword co-occurrence analysis reveals how, when and where the terms cadastre and land registration are being used and applied, and with which (other) terms 3D models are being associated. It is important to understand the Chinese connections to cadastre and hence the implications of these to the term 3D cadastre. The Chinese equivalent of cadastre is diji, written as '地籍'. The first Chinese character '地'（di）means ground, soil and land. The second character '籍'（ji）means book and register. Literally, cadastre in China is a register of land and not necessarily a register of 3D properties. The act of surveying land and recording information in writing dates back to BCE. From its beginnings as a service for tax purposes and as an adjunct to the civil registration, the cadastre has evolved to become equal to the civil registration. Nowadays, the cadastre has a completely independent status.

Before 2018, the registration and the preliminary surveying of real estate and other natural resources are carried out by different departments, including land resources departments, agricultural departments, housing and construction departments, and surveying and mapping departments and so on. This fragmented mandate has resulted in unclear responsibilities, ineffective management and overlapping spatial planning amongst organisations and stakeholders. In order to address these issues and unify the execution of management responsibilities, the State consolidated and optimized the various departments and their respective responsibilities, and formed a unified Ministry of Natural Resources of the PRC.

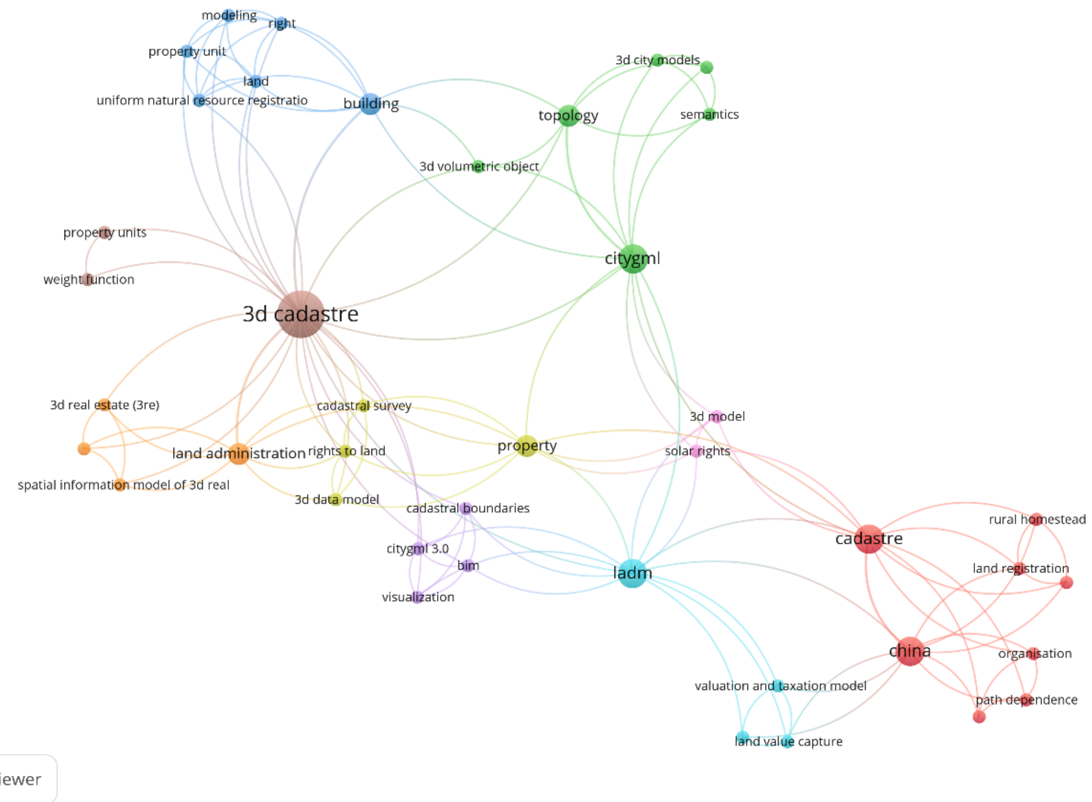

Figure 1. Keywords co-occurrence analysis

Nowadays, China's real estate registration is moving towards a unified rights registration of natural resources, which also has 3D implications, as many of these resources as well as rights exist in a 3D environment. In 2019, the Ministry of Natural Resource together with the Ministry of Finance and ministries, triggered a circular on Interim Measures for Unified Registration of Natural Resources Rights(Ministry of Natural Resources of the PRC, 2019b). This unified registration base on the real estate registration. It needs to be noted, however, that before 2018, different natural resources were under the jurisdiction of a different sectoral institution. Institutional integration has however an effect on what is a valid 3D cadastre.

From the literature study we find that the three-dimensional cadastre emerged from describing three-dimensional use of land, which needed to be connected to both the 3D and 2D space under the policy of unification. By integrating housing and land management the basic unit of registration was extended from registering land to registering 3D property(Zhang et al., 2010). Property units are seen as part of the spatial domain (real estate property unit) with a fixed geospatial location, shape, closed by the boundaries of ownership (surface), independent of the subject and independent of the rights. In the Representation of 3D features of urban real estate, which was implemented from 2021, 3D property unit is defined for the first time in the national standard: a three-dimensional spatial domain with fixed geospatial location and shape with fixed boundaries of tenure and independent rights, and consistent tenure, which is the basic unit of the 3D features of urban real estate (three-dimensional spatial features of real estate with three-dimensional characteristics of urban real estate), and contains three-dimensional parcels of land and structures such as houses (Ministry of Natural Resources of the PRC, 2021). Based on the urban development in China and the needs of cadastral management, Guo and Ying (Guo et al., 2013) model 3D property body into three categories: open, semi-restricted and fully restricted. All three-dimensional land use scenarios can be expressed in terms of these three categories and their combinations. Bounded three-dimensional parcels, which are three-dimensional spaces with closed boundaries, are the most typical form of 3D cadastral property rights and the key reason for the complexity of the 3D cadastre. Open parcels are the traditional 2D parcels, it is sufficient to represent them in conventional two-dimensional representation form (Ministry of Natural Resources of the PRC, 2021).

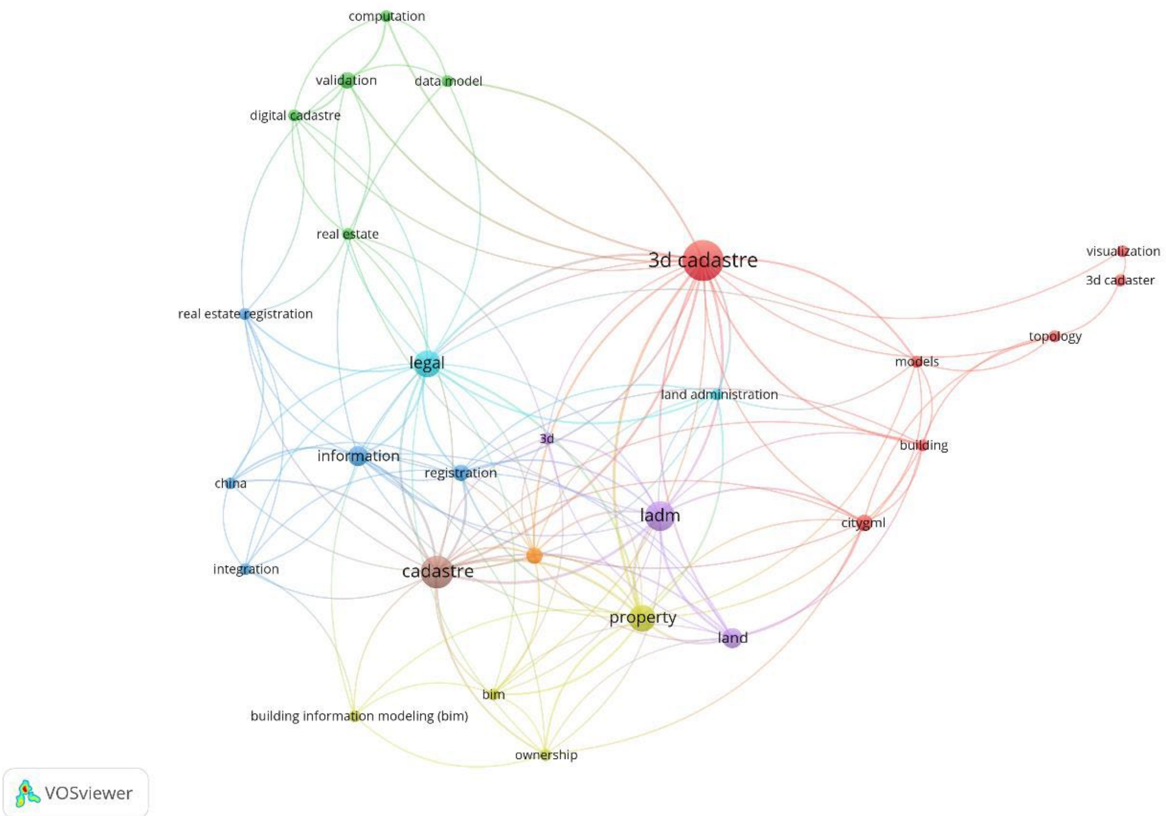

Figure 2. Keywords co-occurrence analysis based on WoS

After these initial publications which focuses primarily on how to model 3D urban features, various researchers have published about 3D models for properties and property management in China. Yu et al. (Yu et al., 2017) designed a Unified Registration Data Model for

Immovable Property; Li et al. (Li et al., 2016) create a CityGML-LADM ADE model to describe the ownership structure of condominium units; Ying et al. (Ying et al., 2018) introduce a uniform real estate registration model (Ying et al., 2018). Zhang et al. (Zhang et al., 2018) propose a 3D cadastral model in the context of actual projects; Wang et al. (Wang et al., 2014) design a hybrid 3D cadastral data model using a mixed modelling approach of B-rep and CSG(H3DCDM). Zhang (Zhang, 2016) describes a spatial data model based on geometric algebra; Zhou et al. (Zhou et al., 2021) design a 3D real estate model which integrates BIM and real estate by extending IFC model is created. This model can associate with building components and spaces in the BIM model. In addition to these examples, many other models have subsequently been proposed and validated. Nevertheless, there is not yet any consensus on a standard model or standards way to represent 3D properties. One could say that many of the models so far draw on 3D city models such as CityGML, whereas only few directly reason from LADM. Some of these include a LADM-based model for registering and managing rural homesteads was presented (Xu et al., 2022) and (Qin, 2020), who proposes a natural resource cadastre model based on LADM. Ying et al. (Ying et al., 2021) put forward a conceptual model of the full range of natural resources and a basic conceptual model for the uniform registration of full natural resources based on LADM. In 2020, *Highlights of Cyber Security and Informatisation Work of the Ministry of Natural Resources in 2020* explicitly proposed to construct a three-dimensional "one map" of natural resources, and unify management and application of the data of the 3D "one map" of natural resources by means of the land spatial basic information platform (Ministry of Natural Resources of the PRC, 2020a). The idea of constructing "one map" was detailed introduced and analysed by (Deng et al., 2022).

The results of the survey and interviews demonstrate and confirm that indeed the developments in both the technical and legal aspects are scattered, but that at the same time several other developments – which may not directly be associated with 3D cadastres – have emerged, which influence and possibly shape the ideas of a de facto system of 3D records of properties in China. From a technical perspective, developments in GIS, remote sensing, BIM and digital twin technologies have generated new ideas and practices in how to shape and manage technical information. Whilst these have resulted in many types and applications of 3D models, the main purpose of these developments was not necessarily to design and innovate 3D cadastres, but to manage and support applications in for example housing, construction and environmental protection which require 3D models to generate useful outcomes. Examples include the use of key technologies for three-dimensional rights registration of natural resources, and the construction of a three-dimensional "one map" of all natural resources, and unify management and application of the data of the 3D "one map" of natural resources by means of the land spatial basic information platform. These developments have generated as a side-effect the development of models which carry 3D information on legal properties, and therefore mirror the original paradigms of 3D cadastres.

From a legal perspective the past 10 to 15 years have seen a lot of changes in legislation to better cope with the fast-growing real estate market. This resulted not only in a revision of the systems of rights and rights registration, but also in advancements of how to manage a system securing and/or enforcing such rights. The legal embedding of 3D properties has followed a slightly different path than the technical modelling. The three-dimensional use of land were originally thought of as an exploration of three-dimensional space. The rights originally based on the surface are extended above and below the ground, and spatial rights are therefore generated. Guaranteeing and supporting spatial rights and management is an important condition for the realisation of a three-dimensional cadastre.

Article 54 of *Some Provisions for Determining Land Ownership and Use Right*s which enacted by the Ministry of Land and Resources in 1995, stipulates that "*where land is used in a three-dimensional manner (except in the case of buildings) on the ground and in the air, or on the ground and under the ground, the right to use the land is determined in favour of the user on the ground, and in the air and under the ground, the right to use the land is determined in favour of the user on the ground, and in the air and under the ground, the right to use the land may be determined as an alternative right*. "(National Land Administration of the PRC, 1995).

The Regulation on the Management of the Development and Utilisation of Underground Space in Cities was published in 1997, which was the first of its kind to realise the management of the utilisation of underground space (Ying et al., 2023). It was revised twice, in 2001 and 2011(Ministry of Housing and Urban-Rural In October 2007, the *Property Law of the People's Republic of China* was implemented, of which article 136 stipulates that the right to use land for construction purposes may be established on the surface of the land, above the surface or below the surface, respectively(The National People's Congress of the PRC, 2007).

The *Civil Code of the People's Republic of China*, which came into force on 1 January 2021(The National People's Congress of the PRC, 2020), replaces the Property Law, and article 345 of the Civil Code carries over the previous provisions on the use rights of building land. This law guarantees the legality of three-dimensional use of land and related rights, and also serves as basis for the establishment of more detailed 3D cadastral laws and regulations in the future.

The *Interim Regulation on Real Estate Registration* has been in effect since March 1, 2015, and were amendment in 2019(Ministry of Land and Resources of the PRC, 2016), thus clearly establishing the concept of three-dimensional space of land at the legal level (Ying et al., 2023). The accompanying *Implementing Rules for Interim Regulations on Real Estate Registration* (Ministry of Land and Resources Decree No. 63) also came into force in 2016(Ministry of Land and Resources of the PRC, 2016). Article 5 of *Rules* defines the immovable property unit under article 8 of the *regulation* and specifies that the object of registration is the spatial unit. In 2019 *Guiding Opinions on Promoting the Reform of Property Right System of Natural Resources Assets as a Whole* once again emphasises the need to accelerate the establishment of separate rights to use construction land above, on and below the surface, to promote the rational development and utilisation of space, and proposes to explore the three-dimensional layering of rights to use maritime areas (General Office of the Central Peoples's Government of the PRC & General Office of the State Council of the PRC, 2019).

The *General Programme for Informatisation of the Ministry of Natural Resources* issued by the Ministry of Natural Resources proposes to "promote the construction of a three-dimensional reality database"(Ministry of Natural Resources of the PRC, In 2020, the State Council issued a notice (Letter No.96[2020] of the State Council), proposing to replicate and popularized "the three-dimensional land management model with a three-dimensional cadastre at its core" nationwide(State Council (PRC), 2020). In 2022, the General Office of the Ministry of Natural Resources issued the *Notice on Comprehensively Promoting the*

Construction of Realistic 3D China, which set new goals for the construction of 3D reality. (General Office of Ministry of Natural Resources of the PRC, 2022)

For the compilation and expression of 3D cadastral data, Shenzhen has drafted and formulated a specification document – *The Data Standard of the Three - Dimensional Property* which is also the first local standard data regulation in China (Shenzhen Digital City Engineering Research Centre et al., 2021). In 2023, Shenzhen issues a specification on 3D real scene and standardises the requirements related to 3D data at city level in Shenzhen City (Shenzhen Planning and Natural Resources Bureau, 2023)

The *Representation of 3D features of urban real estate* specifies the basic requirements for the expression of spatial and attribute information of three-dimensional spatial elements of urban real estate (Ministry of Natural Resources of the PRC, 2021). The *Technical specification for three-dimensional modelling of urban underground space* specifies the basic requirements for three-dimensional modelling of urban underground space (Ministry of Natural Resources of the PRC, 2022). In addition to these two national norms, some provinces or municipalities have drafted and issued local norms (Department of Natural Resources of Jiangsu Province, 2020; Fujian Basic Geographic Information Centre, 2015; Hubei Provincial Government, 2015; Qingdao Survey and Mapping Research Institute.

6. DISCUSSION AND CONCLUSION

The evidence demonstrates that in China neither in technology nor in legal the definitions of cadastre and 3D cadastre or 3D land administration are harmonised. The understanding of the 3D cadastre is a simple combination of the definition of 3D and the definition of cadastre. Is a 3D cadastre a collection and presentation of data? Or does it only refer to a 3D model or is it a system that combines 3D surveying, 3D modelling, 3D data visualisation and the corresponding management and legislative systems? The ambiguity of the definition of cadastre and three-dimensional cadastre may be due to the fact that cadastre is a traditional concept. As the demand for land use increases and land use becomes more complex, whether for tax or other purposes, land is surveyed and registered by the authorities. However, in the modern world, with the development of technological means, changes in management models and the establishment of legal systems, as well as the development of property rights systems and land use in a more comprehensive direction, the traditional concept of cadastre can no longer fully cover the content of the concept of "cadastre" in real life. Cadastre is no longer just a result of recording, but a system.

The possibility of a more precise definition of the three-dimensional cadastre is also influenced by the above-mentioned reasons. In addition, three-dimensional cadastre has been in the research field for many years and scientists have made many achievements. However, there has been no real promotion of 3D cadastre so far, and 3D cadastre is still in the process of practical exploration, so it is difficult to define this concept by its characteristics and attributes. The perceived consistency of concepts such as digital twins, twin cities, etc. is due to the fact that these concepts were developed later and do not require an update of the original concepts.

China's land registration has undergone two changes in the past, a unified registration of real estate and a unified registration of natural resources. As the management of various natural resources belonged to different departments before the unified registration, both changes meant that data from different sources needed to be integrated. At the technical level, it is necessary to establish a unified global coordinate system to ensure that all types of spatial data are integrated under a unified coordinate system. Secondly, it is necessary to establish unified data standards and formats and to set up a data-sharing platform. Next is the third step, which is to collate existing data, clean redundant data and clarify the relationship between data so as to improve data quality. Data integration is a long-term process, which not only requires the collation of past data, but also puts forward new requirements for the investigation of new resource data. China's three-dimensional cadastre should have come a long way in terms of technology, and at present the technical problems of basic data collection and modelling have been solved. However, the demand in practical application is far more than that, efficient and accurate modelling and updating with the timeliness of 3D scene is the development goal. And the realisation of this goal largely depends on the efficient and high precision acquisition of 3D data. The research on technology account for a large portion in the English and Chinese literatures on 3D cadastre in China. From these studies, it is evident that Chinese researchers and scholars have overcome many difficulties in realising the technical aspects of 3D cadastre and have found methods and means suitable for China's national conditions, from data acquisition to expression to modelling to visualisation. Nowadays, the focus of the research has gradually transitioned from the development of 3D cadastre which only for land and real estate to the construction of models and data platforms for the unified registration of natural resources, including water, seas, forests, minerals, and so on. This shift implies the renewal and replacement of technologies. For example, while buildings have different shapes and underground spaces are difficult to measure, there is a need for more efficient means of obtaining three-dimensional data when dealing with more difficult to define boundaries and a wider range of objects, such as the sea, forest.

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BIOGRAPHICAL NOTES

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Piloting 3D Cadastre in Singapore

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Keywords: 3D Cadastre, Digital Cadastral System, 3D Strata, LADM, IFC

SUMMARY

Since 2000 various initiatives have been carried out to modernise Singapore's digital cadastral survey system by the Singapore Land Authority (SLA). The initiatives include the implementations of coordinated cadastre (2004) and electronic submission (2005), establishment of Singapore CORS network (SiReNT) (2006), and digital cadastre through the implementation of Cadastral Survey Management System (CSMS) (2018). CSMS introduced new digital workflow for land-based cadastral survey submissions and a digital format called SG LandXML, which allows for automated pre-validation against Singapore's cadastral survey rules, to improve the overall productivity. Though SLA has proposed a preliminary roadmap in 3 phases (i.e, feasibility study, pilots and implementation) (Khoo, 2011), and developed CSMS to support digital cadastre (Soon, et. al, 2016), the digitalization for strata survey was excluded in the initial implementation of CSMS.

With the advancement of Building Information Modelling (BIM) technologies, the Architecture, Engineering and Construction (AEC) industry in Singapore has geared towards the adoption of BIM. The submissions in BIM for regulatory building works have been implemented with the launch of CORENT X, a Whole of Government (WoG) submission platform in Singapore in December 2023. This has led to a new digital 3D era in AEC industry and impacted the land surveying industry to investigate the development of 3D digital cadastral submissions, especially for 3D strata survey submission. Consequently as authority for property ownerships, SLA embarked on pilots to implement 3D cadastre.

3D cadastre eco-system is comprehensive and has been studying by domain experts globally. After reviewing the latest 3D cadastre development by domain experts and researchers, SLA decides to focus on 4 core areas, which are 1) digital 3D cadastre survey techniques and workflows; 2) 3D data model and modelling methodologies; 3) regulatory validation and visualization for 3D submission; and 4) legislation and institutions framework. Presently, SLA is piloting the works in the first 3 areas which are more technical in nature.

This paper will introduce the works of the pilots, as well as the corresponding findings.

Piloting 3D Cadastre in Singapore

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1. INTRODUCTION

Since 2000, various initiatives have been carried out to modernize Singapore's digital cadastral survey system by the Singapore Land Authority (SLA). The initiatives include the implementations of coordinated cadastre (2004) and electronic submission (2005), establishment of Singapore CORS network (SiReNT) (2006), and digital cadastre through the implementation of Cadastral Survey Management System (CSMS) (2018). CSMS introduced new digital workflow for land-based cadastral survey submissions and a digital format called SG LandXML, which allows for automated pre-validation against Singapore's cadastral survey rules, to improve the overall productivity. Though SLA has proposed a preliminary roadmap in 3 phases for 3D cadastre development (i.e, feasibility study, pilots and implementation) (Khoo, 2011), and developed CSMS to support digital cadastre (Soon, et. al, 2016), the digitalization for strata survey was excluded in the initial implementation of CSMS.

In Singapore, the current strata survey submission made by industry is in PDF format, which is a non-digital, non-georeferenced, and non-GIS compatible format. Such non-digital format is unable to support machine checking automatically. Hence, the current regulatory process for strata submission in CSMS is manual based. It is tedious and time-consuming using eyeballs to check all the details to assure the data quality based on PDF plan. In downstream usage, the approved strata plan in PDF format could not be overlayed with GIS map directly, and the geospatial linkage between individual strata unit and the residing land lot could not be visualized in GIS map too. There is no doubt that we need the digitalization for strata survey, to increase the productivity for regulatory process, and improve the data quality for the strata survey submission. There are many reasons for why digitalization for strata survey should move to 3D form.

First, the demands on effective land administration and management which based on accurate as-built 3D geometries with RRR information. The 2D digital strata boundary is unable to visualize the vertical geospatial relationship among different lot types in a complex building, e.g, an integration building in the city area which have underground tunnel (subterranean lots), commercial podium on the ground (land lot), overhead bridge to connect to another building or even a bus interchange (airspace) within the building, and multi-story residential units (strata lot). Some buildings are very complex and innovative design in Singapore, such as the examples shown in Figure 1. It is very challenging for surveyor to represent and depict the strata lots in 2D plan for such buildings. Furthermore, the regulatory authorities' officers also have difficulty in reading and interpreting the 2D plans. This suggest that 2D digital strata plan cannot meet the regulatory authority's demands on effective land administration and management.

Second, there is a trend on 3D transformation in Singapore. The importance of 3D cadastre is illustrated by SLA's vision statement containing an explicit 3D component: ''Limited Land – Unlimited Space'' (van Oosterom, P., 2013). As a land-scare country, a reliable 3D cadastral dataset can help the urban planners to synergize the land development from aboveground to underground better in Singapore. From Digital Twin development perspective, a reliable 3D strata dataset could associate with high quality information at unit-level, e.g. to manage and analysis the approved use and energy consumption for individual unit in a 3D environment.

a. Ferrell Residences
b. Reflections at Keppel Bay
c. The Interlace

Figure 1. Some examples of complex and innovative development design in Singapore

Third, with the advancement of Building Information Modelling (BIM) technologies, the Architecture, Engineering and Construction (AEC) industry has geared towards the adoption of BIM in Singapore. The submissions in BIM for regulatory building works have been implemented with the launch of CORENT X, a Whole of Government (WoG) submission platform in Singapore in December 2023. This has led to a new 3D era in AEC industry and impacted the land surveying industry to investigate the development of 3D digital cadastral submissions, especially for 3D strata survey submission.
Hence, for strata digitalization, we should move to 3D directly rather than 2D digital form. With the advancement of rapid 3D data capturing and modelling technologies, such as laser scanning, BIM etc, which are getting more and more mature and affordable, SLA is continuously leading the 3D cadastre development and have been embarking some pilots to leverage laser scanning and BIM technologies for as-built 3D digital strata survey submission. This paper focuses on the piloting works that SLA has been doing. The paper is organized as such: Section 1 introduces the needs for 3D cadastre; Section 2 reviews the 3D cadastre researches and initiatives from different jurisdictions; Section 3 introduces SLA's pilot works and findings; Section 4 produces concluding remarks.

2. INTERNATIONAL 3D CADASTRE RESEARCH AND INITIATIVES

Over the last few decades, rapid urbanization has resulted in substantial pressure on development and use of land in urban environments across the world. The growth in complex building structures, possess new challenges for current 2D-based land administration systems globally. To address these challenges, the 3D cadastre has been researched and prototyped by domain experts in many different jurisdictions.

During the last decade, many jurisdictions investigated the 3D cadastre initiatives, including The Netherlands, Australia, New Zealand, China, Korean, and Malaysia etc. These jurisdictions' researchers notably contributed to practical implementations of 3D cadastre concepts. Many practices and literature have provided numerous publications related to 3D cadastre development, which have been documented in the FIG Best Practices 3D Cadastres (Oosterom (2018)). The research and demonstration of 3D cadastre across the world have been up to a certain level. For example, in The Netherlands, Stoter et al.(2016) describe how a 3D PDF was registered as legal document in the Dutch Kadaster with RRR. In Australia, the 3D ePlan prototype have been developed to illustrate how the legal and physical objects of a building subdivision plan can be stored, visualised and queried in a 3D digital system (Olfat et al. 2016), see Figure 2. In China, a 3D cadastral system has been developed to visualize 3D property formation in Shenzhen (Urban Planning, Land and Resources Commission of Shenzhen Municipality) (Ying et al. 2012), as shown in Figure 3.

Figure 2. Land Use Victoria 3D ePlan Prototype, Australia (https://www.spear.land.vic.gov.au/spear/pages/eplan/3d-digital-cadastre/3dprototype/prototype.html)

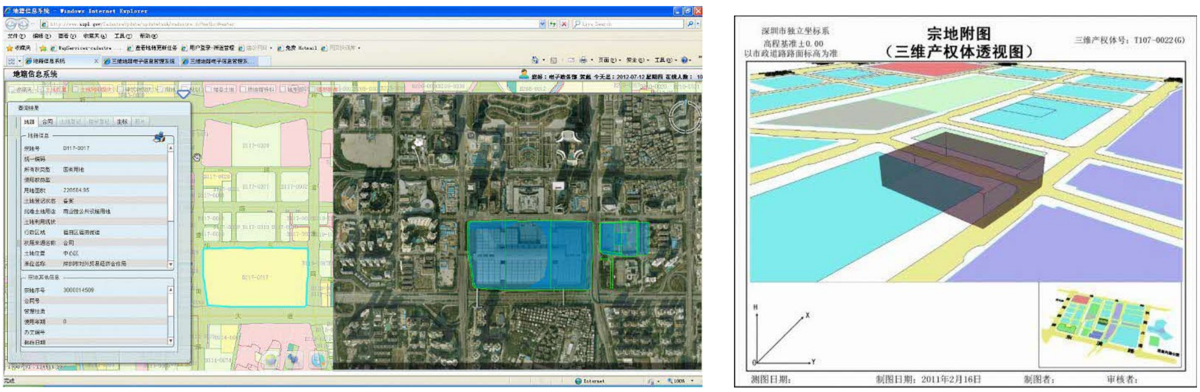

Figure 3. 3D Cadastral System based on B/S architecture, Shenzhen (Source: Ying et al. 2012)

All these initiatives are very insightful and have made a big move in 3D cadastre development. It is notable that 3D cadastral information modelling and 3D cadastral data visualisation are two of the most focusing aspects over the years. However, there are still technical difficulties which need to be resolved. The common issues are insufficient 3D measurements and contents due to the challenges in 3D data capturing onsite, and incompletion of the vertical information of the existing 2D plans regarding elevation, height, and depth etc., which resulted in the 3D cadastral modelling difficulties and 3D models reliabilities. This suggest that the 3D cadastre implementation needs further development of technical solutions for 3D data acquisition and modelling process.

The latest research and developments show that the technical aspects have been investigated significantly across world. These technical aspects typically refer to various stages of the digital data lifecycle, not only 3D data acquisition, and 3D data model and standards, but also including 3D data visualization and storage, 3D data validation, 3D data queries and analysis (Olfat et al. 2021). Compared to the technical aspects, the studies of legal and administrative domains received less research attention, though these two aspects have been deep dived into in the early studies in different jurisdictions.

Some international standards such as LADM (2012), CityGML (2012), and IndoorGML (2014) have been developed, and keep updating over the years due to the raise of requirements on the standardization and data interoperability. Korean and Singapore have designed and implemented their cadastral system based on LADM. With the advantages of Building Information Modelling (BIM) development, the integration of BIM data into 3D cadastre is relatively new field of research too. The researchers from Australia, Sweeden, Korean etc have published some research paper on how to utilise BIM for 3D cadastre modelling and information integration during the building lifecycle, e.g. Atazadeh et al. 2016 proposed an extension to the openBIM standard, which is implemented in a prototype BIM model to showcase the potential capability of using BIM for high-rise land administration and for modelling 3D ownership rights in Australia. Sweden also initiated a research project which leverage on BIM-based approach for 3D cadastral management across the lifecycle of the building (Sun et al. 2020).

Overall, the development of 3D cadastre has been studied with significant milestone achievements in legal and technical research, international standardization, and practical implementations across jurisdictions over the years. However, a 3D cadastre implementation solution always depends on the local situation and is driven by user needs, land market requirements, the legal framework, and technical possibilities. Hence, to develop a practical solution for 3D cadastre implementation at nation-level is still a big challenge for many countries. This motivates the authors to write this paper to share the piloting works in Singapore, to contribute the practical experience, and look forward to gaining more insights and feedback from the global experts.

3. PILOTING 3D CADASTRE IN SINGAPORE

SLA has been exploring 3D cadastre development since 2011, and actively participating in FIG, 3D GeoInfo, UN-GGIM conferences related to effective land administration and management. After learning the ideas and experiences from the global domain experts via the literature review, SLA decided to step into the pilot stage to gain more practical experience for 3D cadastre development. According to Singapore's situation, i.e. the strata submission is non-digital, SLA prioritized the implementation of 3D strata submission by leveraging laser scanning and BIM technologies. The core work areas are: 1) digital 3D strata survey techniques and workflows; 2) 3D data model and modelling methodologies; 3) regulatory validation and visualization for 3D submission; and 4) legislation and institutions framework, shown as Figure 4. Presently, SLA is piloting the works in the first 3 areas which are more technical in nature. The current legislation in Singapore supports digital form submission regardless in 2D or 3D, which could be further investigated and then to make necessary amendments for 3D cadastre submission enforcement from regulatory perspective in near future.

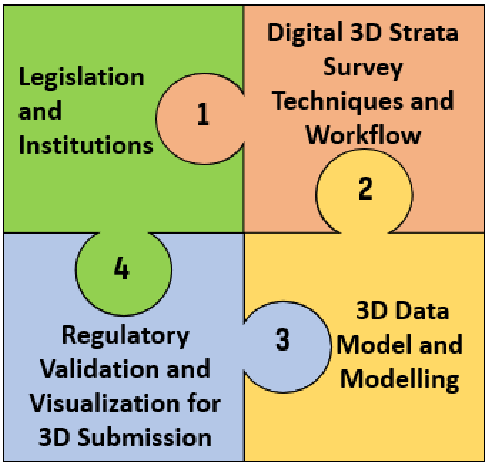

Figure 4. Singapore's 3D Cadastre Works Areas

3.1 Pilot 1 - Digital 3D Strata Survey

3.1.1 <u>Objective</u>

This pilot is a co-creation initiative between SLA and its panel Registered Surveyor, Surbana Jurong Pte. Ltd. It aims to figure out the technical challenges, time spent, and identify the suitable workflow by conducting the as-built 3D digital strata survey using laser scanning and BIM technologies.

Figure 5. Pilot Site – Block 213C at Woodleigh Hill Estate

The pilot site locates at Woodleigh Hill Estate in Singapore, which is a newly built public housing estate by Singapore's Housing & Development Board (HDB). The Block 213C (Figure 5) was selected for this pilot, due to it is a typical newly built building and is ready for strata survey. There are 16 floors in this building, including 130 housing units, lift cores, staircases, with long corridors connecting the two main blocks of the building, as well as a childcare center at ground level.

3.1.2 Workflow

To achieve the pilot's objective, we carried out the digital strata survey using the laser scanning technology. The workflow could be as follows:

1) **Site survey**

The as-built 3D digital strata survey must be based on the Singapore national geographic coordinates system (SVY21) and Singapore Height Datum (SHD). To ensure the survey data is accurate and the subsequent 3D strata modelling could refer to the control points for georeferencing, the first thing is to establish horizontal and vertical ground control points based on SVY21 and SHD for Block 213C. The nearest existing vertical control point (VCP80118) is about 0.9km away. The engaged surveyor established 2 RTK points (MK11 & MK12) nearby the estate (Figure 6a) using SiReNT, and then transferred level from VCP80118 to the RTK points by digital level. Thereafter, conducted the traverse using total station, to transfer the Northing, Easting and Elevation to the newly established control points surrounding the Block 213C. The layout of the control points is shown as Figure 6b.

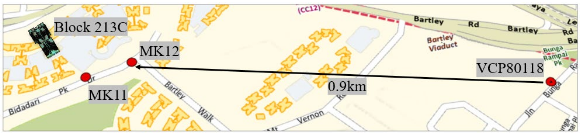

Figure 6a. Nearest VCP and new RTK points

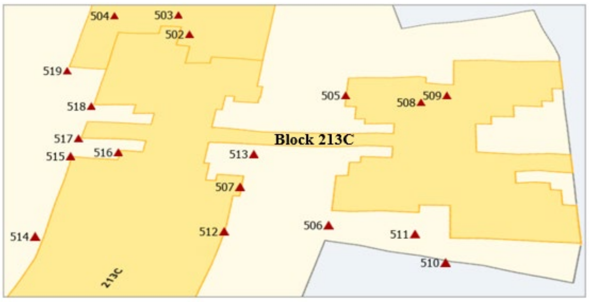

Figure 6b. Newly established control points surrounding Block 213C

2) **Scanning on site**

There are different reality capture solutions available in the market, e.g. terrestrial laser scanners (static scanners, mounted on the tripods), handheld laser scanners, and mobile laser scanners (mounted on a platform such as a trolley or backpack). To choose a scanner for 3D strata survey, several factors should be considered, such as accuracy, range, portability, and ease of use. High-end terrestrial laser sacnners often provide better accuracy compare handheld and mobile scanners. Handheld and mobile scanners offer greater flexibility and ease of use in indoor environments, and tend to be more affordable compared to static terrestrial laser scanners.

The engaged sureveyors used the terrestrial laser scanners (LiDAR Trimble X7) in this pilot. The main reason is the consideraion of high accuracy requriement(not more than 3cm) in cadastral survey in Singapore. Howerver, the disadvantages are obvisouly, which inlcuding the range limitation of the scanners due to the limited spaces within the units and surrounding

of the building. Also it is unable to scan some external corrners which block by building structures such as walls.
The scanning works including scan the exterior for the entire building, and then scan every individual unit, staircases, corridoors, aircon ledge etc., floor by floor, see Figure 7. As the building was scheduled to be handed over to HDB, the scanning works were delayed by on-going renovation and inspection works too. Hence, additional surveyors and scanners were deployed (Reigl VZ400). To make sure there were adequate overlapping point clouds were capured for post porcessing, multiple scans at each station were conducted. It took almost 1 month to complet the scanning works for all the units, which delay a lot due to the above reasons.

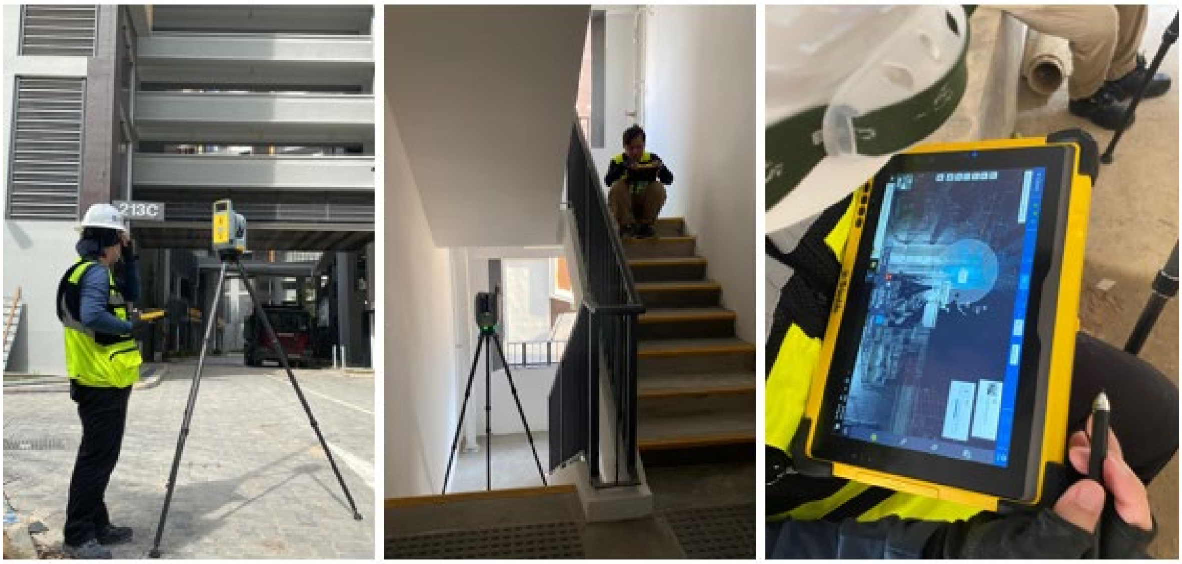

Figure 7. 3D digital strata survey on site

3) **Point cloud registration**

The point cloud captured by Trimble X7 was processed using Trimble Business Centre & Trimble Perspective, while the point cloud captured by Reigl VZ400 was registered by RiscanPro. The point clouds were georeferenced based on the control points that established during the site survey stage. The noise and irrelevant data have been removed from the point clouds. The two datasets were aligned as one single, unified point cloud dataset using Trimble Business Centre, see Figure 8. The combined point cloud was exported to Autodesk Redcap format for next step.
One of the learning points is, that the density of the two point clouds is better to be the same, so that the same feature is easier to identify and take it as reference point for combination. The two datasets from two scanners have differnt density, which cause some extra efforts on the combination.
Another learning point is, a hign-end PC/Laptop is necessary for point cloud processing. In this pilot, the filesize of raw point clouds are up to 1TB. The surveyors' computer is unable to process such massive raw data expeditiously and efficiently. It took a few days to figure out the issue and then the team have to extract the point cloud floor by floor to process, and then merged them into one final point cloud dataset. Also, the Trimble Business Centre was unable to generate the overall point cloud registered report due to such procedure.

Figure 8. Point cloud of the Block 213C

4) **3D Modelling**

3D digital strata information requires two main dimensions, i.e. physical, and legal information. Physical information refers to the shape and geometrical aspects of building elements, such as walls, floors, ceilings etc. Legal information is derived from the strata subdivision process, it refers to ownership information, e.g, the boundaries of strata lots and common properties.

In Singapore, unless otherwise stipulated on the strata certified plan, the common boundary of any strata lot with another lot or with the common property shall be the centre of the floor, wall or ceiling (Chief Surveyor Directive on Cadastral Survey Pratices of Singapore, i.e. CS Directive). In the current 2D strata plan, the strata boundaries were drawn in solid line, and the physical strutures such as walls were drawn in dotted lines, as shown in Figure 9.

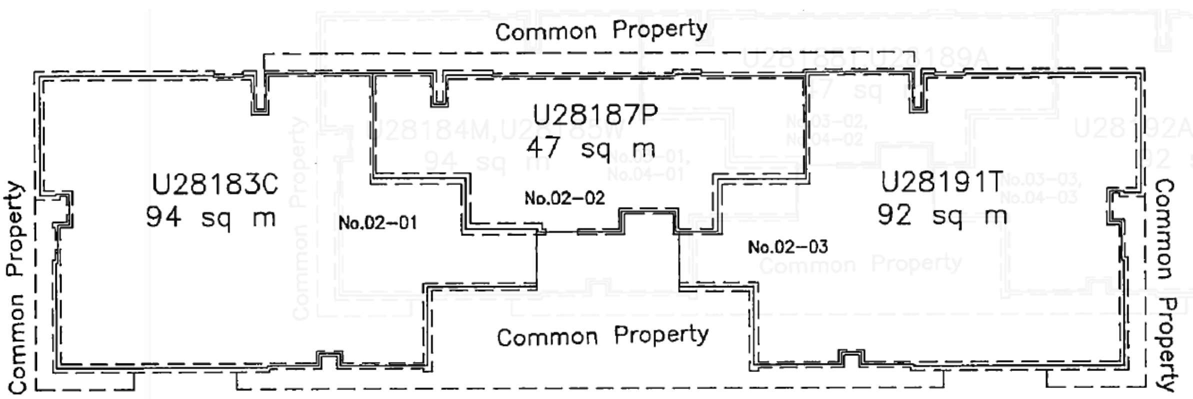

Figure 9. Part of a sample of 2D strata plan

Move to 3D strata, the model should continue not only contain the 3D legal space, but also the necessary 3D physical structures, such as walls, slabs and ceilings. BIM have been adopted for submission in AEC industry in Singapore, and BIM can integrate physical model and legal model with cadastral information, as well as BIM possess the 3D visualizaion capability, hence BIM-based approach was adopted for 3D strata modelling in this pilot.

The unified point cloud in ReCap format has been imported to Autodesk Revit. The physical model was created first based on the point cloud, i.e., the necessary building elements such as walls, slabs, ceilings have been modelled in 3D, see Figure 10.

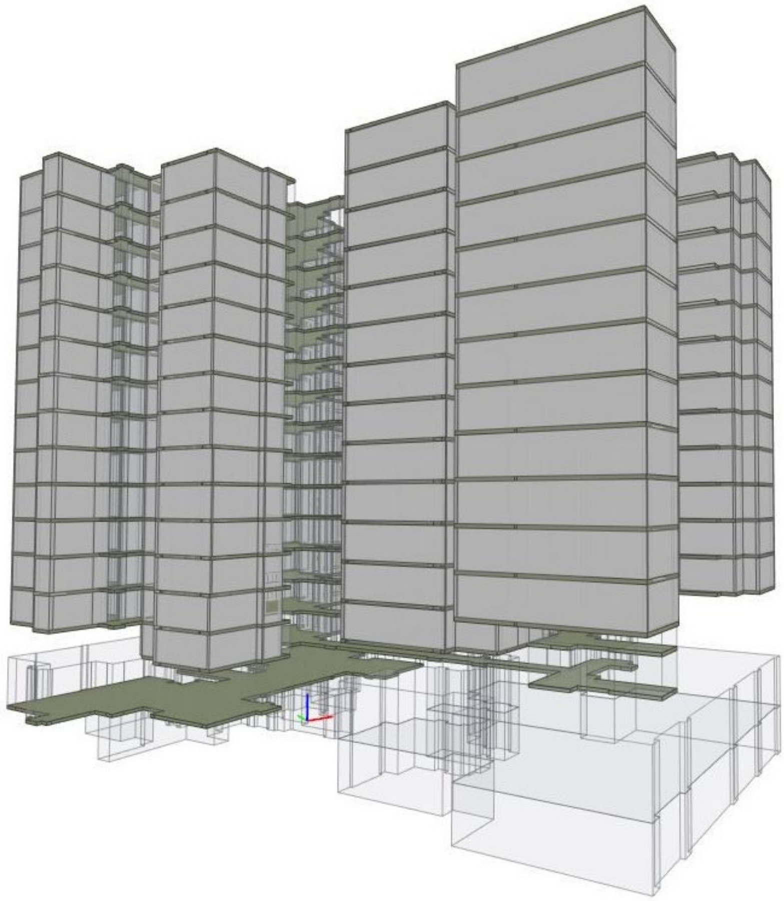

Figure 10. BIM model of Block 213C

The legal model was then created based on physical model manually, with the interpretation by registered surveyor according to the current requirements of strata survey which specified in the CS Directive, e.g, strata boundary determines by the centre of the walls/slabs/ceilings, see Figure 11. At this step, not only the 3D geometries of strata lots were created, but also the cadastral information required by SLA for regulatory approval purpose have been tagged to the individual 3D strata lot. The modelling approach based on existing BIM model using Revit, regardless it is as-built BIM model or as-designed BIM model, has been introduced in Pilot 2 in section 3.2 below.

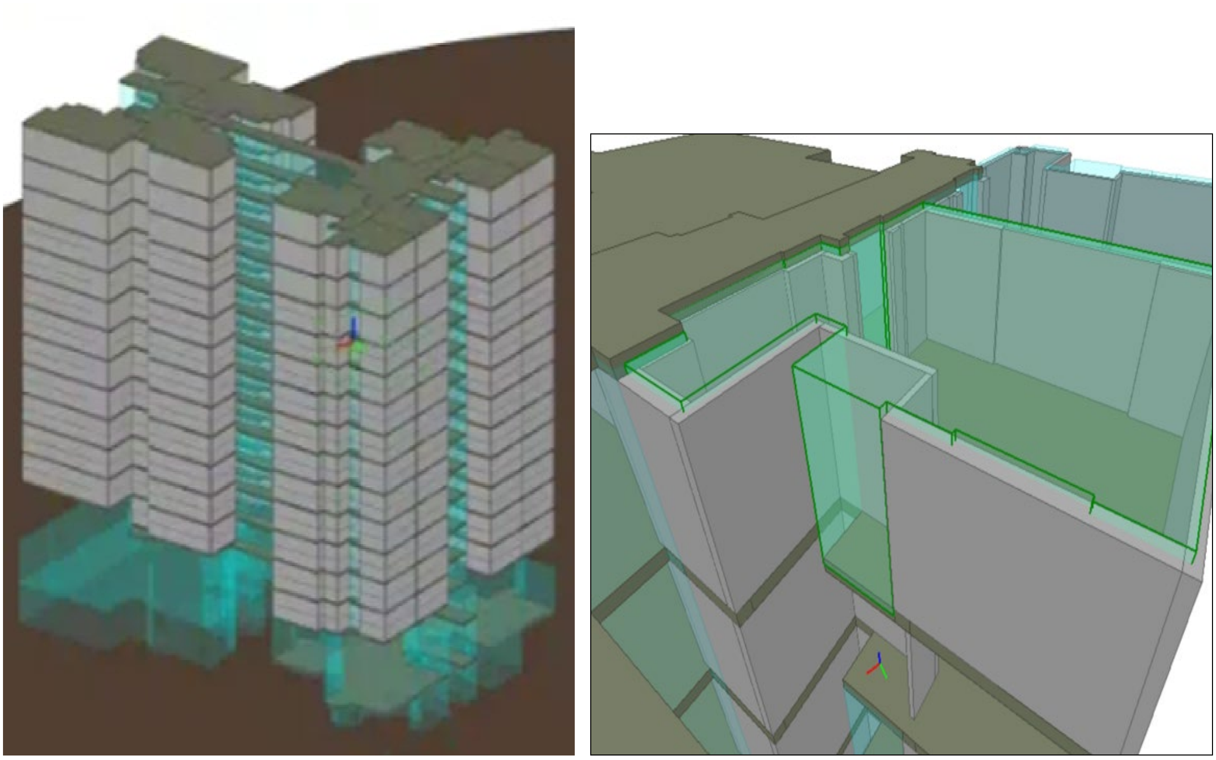

Figure 11. 3D Strata Model contains 3D physical structures and 3D legal space

3.1.3 Findings

This pilot has gone through the as-built digital 3D strata survey techniques and workflow. Some takeaways from this pilot are:

1) 3D laser scanning is a practical solution for implementing the as-built 3D digital strata survey. Surveyor can use the scanned data to create 3D model, and re-measure any dimension without re-visiting the site. Regulatory officers can use it to verify the submitted model. The scanned data is "time stamped" that can be used as survey evident in time of dispute.
2) There is no doubt that the accuracy of the data captured using laser scanning method is more accurate than conventional linear taping especially when the design of a building is a curve or not in right angles.
3) However, the static tripod laser scanner used in this pilot is unable to scan 100% of every part of the building, due to the site conditions and the scanner's range constrains. In such

case, using the conventional measurements or using handheld scanner to capture those difficult parts is a good alternative approach.

4) It is time-consuming to use static tripod 3D laser scanner to scan every single unit and common area of whole building. The pilot suggested to only scan the non-typical floors, and one of the typical floors, as long as the final 3D strata model of the whole building full fill the strata survey accuracy requirements.
5) The pilot also suggested to obtain the georeferenced designed BIM model which had been approved by the regulatory authority prior to conduct the as-built 3D digital strata survey. Such BIM model would be very helpful for the surveyor to understand the strata subdivision and the site conditions better. Also, the approved designed BIM model could be an important supplemental data source for as-built 3D strata modeling in later stage.

3.2 Pilot 2 – 3D Strata Modelling

3.2.1 Objective

The AEC industry is required to make BIM-based submission via Corenet X for regulatory approval for building works in Singapore from Dec 2023. And the Code of Practice (CoP) for BIM submission has been developed for AEC industry use. However, this CoP only emphasizes the construction of 3D physical building objects by architects and professional engineers at design stage. The construction of the 3D legal strata model by registered surveyor at as-built stage has yet covered by the AEC CoP.
This pilot aims to explore the BIM-based as-built 3D strata modelling methodologies. The outcome from this pilot is expected to be incorporated in a BIM-based Cadastral CoP which is under developing for RSs' use.

3.2.2 Data Source for 3D Strata Modelling

For as-built strata subdivision survey in Singapore, the RSs currently use 2D building plan in CAD format approved by the regulatory authorities, which RSs usually received from architects, as the base for creating 2D strata subdivision plans, with the field measurements details which captured on site when the building was built to roof top.
Move to 3D era, it is highly likely that RSs would work on the creation of 3D strata model based on the obtained physical model in BIM. There will be two (2) ways for RSs to get the physical models in BIM to work on:

Option 1: As-designed BIM from architects or the regulatory authority
The main issue for this option is, that the BIM model is an as-designed BIM. SLA is looking for as-built 3D digital strata survey and submission. Therefore, RS is required to conduct 3D digital survey, i.e. laser scanning, to obtain the point clouds first. The point cloud will be used as the base to validate the obtained design BIM model. If the offsets between the point cloud and the BIM model are within an acceptable tolerance, RS can create the 3D strata model based on the designed BIM directly.
Using as-designed BIM model to create 3D strata model can save RS's time to create physical BIM model. However, the overall time for the whole process may not reduce. This is because, the as-designed BIM usually is rather complicated with very detailed geometries of walls, slabs, columns, roofs, rooms, indoor furniture, even pipes and cables, as well as the thickness and material information of the structures. Some of the physical elements and information are not important in the context of strata boundaries modelling. Therefore, the BIM model should

be generalized to eliminate unnecessary physical information. Such “generalization” works could be time-consuming works due to its complexity and computer’s performance. Another issue is that the designed BIM model provided by architect or authority might not be the latest version, and without proper georeferenced. This also required time and cost for RS to verify after the construction of the building.

Option 2: As- built BIM derived from the point cloud
In this option, RS would create the physical model in BIM based on the point cloud which captured from the site survey after the building reach to roof top, and then construct the 3D legal space accordingly, as described in section 3.1.2 above. In such case, the physical structures and legal space would align well with each other in the final as-built 3D strata model, and the 3D model’s overall accuracy would be higher than Option 1. SLA is working with the survey industry to implement the as-built 3D digital strata survey submission via Option 2.

3.2.3 3D Data Model and Modelling Methodologies

1) Adopt LADM as the fundation of cadastral database

The Land Administration Domain Model (LADM) is an international standard (ISO 19152) for land administration. It creates a conceptual framework which including Parties, RRRs, Spatial Units and Surveying components for land administration systems worldwide. LADM has been used in many projects, from database design to 3D modelling and 3D visualization, from LandXML-based applications to BIM-based applications (Ying et al., 2011, Soon et al. 2016, Atazadeh et. al.2017, Cemellini et al. 2020). The existing data model implemented in the current national cadastral system in Singapore (CSMS) is based on LADM (2012) (Soon et al. 2016).

2) Adopt IFC as the encoding format for BIM-based 3D strata model

Some international open standards have been developed for data interoperbility and data integration in geospatial and built enviroment domains, wchih inlcuding CityGML, GeoJson, IFC, LandInfra etc (OGC, buildingSMART 2020). IFC (Industry Foundation Classes) is an open BIM format used predominantly for exchange of rich, fine-scale building and infrastructure data in the AEC industry, which has been supported by main BIM modelling software, such as Revit, Archicad, Takla, OpenBuilding etc. In Singapore, the IFC 4 standard has been adopted and localized as IFC-SG standard accoring to Singapore goveryment agencies’ requirements of regulatory approval for building works. The IFC-SG standard has been published as the Code of Practice for BIM Submisson with the launch of CORENET X in Singapore. SLA is working on the development of 3D cadastral CoP which is IFC-SG based.

3) Mapping strata elements to IFC entities

Idealy, A BIM-based 3D strata model should include legal, physical and survey information. The application of IFC standard in cadastre has been investigated a lot in different countries (Atazadeh et al. 2021). For example, in Australia, researchers have developed approaches for extending BIM with cadastral information (Atazadeh et al. 2016). For managing legal and physical data requirements, previous studies have identified relevant IFC entities based on the LADM, e.g. “IfcSpace” and “IfcZone” entities are considered for modelling strata boundaries.

In addition, the “IfcSite” entity was also considered for modelling 2D land parcels on a construction site. And IfcGeographicElement was selected as the appropriate entity for managing survey data elements (Atazadeh et al. 2021).
The major knowledge gaps in the integration of building and cadastral information have been addressed by those studies. This paper relies on the outcomes from those studies. Hence, IFC was selected to be the format to integrate the building information and cadastral information in a 3D strata model in SLA’s pilot. Particularly, the “IfcSpace” entity was chosen for representing the 3D strata lot, 3D accessary lot, 3D common property and 3D VOID space. To model the 3D space attributes, the “IfcSpace” entity was enriched with different sets of attributes or properties (e.g, SGPset_StrataLot) according to Singapore’s context. Table 1 lists the strata elements to be mapped to the IfcSpace with required attributes. Table 2 illustrates the strata lot attributes are mapped to the IFC PropertySet.

Table 1. 3D Strata Elements to be mapped to the IFC entities

Strata Elements to be modelled	**Mapping to existing entity (IFC4 Entities)**	**New Subtypes (IFC4 Userdefined Object Type)**	**IFC-SG_PropertySet (IFC4 Userdefined Property Set)**
Strata Lot	ifcSpace	STRATALOT	SGPset_StrataLot
Accessory Lot	ifcSpace	ACCESSORYLOT	SGPset_AccessoryLot
Common Property	ifcSpace	COMMONPROPERTY	SGPset_CommonProperty
Void	ifcSpace	VOID	SGPset_Void

Table 2. Mapping strata attributes to IFC-SG PropertySet_

IFC4 (USERDEFINED) IFC-SG_PropertySet	**IFC4 (USERDEFINED) IFC-SG PropertyName**	**Property Type**	**Sample Values**
SGPset_StrataLot	StrataLotNumber	Label	MK03-U017049L
	StrataLotArea	Area	120
	LotStatus	Label	Live
	ParcelType	Label	Strata
	ResidingOnLandLot	Label	MK03-01847M
	SVYFileNumber	Label	0226-1985
	TypicalFloor	Boolean	TRUE
	UnitNumber	Label	05-02

4) Modelling methodologies

In this pilot, the 3D strata modelling in Revit is based on the physical model of Block 213C which have been created in Pilot 1. As the strata boundary in Singapore is defined as from the middle of the walls, slabs and ceilings, with different treatments at balcony, aircon ledge, curtain walls and walls with different thickness, RSs’ interpretations are required during the modelling process. Mass family in Revit was selected to create 3D strata boundaries, due to Mass objects can easily create complex, irregular geometries that are often required for strata boundaries. Mass object provides flexibility in modifying intricate shapes, which might not be as straightforward with other Revit families. Figure 12 illustrates the strata boundary was created using Mass family.

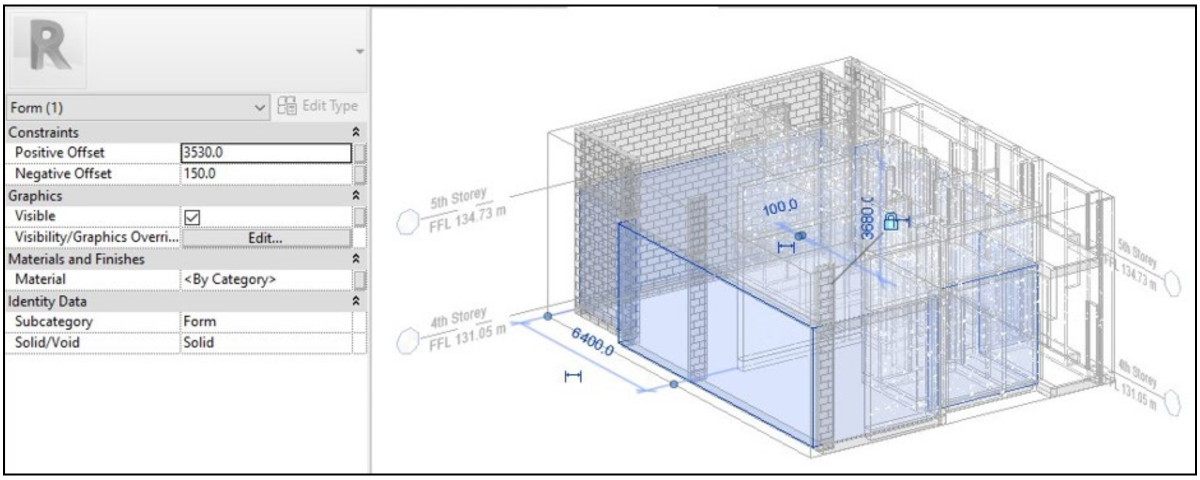

Figure 12. Using Mass family to create 3D strata boundary

In this pilot, the 5th storey is typical floor. Hence, the 3D strata boundaries of 5th storey were duplicated for the rest of typical storeys (6th -16th storey) after it was modelled. For those lower storeys (1st- 4th) which are not typical floors, the non- relevant units were removed, and some strata boundaries were adjusted accordingly. The attributes associated to individual strata lot were modified according to the actual information as well. The accuracy of the duplicated strata boundaries was verified against to the point cloud, and it was within the acceptable tolerance (3cm). And the rounded up as-built strata areas aligned with the approved strata areas too. This presented that the overall accuracy of the as-built 3D strata model is acceptable. The completed 3D strata model was exported from Revit to IFC-SG format. Figure 13 shows the final 3D strata model with attributes of Block 213C in a free IFC viewer called BIMVision.

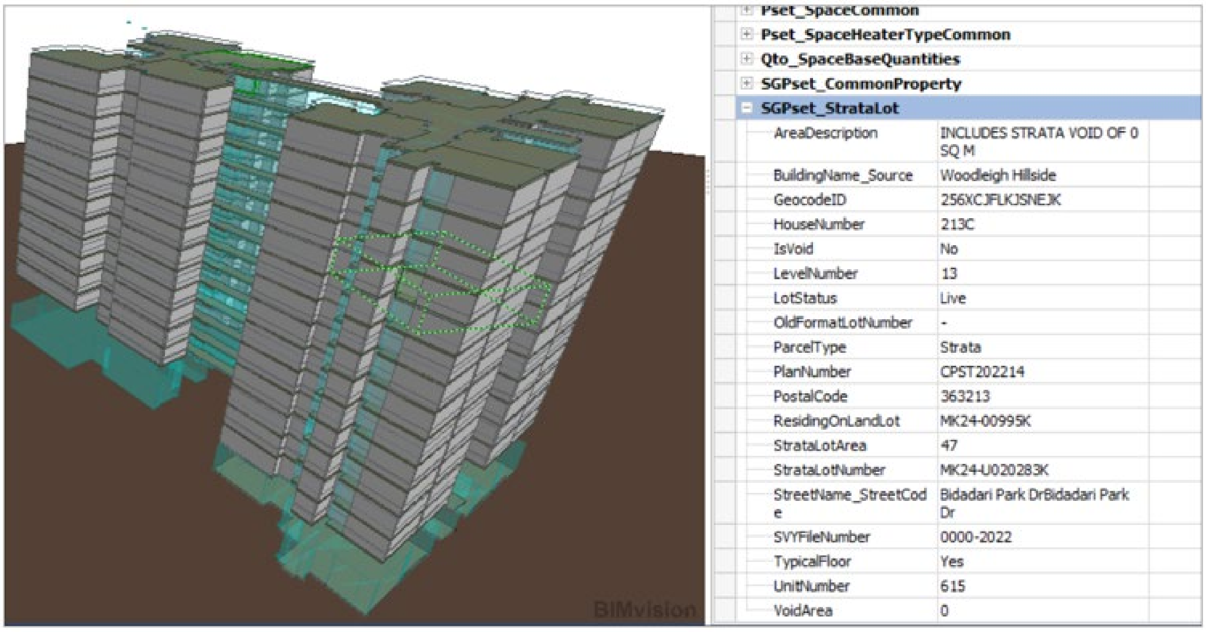

Figure 13. As-built 3D strata model of Block 213C

3.2.4 Findings

This pilot has explored the BIM-based as-built 3D strata modelling methodologies. Some takeaways are:

1) The adoption of LADM as data model which consistent with the existing cadastral system in Singapore, and leveraging on other jurisdictions' research outcome on IFC standard, built the technical foundation of this pilot.
2) Technically, the creation of 3D Strata Model based on existing BIM model using Mass object in Revit, associated the strata property sets to individual strata unit, and then exported the model as IFC format, where the 3D geometries were mapped to IfcSpace entity and attributes were mapped to IFC-SG Property Set, have been demonstrated that the methodologies are workable.
3) Most BIM modeling software focus on the physical structures' modelling. There is no BM-based tool for 3D strata modelling available fit for Singapore's strata submission context. It is time-consuming for as-built 3D strata modelling manually, especially surveyor's inputs are required for strata boundaries determination for different scenarios.
4) There is a need to develop a more intelligent 3D strata modelling tool to facilitate the modeler to generate the middle line of the walls/slabs/ceilings, and key-in the attributes automatically or semi-automatically.

3.3 Pilot 3 – Regulatory Validation and Visualization for 3D Strata Models

3.3.1 Objective

This pilot is more focusing on regulatory process using IT system in SLA. It aims to figure out the technical solution to enable the current CSMS system for digital 3D strata submission. This pilot is at initial design stage. It mainly covers two key components: regulatory validation and visualization.

3.3.2 Regulatory Validation

The integrity of any cadastral survey system is dependent on the quality of the data. Prevention of ambiguity in survey data is fundamental to safeguard the land title registration. The process of validating cadastral data prior to it entering into a cadastral database is an essential quality assurance process (Karki et al. 2013).

In Singapore, the CSMS has implemented the regulatory validation for 2D land submisions since it was launch in 2018. A set of complex validation rules has been applied to the validation process, from surveyor's license to the encoding file schema (SGLandXML), to single object geometric and textual information of the survey data, and to the relationship of objects on the certified plan. The digital format SGLandXML enables the pre-validation is an automated workflow at the front-end portal (RS Portal) of CSMS (Soon, et al. 2016).

Move to 3D, the same RRR apply to 2D strata unit also apply to 3D strata unit, though the surveying and creation requirements would be different between 2D plans and 3D models. As current 2D submission pratice, a registered surveyor carries out a 3D digital strata survey and produces the 3D model accordingly. The 3D model will be submitted to SLA and then will be examined for completeness and correctness against the validation rules.

The validation rules for 3D strata submission will be proposed and tested in CSMS in this pilot. The challenges that demand attention including:

1) validation rules on the field data, e.g. control points, leveling, traverse, point cloud;

2) validation rules on the 3D geometries, e.g. 3D geometry must be closed and watertight, no gap and no overlap between two 3D ownership boundaries;
3) validation rules on the textual information associated with the 3D model, e.g. the lot number consistency between submitted data and SLA cadastral database records;
4) further development and refinement of the validation rules even they have been implemented initially in CSMS;
5) develop the intelegent process for validation (e.g, automated valiation), to maintain the integrity and quality of 3D cadastral databases

3.3.3 3D Visualization

Beside the automated validation process to the 3D strata submission, it is important for the regulatory processing officers to further inspect the submission in a 3D environment and raise any query to registered surveyor, to ensure the whole process is reliable, consistent and justifiable before granting approval. The current absence of a fully 3D viewer for 3D strata submission in Singapore is another challenge for 3D cadastre implementation.

Various prototypes have been developed for 3D cadastre visualization, including using 3D PDF in The Netherlands, 3D ePlan in Australia (Shojaei et al. 2018), and the web-based 3D cadastral system in China. This pilot will explore the technical solution on developing an IFC-based 3D viewer with the functionalities of integrating BIM and the surrounding GIS data, viewing 2D plan and 3D model for cross checking, generate 2D plan from 3D model, as well as detect/verify encroachment etc. Figure 14 below illustrates the concept on how the 3D strata models (different color represent different physical and legal parts of the building) integrating with various geospatial data such as 2D land lots, terrain data, basemap etc. in the desired 3D Viewer. Some 3D platform including ArcGIS, Bentley, even opensource platform like Cesium, BIMVision etc, will be further assessed in this pilot.

Figure 14. Illustration of BIM/IFC + GIS data integration

The development of 3D validation rules and process, and the 3D viewer, to support the 3D strata submission is progressing at this initial stage. The current CSMS architecture has been discussed in detail by Soon et al. 2016. Figure 15 illustrates an enhanced architecture of CSMS for 3D strata submission, where the enhancements are indicated in red fonts. The proposals will be tested based on the CSMS in this pilot. The authors keen to further share once there is significant milestone reached in near future.

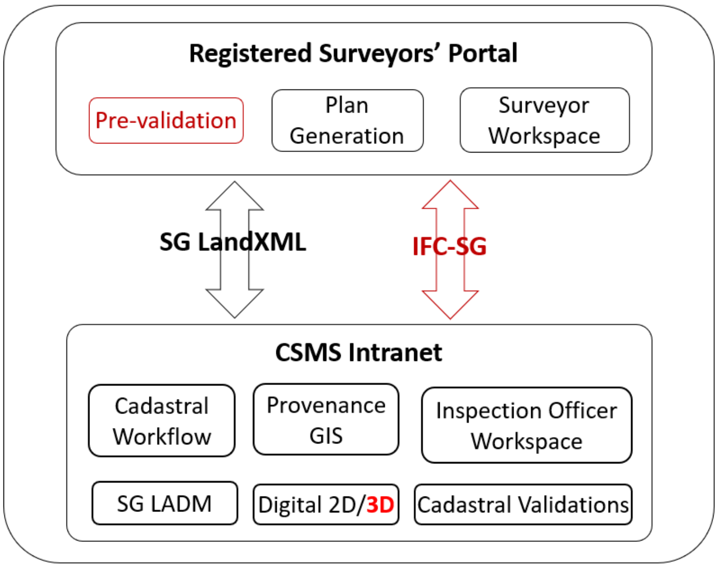

Figure 15. Enhanced architecture of CSMS

4. CONCLUDING REMARKS

3D cadastre development has been studied with significant milestones in legal and technical research, including standards and prototyping in different jurisdictions in the past decades. Particularly, the BIM-based solution for 3D strata implementation received significant attentions with the advancement of BIM and GIS development in the last decade. However, there is no nation-wide operational 3D cadastral system being used in the world up to date. The reasons are various, probably partially due to the desire on the 3rd dimension (vertical) of cadastre has different priorities in different jurisdictions.

Singapore pursues full digitalization for cadastral survey submission since the last decade of 20th century. After the digitalization for land survey submission using SG LandXML in 2018, SLA has been urged on 3D digital strata survey submission. This paper mainly discussed the current 3D strata pilots in Singapore, including 3D digital survey workflow, 3D modelling methodologies and 3D data validation and visualization. Through the piloting works which are progressing, some main remarks could be summarized as below:

1) Laser scanning is workable technology for as-built 3D digital strata survey. Generally, handheld laser scanner is more effective and economical than terrestrial laser scanner.
2) Georeferenced designed BIM is a good reference for surveying onsite, and a good data source for 3D strata modelling.
3) Modelling the typical floor and then duplicate it to the rest typical floors can fulfill the accuracy requirements in Singapore, which reduce modelling time and cost significantly.
4) IFC-based encoding and mapping for 3D strata model submission demonstrated that it is a workable solution in Singapore.
5) The CoP for 3D strata survey submission should be developed with maximum clarity on the regulatory requirements, e.g, the 3D strata survey and modelling specification.
6) The 3D enabling for CSMS, the development of a 3D strata modelling tool according to Singapore context, and the change management for the transition from 2D to 3D, are the main challenges for 3D cadastre implementation in Singapore in the next few years. The

overall productivity and data quality for 3D digital strata survey submission will be improved by overcoming these challenges.

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BIOGRAPHICAL NOTES

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Design of Mixed Reality Applications for Visualizing Integrated 3D Land Information Services

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Key words: Mixed Reality, 3D Land Information Services, 3D Cadastre, AR, VR

SUMMARY

Applications of mixed reality (MR), targeting users of augmented reality (AR) and virtual reality (VR), have become more popular because of their unique advantages. This paper presents both virtual reality and augmented reality applications that use 3D models from cadastral surveys and property-based data that follows the Land Administration Domain Model (LADM). Applications are designed to be able to present integrated 3D models and 2D land information for property professionals. This paper presents the procedures and challenges to process 3D point clouds data from various sensors i.e., drones, visual GNSS, handheld SLAM and to implement visualization and interaction designs of 3D and 2D land related data for AR & VR apps. The pipeline—which includes data collecting utilizing a variety of sensors and AI algorithms for model development—for converting 3D cadastral data into integrated land information is presented in this study. One of critical challenges that this paper worked on has been the integration of user location and 3D property representation on the mobile app, used by land professionals in the field. The land information systems on the AR systems superimpose digital data on the real world. Using the same 3D model, we also investigate how various placement strategies for MR might be used to give 3D city models for land administration services. For the VR users, both land professionals and landowners, utilize the glasses to explore the same 3D models and their related 2D land information for inspection and analysis purposes. Determining, documenting, and sharing data about land ownership, value, and planning is a complicated process that is part of land administration. Both developed AR and VR apps can help traditional systems overcome their inefficiencies and errors by offering real-time insights to land professionals.

Design of Mixed Reality Applications for Visualizing Integrated 3D Land Information Services

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1. INTRODUCTION

Land administration deals with complex processes of determining, recording and disseminating information related to tenure, value and land use planning of property and land resources (United Nations & Economic Commissions for Europe, 2005). Traditional paper-based systems often suffer from inefficiencies, inaccuracies, and delays which cause a delayed response time, increased cost or low quality (Atazadeh, Olfat, et al., 2021). In order to address this, a technique based on the Fit for Purpose (FFP) principles is put forth for use in community-based land registration initiatives with the goal of enhancing surveyors' roles and assisting with the land administration procedure (Enemark et al., 2014). Land information systems play a crucial role in urban planning, real estate management, and environmental monitoring (Rajabifard et al., 2012). Hence, land professionals coming from municipality and land offices, private surveyors, bank institutions, professional valuers, notaries often require on-site assessments and visits. Traditional 2D maps and GIS interfaces often fall short in conveying and integrating the complexity and fragmented sources of land data. Mixed reality bridges this gap by overlaying digital information onto the physical environment through a mobile app, allowing users to interact with 3D models and geospatial data in a more intuitive manner.

Mixed reality (MR) applications that range from Virtual Reality (VR) to Augmented Reality (AR) have gained prominence in various domains due to their ability to blend virtual and physical world elements seamlessly. MR mixes real and virtual objects in a single display at the same time and location (Gyawali, 2023; Milgram, 1994). AR applications can bridge this gap by overlaying digital information onto the physical environment, allowing professionals to interact with land data seamlessly. AR technology has the potential to revolutionize land administration services by providing real-time, context-aware information to professionals in the field. An AR app offers a seamless integration into users' real world, while a VR app offers an immersive digital environment, distanced to users' real world.

In this paper, we propose the design of an AR application specifically tailored for disseminating integrated 3D land information services for property professionals. Our focus is on leveraging the 3D models from 3D cadastral survey and integrated property-based information, adhered to standardized Land Administration Domain Model (LADM) to enhance data visualization, decision-making, and collaboration when used by professionals such as land surveyors, valuers, bank officers, and urban planners in the field. We discussed key components, challenges, and considerations in developing such an application. Our goal is to enhance the user experience by providing an intuitive interface that combines 3D geospatial data with real-time visualizations. We discussed the key components of the application, including 3D data acquisition and processing, visualization techniques, and user interaction paradigms. Additionally, we explore the positioning challenges associated with AR development in the context of land information.

Our proposed AR application aims to empower land surveyors, valuers, bank officers, and urban planners with real-time insights. By leveraging LADM and AR technology, it is expected that the service provider can streamline land administration processes, improve accuracy of decision-making, and enhance collaboration. Additionally, this innovative approach can significantly reduce the time, and resources required for land-related tasks, ultimately leading to more efficient and effective land management.

This paper will first present the pipeline processing in transforming 3D cadastral data into 3D integrated land information. Data acquisition is done to three urban wards of 215 ha in Yogyakarta City using three different sensors: Aerial Photos Drone, handheld SLAM, and Visual GPS. Later, the paper will discuss data processing and integration. The point clouds and imageries will be used to develop a set of 3D city models of the study area. The generated 3D models were prepared for two different types of users, i.e., the LOD 1 3D wireframe model for users working in the field with AR and the LOD2 and LOD 3 3D model for users working in the office with VR. The data integration will superimpose 2d land information with 3d models using pixelization approach.

2. LITERATURE REVIEW

2.1 3D Data Acquisition

The evolution of cadastral systems from 2D to 3D has significantly impacted various processes such as data acquisition, processing, management, storage, and visualization. Modern 3D cadastre requires advanced instruments. Teicu et al. (2022) employ a combination of Total Station (TS), GNSS instruments, UAVs with LiDAR sensors and RGB cameras, and Mobile Mapping Systems (MMS) for data acquisition. The work of Kocur-Bera & Grzelka (2022) compares the process of collecting cadastral data by using traditional methods and modern remote data acquisition methods with aerial photogrammetric image. Chio & Hou (2021) study the feasibility of a handheld LiDAR scanner to perform an urban cadastral survey.

Research shows several methods for capturing 3D cadastral data. Planimetric surveys, aerial photogrammetry, and laser scanning are the most common techniques used for cadastral measurement. Aerial photogrammetry covers wide areas quickly, while laser scanning offers the highest accuracy. Using both methods together can optimize data results. This research chose UAV and LiDAR for 3D data acquisition due to their superior accuracy, efficiency, and effectiveness.

2.2 3D Data Modeling

3D data modeling aims to create digital representations of real-world objects. Researchers have developed manual, semi-automatic, and automatic approaches for 3D modeling. Noardo et al. (2021) investigate several problems related to the implementation of the standard and the use of standardized data, especially IFC and CityGML. Rajabifard et al. (2022) use the

BIM-IFC format for modeling cadastral data, employing IfcSpace to define legal boundaries in 3D and storing Right, Restriction, and Responsibility (RRR) information as attributes. Olfat et al. (2021) and Stoter et al. (2024) also advocate for using the BIM format in IFC for 3D cadastres, focusing on effectively modeling, storing, and visualizing multi-story data. Atazadeh, Olfat, et al. (2021) propose extending IFC to LADM for 3D digital cadastres, linking LADM with BIM to integrate the legal and physical dimensions of buildings internationally.
Most research on 3D cadastral data modeling prefers the BIM-IFC format, which includes hundreds of entity classes. However, visualization typically relies on static web tools like Cesium JS. This research explores enhancing 3D cadastral data visualization by implementing MR through VR and AR, aiming to combine comprehensive data with immersive visualization for more effective evaluation and decision-making.

2.3 Data Integration

The integration of 2D and 3D cadastral data is becoming a prominent topic due to the increasing demand for converting 2D data to 3D. This shift is driven by the need to manage land limitations and overlapping vertical property rights (Rajabifard, 2014). Atazadeh, Halalkhor Mirkalaei, et al. (2021) explore the connectivity and integration possibilities between 2D and 3D cadastral data, supported by Gürsoy Sürmeneli et al. (2022) who examine the inadequacies of current models in effectively representing 3D data and integrating legal and physical objects.
As 2D and 3D integration advances, AI technologies like deep learning (DL) and machine learning (ML) are increasingly used in cadastral and property valuation. Lee et al. (2022) used ORB-SLAM, YOLO, and ICP algorithms for tracking and 3D estimation in AR. Zou et al. (2023) employed object detection models to create AR map symbols. Potsiou et al. (2023) proposed a low-cost property evaluation using BLE technology and ML for indoor positioning. Land (2022) highlighted GeoAI's role in change detection and feature extraction, while Shende (2021) explored ML and fuzzy logic in property valuation. These approaches illustrate AI's potential in enhancing LADM frameworks.

2.4 Data Visualization

3D spatial data represents objects in three dimensions, including height (z-values) and geometric details (Apeh & Rahman, 2023). Its demand is rising, with uses in computer graphics, VR, and MR. 3D objects can be modeled using wireframe, surface, or solid modeling. Wireframe lacks surface detail, while solid modeling includes topological and geometric data, with examples like Constructive Solid Geometry (CSG) and Boundary Representation (B-Rep). B-Rep defines objects by boundaries, whereas CSG uses a tree structure with Boolean operators (Hoffmann, 1989).
Besides the data model, tiling is crucial for efficiently visualizing large 3D objects. Tiling allows vast and intricate 3D data to be broken down into smaller 'tiles,' enabling smooth and detailed visualization by streaming the data efficiently. A common use of 3D tiles is seen in 3D Tiles Cesium, a cross-platform virtual globe designed for dynamic spatial data visualization. 3D Tiles facilitate the streaming and rendering of massive 3D geospatial content such as Photogrammetry, 3D Buildings, BIM/CAD, Instanced Features, and Point Clouds.

They define a spatial data structure and a set of tile formats optimized for 3D streaming and rendering (Open Geospatial Consortium, 2022).

2.5 Application Design & Usability

The development of technology has extended beyond 3D visualization to include virtual environments like VR and AR. VR allows users to enter and interact with virtual scenes, providing immersive experiences that can substitute for real-world visits, particularly in cases of limited mobility or external factors like a pandemic (Meirinhos et al., 2022). VR experiences are often built on game engines such as Unity, which supports high-quality 2D and 3D game design and cross-platform capabilities (Tsai et al., 2021).

Research utilizing game engines for 3D modeling includes Pavelka & Landa (2024), who used Unreal Engine for 3D GIS data visualization, and Helbig et al. (2022), who used Unity3D for 3D visualization from environment mobile sensor data. Laksono et al. (2019) presented a 3D city using the Structure from Motion (SfM) method from aerial photos to obtain LoD 1, integrating parcel data. Studies by Nesaif & Shagufta (2023) found that VR technology can enhance clients' purchase intentions by improving presentation efficiency and providing product information interactively.

AR integrates virtual objects into the real world, blurring the boundaries between them. It combines views of physical objects with virtual environments. Research in AR includes Boboc et al. (2022) survey of AR systems in cultural heritage in last decade and studies by Loaiza Carvajal et al. (2020), Rizvić et al. (2021) and Zimmer et al. (2021) exploring VR-AR in cultural heritage to relive the past and complement museum information. In engineering, VR-AR is used for visualization, such as Bauer & Lienhart (2023) implementation of automatic remote Total Station monitoring for dynamic urban scenes in Unity, and Bauer et al. (2024) use of MR in monitoring applications. Boos et al. (2023) utilized AR to visualize planned buildings in construction, and Fridhi & Frihida (2019) integrated 3D GIS and AR to visualize architectural objects from laser scanning, modeled in Sketchup.

A review of the literature reveals a gap in the use of MR within the LADM. While current MR studies focus on immersive visualization for tourism and cultural purposes, LADM, 3D cadastre, and land parcel visualization remain primarily in 3D or web-based formats. Given MR's ability to provide immersive experiences and supplement digital information in real-time, this research aims to bridge the gap in land administration visualization. This study proposes using MR, specifically VR and AR, to enhance land administration. It introduces pixelization for efficiently gathering, storing, and analyzing 2D attributes and legal information related to land parcels. By combining land scoring parameters, AI, and advanced statistical analyses within the pixelization framework, and integrating detailed attribute information with immersive VR and AR visualization of land and building geometries, this research aims to offer a novel approach to land administration visualization.

3. METHODS

In regard to the 3D model development, the created 3D models in the study area were done partly with help of Artificial Intelligence (AI) such as Machine Learning (ML) and Deep Learning (DL). For generating Digital Terrain Model (DTM) out of Digital Surface Model

(DSM), this work extracted ground point clouds (by implementing DGCNN algorithm (Wang et al., 2019)) and developed building footprints (by using YOLO algorithm (Redmon et al., 2016)). Further this work developed LOD 1 (by extruding OHM i.e., DSM – DTM (Fissore & Pirotti, 2019)). Semi-automatic data conversion and editing was done to convert 2D parcel boundaries into 3D primitives and 3D building models into LOD2 3D models. Work is still done to generate automatically from 3D property wireframe visualization out of 3D city models representing property boundaries (3D building models and 2D parcel extrusion). For the time being, this work also uses manual editing to improve building facades of LOD3 models. The overarching concept of the proposed research is depicted in the Figure 1.

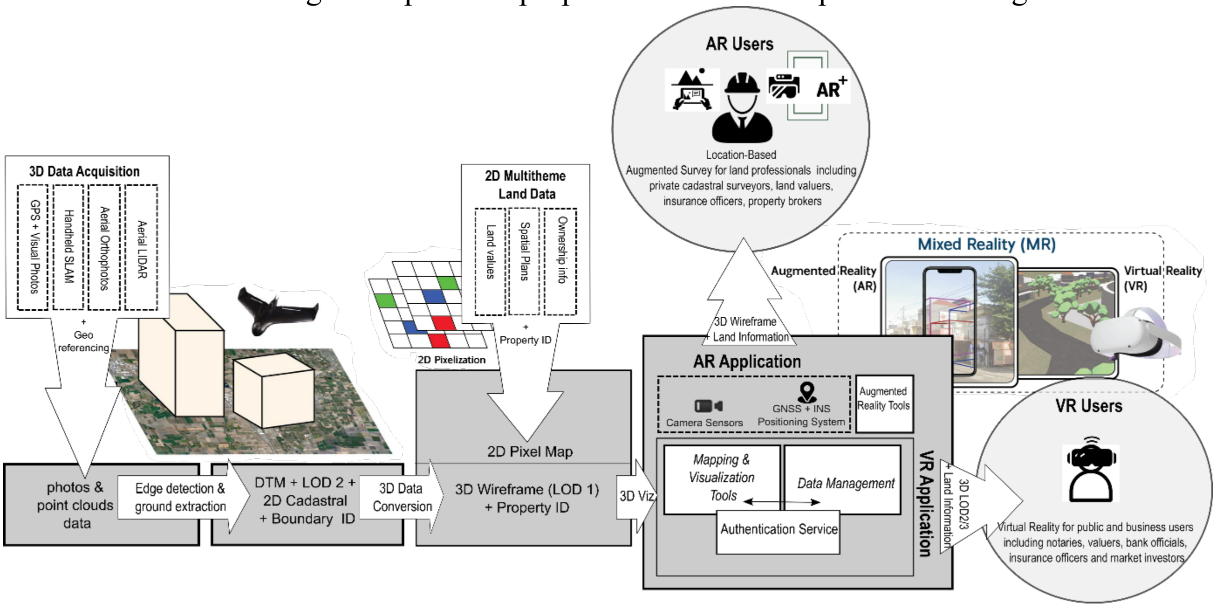


Figure 1. Propesed framework

3.1 Data Acquisition

The dataset collected from field measurements included LiDAR, SLAM, and visual GNSS, using three distinct sensors: a UAV drone, a handheld SLAM device, and Visual GPS. The UAV drone and Visual GPS generate high-resolution photographs, which, when taken with sufficient overlap, can be aligned to derive point cloud data. This process is further enhanced by the handheld SLAM, which also produces point clouds. Point cloud data forms the foundational element for constructing 3D models. Additionally, orthophotos from the UAV drone are used to delineate building outlines and land parcels. Each dataset undergoes pre-processing and is combined into one comprehensive dataset for generating 3D models.

The UAV drone generates two primary datasets: orthophotos and point clouds. Ensuring the accuracy of LiDAR data, which serves as the main dataset for 3D models, is crucial as it covers a significantly larger area than other instruments. The Visual GPS complements the SLAM and UAV LiDAR by creating accurate positions with panoramic photos or videos, which can also be processed into point cloud data. The collected data from Visual GPS are important to develop LOD 3 models. All the datasets are integrated into a comprehensive dataset representing the 3D conditions of the research location, with each dataset complementing the others to result in detailed point cloud data (Figure 2).

Figure 2 Sample result of dataset

3.2 3D Data Modeling

The objective of 3D data modeling is to create detailed 3D models from field data measurements. The pre-processed and integrated data from SLAM, UAV drones, and Visual GNSS results in a comprehensive dataset that accurately represents the terrain and objects within the research location. However, not all objects in the dataset are modeled into 3D models; the selection of target objects depends on the research focus and desired outcomes. This work specifically processes the following 3D objects:

- VR: Buildings, Trees, and Terrain. Buildings are modeled in LOD2, providing detailed information about each building's geometry, height, number of floors, and other relevant attributes essential for valuation.
- AR: Land Parcels, modeled into LOD1 and represented as a wireframe box only, representing the boundaries of each parcel.

These targeted 3D models enable land surveyors, valuers, bank officers, and urban planners to accurately assess buildings and their boundaries, facilitating informed decision-making.

3.2.1 Generation of 3D Terrain Model

In this study, the DTM provides the 3D terrain base for visualizing buildings and land parcels. Both DSM and DTM data are used to compute the Object Height Model (OHM), representing building heights. The process involves classifying ground point clouds into ground, vegetation, and buildings, with ground points forming the DTM and building points creating 3D models. Deep Learning techniques, particularly the DGCNN algorithm, enhance classification efficiency and accuracy. The OHM is calculated by subtracting the DTM from the DSM, serving as a height reference for 3D models. Ensuring consistent pixel resolution between DSM and DTM is vital for accurate OHM representation. The DTM is used as the ground base in VR/AR, while the OHM provides height references for 3D building models and land parcels.

3.2.2 3D Buildings Model (LOD2 and LOD3)

The 3D building models are generated at LOD2 and LOD3 per CityGML standards, including detailed walls and roofs. The semi-automatic creation process uses AI for building detection and manual modeling for roofs and facades to ensure accuracy. Building footprints are detected from orthophotos using the YOLO algorithm and serve as the base for real-world positioning. Roofs are manually modeled in Sketchup Pro, and classified point cloud data ensures accurate heights and geometry. This results in detailed LOD2 3D models accurately representing the buildings in the research area (Figure 3).

3.2.3 3D Land Parcel Model (LOD1)

A land parcel defines legal ownership and use, traditionally recorded in 2D by the Ministry of Agrarian Affairs and Spatial Planning/National Land Agency. This research aims to convert Indonesia's 2D cadastre to 3D, visualizing it via VR and AR to delineate boundaries and improve access for stakeholders. Unlike LOD2 3D building models, 3D land parcels are visualized at LOD1 with simple extrusions from the ground to a specific elevation, using the OHM value. This wireframe representation reduces load times in AR applications due to its lightweight nature.

(a) (b)

Figure 3. AI result for building detection (a) and sample result of 3D building modeling (b)

3.3 Pixelization and Data Integration

This research integrates both 2D and 3D visualizations. The application uses pixelization for 2D data, enabling analysis and planning with land scoring parameters, while AR technologies provide seamless integration between objects in camera and 3D visualization. In order to enhance 3D AR geometry, a 2D attribute layer was added. The pixelization approach divides maps into 5x5 grids, each with selectable 2D information layers like land value, ownership, and transactions, offering simple and clear spatial data visualizations.

This research combines field measurements and agency data into a comprehensive dataset for 3D modeling. The design is to offer comprehensive and complete grids regarding land values, land title status and property taxes in the area. The data were collected from the local land offices and local municipalities. The public data related population density and disaster risk are pixelized for the study area. Pixelization of these datasets provide fast and comprehensive 2D analysis of the area which can be useful for land professionals in the field. 2D views use pixelated datasets for a top-down perspective, whereas 3D visualizations provide immersive VR-AR experiences with detailed LOD2 buildings and LOD1 land parcels, integrating 2D attributes for enhanced and intuitive data access. The ultimate outcome of this research is to optimalize data and information delivered through the apps for monetization in forms of either users' subscriptions or information accesses. However, the monetization model is out of scope to be presented in this paper.

3.4 Data Visualization with VR-AR

Data visualization is crucial in this research, serving as the main interface for user interaction. We chose VR-AR environments to create mixed reality (MR) experiences, allowing users to view 3D models from multiple perspectives. We use Unity as the game engine for developing the VR environment. Each model is meticulously scaled to ensure accurate dimensions. A two-dimensional attribute information layer is appended to each building, detailing legal and pertinent data for taxation or valuation purposes. The Meta Quest headset is used to visualize the VR game, providing an immersive experience for exploring 3D property and land data.

The application employed for creating AR utilizes Unity AR development to generate and simulate the LOD1 wireframe of land parcels. This modeled wireframe is enriched with comprehensive land information, including legal status, tax records, transaction history, and spatial patterns. The AR application is developed for Android devices as standalone applications, incorporating both 3D AR visualization and 2D pixelization. The integration of 2D and 3D visualization provides a robust tool for field surveyors and valuators in cadastral surveying.

Both VR and AR applications were developed using Unity, a robust game engine renowned for its versatility in game development. The choice of a game engine and game-based output for these visualizations aims to foster interactivity between users and digital objects, whether they are buildings or wireframes of land parcels. While Android ARCore was considered, it lacked the capability for interactive object manipulation and information retrieval. Therefore, Unity was selected to enhance interactivity and user engagement in both VR and AR applications. 3D Models for the VR app are represented as LOD2 and LOD3 models, while models for the AR app use LOD1 of land parcels.

4. RESULT

4.1 3D Model Result

This research leverages 3D models enriched with property-based information, adhering to LADM standards, to enhance visualization, decision-making, and collaboration for professionals such as land surveyors, valuers, bank officers, and urban planners using MR experiences with VR and AR. The transformation of 2D data into 3D models improves its visualization and application as real-world data. The models, created semi-automatically from field measurements and point cloud data, ensure high quality through advanced instruments and AI extraction methods.

The research tailored 3D models for VR and AR visualization: buildings, trees, roads, and terrain for VR, and land parcel wireframes for AR. VR buildings were modeled at LOD2, with notable landmarks at LOD3, while AR wireframes were at LOD1. The semi-automatic modeling process involved extruding land parcels based on the OHM and manually creating LOD2-3 models. These 3D models serve as digital twins, enabling remote assessment by professionals, resolving land parcel boundary issues without physical presence, and facilitating efficient land management through immersive VR experiences. Figure 4 below illustrates the 3D models for three urban wards in the research location.

(a)

(b)

Figure 4. 3D Building Model (a) and 3D Wireframe Model (b) in research location

4.2 Pixelization Result

This research uses MR, incorporating VR and AR, to visualize 3D land information services, alongside 2D techniques for accurate position determination. The CityDB Web Map Client is employed for high-performance 3D web visualizations of CityGML models. 3D building models are created in CityGML LOD2 format and visualized with web client services. The database system uses PostGIS with PostgreSQL, enriching 3D models with 2D attributes like legal status and IDs. This combination of a comprehensive database and interactive visualizations results in a complete web-based information system.

Pixelization approach was proposed in this research to complement the 3D visualization with 2D attribute regarding land information. The use of 'pixel' is based on various factors, but mostly inspired by tiling concept. However, for each tile or each pixel (defined in 5 x 5) pixels contain various insight and information delivered to the user. The user of pixel facilitates the user even without geospatial background to understand and get to know information of a location. Inside each pixel then assisted with AI for real-time analysis and simulation for the user. Users can pick a location and draw to create an area to determine which area to explore. From user input, backend server will create a query and real time analysis and delivered for user. Various land information has been imported in the database including legal status or ownership, property taxes, and land value (Figure 5).

(a) (b)

Figure 5. Pixelized data and 3D model in AR app (a) 2D map of area (b) 3D building close to users' location

4.3 VR-AR Result

The 3D property objects, including the 3D building model and 3D land parcel wireframes. VR creates a virtual world for users to explore building models without visiting the actual location, while AR overlays real-life objects with virtual ones, merging reality with the virtual world. This dual approach enhances land administration processes by providing immersive and interactive experiences for various stakeholders. This approach is motivated by the lessons learnt from the current national land administration project which still finds that the same time-same place interaction involving owners and related parties is difficult to implement. Meanwhile AR app can accelerate accurate and comprehensive field inspection connecting contextual information from the office with property objects.

Figure 6. Sample of VR result of 3D building model visualization

In the 3D VR model (Figure 6), the geometry, scale, and size of each building are meticulously maintained. The scale corresponds accurately to real-world structures, with the modeling process starting from a point cloud base to ensure precision. Although the current VR version lacks a feature for measuring building geometries, this will be added in a future update. Users can freely explore the virtual world by controlling the VR controller using VR glasses (Figure 7), walking or teleporting to navigate across the map.

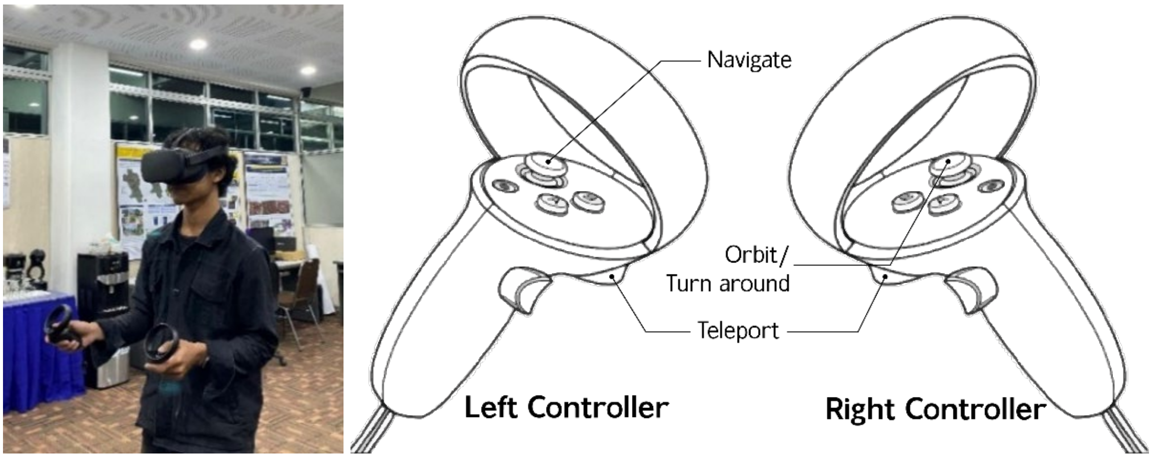
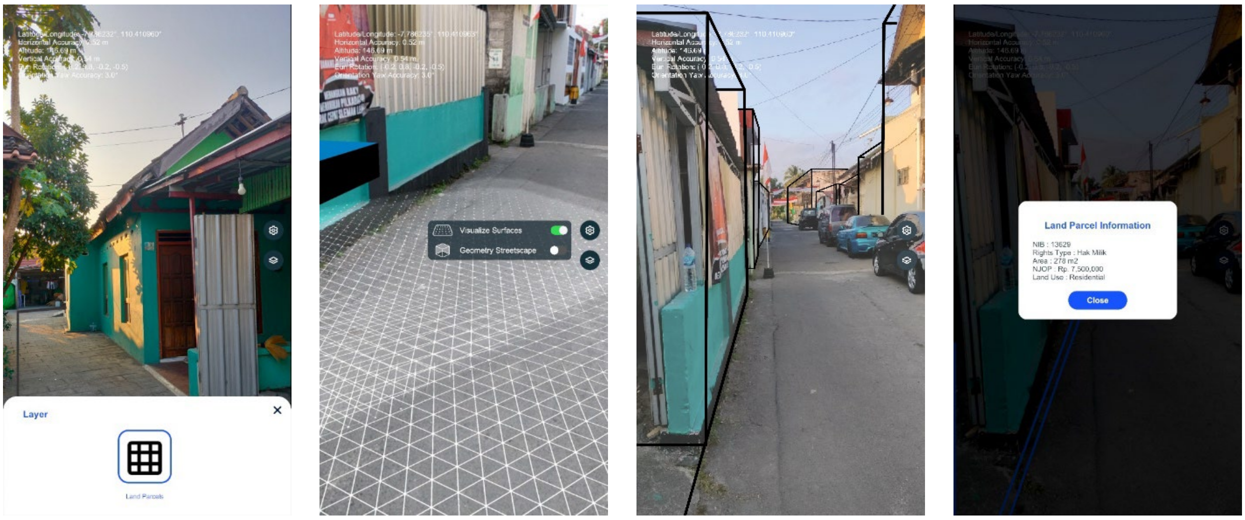


Figure 7. Controller system in exploring VR of 3D building model

VR app targets notaries, managers, the public, banks, insurance companies, and property audiences, offering integrated digital and real-world visualizations of 3D models, including buildings and environmental elements like trees and roads. Thus, using VR in their corresponding places or in a coordination meeting at a typical mediation room (i.e., commonly found in the local land offices), VR users interact with 3D models and land information. AR is intended for field surveyors, valuers, insurance officials, and brokers, requiring real-location visits to interact with overlaid virtual objects, focusing on land parcels in a wireframe form.

The developed AR application is a standalone Android application enhanced with 2D pixelization. It includes several key components designed to assist users in acquiring land information. The process begins with selecting land parcel layers, followed by detecting and visualizing ground surfaces. The application then displays a wireframe in AR, and when the user interacts with this wireframe, detailed land parcel information is presented on the screen. The application requires Android devices with specifications that support depth information and GPS sensors for accurate positioning. This AR tool aims to aid surveyors and valuators in the field by providing an efficient means of determining land parcel information (Figure 8).



(a) (b) (c) (d)

Figure 8. Sample of AR result of 3D wireframe land parcel visualization: (a) menu, (b) detecting ground, (c) wireframe, (d) popup information

5. CONCLUSION

The research proposes a workflow for implementing AR & VR apps for land administration services and their potential for monetization of land information to wider users. VR and AR offer benefits to provide more efficient and effective cadastral data visualization and interaction, beyond the merely same time-same place interactions in delivering land administration services. This research framework integrates 3D cadastral data and land information with mixed and extended reality tools. It also uses pixelization to store 2D attribute information, enabling real-time analysis with AI algorithms. This approach provides a comprehensive experience for professionals like land surveyors, valuers, bank officers, and urban planners, combining 2D and 3D data to create detailed land parcel stories. The research uses CityGML for 3D data modeling, with VR app is visualizing LOD2 and LOD3 of building models and AR app is visualizing the wireframes of LOD1 of land parcels. The framework ensures accurate legal land information. Future improvements could integrate environmental and mitigation data. Pixelization could enhance data analysis and delivery. Overall, the framework showcases that AR and VR uses for 3D land information services offer potential to be improved further.

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A digital twin based on Land Administration

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Key words: 3D land administration, Visualization, LADM, Digital Twin

SUMMARY

As urban architectural environments become increasingly complex and densely populated, the demand for precise registration of legal statuses, encompassing both private and public interests, has become more urgent. Traditional 2D cadastral registration systems are increasingly inadequate for addressing the multifaceted and vertical nature of modern urban landscapes. These systems are limited in scope and unable to fully capture the intricacies of multi-level property rights, overlapping parcels, and underground constructions.

This study uses a BIM/IFC model for the building's physical representation. The party and Rights, Restrictions, and Responsibilities (RRRs) data are stored in a DBMS following ISO 19152-2 (Land Administration Domain Model, LADM) All data and the building location are fictitious and represent the most important categories of Land Administration cases. Visualization and interaction is achieved in 3D over the web using Cesium JS, an extensible globe viewer.

Unlike earlier 3D cadastral systems, this research has developed a new 3D Land Administration prototype based on the complete scope of LADM and not just focusing on the 3D spatial information. The objective is to explore improved methods for analyzing and visualizing RRRs in complex buildings. Novel techniques include presenting UML instance-level LADM diagrams for selected parties and/or apartments, showing RRRs and BAUnits linking them to the spatial units. The study further introduces a new method for displaying surrounding buildings at varying Level of Detail (LoD), with closer buildings rendered in higher detail and more distant buildings shown in less detail. This selective detailing enhances both performance and clarity in visualizations.

A key feature of this digital twin system is its real-time update capability. The prototype developed in this study supports the updating of party and rights information in the backend database, accurately reflecting these updates in the public front-end version. This ensures the maintenance and visualization of the most current property rights data. The system also integrates sunlight simulation, which is crucial for urban planning, architectural design, and aiding buyer decision-making. The prototype is (still) online available at https://www.gdmc.nl/LADM3Dview/ and via a usability study evaluated.

A digital twin based on Land Administration

Ping MAO, China, Peter VAN OOSTEROM, and Azarakhsh RAFIEE, The Netherlands

1. INTRODUCTION

The rapid growth of urban populations and the corresponding expansion of city infrastructures have triggered a fundamental reevaluation of spatial utilization strategies in contemporary urban environments. This growth often pushes cities to expand not only horizontally but also vertically into the sky and downward into the earth. Such multidimensional expansion has become crucial in densely populated urban centers, where the availability of land for housing and infrastructure is severely limited. This limitation naturally drives the development of multi-story and vertical buildings to maximize the efficient use of space.

This study is motivated by the critical need for efficient and transparent management of urban land, particularly in vertical developments. Traditional land management systems, which are largely two-dimensional, are increasingly challenged to manage the complexity inherent in vertically integrated property rights. The representation of parcels in 2D maps of multi-layered overlapping properties is handled by dividing the map into multiple parcels. Each parcel illustrates various rights. This method may be straightforward for those involved in property registration, but it can be difficult for those unfamiliar with the actual scenario to understand (Broekhuizen, et al., 2021).

Against this backdrop, this study is dedicated to exploring and implementing an innovative land management solution focused on the visualization of apartment rights. A prototype 3D Land Administration System (LAS) is developed that not only integrates the physical and legal spatial models of multi-story apartments but also dynamically displays LADM data on a web interface. This enables users to intuitively query apartment units and their associated legal information, such as ownership, usage restrictions, and responsibilities. Moreover, the system allows various stakeholders—including real estate developers, governmental agencies, buyers, and sellers—to access and update information, thereby ensuring the timeliness and accuracy of the data.

By integrating modern GIS technology with land management standards, this study's information system prototype not only enhances the transparency of land management but also deepens users' understanding of apartment rights and the LADM framework. Furthermore, it provides a valuable reference and foundation for the development of future technologies and policies related to this field.

This paper aims to provide an overview of the research background, motivation, and objectives, with a focus on exploring a digital twin platform based on land administration. Section 2 examines existing 3D land administration systems, explaining how this study builds upon and innovates previous work. Section 3 discusses the methods used for visualizing apartment rights and Section 4 presents the results of usability testing. Finally, Section 5 summarizes the research findings and suggests potential directions for future research.

2. RELATED WORK

A land administration system is a modern, parcel-based land information system that maintains records of land interests, including Rights, Restrictions, and Responsibilities (RRRs). Typically, it comprises a geometric description of land parcels, linked to additional records that explain the nature, ownership, or control of these interests, as well as the value of the parcels and any improvements. It can be used for fiscal purposes, such as valuation and fair taxation, for legal purposes like property conveyancing, to aid in land and land-use management, including planning and administrative tasks, and to promote sustainable development and environmental protection (FIG, 1998). The fundamental entities in cadastral registration are "real estate", "immovable property" or "property", and "subjects" (Stoter, 2004). Typically, land and the buildings on it are called real estate. The various rights associated with the land are termed real property (FIG,1998). The Land Administration System (LAS) aims to provide a foundation for land management by integrating spatial, legal, and administrative data. Notably, the term "3D Land Administration" is increasingly favored over "3D Cadastre" because it encompasses the entire scope of land registration and cadastral work (Kalogianni, et al., 2020). The adoption of 3D LAS is driven by the fact that a 2D representation of ownership in complex apartments may be insufficient to fully describe and register these rights (Atazadeh, et al., 2017).

The research by (Cemellini, et al., 2020) presents a 3D LAS prototype that significantly enhances the visualization and management of 3D cadastral parcels and utilizes Cesium JS to visualize 2D and 3D data in a 3D format, aiming to better represent legal boundaries and visualize underground spaces; see Figure 1. However, users encountered a single level of detail and administrative information was presented in table form (and not in intuitive graph of instance level diagram). The 3D model, not being based on Industry Foundation Classes (IFC) data, lacked sufficient detail and did not include the surrounding environment of the studied buildings. This study focuses on usability testing and continuous improvement based on user feedback, demonstrating the effectiveness of a user-centered design approach.

Additionally, this research references the list of functionalities for 3D visualization of cadastral data presented in the work of Cemellini et al. (2020).

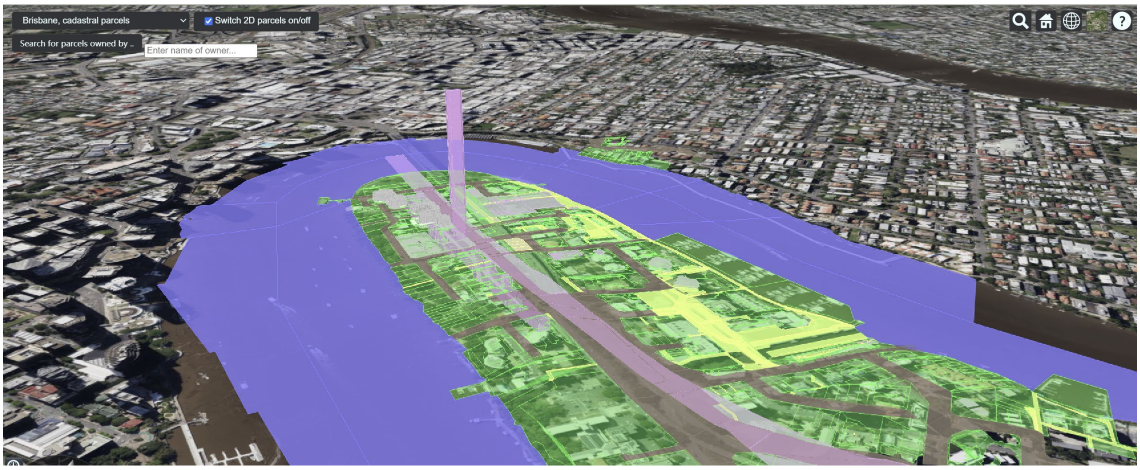

Figure 1. Visualization of the urban area using Cesium JS (system online at http://pakhuis.tudelft.nl:8080/edu/Cesium-1.43/Apps/3dcad/)

The 3D LAS system described in OGDB (https://bpd2.ogdb.nl/bpd/project/9531/landgoed-hoevesteijn) provides both physical and legal models that can be displayed separately; see Figure 2. This system supports interactive functionality, allowing users to click on each apartment unit to retrieve specific information. Additionally, it includes sunlight simulation for individual buildings. However, it does not account for the shadowing effects of surrounding buildings and does not incorporate the LADM.

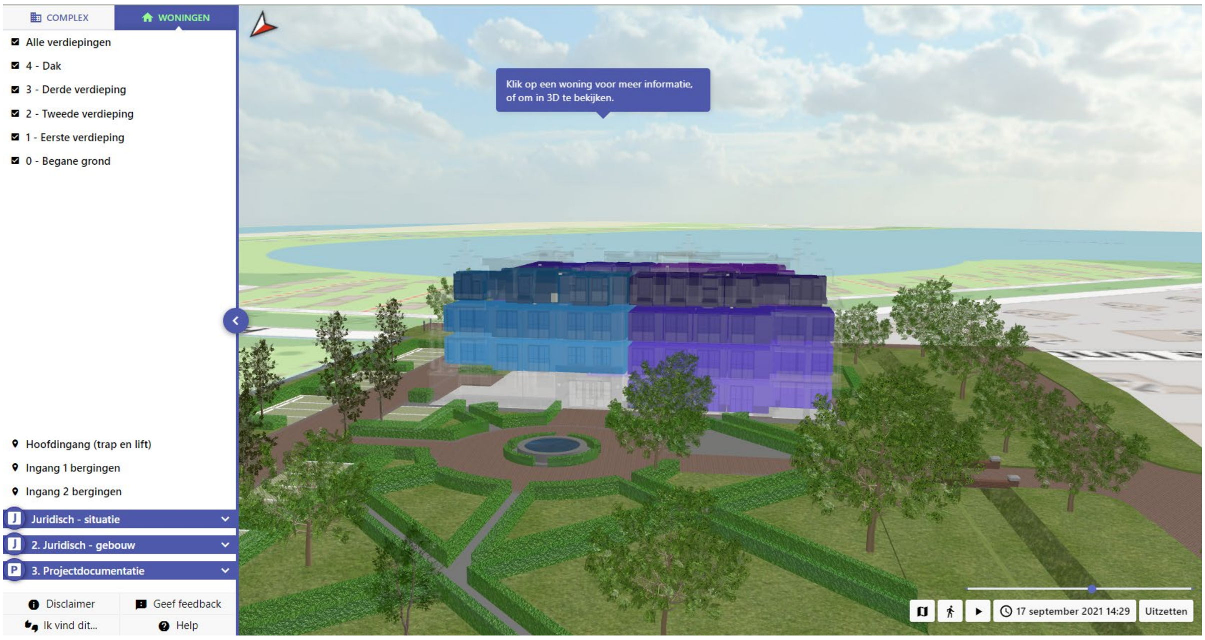

Figure 2. 3D LAS system interface showing physical and legal models (system online at https://bpd2.ogdb.nl/bpd/project/9531/landgoed-hoevesteijn)

The study by Broekhuizen added legal information based on LADM to IFC models, stored it in a spatial database, and visualized it on a 3D platform. However, all the LADM information is provided to users in tabular form (Broekhuizen, et al., 2021); see Figure 3.

Figure 3. Visualization of legal information based on LADM in a 3D platform

3. SYSTEM DESIGN PRINCIPLES

This section introduces the main system design principles (components) to be used in the development: Digital Twin approach, specific requirements of 3D Land Administration Systems, and the used system integration and implementation strategies.

3.1 Digital twin

The term Digital Twin (DT) was first used by the National Aeronautics and Space Administration (NASA) in technology domains such as modeling, simulation, information technology, and integrated technology roadmap. NASA's Apollo program introduced the concept of "twins," referring to two identical spacecraft built to mirror the condition of the spacecraft for the mission duration (NASA, 2010).
Digital twins digitally represent real-world scenarios. The most advanced urban digitization method appears to begin with 3D city information models (Schrotter & Hürzeler, 2020). These models primarily describe the urban physical environment's state. However, there is widespread consensus that digital twins are not merely equivalent to 3D city models; they also include attributes such as lifecycle management of individual urban objects and assets (Lehtola, et al., 2022).
This study presents a sophisticated 3D system that accurately replicates the physical structure of an apartment building and its individual rooms. The system allows users to interactively select any apartment to access real-time updates of basic apartment information and Land Administration Domain Model (LADM) information, ensuring that legal data is dynamically synchronized with the physical world.
A key feature of this system is its advanced sunlight simulation capability. It follows the system's current time and enables users to simulate sunlight and shadow effects for any specified time. This functionality supports architects in optimizing their designs and aids potential buyers in assessing room lighting conditions. By providing dynamic visualization and real-time updates, this 3D system significantly enhances decision-making processes, showcasing the practical applications of DT technology, such as real-time data integration, predictive analysis, and effective decision support.

3.2 Requirements of 3D Land Administration Systems

A 3D LAS is structured into three distinct layers to optimize performance and user interaction. The Presentation Layer serves as the system's front-end, directly interacting with users. It includes land administration features that visually represent critical data such as property boundaries and ownership details, alongside visualization features equipped with dynamic scaling, rotation, and other interactive elements to enhance user engagement. The Application Layer includes non-functional components that bolster technological diversity, system interoperability, and overall usability. These features, while not directly tied to visualization, indirectly uplift the visual quality by ensuring system robustness and seamless integration with diverse technologies. This layer acts as a bridge between the user interface and backend data management. The Data Access Layer ensures data accessibility and supports format conversions. It links to spatial databases, flat files, and web services, essential for versatile and scalable data management in various formats. Collectively, these layers form a comprehensive system that facilitates effective data visualization and enhances system reliability and user experience in land administration (Shojaei, et al., 2013).

3.3 System Integration and Implementation

The primary challenge addressed in this study revolves around the visualization of legal data on the front end and the precise integration of legal models with physical models within a 3D Land Administration System (LAS). Achieving a functional and efficient system necessitated a comprehensive approach encompassing several critical steps.

Data standardization was a fundamental aspect of the integration process, ensuring seamless interoperability between different data sources. To facilitate this, legal data was formatted according to the ISO 19152:2012 standard, which governs the representation of land administration data. Concurrently, spatial models were formatted in either IFC or OBJ, ensuring compatibility with the system. This dual approach to standardization allowed for the effective combination and visualization of diverse data types within the 3D LAS.

The development of the user interface (UI) was another crucial component, designed to enhance user interaction and experience. The UI was created using Vue.js and Cesium, chosen for their capabilities to provide an interactive and intuitive interface. This choice of technologies was instrumental in delivering a user-centric design that facilitated ease of use and engagement with the system.

Backend development and data handling formed the backbone of the system's operation. The backend was constructed using Node.js, which managed data requests and served as the intermediary between the frontend interface and the PostgreSQL database. This architecture ensured efficient data processing and retrieval, supporting the system's overall functionality and performance.

4. SYSTEM DEVELOPMENT

This research presents the development of a 3D mapping application that integrates Cesium within the Vue.js framework. By leveraging Vue's component-based architecture, various objects and methods from Cesium were effectively encapsulated. The development process involves several critical technical steps, as illustrated in Figure 4. The application enables the visualization of apartment building models, including their legal spaces, and allows users to access detailed ownership information for each apartment unit. The ownership information is structured based on the Land Administration Domain Model (LADM), ensuring standardized property data representation.

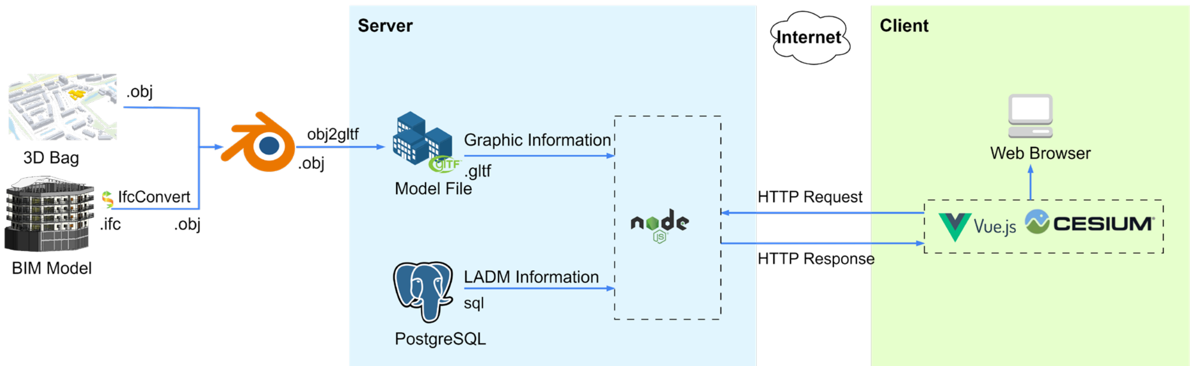

Figure 4. Web-Based 3D Visualization Architecture

4.1 Data Collection

The system employs a 3D BAG dataset in OBJ format, which includes three levels of detail: LoD1.2, LoD1.3, and LoD2.2. Apartment models, initially in Industry Foundation Classes (IFC) format, are utilized for sharing and exchanging construction and building data. All models were adjusted for accurate 3D positioning using Blender. By modifying the origin of each model, alignment with the WGS84 coordinate system was achieved. For integration with Cesium, the models were converted to the glTF format. This conversion was accomplished using the obj2gltf tool from Cesium and IfcConvert from IfcOpenShell.

4.2 Adaptive Level of Detail

The system features an "Adaptive LoD" functionality that adjusts the visualization of the surrounding area based on the distance from the central building. This approach enhances both efficiency and clarity by varying the model complexity according to proximity. In Blender, modifications were made to set different Levels of Detail (LoD) based on distance. Specifically, LoD2.2 is used for areas within 200 meters, LoD1.3 for areas between 200 and 300 meters, and LoD1.2 for areas beyond 300 meters. Users can toggle between these levels of detail using the "Adaptive LoD" button. This feature improves the user experience by enabling high-detail visualization close to the building and reducing detail for distant areas. This dynamic adjustment optimizes performance and maintains visual clarity, as shown in Figure 5.

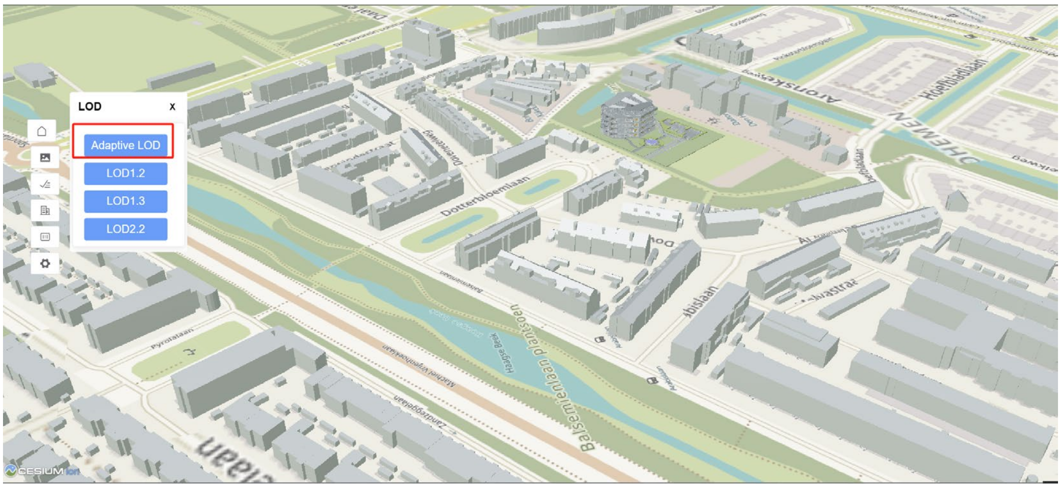

Figure 5. Adaptive LoD Visualization in the 3D LAS System

4.3 Sunlight Simulation

To achieve realistic sunlight simulation, the system utilizes Cesium's global lighting feature, which dynamically adjusts the scene's illumination based on the sun's position. This adjustment enhances the scene's visual realism, reflecting actual solar conditions. A custom function was developed to control lighting effects further, determining whether it is day or night based on the positions of the sun and camera. This function adjusts the lighting intensity to accurately represent day and night conditions, significantly improving lighting realism, as illustrated in the comparison between scenes with and without this function. Additionally, shadow effects were enabled to enhance the scene's depth and realism. Cesium's automatic settings synchronize the scene's time with the system clock, enabling real-time lighting and shadow rendering. To further improve user interaction, a date and time selection feature was incorporated, allowing users to choose specific dates and times, as shown in Figure 6.

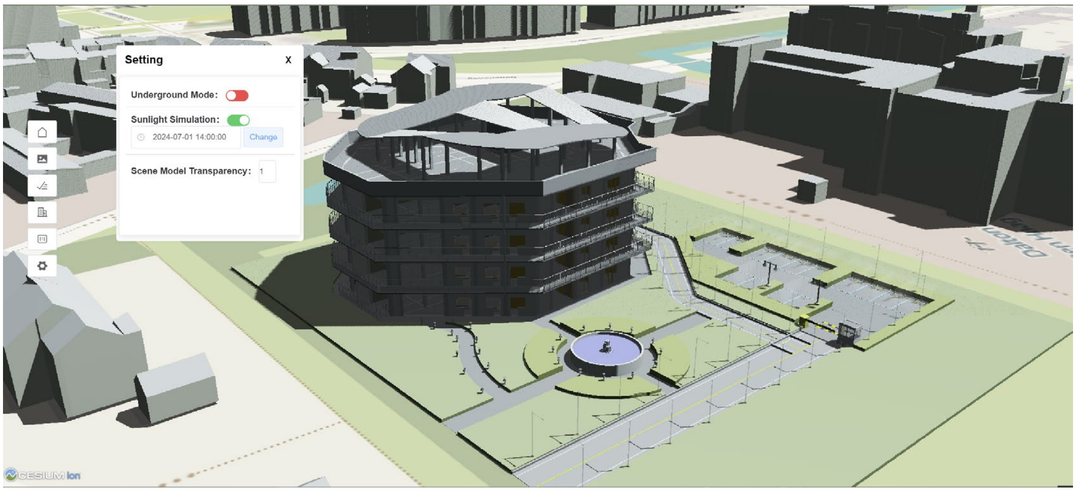

Figure 6. Sunlight Simulation Effect

This combination of dynamic lighting adjustments, shadow effects, and interactive date and time selection creates a highly immersive environment, making it ideal for applications in architectural design and real estate decision-making. Users can observe how various times of the day influence lighting and shadows, providing a realistic simulation for better decision-making.

4.4 Visualizing Apartment Model

The platform supports the visualization of both 3D physical models and legal space models for condominium ownership. Inspired by the https://bpd2.ogdb.nl/bpd/project/9531/landgoed-hoevesteijn project, users can toggle the display of physical and legal spaces on and off. This feature provides valuable context, enabling users to better understand the location and extent of legal spaces in relation to their corresponding physical structures. By incorporating physical spaces into the visualization, the system effectively demonstrates the relationship between legal boundaries and the actual built environment, enhancing users' comprehension of condominium ownership and the associated rights.

Additionally, the platform includes functionality for visualizing underground spaces. The underground space visualization feature can be activated by selecting the Underground Mode button. This capability draws inspiration from the globe translucency example provided by Cesium Sandcastle. To enable camera navigation into underground areas, camera collision detection is turned off. This adjustment allows the camera to move seamlessly into and through the underground spaces. To enhance visibility of these spaces, the transparency of the globe is adjusted. This configuration makes the globe more transparent based on the camera's distance, thus allowing users to see through the globe and observe underground structures. The effect of this function is demonstrated in Figure 7.

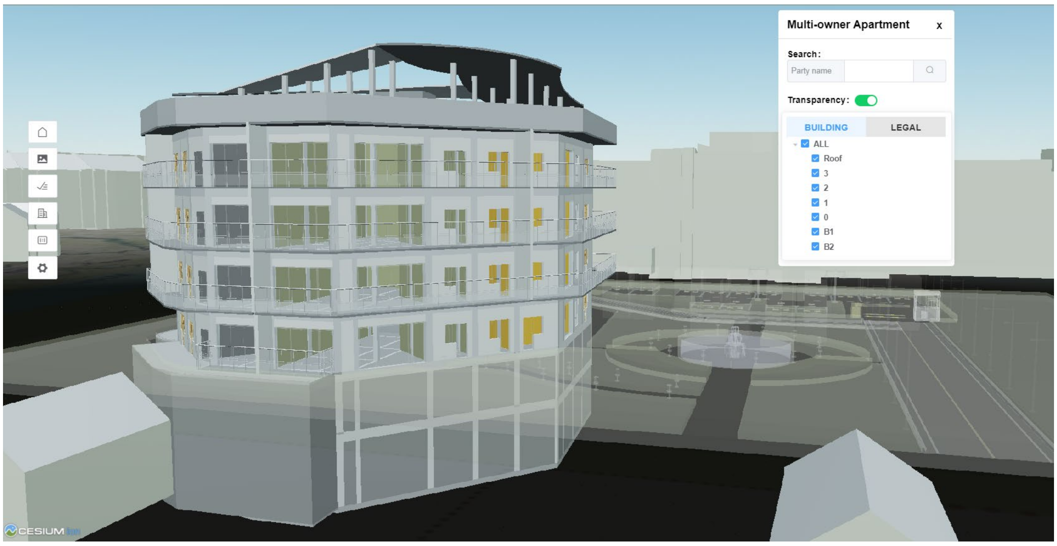

Figure 7. Visualization of underground spaces

4.5 LADM Chart Visualization

This study visualizes legal scenarios using instance-level cases from ISO 19152:2012 and examples by (Lemmen, et al., 2022). UML instance-level diagrams are created to illustrate various legal scenarios in the 3D land administration system. Figure 8 shows a UML instance-level diagram for a hypothetical case where James and Bella jointly own an apartment and a parking lot. Figure 9 presents another hypothetical scenario where homeowner Jack rents three apartments to Sophia, Mia, and Ella. Additional examples include a scenario where an apartment owner secures a loan from a bank during the purchase and a transaction involving both previous and current apartment owners (available online https://www.gdmc.nl/LADM3Dview/).

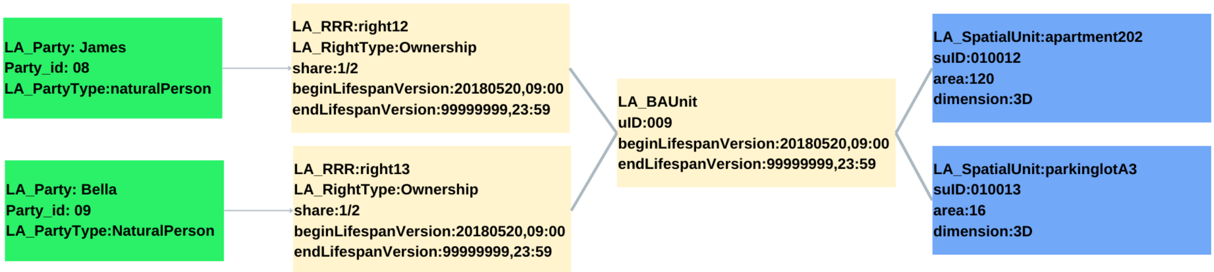

Figure 8. LADM Information of James and Bella

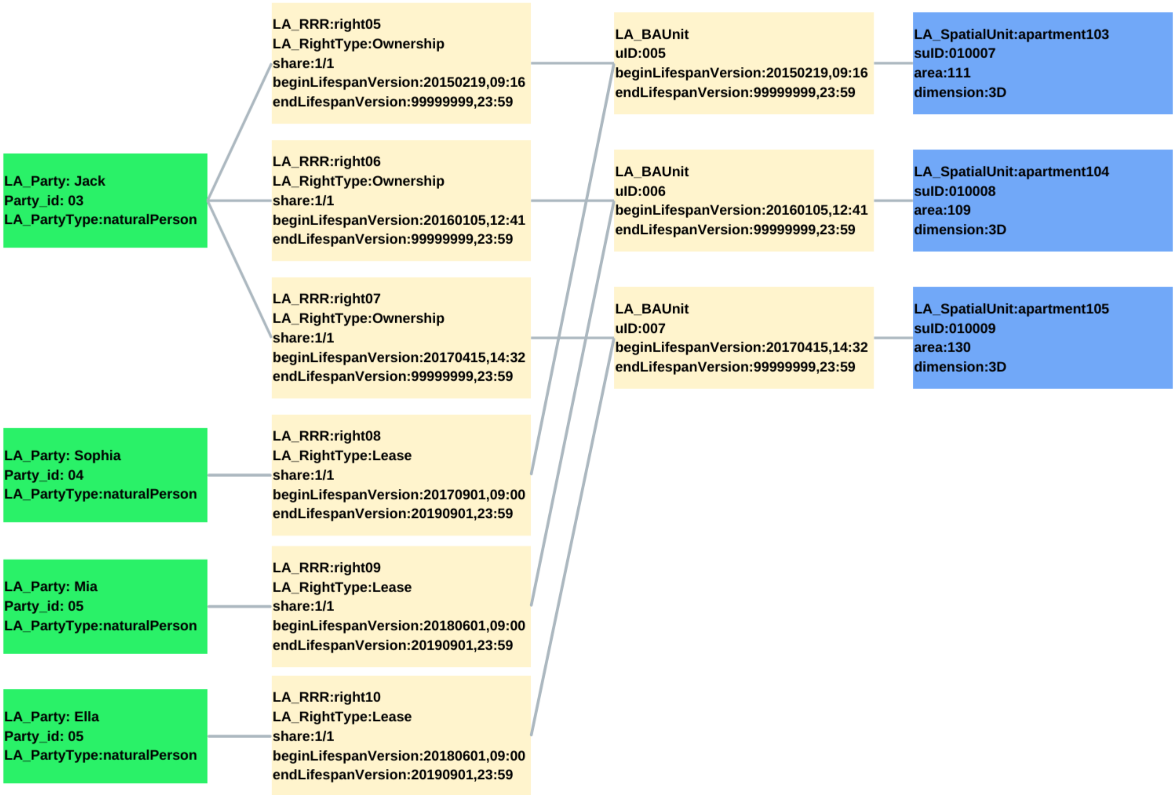

Figure 9. LADM Information of Jack

In this system, each model is assigned a unique ID upon loading, which is used for subsequent queries and processing. A click event handler is set up to detect user interactions, retrieving the model's ID when clicked. This ID is then sent to the SelectInfo component, which updates its display with information related to the clicked model. The basic information for each apartment unit is stored in a JSON file, with each unit assigned a unique ID. LADM data is maintained in a database, which, upon opening the platform, is organized into two map structures: one keyed by apartment unit IDs and the other by party names. This setup supports two modes of querying—by unit ID or by party name—ensuring comprehensive and flexible access to information. The process then involves custom methods to collect all relevant information. Finally, the getAntVG6Data method is used to convert the collected data into the AntV G6 graph format, organizing nodes and edges to accurately represent the relationships and details of the properties and individuals involved. This approach ensures that the graph is effectively visualized and remains updated in real-time as the database content changes.

5. REFLECTION

As mentioned in the requirements and the development, the frontend features an interactive graphical representation, supported by AntV G6, for visualizing relationships within the LADM data in the form of a instance level diagram of a selected subset). This tool handles data conversion and display, transforming input data into nodes and edges that illustrate complex property relationships and rights structures. The graph is designed to handle updates dynamically, ensuring that it accurately reflects any changes in the database. When the user clicks the "Query" button, the information view in the lower-left corner of the system refreshes to display a list of all properties owned by the selected individual, as shown in Figure 10. The system also supports viewing previous owner/property transaction information, as illustrated in Figure 11.

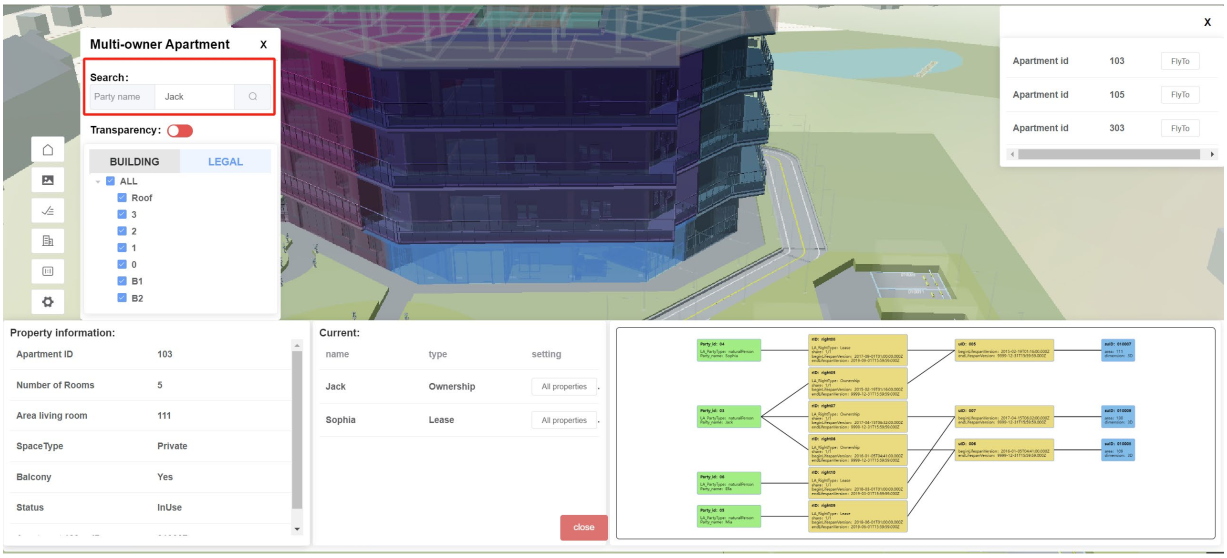

Figure 10. Search by Owner Name

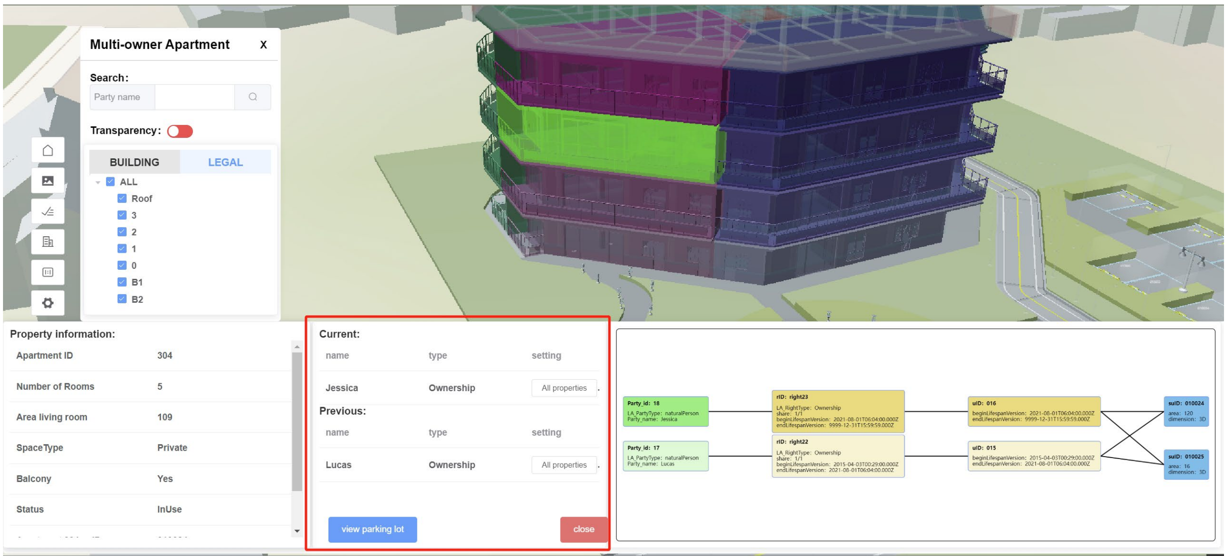

Figure 11. Show property transaction information (new owner/right in bright color, old owner/right in light colors in the LADM instance level diagram)

5.1 Usability testing

This study evaluates the usability of the system by assessing users' ability to accurately respond to questions while simultaneously rating the system during the feedback collection process. It is crucial to acknowledge that the participants involved in this usability test do not fully represent the broader user base. Nonetheless, the test effectively gathered valuable

feedback, enabling the identification of both strengths and weaknesses within the current system and highlighting areas for future improvement.
The participant groups were categorized based on their familiarity with the Land Administration Domain Model (LADM), including individuals who are familiar with LADM, those with limited knowledge of LADM, and individuals who are completely unfamiliar with LADM. To collect comprehensive feedback, specific tasks were defined for the users to perform, and corresponding questions were designed to evaluate their interactions. The tasks were carefully crafted to be clear and non-misleading, with straightforward prompts to assist users in locating the relevant controls. The tasks included switching base maps, panning, zooming, and rotating the view to identify target areas, testing 3D scene operations; controlling floor visibility; visualizing underground spaces; viewing LADM information; and simulating sunlight at various times of the day.

5.2 Test Results

Figure 12 shows the familiarity of the 24 participants with LADM. The majority of participants were either generally familiar or not familiar with LADM, with only a small portion being experts. This distribution helps in understanding how different user groups interact with the system and provides insights into usability across varying levels of familiarity.

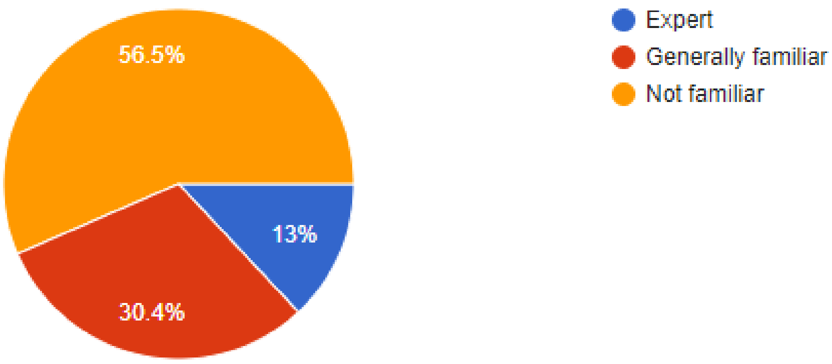

Figure 12. Pie chart of three types of participants

Test results show that in general the users were quite stratified with the available functionality and they assessed the various components with a mark on a 10-point scale:

- Navigation (panning, zooming, rotating): 8.3
- Floor visibility and underground space: 9.5
- Viewing ownership information: 9.2
- Lighting simulation: 7.0

Although the overall ratings are positive, further analysis reveals interesting differences in how users perform various tasks. For example, users found the lighting simulation feature somewhat challenging, resulting in a lower rating of 7.0. Feedback indicates that this issue stems partly from the need for more intuitive control buttons and partly from the time zone discrepancy. The platform's sunlight simulation uses Dutch time zones, but when users access the platform, it defaults to the system time of their computers, causing some confusion.

Additionally, users who are more familiar with LADM generally complete tasks more quickly and make fewer errors, particularly noticeable when viewing LADM information. In contrast, users less familiar with LADM often need more time to interpret graphical information, which affects their performance on this task.
In the final two questions of the usability test, participants were specifically asked for their suggestions on system improvements and their difficulties with terminology. The first question was, "If this digital twin system were to be redesigned, what features would you suggest?" The second was, "Did you encounter any difficulties understanding the terminology used in the system?" The responses provided valuable insights. For instance, users recommended replacing the current time selector with a more interactive time slider to improve timeline navigation. They also suggested making the search functionality more intuitive by enabling the Enter key for searches and providing clearer case sensitivity prompts. Additionally, for tasks involving 3D navigation, users proposed adding a first-person view option to facilitate easier exploration of building interiors. Because basic information about LADM was provided at the beginning of the usability test, understanding the terminology did not pose a challenge for the participants.

6. CONCLUSION

The 3D LAS developed in this study offers a range of features, including the integration and display of 3D BAG and BIM models, interactive functionalities, floor visibility control, sunlight simulation, dynamic slicing views, and underground space visualization. Most importantly, it provides dynamic, real-time UML instance-level LADM diagrams for selected parties and apartments, displaying the relationships between RRRs and BAUnits. The results have been evaluated via an usability study. Besides confirming the usefulness of the various developed 3D Land Administration interaction and visualization techniques, this also raised more wishes for future work. In future work, several key areas could benefit from further investigation to advance the capabilities and applicability of the 3D Land Administration System (LAS) developed in this study:

- Firstly, the legal data employed in this research was hypothetical and simplified, primarily for demonstration purposes. Real-world legal data is inherently more complex, and addressing this complexity poses significant challenges. Future research should therefore focus on real-world legal data, ensuring that the system can accommodate the varied and detailed nature of legal information encountered in practical applications.
- Additionally, while the current study integrates legal data with 3D models, there is potential for further enhancement by incorporating graphic data, such as Building Information Modeling (BIM) directly into the database as explored by Yang (2024).
- Another promising direction for future work involves expanding the system's capabilities to encompass various types of 3D legal spaces. For instance, the inclusion of airspace rights, underground utility networks, and mining concessions. Such advancements would enable the system to accurately represent and manage these complex legal domains, broadening its applicability and utility.
- Finally, extending the system to incorporate valuation and spatial plans in 3D, in alignment with the new Land Administration Domain Model (LADM) Parts 4 and 5,

could significantly enhance its functionality. This extension would involve creating valuation models, tools for spatial plan development and management, and ensuring compliance with the updated LADM standards.

Overall, these avenues for future research and development hold the potential to refine and expand the 3D LAS, ultimately leading to more sophisticated and practical applications in the field of land administration.

ACKNOWLEDGEMENTS

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Initiating the development of a LADM II-based Country Profile for the Swedish Real Property Register RRRs

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

Key words: country profile, LADM, LADM Edition II, land administration system, Sweden real property register

SUMMARY

The Swedish real property register, administered primarily by the Swedish Mapping, Cadastral and Land Registration Authority (Lantmäteriet), has a long history of providing reliable and comprehensive land records. There is a growing need for improved interoperability and data sharing among different stakeholders, integration of 3D spatial data, and addressing the legal and institutional barriers to further digitization. The Land Administration Domain Model (LADM) provides a standardised framework for modelling land administration systems worldwide, defined and developed as an international standard ISO 19152:2012 (ISO, 2012). Given the promising research of LADM-based country profiles by academics and authorities in other countries, we start developing a Swedish LADM-based country profile.

The main purpose of this paper is to initiate the development of a Swedish LADM II-based country profile for a part of the content of the Real Property Register. This study will use the three-phase methodology that has been presented by Kalogianni et al. (2021), and then focus on the Phase I to analyse current Swedish land administration and its RRRs. As the initiation step, this paper will not implement a full LADM II-based Swedish country profile, mainly focusing on the administrative aspects.

The paper presents the research methodology to initiate the development of a Swedish LADM II-based country profile, and then introduces the Swedish real property register and its content, focusing on registered RRRs. The Swedish LADM model presented in this paper is only illustrative and discusses the complexity of Swedish RRRs as an early step in producing a national Swedish model, since the legal basis for the future content and structure of the register is yet unsure. For the future work, the core LADM classes will be customized to reflect the specific requirements of the Swedish context, and relationships and associations between the classes will be established to accurately represent the interactions and dependencies within the Swedish land administration system.

Initiating the development of a LADM II-based Country Profile for the Swedish Real Property Register RRRs

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

1. INTRODUCTION

The efficient management of land and property rights is fundamental to economic development, environmental sustainability, and social stability. In Sweden, the land administration framework is advanced and centralised, ensuring a high degree of accuracy, transparency, and accessibility in land-related information. The Swedish real property register, administered primarily by the Swedish Mapping, Cadastral and Land Registration Authority (Lantmäteriet), has a long history of providing reliable and comprehensive land records. This system is underpinned by robust legal frameworks such as the Swedish Land Code (Jordabalken) and integrates cadastral and registry functions to support various administrative and economic activities. This code governs the regulations related to land ownership, leases, easements, and other property rights, ensuring that legal and administrative processes are clearly defined and consistently applied. Over the years, Sweden has made significant progress in digitising land records and improving public access to land information through online platforms and services. However, the increasing complexity of land management, driven by factors such as urbanisation, sustainable development goals, and technological innovations, poses new challenges for the existing framework. There is a growing need for improved interoperability and data sharing among different stakeholders, integration of 3D spatial data, and addressing the legal and institutional barriers to further digitization, see e.g. Larsson et al. (2023) and Seipel et al. (2020).
The Land Administration Domain Model (LADM) provides a standardised framework for modelling land administration systems worldwide, defined and developed as an international standard ISO 19152:2012 (ISO, 2012). The LADM framework includes core classes such as parties, rights, restrictions, spatial units, and administrative units, which can be tailored to reflect the specific requirements of a country's land administration system. Additionally, the increasing focus on 3D representations in land administration is evident across various stages of spatial development, including planning, design, permitting, construction, enforcement, and more (van Oosterom et al., 2020). In this context, according to the statistics from research made by Kalogianni et al. (2021), LADM-based country profiles have been reported and/or developed by 40 countries, for example the Netherlands, Malaysia, Greece, Croatia, Portugal, Scotland, Serbia, Czech republic, Korea and Turkey. Given the promising research of LADM-based country profiles by academics and authorities in other countries, we start developing a Swedish LADM-based country profile.
The LADM Edition II is the ongoing revision of the LADM Edition I that aims to refine the existing content and to extend the scope of Edition I (Lemmen et al., 2021). The LADM Edition II is a multi-part standard that includes six parts: Part 1 – Generic conceptual model, Part 2 – Land registration, Part 3 – Marine georegulation, Part 4 – Valuation information, Part 5 – Spatial plan information and Part 6 – Implementation aspects. Compared with LADM Edition I, the design and development of LADM Edition II is more comprehensive as it is

based on the inclusion of rights, restrictions and responsibilities (RRRs) concerning marine georegulation, valuation information, spatial plan information as well as LADM implementation (Kara et al., 2024). Moreover, as stated in Kara et al. (2024), any country profile established using the elements defined in conformance with ISO 19152:2012 shall remain conformant with the LADM Edition II standard. By developing a LADM II-based country profile, tailored specifically to Sweden's real property register, it will be an opportunity to apply a standardised description of the system, beneficial for transparency and management of the system.

To achieve that, the main purpose of this paper is to initiate the development of a Swedish LADM II-based country profile for a part of the content of the Real Property Register. This tailored profile will facilitate data sharing, improve decision-making processes, and support the integration of new technologies into the land administration system. Therefore, this study will learn the lessons from the developed LADM-based country profiles that were modelled in accordance with the LADM Edition I, as well as the three-phase methodology that has been presented by Kalogianni et al. (2021), and then focus on Phase I to analyse current Swedish land administration and its RRRs. As the initiation step, this paper will not implement a full LADM II-based Swedish country profile, mainly focusing on the administrative aspects.

The rest of the paper is structured as follows. Section 2 describes the background of LADM Edition I and LADM Edition II briefly, and related work of the methodology for the development of LADM-based country profiles. Section 3 presents the research methodology to initiate the development of the Swedish LADM II-based country profile, and then introduces the Swedish real property register and its content, focusing on registered RRRs. Finally, Section 4 provides discussions and conclusions.

2. RELATED WORK

2.1 LADM Edition I and LADM Edition II

The LADM Edition I, formalised as ISO 19152:2012, was developed to provide a standardised framework for modelling land administration systems globally. This edition introduces a structured approach to represent land-related information and the relationships between people, land, and rights, which are fundamental to effective land administration, promoting interoperability and consistency across different jurisdictions (Lemmen et al., 2015). The LADM Edition I defines specific attributes for each core class. For example, LA_Party includes attributes like Party ID, name, and type, while LA_SpatialUnit encompasses geometric representations (2D and 3D), area, volume, and other spatial characteristics. The model also establishes relationships between these classes, such as the association between a party and their rights over a spatial unit, or the link between a spatial unit and its corresponding cadastral survey documents.

The LADM Edition II builds upon the foundation laid by the Edition I, incorporating feedback from implementations and addressing the evolving needs of land administration. Kara et al. (2024) have clearly introduced the design of the LADM Edition II with detailed collected requirements and package structures. Compared with the LADM Edition I, the LADM Edition II emphasises interoperability and data integration, supporting the seamless exchange of information between different land administration systems (Lemmen et al.,

2021). This is particularly important for addressing cross-border land issues and facilitating international cooperation.
Both the LADM Edition I and the Edition II provide robust frameworks for modelling land administration, while the Edition II is offering enhanced features and greater flexibility to address complex challenges. Figure 1 shows that the basic classes of the LADM Edition II are the same as in Edition I: LA_Party, LA_RRR, LA_BAUnit, and LA_SpatialUnit.

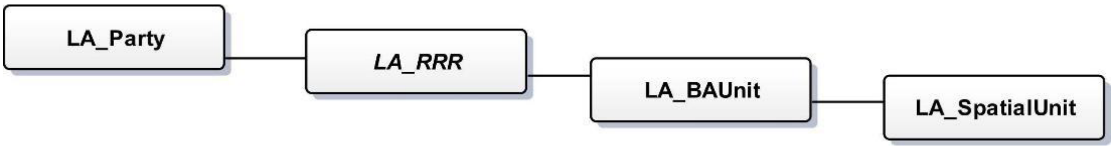

Figure 1. Generic conceptual model - basic classes of the LADM without LA_Source and VersionedObject, same basic classes as in Edition I (ISO 19152:2012; Kara et al., 2024)

In addition, the Part 1 generic conceptual model of Edition II includes two more basic classes: VersionedObject and LA_Source, as shown in Figure 2. The VersionedObject class is an abstract class that provides inheriting classes with optional attributes for indicating the beginning and end of lifespan, as well as optional real-world timestamps (Kara et al., 2024). One improvement is that the cardinality of the beginLifeSpanVersion was changed from mandatory (1) to optional (0.1), and value type for this characteristic was defined as 'real_world_time'; and another improvement is that with the associations between VersionedObject and LA_Source, instances of sources can now be versioned.

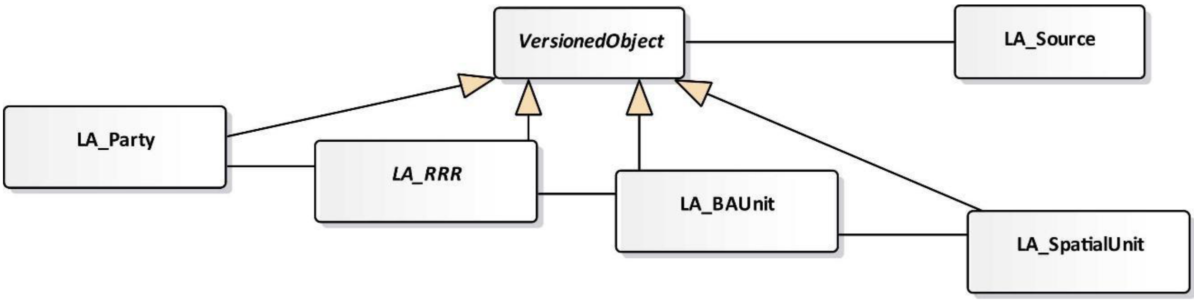

Figure 2. Basic classes of the core LADM, all inheriting from VersionedObject and associated to LA_Source (Kara et al., 2024)

As introduced by Thompson and van Oosterom (2021), VersionedObject and LA_Source have a second set of optional temporal attributes (beginValidLifespanVersion, endValidLifespanVersion, and acceptance), representing to the corresponding valid times in the real world. Which means, it could be used as version management to update, manage and maintain both spatial (2D and 3D), legal data and matching the relevant real-world valid times (4D) in land administration. In other words, this makes it easier and clearer to track the evolution of the model with a real and clear history of what changes were made, by whom, when and why. On the legal side, it will enable compliance with standards and regulations by providing a clear record of changes and updates. Meantime, for further data interoperability, it will help maintain a consistent version of the model across different implementations and stakeholders, reducing discrepancies and inconsistencies.
As introduced above, those improvements of LADM Edition II are the main reasons to initiate a Swedish LADM-II based country profile.

2.2 LADM-based country profiles

Many LADM-based country profiles have been developed and published/presented focusing on various aspects. For example conceptual models, extensions, implementation and 3D visualization (Bydłosz, 2015; Janečka and Souček, 2017; Radulović et al., 2017; Alkan and Polat, 2017; Kim and Heo, 2017; Kalantari and Kalogianni, 2018; Kebede et al., 2018; Yan et al., 2019; Indrajit et al., 2020; Kara et al., 2019).

According to related work, Kalogianni et al. (2021) summarized good practices in country profile development and proposed a three-phase approach on developing a LADM country profile in three phases: Phase I – Scope definition, Phase II – Profile creation (modelling), and Phase III – Profile testing (implementation). This methodology is expected to become part of LADM Edition II. Phase I was designed to define the scope that concerns stakeholders, current and/or future situation, national land administration legislative framework and regulations, RRRs and strategies. The authors fully agreed that the status of the LAS and its description are the fundamentals for developing the LADM-based country profile. Research for example, Buuveibaatar et al. (2022), was based on the three implementation stages for the land administration development perspective of Mongolia "Vision 2050", where each phase has specific purposes, particular goals and action plans. Thus in this paper we focus on the Phase I to analyse current Swedish land administration and its RRRs. Additionally, Ahsan et al. (2024), based on the Kalogianni et al. (2021) three-phase approach, employed a design science research approach to create a Pakistan LADM-based country profile.

3. CONCEPTUAL MODELLING

The aim of the paper is to initiate the development of a Swedish LADM II-based country profile for a part of the content of the Real Property Register. To address the challenges described, according to the methodology that Kalogianni et al. (2021) proposed, the study focuses on the Phase I to analyze current Swedish land administration and its RRRs. The research methodology is shown in Figure 3, more details presented in the following sections.

Figure 3. Research methodology to develop the Swedish LADM II-based country profile

As the initiation step, this paper will not implement a full LADM II-based Swedish country profile, mainly focusing on the administrative aspects.

3.1 Scope of the model

The primary challenges in the current Swedish land administration system include managing data interoperability, ensuring the accuracy and completeness of spatial data, and integrating new technologies such as 3D cadastres and blockchain. Legal and institutional barriers also pose significant challenges, complicating the harmonization of data and the digital transformation of land records. Additionally, issues related to data privacy and security need

to be addressed to maintain public trust and compliance with regulatory standards. The introduction of the LADM Edition II builds upon the original framework, incorporating additional classes and refining existing ones to better capture the complexities of modern land administration.
Therefore, the entire scope of the Swedish LADM-II based country profile is to describe both the current situation and the future situation that will evolve with the development of the LADM Edition II packages to further develop spatial plan, marine cadastre, valuation model, and underground cadastre. In this paper, we will only focus on the RRRs of the current Swedish Real Property Register.

3.2 Current Swedish Real Property Register

The Real Property Register is Sweden's official registry of how the land in Sweden is divided and who owns what, containing information on addresses, buildings and property tax assessment. Specifically, the Swedish cadastre serves as a foundational element for land registration, property taxation, urban planning, and infrastructure development that includes detailed records of parcels, property boundaries and cadastral surveys, while the registry maintains records of property ownership, rights, restrictions, and other legal interests in land. Together, these systems support various administrative functions, including property transfers, mortgage registration, and land dispute resolution.
The register is divided into several sections (SFS, 2000a; SFS, 2000b). The sections are: 1. general section, 2. land register section, 3. address section, 4. buildings section and 5. tax assessment data section.
A governmental committee report (SOU, 2024) published earlier this year recommends, among other things, a revision of the Swedish Real Property Register. A result of this is that the Swedish government is currently proposing to modernize the existing Real Property Register legislation, replacing it with two new laws, initially named Real Property Data Act and Real Property Register and Electronic Provision Act, planned to be implemented July 1st 2026.
The classification in this paper is based on the RRRs registered in the Real Property Register and described in the Real Property Registration Ordinance (SFS, 2000b). Other RRRs outside the register exist, but they are omitted from this initial version of the Swedish LADM profile. This study focuses on RRRs and does not aim at modelling the entire content of the Real Property Register database, which today is divided into different parts, see Section 3.3 below.

3.3 RRRs

The right to own real property is conceptually part of the family of RRR and can be said to be the central information stored in the Real Property Register. The central provisions regarding ownership and use of land are the Land Code (SFS, 1970a) and the Real Property Formation Act (SFS, 1970b). Other provisions are e.g. the Utility Easements Act (SFS, 1973a), the Joint Property Units [Management] Act (SFS, 1973b) and the Joint Facilities Act (SFS, 1973c). A real property unit (in Swedish: fastighet) is in the Land Code described as that real property is land, which is divided into property units. It should be noted that the Land Code does not exclude air and water from the concept of land.
Swedish real property can be classified into traditional real property that is owned by a private (or legal) person through individual ownership, or common ownership. A rather new concept is the existence of three-dimensional (3D) real property. There are approx. 3.2 million real

property units registered in the Real Property Register. There also exist a limited number of other, rather archaic, types of real property. An example is the shared property (in Swedish: andelsfastighet), only existing as shares in one or more real properties. Another type of real property is the exclusive right to fish in certain streams and lakes. The right normally is connected to a number of (rural) properties. Another type of real property is the exclusive right to fish in certain streams and lakes. The right normally is connected to a number of (rural) properties. The title to the fishing right may be separated from the title of the land and can be part of another real property or even exist as a real property in itself. This real property unit does not have a specific name in Swedish legislation, but is today sometimes named "fishery property" (in Swedish: fiskefastighet). An example is an old fishing right not connected to the title of the land, the "land book fishery" (no official English translation has been found, but the term has been translated directly from the Swedish term "jordeboksfiske").

These examples illustrate the complexity of traditional ownership, but other types of RRRs exist to manage the (legal) relations between owner/user and land. The major RRRs are joint property unit, site leasehold, joint facility, easement, public road right and utility easements. There are also a number of historical rights registered in the Real Property Register.

Joint property unit: Land (and water) can be legally attached to two or more real property units by forming a joint property unit (in Swedish: samfällighet). A joint property unit can e.g. be used for extracting natural resources like timber or fish, or used as grazing pasture for animals benefitting several real properties in a local community. The shares are attached to the real properties being part of the joint facility, not their owners. The share in the joint property unit follows the property if a shareholder property is sold. The registration includes unique real property and joint property unit identification numbers as well as area identification numbers, municipality in which it is located, etc.

Site leasehold: A site leasehold (in Swedish: tomträtt) is a right to use a specific part of a real property owned by a municipality, the State, or otherwise in public possession, to erect a house for dwelling purposes. The use of site leasehold was popular in urban areas in the first half of the 20th century, offering plots of land to citizens who could not afford to purchase a real property unit. The right is granted for an undefined period of time, and cannot be cancelled by the state or municipality. The lessee pays a yearly payment. The payments are regulated by the land owner and fixed for certain periods. It is possible for the lessee to buy the plot of land, thus becoming the owner of a real property unit. Site leasehold is a very strong right and almost equal to ownership. The rightsholder owns the buildings, etc. constructed on the site-leasehold plot. The right can be sold on the open market. If the land owner wants to end the site leasehold, procedures similar to expropriation apply.

Joint facility: A joint facility right (in Swedish: gemensamhetsanläggning) is a right for a construction (facility) beneficial for two or more real property units. Examples are private roads, a bathing jetty or a parking area where the owners of the properties have a common interest in using or maintaining the facility. When a joint facility no longer has any use it may be physically removed, or just being abandoned or in some cases still exist as a ruin. They however still exist as a right in the register, if they have not been removed through a cadastral procedure that is normal, but resulting in some inconsistency between the real world and the Real Property Register (Paasch et al., 2017).

Easements: An easement (in Swedish: servitut) is a right executed by a real property (the dominant tenement) to use a specific part of another real property (the servient tenement), such as the right to keep and maintain an electric cable on a property, or the right of way over a neighbouring property. An easement can even, however uncommon, be unspecified such as the right to drill and use a well on another property, where the exact location of the well is not described. The easement is created by cadastral procedure. The right is registered in the FR today, but rights created prior to 1972 may not be registered. It is even possible to create an easement by private agreement (in Swedish: avtalsservitut). It is not mandatory, however recommended, to register these private easements in the register. They still have legal force, even if not registered. The purpose of an easement can be formulated in free text, but Lantmäteriet has produced examples to be used in order to facilitate the use of standardised descriptions in the cadastral documents (Lantmäteriet, 2024).

Public road right: Public road right (in Swedish: vägrätt) is a right where the road manager (State or municipality) is granted the use of (parts of) real properties for construction and maintenance of public roads. The right holder, in principle, takes over (almost) all ownership rights from the property owner. The right holder takes the owner's place and may allow certain constructions within the road area. The right is granted to ensure control of land occupied or used in the construction and maintenance of public roads.

Utility easement: Utility easement (in Swedish: ledningsrätt) is a right allowing a person to use a space within the property for construction and maintenance of an installation used for the common good, e.g. an electric cable or a pipeline for water supply.

Historical personal rights: Some historical rights not granted anymore also exist, such as the right to electrical power (in Swedish: rätt till elektrisk kraft), and a right for a person to receive benefits in form of money or goods from a real property (in Swedish: avkomsträtt). The historical rights are registered in the FR.

Lien, Mortgage lien: A mortgage lien (in Swedish: panträtt) in an instrument for security in registered real property. The right allows security for loans through mortgaging of real property and certain rights in real property (site-leasehold). A real property can only be mortgaged as a whole because a joint owner cannot mortgage a single share of the real property. Mortgage lien is registered in the FR.

4. DISCUSSION AND CONCLUSIONS

The Swedish LADM model presented in this paper is only illustrative and discusses the complexity of Swedish RRRs as an early step in producing a national Swedish model, since the legal basis for the future content and structure of the register is yet unsure. It is important to align the model with the upcoming modernisation of the Real property Register legislation in order to follow the proposed legislative changes and their impact on the components of a possible LADM model for Sweden. However, we believe that the initiation and preparation can be made at this stage on a more conceptual level.

For the future work, considering the unique characteristics of Sweden's land administration system, the core LADM classes will be customized to reflect the specific requirements of the Swedish context, including attributes and relationships for parties, rights, spatial units, and administrative units. Relationships and associations between these classes will be established to accurately represent the interactions and dependencies within the Swedish land administration system. In addition to the more general and most basic RRRs presented in this paper, additional and more detailed RRRs will be included and further elaborated. The later steps in the proposed research methodology to develop the Swedish LADM II-based country profile will include these aspects and are planned for continued research on this topic. Of use then will be the methodology presented by Kalogianni et al. (2021), as well as lessons learned from the already developed country profiles from other countries.

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BIOGRAPHICAL NOTES

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Extending LADM to Support eLAS Implementation Toward Sustainable Land Administration: A Case Study in Malaysia

Kamarul Akhtar IDRIS, Malaysia

Key words: sustainable land administration, Land Administration Domain Model (LADM), electronic Land Administration System (eLAS), Sustainable Development Goals (SDGs)

SUMMARY

The rapid urbanization and infrastructural development in Malaysia have necessitated a shift from traditional land administration practices to more advanced systems that can accommodate the complexities of modern land use. This study investigates the integration of the Land Administration Domain Model (LADM) with electronic Land Administration Systems (eLAS) to foster sustainable land administration in Malaysia. As the nation grapples with rapid urbanization and the complexities of modern land use, traditional land administration practices have proven inadequate. The study posits that adopting LADM, an internationally recognized standard, can standardize land administration processes, enhancing consistency, interoperability, and sustainability. By leveraging eLAS, which automates land administration functions such as cadastral surveying, land registration and land information management, Malaysia can aims to create a comprehensive land information infrastructure that supports effective decision-making and policy implementation. However, the study also identifies significant challenges, including data quality, interoperability, and the necessity for robust legal and institutional frameworks to facilitate successful eLAS implementation with LADM support. The study emphasizes the importance of a collaborative approach involving government agencies, private sector stakeholders, and the public to address diverse needs and align land administration practices with the Sustainable Development Goals (SDGs). Ultimately, the study highlights the critical role of standardized frameworks in enhancing the efficiency, transparency, and accessibility of land administration systems. By providing insights into the practical challenges and benefits of integrating LADM with eLAS, this study contributes to the broader discourse on sustainable land governance in the digital age, offering pathways for Malaysia to achieve a more efficient and sustainable land administration system that meets the demands of its evolving urban landscape. Through this case study, valuable insights provided into the practical challenges and benefits of integrating LADM with eLAS, paving the way for a more sustainable future in land administration.

Extending LADM to Support eLAS Implementation Toward Sustainable Land Administration: A Case Study in Malaysia

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1. INTRODUCTION

Sustainable land administration in Malaysia is an imperative component of the nation's broader agenda for sustainable development. Sustainable land administration or governance represents a critical paradigm shift in the management and stewardship of land resources, acknowledging the intricate interplay between environmental, social, and economic factors. Land administration encompasses the processes of recording and managing land ownership, land use, and land value (Williamson, I. 2015). As Malaysia continues to urbanize and develop economically, the need for a robust, transparent, and efficient land administration system becomes increasingly crucial. Sustainable land administration ensures that land resources are managed in a manner that supports economic growth, social equity, and environmental protection (World Bank Group, 2017). Sustainable land administration or governance within the land administration system represents a comprehensive and forward-thinking approach to managing land resources. By incorporating principles of equity, environmental stewardship, and community engagement into land administration practices, nations can build a foundation for enduring prosperity (Enemark, S. 2012). This approach not only ensures responsible land use and tenure security but also aligns with broader global agendas such as the Sustainable Development Goals (SDGs) (World Bank Group, 2017).

Figure 1. The 2030 Agenda for Sustainable Development Goals (SDGs) Components (UN, 2015)

Figure 1 above, is the 17 components of the 2030 Agenda for SDGs. The SDGs are designed to eradicate poverty, protect the earth, and ensure peace and prosperity for all by 2030 (UN, 2015).

Malaysia's current land administration system faces several challenges, including inefficiencies, lack of transparency, fraud, forgery and difficulties in data management (Ganason, A. 2022). These issues can lead to land disputes, corruption, and an overall lack of trust in the system (Oruonye, E. D. et al. 2021). Sustainable land administration seeks to address these problems by integrating modern technology and international standards to improve the efficiency and reliability of land-related processes (Hull, S. et al. 2020).

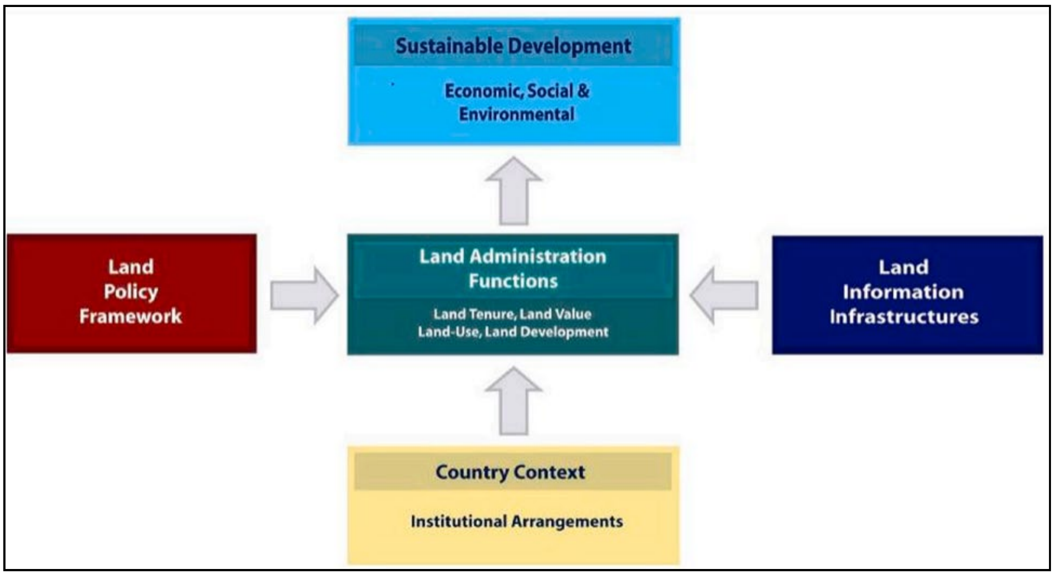

Figure 2. Land Management Paradigm Perspective of land administration functions (Williamson, I. et al. 2010); (Adam, A. G. 2023)

The advent of eLAS marks a transformative shift in the way we manage and govern land resources. An eLAS integrate various functions such as cadastral surveying, land registration, and land information management. This integration is crucial for creating a comprehensive land information infrastructure that supports decision-making and policy implementation (Adam, A. G. 2023). This paradigm shift not only enhances the efficiency and accuracy of land-related transactions but also fosters transparency and reduces the likelihood of disputes (Hull, S. et al. 2020). By digitizing cadastral maps, automating registration processes, and providing accessible online interfaces, eLAS contribute to improved land governance, equitable access, and sustainable development (Hull, S. et al. 2020).

One of the critical components of achieving sustainable land administration to be focus in this study is the adoption of the LADM. The LADM is an international standard that provides a structured framework for managing land information. By implementing LADM, Malaysia can standardize land administration practices, enhance data consistency and ensure interoperability among different stakeholders. In addition to adopting international standards, Malaysia is also focusing on the development and implementation of eLAS by expending e-Tanah system implementation throughout Peninsular Malaysia. eLAS leverages digital technology to automate land administration processes, thereby reducing the time and cost associated with these activities. The integration of LADM with eLAS can lead to a more transparent, efficient, secure and accessible land administration system. Achieving sustainable land governance involves addressing several complex issues and challenges such as, ensuring equal access and control over land, secure tenure rights, developing accurate cadastral data, institutional and legal frameworks and integrating various land uses and interests (Olfat, H., & Shojaei, D. 2019). Sustainable land administration requires comprehensive and coordinated efforts to address legal, technical, institutional, and socio-economic challenges. Modernizing eLAS with LADM integration and leveraging technology, while ensuring inclusivity and equality, are key steps towards achieving this goal.

2. eLAS IMPLEMENTATION IN MALAYSIA

The land administration system in Malaysia is based on the Torrens System except for the State of Sabah, which was introduced by Sir Robert Torrens from South Australia around 1882 in the State of Selangor through the General Land Administration (Fathi Yusof, 2016). Since then, land legislation in Malaysia has developed and three (3) main pieces of legislation have been introduced, namely the National Land Code 1965 (Act 56) for the formalities of land transactions in Peninsular Malaysia which every state have their own land laws, the Sarawak Land Code (Cap 81) in the State of Sarawak and the Sabah Land Ordinance (Cap 68) in the State of Sabah (Fathi Yusof, 2016). The three (3) principles that the Torrens System holds are the mirror principle which is the information registered on the title is a reflection on the land, the screen principle which is the information on the title giving a complete picture of the title without having to study the history of the land and the principle of insurance which is a form of protection against land fraud or fraud (Fathi Yusof, 2016). The land administration system in Malaysia uses only two (2) principles which are the mirror principle and the veil principle.

eLAS is a digital framework designed to manage land information and transactions electronically. It encompasses various components such as land registration, cadastre, valuation, and spatial planning. The primary objectives of eLAS include improving the accuracy of land records, reducing corruption, facilitating access to land information, and streamlining land transactions (Williamson, I. et al. 2010). Early 2000s, the Malaysian Government began to develop an online portal for land transactions, allowing citizens to view and manage land and property information from home through the internet mechanism, information at the fingertips (Halid, S. N. B. et al. 2022). In the mid-2000s, the government introduced electronic land registration, enabling the electronic recording of land transactions and the maintenance of a digital database of land ownership information (Halid, S. N. B. et al. 2022). In this era, various land management and administration systems have been introduced and used such as the Land Revenue Collection System (SPHT), Computerized Land Registration System (SPTB), e-Land System, Secure Land Management System (SELAMAT) and Cadaster Data Management System. (SPDK). (Sallehuddin Ishak et al. 2017). The government is working to integrate eLAS with other government systems, such as tax and revenue collection systems, to improve efficiency and reduce the risk of fraud (Karim, N. S. A. et al. 2011).

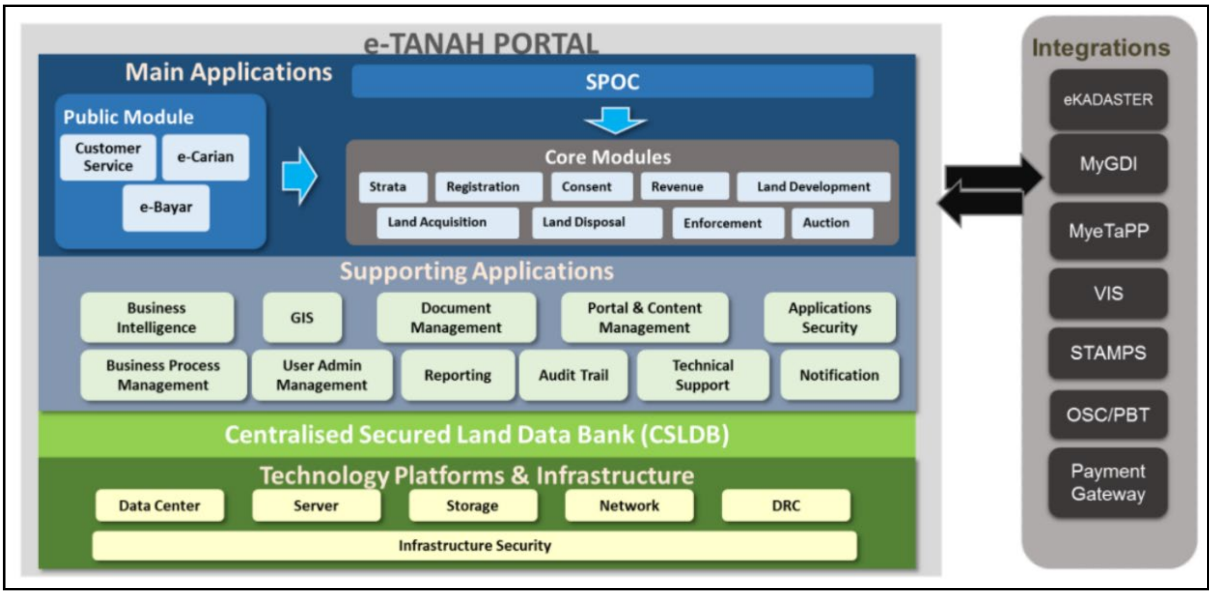

Figure 3. e-Tanah system architecture (JKPTG, 2019)

In 2021, the Government have acknowledged that will use e-Tanah system as a unified eLAS in Peninsular Malaysia ahead year 2026. Up to now, Kuala Lumpur, Perak, Putrajaya, Labuan and Selangor have implemented e-Tanah. Figure 3 above show the e-Tanah basic architecture fir for all state. The e-Tanah system is an integrated land management and administration system through the full use of computers to achieve the government's desire to implement electronic government in public services (JKPTG, 2019). This system aims to speed up the process of land dealings by users in the land office and access to information by customers without neglecting the security aspect (JKPTG, 2019). e-Tanah is an integrated system intended to replace previous legacy systems (JKPTG, 2019). Customers can apply for land matters at the Single Point of Contact (SPOC) counter which is a local counter to improve service more efficiently for customer satisfaction (JKPTG, 2019). The addition of online services such as application status checks, private searches, form filling and online help that will improve the achievement of the land administration system (JKPTG, 2019). Integration with systems from other agencies such as the Inland Revenue Board (LHDN) and the National Registration Department (JPN) for the implementation of related matters (JKPTG, 2019).

Figure 4 below show the evolution of eLAS globally toward spatially enabled society land administration system. The evolution of eLAS in Malaysia has been driven by the global eLAS evolution toward sustainable land administration system that is the need to improve the efficiency and accuracy of land transactions as well as reduce bureaucracy in the land sector (World Bank Group, 2017). Overall, the modernization of the land administration system in Malaysia has helped improve the quality, effectiveness, accuracy, transparency and integrity of Government service delivery but not yet archiving interoperability and spatially enabled society (Ganason, A. 2022) ;(Halid, S. N. B. et al. 2022).

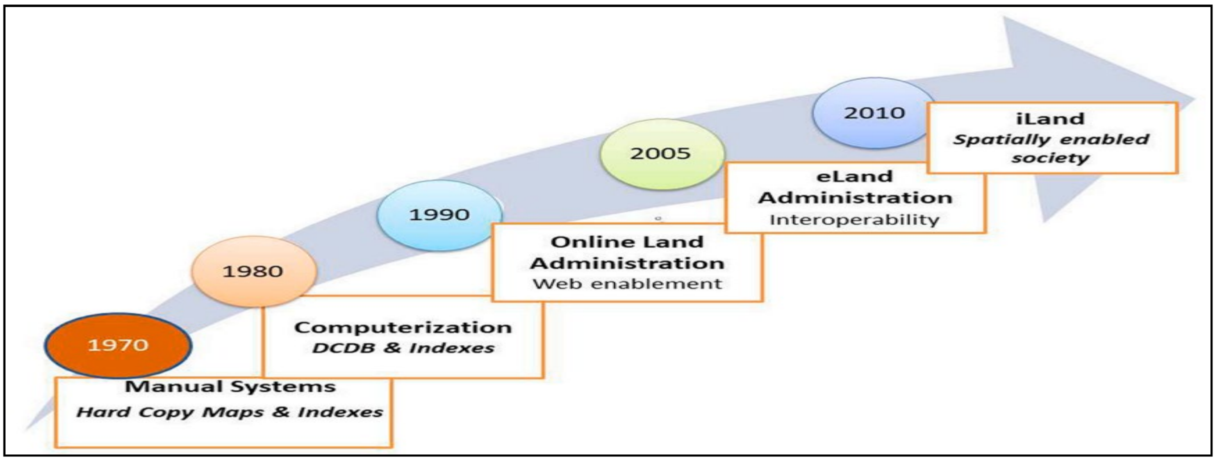

Figure 4. Evolution of modern land administration system (Adam, A. G. 2023).

2.1 eLAS Implementation Issues and Challenges Toward Sustainable Land Administration

Sustainable land administration is crucial for achieving SDGs, particularly in the context of rapid urbanization, population growth, and environmental concerns. The implementation of eLAS has been proposed as a solution to enhance land administration efficiency, transparency, and accessibility (de Zeeuw, K. et al. 2020). However, while the implementation of eLAS presents a transformative opportunity for enhancing land governance, it is accompanied by a range of challenges that must be addressed. Technical difficulties, capacity building, data quality, user acceptance, legal frameworks, and interoperability are critical issues that require strategic planning and stakeholder engagement (Idris, K. A. 2024). By proactively addressing these challenges, stakeholders can harness the potential of eLAS to promote sustainable land administration, ultimately contributing to improved governance, equitable access to land resources, and the achievement of SDGs.
The journey toward effective eLAS implementation is not merely a technological upgrade but a comprehensive approach to fostering transparency, accountability, and efficiency in land management practices (Unger, E. M. et al. 2022); (de Zeeuw, K. et al. 2020). New technology approach such as blockchain-based solution, 3D visualization and geospatial domain is likely can boost eLAS implementation towars sustainable land administration (Idris, K. A. 2024). With also good governance approach suggestion such as efficient, effective, inter-agency collaboration, data sharing, interoperability and integration for implementing eLAS toward sustainable land administration (Azadi, H. et al. 2023). This study will explore the posibility to extending LADM supporting eLAS implementation in addressing challenges and issues on data quality and interoperability toward sustainable land administration. Futhermore, identifying expected issues and challenges regarding the LADM extendation to support eLAS implementation toward sustainable land administration in Malaysia.

3. WHY LADM?

LADM is an international standard designed to facilitate the efficient management and exchange of land-related information. Developed by the International Organization for

Standardization (ISO) and designated as ISO 19152, LADM aims to standardize the representation of land administration systems, ensuring consistency and interoperability across various jurisdictions and contexts (Zamzuri, N. A. A. et al. 2021). LADM provides a conceptual framework for describing the relationships between people, land, and rights. It encompasses key components such as land parcels, legal entities, and administrative units, as well as the rights, responsibilities, and restrictions associated with land. By offering a common language and structure, LADM supports the integration of cadastral and land registration data, enhancing the accuracy and reliability of land information systems (Rajabifard, A. et al. 2021).
The establishment Malaysian LADM Country Profile aims to harmonize wide range of land administration aspects, including rights, restrictions, responsibilities, and the representation of spatial units in both two-dimensional and three-dimensional formats (Choon, T. L. et al. 2015). Thereby, its enhancing the efficiency of land registration processes and supporting the development of a national Spatial Data Infrastructure (SDI). By leveraging international standards, the Malaysian LADM Country Profile not only addresses local land administration challenges but also positions Malaysia as a proactive participant in the global discourse on land management. This initiative is expected to improve data consistency, quality, and accessibility, ultimately leading to better governance and sustainable land use practices (Choon, T. L. et al. 2015) ;(Rajabifard, A. et al. 2021).

Table 1. LADM country profile criterias to address challenges and issues on data quality and interoperability by eLAS implementation toward sustainable land administration

Criteria	Discription
Alignment with SDGs	The Malaysian LADM profile aims to support the realization of various SDGs by providing a structured framework for land administration that enhances the management and equitable distribution of land resources. This alignment helps in addressing critical areas such as poverty eradication, environmental sustainability, and social equity (Chen, M. et al. 2024).
Improved Land Governance	The LADM facilitates better land governance by standardizing land administration practices. This standardization helps in reducing ambiguities in land rights and ownership, thereby promoting transparency and accountability in land management (Chen, M. et al. 2024).
Enhanced Data Management	The LADM provides a comprehensive framework for managing land-related data, which is essential for effective decision-making in land administration. By utilizing the LADM, Malaysia can improve the efficiency of data collection, processing, and dissemination, leading to more informed policy-making and land management practices (Chen, M. et al. 2024).
Support for Policy Development	The insights derived from the LADM can inform the development of policies that address land-related issues, such as gender disparities in land rights and disaster risk management. This capability allows policymakers to create targeted strategies that enhance land administration and contribute to sustainable

Criteria	Discription
	development (Chen, M. et al. 2024).
Facilitation of Stakeholder Engagement	The LADM framework encourages collaboration among various stakeholders, including government agencies, local communities, and private sector actors. This engagement is crucial for ensuring that land administration practices are inclusive and reflect the needs and rights of all stakeholders involved (Chen, M. et al. 2024).
Integration of 3D Attributes	The LADM standard supports the incorporation of 3D spatial units, which is essential for managing complex marine environments where both land and marine spaces are involved. This capability allows for better representation and management of rights, responsibilities, and restrictions (RRRs) in marine areas, which are increasingly recognized as critical for sustainable development (Zamzuri, N. A. A. et al. 2021).
International Standards Compliance	By adopting the LADM, Malaysia aligns its land administration practices with international standards, facilitating cross-border transactions and enhancing cooperation with other countries. This alignment is essential for sustainable land administration as it promotes best practices and knowledge sharing (Zamzuri, N. A. A. et al. 2021).

Table 1 above show criterias of LADM country profile that vible and posibley can manage challenges and issues on data quality and interoperability by eLAS implementation toward sustainable land administration. Overall, the expendation of the Malaysian LADM country profile supporting eLAS implementation toward sustainable land administration is motivated by the need for a robust, integrated, and sustainable approach to land administration system that can adapt to the complexities of modern governance challenges. Its posibley can serves as a vital tool for advancing sustainable land administration by promoting effective governance, enhancing data management, and supporting the achievement of SDGs.

3.1 Issues and Challenges Expending LADM supporting eLAS Toward Sustainable Land Administration in Malaysia

In Malaysia, the integration of LADM with the eLAS presents a significant opportunity to enhance land governance and promote sustainable land administration. However, the expansion of LADM to support eLAS in Malaysia faces several issues and challenges that must be addressed to achieve sustainable land administration. While the integration of LADM can enhance sustainable land administration by improving data management, governance, and stakeholder engagement, it is essential to address the technical, institutional, and socio-economic challenges that may arise (Chen, M. et al. 2024). From literature, there are issues and challenges have arise when expending LADM into supporting eLAS implementation to archive sustainable land administration environment, such as:

3.1.1 Technical Challenges:

One of the primary technical challenges in expanding LADM to support eLAS is the need for data standardization and interoperability. Currently, Malaysia's land administration relies on various independent systems, such as e-Tanah and eKadaster, which operate primarily in 2D. The transition to a 3D cadastre, as proposed by LADM, requires significant modifications to existing databases and data models (Zulkifli, N. A. et al. 2021). The current strata XML format used by the Department of Survey and Mapping Malaysia (DSMM) is not compliant with LADM standards, necessitating a comprehensive data conversion process (Zulkifli, N. A. et al. 2021). The transition to a 3D land administration system requires the development of new data collection methods, standards, and protocols that can accurately capture and represent vertical land use (Rajabifard, A. et al. 2021).

Moreover, the integration of spatial and administrative data poses challenges in terms of data accuracy and consistency. The existing systems may contain discrepancies that need to be resolved before a unified LADM-compliant system can be established (Zulkifli, N. A. et al. 2021). The LADM framework promotes a standardized approach to land data management, but achieving interoperability between different jurisdictions and systems remains a complex task. In Malaysia, where multiple agencies are involved in land administration, the lack of a unified data standard can lead to inconsistencies and inefficiencies in data sharing and collaboration (Rajabifard, A. et al. 2021). Ensuring that all stakeholders adhere to the same data standards is crucial for the success of the eLAS initiative.

3.1.2 Institutional Challenges:

Institutional challenges also play a significant role in the expansion of LADM to support eLAS. The Malaysian land administration system involves multiple agencies, each with its own mandates, processes, and information management systems (Zulkifli, N. A. et al. 2021). This fragmentation can lead to inefficiencies and hinder the establishment of a cohesive land administration framework. The legal and institutional frameworks governing land administration in Malaysia also present challenges to the expansion of LADM. The existing laws and regulations may not fully accommodate the principles of LADM, particularly concerning the recognition of 3D rights and the management of marine resources (Zamzuri, N. A. A. et al. 2021).

The successful implementation of LADM in Malaysia also hinges on the establishment of a supportive legislative and regulatory framework. Current land laws and regulations may not adequately accommodate the nuances of 3D land administration, leading to potential conflicts and ambiguities in land rights and ownership (Rajabifard, A. et al. 2021). Furthermore, the lack of a clear policy framework and governance structure to guide the integration of LADM with eLAS can create uncertainty. Without strong leadership and commitment from government authorities, the expansion of LADM may stall, and the potential for improved land administration may not be realized (Chen, M. et al. 2024).

3.1.3 Socio-Economic Challenges:

The socio-economic context in Malaysia presents further challenges to the expansion of LADM supporting eLAS. Rapid urbanization and population growth have increased the demand for land, leading to complex land use issues (Zulkifli, N. A. et al. 2021). The LADM framework, with its emphasis on 3D property rights and responsibilities, has the potential to address these issues by providing a more comprehensive understanding of land use and ownership. However, the successful implementation of LADM requires the active participation of various stakeholders, including landowners, developers, and local communities. Resistance to change, particularly among traditional landowners who may be unfamiliar with new technologies, can pose significant barriers to the adoption of LADM and eLAS (Zulkifli, N. A. et al. 2021). Moreover, public awareness and acceptance of eLAS and LADM are vital for successful implementation. Many landowners and stakeholders may be unfamiliar with the concepts of digital land administration and may be resistant to change (Chen, M. et al. 2024).

Capacity building is essential for the successful implementation of LADM and eLAS in Malaysia. Many stakeholders, including government officials, land administrators, and the public, may lack the necessary knowledge and skills to effectively utilize the new systems (Zamzuri, N. A. A. et al. 2021). Therefore, targeted training programs and workshops are essential to equip professionals with the competencies needed to navigate the complexities of 3D land administration. Additionally, fostering a culture of continuous learning and adaptation within land administration agencies will be vital for sustaining the momentum of LADM implementation. Implementing a comprehensive LADM-driven eLAS system also involves significant financial investment, which can be a major hurdle for many jurisdictions in Malaysia (Rajabifard, A. et al. 2021). The costs associated with upgrading technology, training personnel, and conducting public awareness campaigns can strain limited budgets, particularly in less developed regions.

The expansion of the LADM to support eLAS in Malaysia presents both opportunities and challenges. While the potential benefits of a sustainable land administration system are significant, addressing the issues of 3D data integration, data standardization, Institutional collaboration, legislative frameworks hurdle and sosio-economic challenges in public and industries awareness and acceptance, capacity building and financial constraints is crucial for successful implementation. By proactively tackling these issues and challenges, Malaysia can pave the way for a more efficient, transparent, and sustainable land administration system that meets the needs of its rapidly evolving urban landscape to archive SDGs targets. The journey toward a robust eLAS supported by LADM is not only a technical endeavor but also a commitment to fostering sustainable land administration for future generations.

4. DISCUSSION

As Malaysia continues to urbanize rapidly, the need for efficient, transparent, and sustainable land administration becomes critical. This article highlights how the traditional land administration practices in Malaysia are inadequate to cope with modern land use complexities, necessitating and a shift to digital land administration system as eLAS is required. But, the implementation of the eLAS in Malaysia faces several current issues and challenges in achieving sustainable land administration. One of the primary challenges is the inconsistency and fragmentation of land records across various states and local jurisdictions, which complicates the standardization and integration processes necessary for a cohesive eLAS. Ensuring data accuracy and integrity during digitization is another critical issue, as errors or omissions can undermine the system's reliability and trustworthiness. Furthermore, resistance to change from stakeholders accustomed to traditional methods also poses a barrier, necessitating effective change management and stakeholder engagement strategies. Lastly, ensuring robust data security and privacy measures is essential to protect sensitive land ownership information from cyber threats and unauthorized access. Addressing these challenges is crucial for the successful deployment of eLAS and the realization of sustainable land administration in Malaysia.

This study found extending the LADM to support an eLAS in Malaysia holds significant potential for enhancing sustainable land administration. By integrating LADM with eLAS, Malaysia can create a unified, standardized framework that improves data interoperability, accuracy, and accessibility across various land administration entities. This integration can streamline processes, reduce redundancies, and enhance the efficiency of land registration, cadastral mapping, and land use planning. Additionally, the LADM's flexibility in accommodating different legal and institutional land tenure systems aligns well with Malaysia's diverse land tenure arrangements, facilitating a more comprehensive and inclusive approach to land administration. Ultimately, this synergy between LADM and eLAS can support sustainable land management practices, foster transparency, and contribute to socio-economic development by providing a robust infrastructure for secure land transactions and efficient resource management as to archive SDGs.

However, this study delves into the challenges and issues associated with integrating LADM with eLAS, focusing on data quality and interoperability. One significant aspect discussed is the role of eLAS in transforming land administration through digitalization, which includes cadastral surveying, land registration, and land information management. This digital transformation aims to create a comprehensive land information infrastructure that supports decision-making and policy implementation. Despite the potential benefits, the study acknowledges the technical difficulties, socio-economic challenges, institutional and legal framework required to implement eLAS with the support of LADM effectively. One significant challenge is the integration of LADM with the existing diverse and fragmented land administration systems across the country's various states and regions, which may have different legal and institutional frameworks. Ensuring data compatibility and interoperability between legacy systems and the new LADM-compliant eLAS requires substantial technical effort and investment. Futhermore, ensuring data security and privacy in the digital system is also a critical concern, especially given the sensitive nature of land ownership information. By addressing these challenges, the integration of LADM and eLAS can lead to a more transparent, efficient, and accessible land administration system in Malaysia. The case study provides valuable insights into the practical challenges and benefits of this integration, contributing to the broader discourse on sustainable land administration practices in the digital age.

5. CONCLUSION

In conclusion, the study findings emphasize the importance of adopting standardized frameworks to ensure consistency, interoperability, and sustainability in land administration practices. The study highlights the potential for enhancing sustainable land administration practices in Malaysia. By integrating LADM with eLAS, Malaysia can aim to create a standardized, interoperable, and sustainable framework for land governance. This integration is expected to address the complexities of modern land use, improve efficiency, and increase transparency in land administration. The study underscores the importance of a collaborative approach involving various stakeholders, including government agencies, private sector entities, and the public, to ensure that the system meets diverse needs and supports the nation's SDGs. However, the study also acknowledges significant hurdles, such as data quality issues, technical complexities, and the need for robust legal and institutional frameworks. The digital transformation through eLAS, which includes cadastral surveying, land registration, and land information management, aims to create a comprehensive land information infrastructure to support decision-making and policy implementation. While acknowledging the technical, socio-economic, institutional, and legal challenges, the study provides valuable insights into the practical benefits and obstacles of integrating LADM and eLAS. The findings contribute to the broader discourse on sustainable land administration practices in the digital age, emphasizing the need for effective collaboration and strategic planning to overcome the identified challenges and achieve the desired outcomes. The case study of Malaysia not only highlights the practical challenges of implementing such integration but also offers valuable insights into the potential pathways for achieving sustainable land administration, contributing to the global discourse on land management and sustainable development.

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BIOGRAPHICAL NOTES

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Towards Sustainable Land Governance: Extending the LADM to Support Global Initiatives Parameters - A Case Study in Indonesia

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Key words Land Administration Systems, Global Initiatives, LADM, Indigenous Rights, Women Rights

SUMMARY

Effective Land Administration Systems (LASs) are critical to economic stability, social equity, and environmental sustainability. By accurately recording rights, restrictions, and responsibilities (RRRs) associated with land, LASs facilitate transactions, prevent conflicts, and promote sustainable management practices. In response to global challenges such as population growth, disasters, and resource scarcity, continuous assessment and enhancement of LASs are essential. Global initiatives, including the SDGs, the New Urban Agenda (NUA), and the Framework for Effective Land Administration (FELA), emphasize the importance of system validation and integration, with data models playing a central role in aligning LASs with these global trends.

Despite the recognized need for improvements, existing research often fails to comprehensively integrate parameters from global initiatives, particularly within the Land Administration Domain Model (LADM), an ISO data model. This study addresses this gap by extending the LADM to incorporate essential parameters such as indigenous land rights, informal rights, women's rights, and valuation and taxation. Adopting a holistic approach, this research aligns the LADM with contemporary global trends and addresses the specific land governance challenges of Indonesia, which serves as the case study.

The study's methodology includes a continuous literature review, conceptual and logical model design, and practical implementation. The extended LADM framework is tailored for Indonesia, showcasing its applicability in addressing the country's unique challenges. The study's findings demonstrate that integrating these critical parameters into LADM leads to a more comprehensive and effective LAS, better aligned with global initiatives.

A crucial aspect of demonstrating the feasibility and practical implications of the proposed extension involves implementing a physical model of the extended LADM in a database schema. Utilizing Enterprise Architecture to extract Data Definition Language (DDL) lays the foundation for the database schema. Subsequently, PostgreSQL is employed to implement the SQL codes derived from the modified DDL, effectively translating the extended LADM framework into a functional database system. By executing queries on the implemented system, the study illustrates the capabilities and functionalities of the new extension for LADM, underscoring its potential to address identified parameters and support sustainable land management practices.

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1. INTRODUCTION

A country's economic stability and sustainability are strongly connected to its land. Effective land administration involves understanding its tenure, value, and use, which are documented and disseminated through Land Administration Systems (LASs) (United Nations Economic Commission for Europe, 1996; Williamson et al., 2010). These systems play a vital role in maintaining the relationship between people and land, improving the accuracy of records regarding rights, restrictions, and responsibilities (RRRs), and enhancing disaster management and resilience, aligning with Sustainable Development Goals (SDGs). The significance of effective and efficient LASs in disaster management, including prediction, prevention, preparedness, mitigation, emergency response, search and rescue, evacuation, temporary shelter, and post-disaster restoration, reconstruction, and recovery, has been extensively emphasized, playing a vital role in enhancing community and regional resilience (Barra et al., 2020).

Between 2011 and 2018, only 25.4% of adults in 33 surveyed countries possessed legally recognized land documentation, falling short of SDG target 1.4.2 (United Nations Human Settlements Programme (UN-Habitat) & World Bank, 2022). One of the reasons for advancing LASs is to effectively address the critical challenges that arise in community resilience and sustainability (Jahani Chehrehbargh et al., 2023). By modernizing LASs, these challenges can be better confronted, as they are currently not efficiently addressed. This is necessary to ensure that LASs are effective, efficient, regularly updated, validated, and maintain data consistency.

Advancing LASs has been and continues to be an ongoing process, which should be in line with the latest global initiatives, technological trends, and new community expectations. Recent research and global development projects indicate that even traditionally efficient cadastral systems need updating due to the rapid societal changes occurring worldwide (Riekkinen et al., 2016). The World Bank (WB), the United Nations (UN), and the International Federation of Surveyors (FIG) have all discussed the need for advancing LAS in many documents and declarations (Ting, 2002). The need for advancement has become increasingly evident since international bodies and land professionals have been working hard to improve land administration practices by developing several LASs-related frameworks and models, such as SDGs, Framework for Effective Land Administration (FELA), and New Urban Agenda (NUA), all of which affect LASs directly or indirectly.

In 1994, FIG's Commission 7 established a working group to anticipate trends and envision the future of land information systems. Tasked with developing a 20-year vision for the modern cadastre, the group formulated the "Cadastre 2014" statements, widely acknowledged

as a seminal document (Kaufmann & Steudler, 1998). Its impact extends to being widely read, quoted, and critiqued, reflecting its significance in the field (Lemmens, 2010).
In 2012, the Food and Agriculture Organization (FAO) of the UN published voluntary guidelines on responsible land tenure governance, emphasizing improved policies, legal frameworks, and transparency. These guidelines, known as VGGT, serve as a reference for globally accepted practices in LASs and verifies that up-to-date information that is consistently available and accessible over space and time is crucial for effective land administration, promoting good land governance, and fostering sustainable development (Food and Agriculture Organization of the United Nations, 2012). In 2021, a report utilized VGGT and the Framework and Guidelines on Land Policy in Africa to enhance tenure governance and environmental use (Christensen, 2021). Also, the World Bank introduced the Land Governance Assessment Framework (LGAF) in 2012, offering an evaluation framework for LASs. LGAF assesses policies, practices, and legal frameworks related to land governance, identifying indicators for policy intervention (Deininger et al., 2012).
In 2015, the UN's SDGs framework has been endorsed by all UN members (United Nations, 2015). The majority of SDGs are interlinked and complementary, and the achievement of one depends on the achievement of all the others (Chigbu, 2021). In accordance with this agenda, five goals are directly related to LASs, each with targets and indicators to achieve them. Habitat III endorsed the New Urban Agenda (NUA) in 2016, aligning with sustainability goals and contributing to SDG 11. The second version of NUA with implementation and monitoring aspects was published in 2020 (United Nations Human Settlements Programme (UN-Habitat), 2020).
The FIG and World Bank collaboration since 2009 led to the Fit-for-Purpose Land Administration (FFP-LA) approach in 2016. FFP-LA aims to provide secure tenure and land use control for all, emphasizing efficient, effective and integrated LAS (Enemark et al., 2014).
The Global Land Indicators Initiative (GLII), initiated in 2012, focuses on monitoring land governance using 15 indicator sets. In its second phase (2016-2021), GLII aims to make global-scale land governance monitoring a reality by 2030, aligning with VGGT and Framework and Guidelines for Land Policy in Africa (Jahani Chehrehbargh et al., 2022; Kumar & Quan, 2017). Doing business of the WB was another tool that assessed land administration quality. It has been paused in 2021 due to some irregularities in the data (World Bank Group, 2021).
The UN Committee of Experts on Global Geospatial Information Management (UNGGIM) requested the development of the FELA framework in 2020, aligning with the Integrated Geospatial Information Framework (IGIF). FELA provides guidance for establishing, strengthening, coordinating, and monitoring national or subnational land administration, emphasizing integrated geospatial information (United Nations Committee of Experts on Global Geospatial Information Management, 2020).
Figure 1 shows some of the land-related global initiatives and tools from 1998 to 2021. These initiatives collectively offer invaluable insights into the future of LASs and the critical parameters for advancing and shaping them. They emphasize the requirement for the effective, efficient, integrated LAS that is ongoing upgraded, validated and ensures consistency of data (Jahani Chehrehbargh et al., 2022).

Figure 1. Land Related Initiatives Time Series from 1998 to 2021 (Source: Jahani Chehrehbargh et al., 2024b)

These global initiatives stress the importance of an effective, efficient, integrated LAS that is ongoing upgraded, validated, and ensures consistency of data by highlighting key parameters essential for LAS advancement. Achieving data validation and integration according to global trends can be facilitated through a data model, a central element of the LAS data lifecycle (Kalantari et al., 2006). Different countries and regions employ diverse cadastre data models, selecting the most suitable model based on the specific needs and demands of the area. Among the frequently utilized models are the Land Administration Domain Model (LADM), the Social Tenure Domain Model (STDM) (a specialization of LADM), the Integrated Land and Property Information System (ILPIS), Infrastructure for Spatial Information in Europe (INSPIRE), and ePlan.

2. LADM

Effective land administration must organize and ensure the majority of feasible connections between people and land, a function facilitated by the LADM (ISO, 2012; Lemmen et al., 2015). The LADM, defined as the ISO 19152 International Standard, encompasses fundamental components of land administration, including water and land areas, and elements above and below the Earth's surface. It provides a conceptual framework with packages covering parties, basic administrative units, rights, responsibilities, restrictions, and spatial units, along with terminology simplification for practical use across diverse jurisdictions (ISO, 2012). It supports software development, ensuring data exchange, interoperability, and quality management in distributed LASs (van Oosterom et al., 2022). Actively employed ISO standards undergo periodic revisions approximately every six to ten years. There is potential to enhance LADM’s ability to achieve sustainability by incorporating further enhancements. Notably, processes such as data acquisition, maintenance, or dissemination were out of the scope of the first edition of LADM (Lemmen et al., 2017). However, there are plans to address this by extending the existing edition of the LADM to include processes, as indicated in the proposed LADM revision (Križanović et al., 2021).
In March 2017, the UNGGIM Expert Group on Land Administration and Management advocated for an acceleration in efforts to document and recognize global land rights,

supporting the imminent review of ISO 19152 – LADM by ISO-TC211 and OGC, aiming to comprehensively enhance tenure security and land rights; given the intricate nature of land administration, a diverse range of stakeholders, including UN-Habitat, UN-GGIM, the World Bank, GLTN, FIG, ISO, IHO, OGC, and RICS, are engaged in the revision process (van Oosterom et al., 2022). Suggestions included addressing inconsistencies, global issues like oceanic cadastre, and the integration of land use/cover information and 3D land administration (ISO, 2018).
Based on TC 211 members' suggestions and workshop outcomes, FIG proposed a NWIP to ISO/TC 211 in April 2018, outlining LADM extensions in conceptual model scope, current model improvements, encodings/technical models, and process models for survey procedures. However, the ISO/TC 211 did not accept FIG's NWIP in April 2018, citing the need to publish LADM Edition II as a multipart standard. The ISO Stage 0 project for LADM Edition II commenced in May 2018 in Copenhagen, Denmark. In the 48th Plenary Meeting Week of ISO/TC 211, SCC proposed LADM Edition II as a multipart standard with parts covering fundamentals, land registration, marine space georegulation, valuation information, spatial plan information, and implementations. While the second edition of LADM has not been published yet, several studies have been released addressing various parts of this data model (Lemmen et al., 2021). The development timeline of LADM is shown in Figure 2.

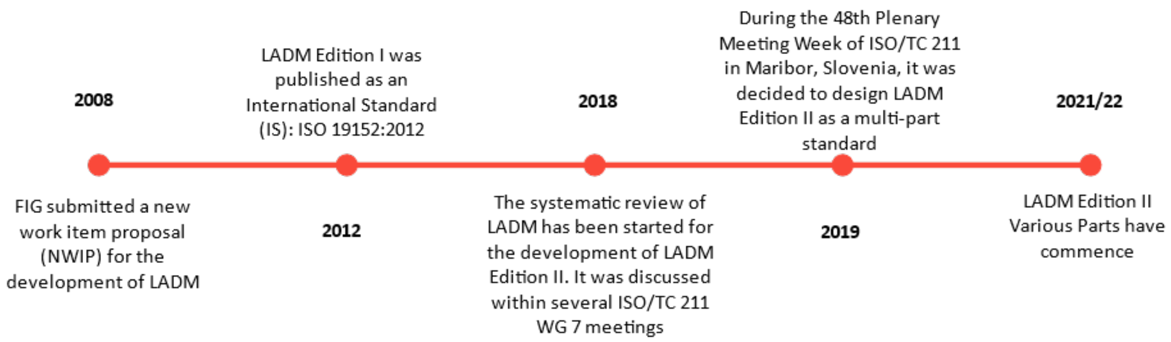

Figure 2. The development timeline of LADM (Body et al., 2022)

Despite the ongoing need for LAS advancements, current research on LAS lacks a comprehensive integration of global trends' parameters into LAS data models, especially in the context of ISO standards. This gap is evident due to limited evidence or studies addressing the integration of global trends into the LAS data model. Each study only focuses on one global trend (Chen et al., 2023) or addresses one specific parameter (Cagdas et al., 2016; Paixao et al., 2015). Also, the existing literature on LAS advancements often highlights the need for modernization but falls short of thoroughly addressing the inclusion of emerging global trends, leaving a gap in understanding how these trends can be effectively integrated into LAS data models, particularly within established standards like ISO. Our study aims to fill this gap by examining indigenous rights, women rights, informal rights, taxation, and land valuation within the LAS ISO data model (LADM). By focusing on these parameters, which are particularly relevant to vulnerable and marginalized communities, our research takes a more comprehensive approach by exploring multiple aspects simultaneously. The ultimate objective is to extend the LADM in a manner that considers all these elements collectively,

aligning with global trends and ensuring that the rights and needs of these communities are adequately addressed. Our study recognizes that there is room for improvement in each research effort, emphasizing the need for ongoing enhancement in understanding and incorporating these crucial components into LAS.
The following section outlines the methodology employed in this study, followed by the implementation details in Section 4, which includes the chosen parameters for advancement and the extension of classes and attributes of LADM. The paper concludes in Section 5 with key findings and directions for future research concerning the advancement of LASs.

3. METHODOLOGY

The methodology employed in this study is designed to advance Land Administration Systems (LAS) in alignment with global initiatives by extending the Land Administration Domain Model (LADM). The research process comprises three key phases:

1. Data Requirement Analysis: The study began with a thorough review of global initiatives related to land administration. Document analysis was conducted in three steps: skimming, reading, and interpreting (Bowen, 2009). The process involved:
- **Skimming:** Initial examination of documents to identify relevant global initiatives.
- **Comprehensive Examination:** Detailed analysis to extract necessary parameters for advancing LAS, focusing on land-related aspects.
- **Interpretation:** Identifying similarities, categorizing parameters, and mapping them to the land management paradigm. Key parameters identified include gender equality, indigenous land rights, valuation and taxation, and informal rights, along with attributes like tenure type, boundary type, and data source type.

2. Conceptual and Logical Extension of LADM: Following the data requirement analysis, the research focused on modifying LADM classes:
- **Conceptual Model Design:** A robust conceptual model was designed, synthesizing modified attributes into a coherent framework, represented using UML diagrams.
- **Logical Model Implementation:** The conceptual model was translated into a logical model using Enterprise Architect (EA). This step involved defining the arrangement of data elements and their interconnections, serving as a blueprint for the physical database. The logical model validated the conceptual framework and provided practical insights into implementation challenges, facilitating the creation of DLL schemas for databases like PostgreSQL, Oracle, and SQL Server.

3. Implementation for Indonesia: The study aims for global applicability but uses Indonesia as a case study to illustrate the practical implementation of the extended LADM:
- **Country-Specific Considerations:** Recognizing the jurisdiction-based nature of cadastral systems, the study includes Indonesia-specific parameters.
- **Case Study Focus:** Introducing additional code lists and features aligned with the recommended extensions, tailored to Indonesia's unique land governance challenges. The country's high number of unregistered land titles presents an ideal context for

implementing the extended LADM, which aims to enhance transparency and applicability in Indonesia's LAS.

4. Physical Data Model Implementation: The final phase involved implementing the extended LADM in a physical data model using PostgreSQL. The steps included:

- **Schema Creation**: Translating the logical model into a physical schema, with tables for each LADM class and additional attributes for Indigenous rights, gender, and informal rights.
- **Data Insertion**: Populating the tables with sample data, including entries for Indigenous groups, gender data, and informal settlements.
- **Query Execution**: Running SQL queries to validate the model's capability to handle complex land administration queries. Examples include listing parcels owned by indigenous groups, analysing the gender distribution of parcel owners, and detailing informal settlements.

Figure 3 shows the steps of the methodology used in this study.

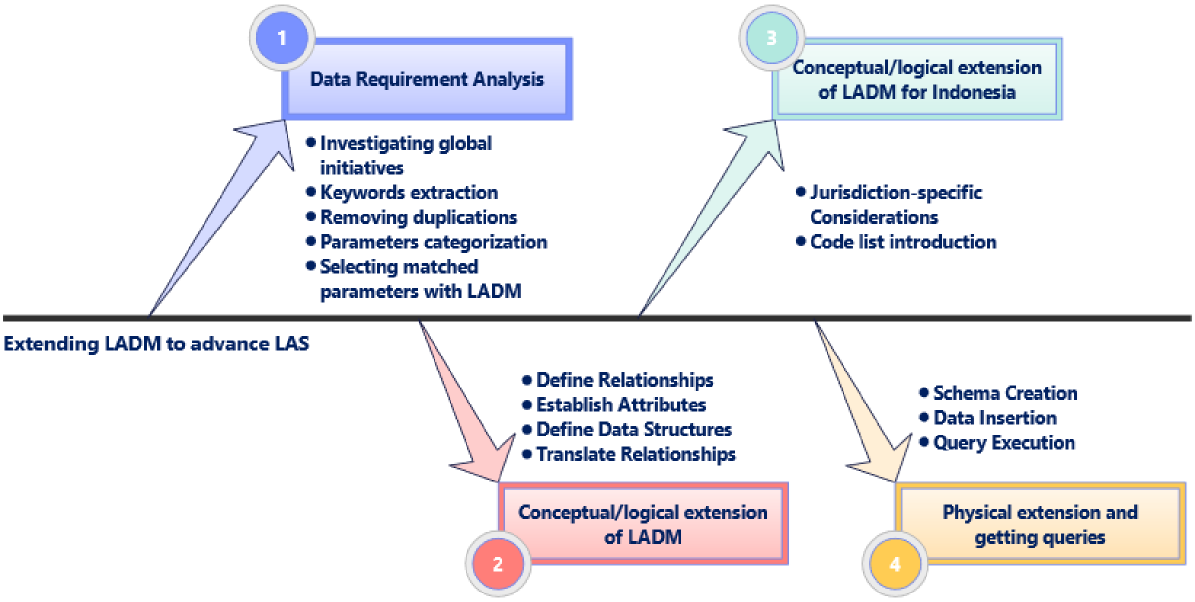

Figure 3. The methodology of extending LADM to advance LAS.

4. PROPOSED EXTENSION OF LADM

Investigating global initiatives has identified essential parameters for advancing Land Administration Systems (LAS) in alignment with global trends (Jahani Chehrehbargh et al., 2024b). These parameters encompass gender equality, Indigenous land rights, valuation and taxation, dispute resolution, informal rights, and specific attributes like tenure type, boundary type, and data source type. These elements are particularly critical for supporting vulnerable and marginalized communities, who often face significant challenges in securing their land tenure and accessing land-related services. Performance evaluation, education, and collaboration are also crucial for enhancing the national context of land management. As depicted in Figure 4, these parameters are carefully integrated into the land management paradigm, a fundamental framework in this domain. Addressing these parameters within LAS is crucial for promoting sustainability in land management.

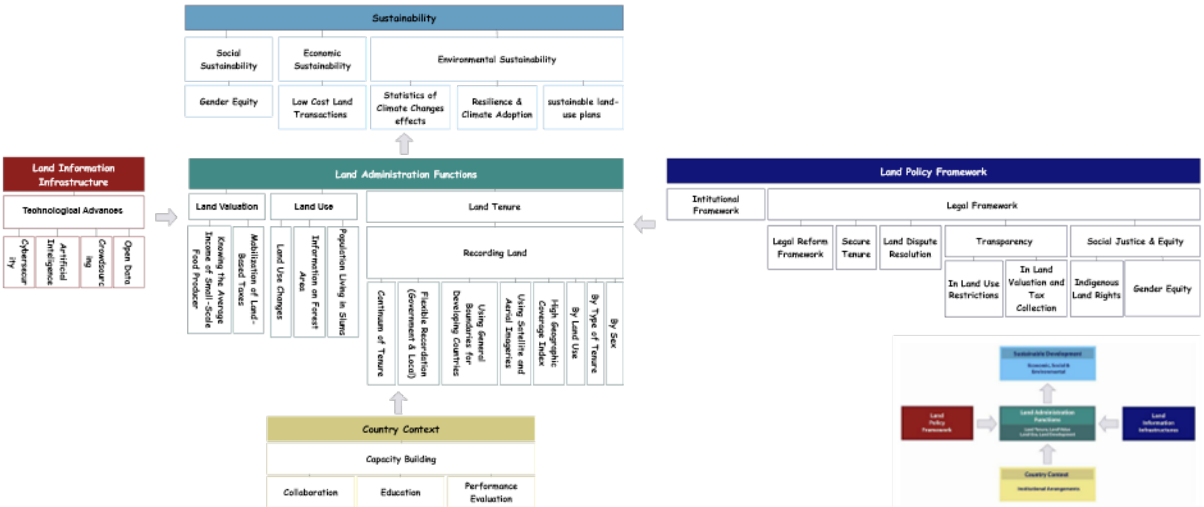

Figure 4. The Extracted Global Parameters for Advancing LAS (Jahani Chehrehbargh et al., 2024b)

Effective LAS is essential for resolving disputes and managing land conflicts. Online Dispute Resolution (ODR) systems offer viable solutions for land rights disputes by improving access to justice and overcoming barriers such as cost, time, and information imbalances. ODR includes various processes, such as negotiation, mediation, facilitation, arbitration, and other adjudication methods outside traditional physical settings, provided by entities like private enterprises, non-profit organizations, and governments (Salter, 2017).

This study outlines parameters that align with the land information infrastructure, addressing significant gaps in previously overlooked rights by land administration systems, such as women's rights, Indigenous land rights, informal rights, taxation, and land valuation. By focusing on the data model, crucial in the information infrastructure's data lifecycle, the study aims to align LAS with global trends, particularly for Indonesia.

4.1 Country-Specific Implementation for Indonesia

Indonesia is modernizing its land administration system to address challenges in land registration and construction permits (Jahani Chehrehbargh et al., 2024a). With millions of land parcels still unmapped, initiatives like the One Map Project, funded by the World Bank, aim to digitalize land services. Implementing the LADM for Indonesia could bring various benefits, including environmental protection and disaster management, along with potential cost savings. Adaptations and expansions are necessary, particularly in code lists to cater to local specifications. Some LADM classes align with existing Indonesian models, such as Person, Right, RegisterParcel, SurveyDocument, LegalDocument, Mortgage, SurveyPoint, GroupPerson, and Member class. However, classes like Responsibility, Restriction, and Serving Parcel, while supported by legal frameworks, await practical implementation (Sucaya, 2009).

The study adopts the basic classes of LADM Edition II (as shown in Figure 5) and extends them based on parameters derived from global initiatives, focusing on women, Indigenous and informal rights, valuation, and taxation.

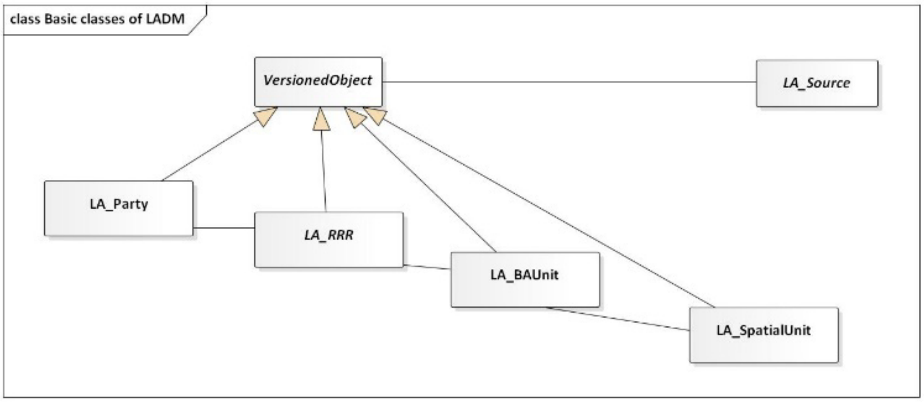

Figure 5. Basic classes of the core LADM Edition II (Lemmen et al., 2021)

4.1.1. Gender Equality

The initial step in securing women's land rights involves identifying the gender of parcel owners. The original LADM does not include a gender attribute in the LA_Party class. To make LAS gender-sensitive, this research proposes adding a gender attribute to the LADM, allowing for the collection of gender-specific data. Unger et al. (Unger et al., 2023) introduced gender as an attribute in the LA_Party class, using the ISO/IEC sex type code list. It is essential to differentiate between sex and gender: sex refers to biological traits, while gender involves societal roles and expectations, and gender identity refers to an individual's internal sense of their gender (World Health Organization, 2023).

To develop a comprehensive gender-sensitive system, it is necessary to recognize a broad spectrum of gender identities. By incorporating these identities under the attribute "LA_GenderType," the system can accurately reflect an individual's gender. Figure 6 shows the proposed gender attribute and its code list, with green boxes indicating modified classes, yellow boxes highlighting new elements and blue boxes for Indonesia's profile.

4.1.2. Indigenous Rights

Indigenous peoples, often referred to as first peoples, aboriginal peoples, native peoples, or autochthonous peoples, have deep-rooted connections to specific regions, maintaining unique traditions and cultural aspects tied to their territories. Recognizing these distinctions is crucial for developing inclusive policies and preserving cultural diversity (IPBES, 2018). Protecting their rights supports sustainable development and social justice, as emphasized by ILO Convention 169 (ILO, 2003), and the UN Declaration on the Rights of Indigenous Peoples (UNDRIP) (Paixao et al., 2015). Integrating these rights into land administration data models ensures their recognition and protection.

Indonesia's indigenous population is diverse, comprising numerous ethnic groups with distinct cultural identities and ancestral ties to specific regions. The government recognizes 1,331 ethnic groups, but many more people self-identify or are considered indigenous by others. The Aliansi Masyarakat Adat Nusantara (AMAN), the national Indigenous peoples'

organization, estimates between 50 and 70 million Indigenous peoples in Indonesia (IWGIA, 2023). Indigenous communities are referred to by terms such as "komunitas adat terpencil" and "masyarakat adat". Recent legislation reflects an implicit recognition of their rights, such as the Basic Agrarian Regulation and laws on human rights, coastal management, and the environment (Mamo, 2020). This study recommends including “masyarakat adat” in the party type classification and listing the 31 most populated ethnic groups in the Indigenous group codes for Indonesia (Na'im & Syaputra, 2010).
Indonesia faces persistent violence and criminalization against Indigenous Peoples, often related to infrastructure projects and dams. For example, in the Ngada district, a reservoir project in Rendu Indigenous territory sparked conflicts that escalated to violence in 2016. President Joko Widodo's 2017 regulation on Land Tenure Settlements in Forest Areas suggests relocating communities unless they prove longstanding habitation before the area was designated as forested (IWGIA, 2023). These challenges highlight the need for comprehensive approaches to protect indigenous land rights.

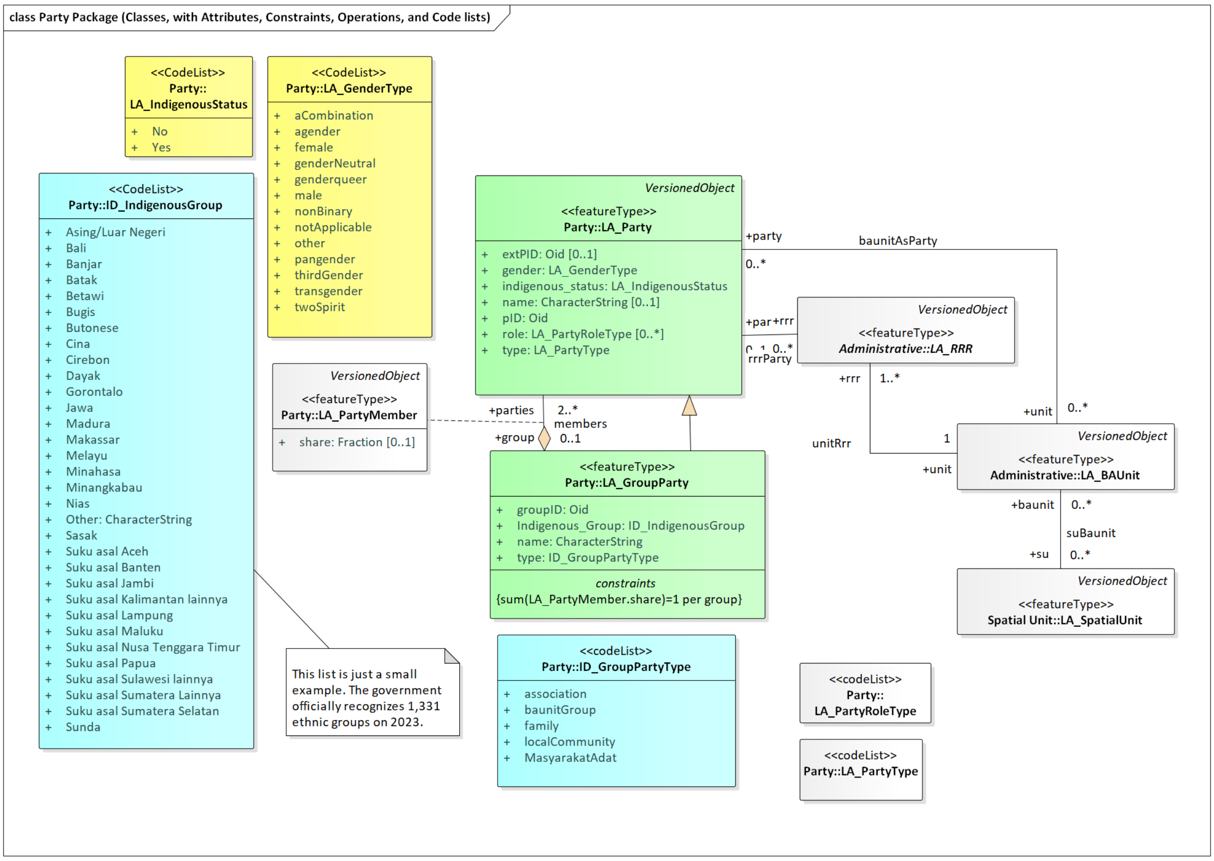

Figure 6. Extended LADM party package for Indonesia

This study introduces the attribute “Indigenous_status” within the LA_Party class of LADM to mark individuals or groups as belonging to Indigenous communities. This binary attribute (Yes/No) simplifies implementation and strengthens the foundation for recognizing Indigenous land rights. Building on Silvane et al.'s research on Indigenous land rights in

Brazil (Paixao et al., 2015), this study expands LADM to include attributes like "Indigenous group" and "Indigenous group type" (local community or Indigenous people). The administrative package of LADM also includes Indigenous unit types in the LA_BAUnitType code list and Indigenous rights in the LA_RightType, ensuring a nuanced understanding of Indigenous land rights within LADM, as shown in Figure 6.

4.1.3. Informal Rights

Land tenure encompasses various forms of ownership, including private, communal, open access, and state-held rights (Paasch et al., 2013). It can be formal (officially recognized) or informal (lacking official recognition and protection). Urbanization has significantly increased informal settlements, with about 25% of the global urban population living in slums as of 2015 (Jones, 2017). Addressing this requires comprehensive data collection and understanding of informal settlements, aligned with SDG indicator 11.1.1 (Berisha et al., 2022).

Traditional land information systems often fail to account for informal and customary tenures. The Social Tenure Domain Methodology (STDM), a specialization of LADM, addresses this gap by enabling the recording of various land rights, including informal land use and diverse property objects or spatial units (Kalogianni et al., 2022).

The LADM standard acknowledges different types of rights, such as ownership and customary rights, allowing flexibility in land administration practices. However, there hasn't been any approach that integrates informal social tenure relationships like informal occupation, tenancy based on non-formal and informal rights, and customary rights into the LADM (Paasch et al., 2013). To enhance international harmonization and facilitate a better understanding of the diverse types of rights, restrictions, responsibilities, and mortgages, it is essential to define and publicize these tenure categories.

According to Paasch et al. (Paasch et al., 2013), extending the LADM to support informal land rights involves careful consideration of hierarchical structuring and the incorporation of definitions and relationships within code lists. Inspired by initiatives like EULIS and the European Environment Agency's GEMET, an approach involving hierarchical coding and broader/narrower relationships can be adopted. This structured approach enables the creation of a more comprehensive and nuanced understanding of informal land rights within the LADM framework. Semantic technologies like RDF and SKOS, along with an open-linked data approach, can further enhance the extension of LADM to support the complex landscape of informal land rights.

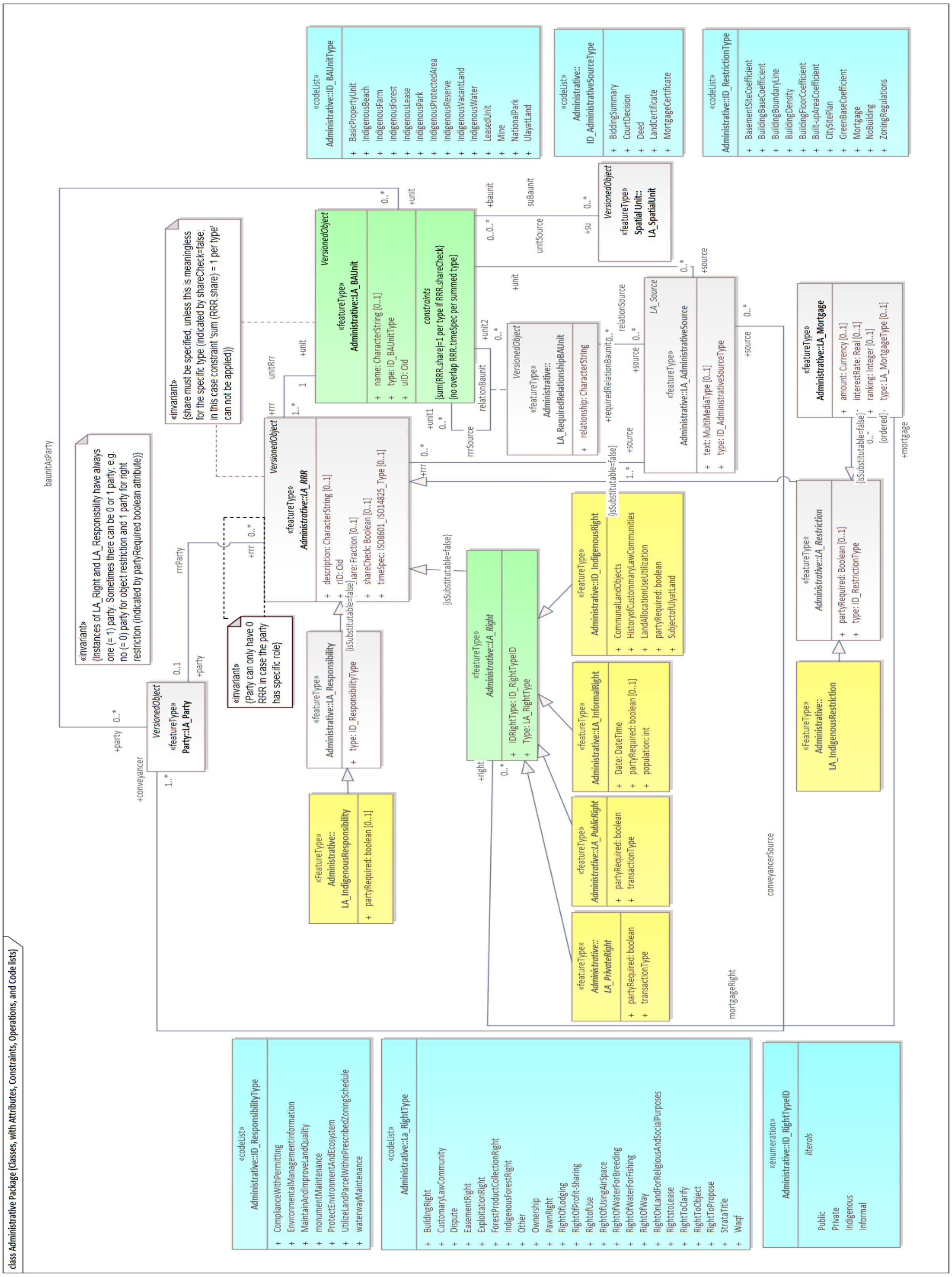

Figure 7. Extended LADM administrative package for Indonesia

The proposed approach can be put into practice, albeit with a slight increase in complexity and potential disruption to the existing LADM naming structure. To address this, as shown in Figure 7, this study recommends incorporating informal rights as generalizations under LA_Right, with attributes such as settlement types, population data, and recorded dates. The settlement type can be derived from the code list associated with the right types, allowing for clear differentiation between informal and formal settlements. Also as customary law in Indonesia requires registering land parcels of indigenous people as Ulayat Land, to avoid conflicts, both physical and juridical data should be verified. Different forms are used for registering land for indigenous people, so incorporating these forms into the data model ensures a comprehensive system, so we included them in the administrative package, information such as:

- **Management rights:** Details applicant information, land status, current use, and physical control of the land.
- **Land designation:** Requires details about the history of customary law communities, location, communal land objects, and land use plans.
- **Statement of physical control:** Confirms the land area and lack of conflicts.

As Figure 7 shows, the administrative package includes indigenous land rights and relevant information, along with code lists for types of rights, restrictions, responsibilities, units, and administrative sources specific to Indonesia.

4.1.4. Valuation and Taxation

United Nations guidelines highlight the importance of land management and property valuation in achieving Sustainable Development Goals (SDGs). Property valuation is essential for various processes, including property taxation, compensation for expropriation, and real estate transactions. Accurate and current property data are crucial for consistent and precise valuation. Efficient LASs should integrate valuation registries with other public registries like cadastre, land, address, and building registries (Cagdas et al., 2016).

In 2016, Cagdas et al. introduced an initial valuation model within LADM (Cagdas et al., 2016), expanding it to meet international taxation and valuation standards. This module facilitates all stages of property taxation, including identification, assessment through various appraisal methods, and management of tax collection, arrears, and appeals. The module records data related to parties and units involved in valuation and taxation, integrating legal information from cadastral systems with fiscal data.

In 2021, Abdullah et al. expanded this model, introducing features like VM_ValuationSource, VM_SpatialUnit, VM_Building, and VM_CondominiumUnit(Kara et al., 2021). This study incorporates additional valuation factors proposed by (Jafary et al., 2022), extending the LADM valuation class according to the latest models of valuation and taxation.

The extended features and attributes are as follows:

- **VM_Valuation:** Focuses on the input and output data utilized and generated within single or mass appraisal processes for property tax assessment.
- **VM_SinglePropertyAppraisal:** A subclass of VM_Valuation, detailing single property appraisal-related information through attributes such as SalesComparisonMethod,

valuationByCostMethod, valuationByIncomeMethod, and their corresponding data type classes.

- **VM_MassAppraisal:** Designed to organize mass appraisal-related information, describing mathematical models, mass appraisal analysis types, and the sample size of the analysis.
- **VM_TransactionPrices:** Includes attributes that characterize transaction contracts or declarations, encompassing details such as the date of contract or declaration, price, transaction date, and type (e.g., sale, heritage, forced sale, and rent prices).
- **VM_SalesStatistics:** Created for time series data generated through the analysis of transaction prices.
- **VM_ValuationUnit:** Serves as the basic recording unit in fiscal registries and is associated with LA_BAUnit, denoting the fundamental registration unit in cadastral systems.
- **VM_SpatialUnit:** Represents cadastral parcels, including sub-parcels that are divisions based on official land use for taxation purposes.
- **VM_Building:** Provides a set of common attributes shared by its sub-classes, encompassing details such as area, volume, type of use, building type, number of dwellings, and floors of buildings. It also includes construction and energy-related attributes, such as the date of construction, construction material, facade material, heating system, heating source, and energy performance.
- **VM_CondominiumUnit:** Records essential condominium unit characteristics necessary for valuation procedures, such as area, volume, use type, condominium type, floor number, and the count of rooms, bathrooms, and bedrooms.
- **VM_ValuationSource:** Introduced to record the type of valuation sources, such as valuation reports, sale contracts, rental contracts, and declarations. This class inherits from the LA_Source class, which includes acceptance and lifespan stamp characteristics, representing the real-world time (valid time) of the source.
- **TM_Taxation:** Dedicated to capturing specific taxation details related to immovable properties. This includes information such as the name or identifier of the property tax, fiscal year, assessed value of the fiscal unit, exemptions granted (including type and amount), assessment ratio, applied tax rates, assessed tax amount, due date for tax payment, as well as specifics about payments and appeals. Payment details like amount and date, appeal identification, appeal subject, and appeal status are recorded. Additionally, values for the attributes exemptionType and AppealStatus are provided by two code list classes, FM_ExemptionType and FM_StatusOfAppeal, respectively.

As part of the ongoing development of LADM, enhancing the existing code lists signifies a significant step forward. This study has introduced new enumerations to the code lists, including:

- **SpecificProperty and MassAppraisal:** Incorporated into the code lists of VM_ValuationApproach within the VM_Valuation class.
- **IncomeValue:** Added to the code lists of VM_ValuationType within the VM_Valuation class.

- Attributes within the **VM_Building** class, such as **designQuality**, **sunlightExposure**, **numberOfBedroom**, **numberOfBathroom**, **numberOfBalcony**, **numberOfCarspaces**, **numberOfStorage**, **Storey**, and **landScapeView**.
- **gymAndRecreation:** Included in the code lists of VM_AccessoryPartType within the VM_CondominiumUnit class.

The proposed valuation classes and attributes tailored to Indonesian conditions, emphasizing the need for such integration in national land management practices. The National Land Agency of Indonesia historically focused on land tenure and use, with land valuation incorporated only in 2006. Challenges persist in implementing mass valuation methods, particularly due to data collection issues in Indonesia’s diverse market landscape. Since 2014, the Directorate of Land Valuation and Land Economy has emphasized the importance of land acquisition. Accurate land valuation is crucial given Indonesia's vast territory. Therefore, integrating comprehensive land management, including accurate land valuation, across all functions is essential. These additions are shown in Figure 8 and Figure 9.

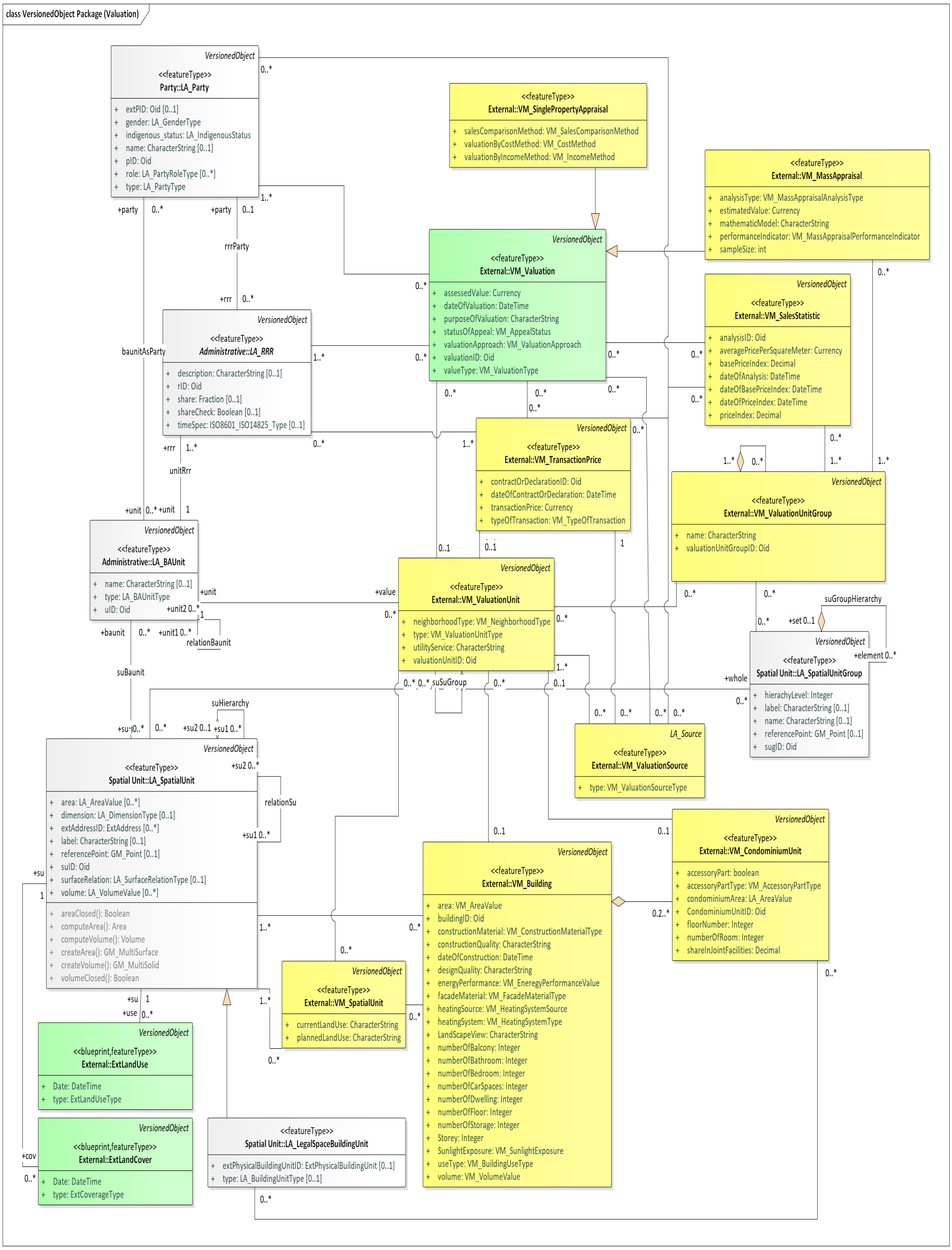

Figure 8. Extended valuation class within the versioned object package of LADM

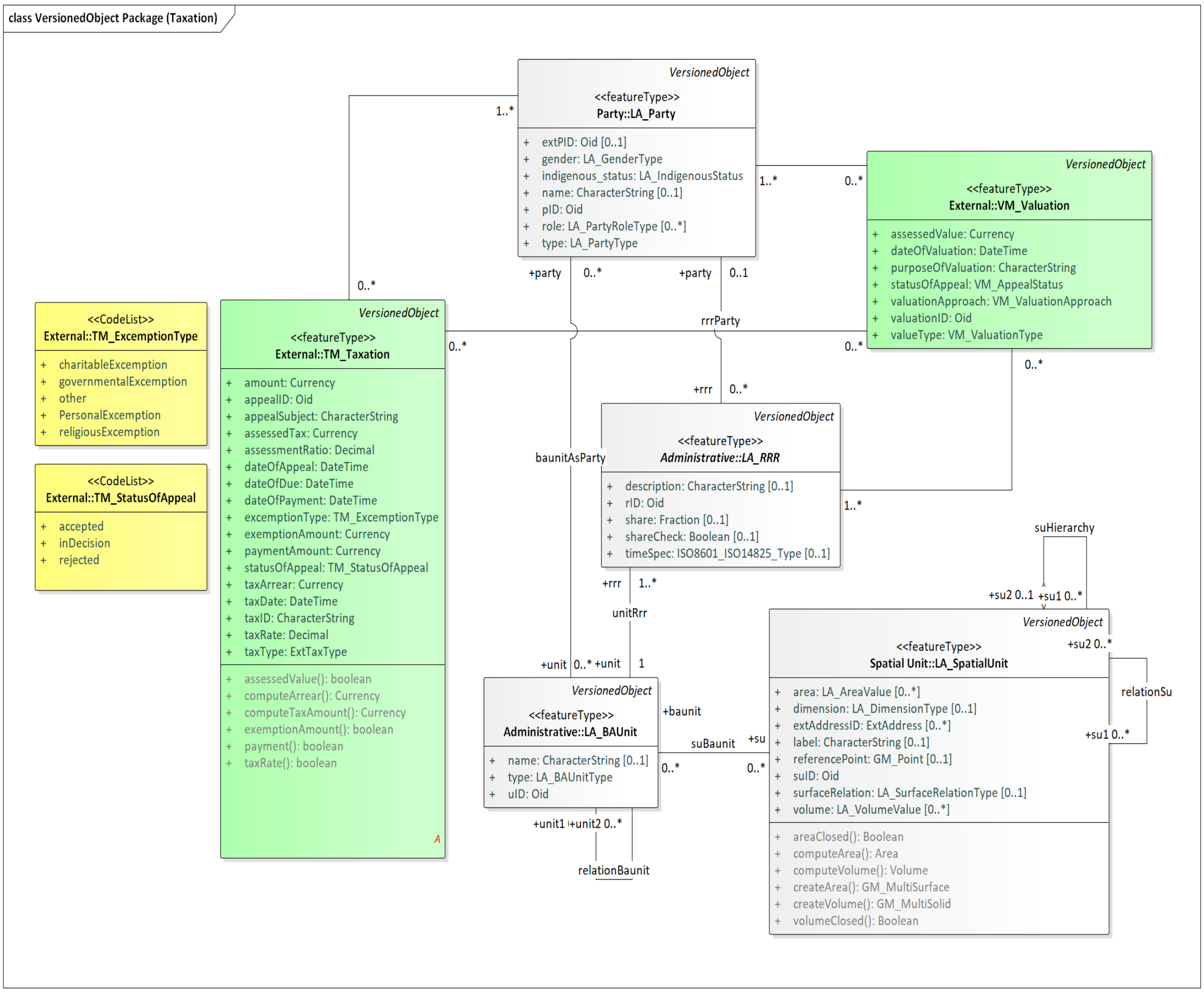

Figure 9. Extended taxation class within the versioned object package of LADM

4.2 Physical Data Model Implementation

The existing Land Administration Domain Model (LADM) is primarily a conceptual model, which lacks detailed guidance for practical application, making it difficult to translate into a physical model for production systems. While conceptual models can be interpreted differently depending on the perspective, a physical model offers a clear and consistent representation that reduces ambiguity (Shahidinejad et al., 2023). Physical models are crucial as they define the semantic and spatial information for various urban structures, such as buildings, roads, tunnels, and bridges (Olfat et al., 2021).

This chapter outlines the physical implementation of the extended LADM, focusing on the inclusion of previously ignored rights such as women's rights, Indigenous land rights, informal rights, taxation, and land valuation.

The physical model is constructed based on SQL codes. The process of creating the physical model from the UML in EA to the implemented physical model in PostgreSQL involves several key steps:

- **Utilize the Extended Logical Model:** Start by using the extended logical model within Enterprise Architecture (EA) software as the foundation for the physical model.
- **Convert UML to DDL:** Transform the Unified Modeling Language (UML) diagrams into Data Definition Language (DDL) within the EA software, establishing the initial blueprint for the database structure.
- **Modify Relationships in DDL:** Refine and adjust the relationships within the generated DDL to accurately reflect the intended data architecture.
- **Convert DDL to SQL:** Convert the refined DDL into SQL code, making it ready for implementation in the database system.
- **Refine SQL in pgAdmin:** Further modify the SQL in pgAdmin (Specifically primary and foreign keys) to resolve any issues and to finalize the database structure.
- **Create Tables with Correct Relationships:** Create the database tables in pgAdmin, ensuring that all relationships are correctly established, completing the physical model.
- **Insert Data:** Populate the created tables with relevant data to operationalize the database.
- **Execute Queries and Connect to QGIS:** Perform queries to validate the model and connect the PostgreSQL database to QGIS for spatial data visualization and analysis.

The SQL insertions and query scenarios are utilized to demonstrate how these extensions are operationalized within a land administration system, specifically tailored for Indonesia.

4.2.1 Data Preparation and Input

The physical model of the extended LADM is built upon several core tables. These tables capture different aspects of land administration, including parties involved, rights associated with the land, addresses, and spatial units. Before executing queries and scenarios, it is crucial to prepare the data by ensuring that all necessary attributes are included and correctly structured within the database. The data used in this study pertains to 156 parcels located in Jakarta, each identified by a unique NIB (Nomor Identifikasi Bidang: Land Parcel Identification Number). The dataset includes information such as parcel areas, and other relevant attributes. However, to ensure that the database can handle queries and provide meaningful results, we need to create dummy data for attributes that are missing or incomplete. This involves adding necessary attributes such as gender, type of land rights, and any other relevant information that aligns with the objectives of the study. The dummy data will be used to populate the database tables, allowing for the execution of various scenarios and queries. For example, if the ownership details or gender information is not fully available in the original dataset, we would generate this data to ensure that all queries, especially those related to gender-based analysis, can be effectively run. Figure 10 show the original data in QGIS software.

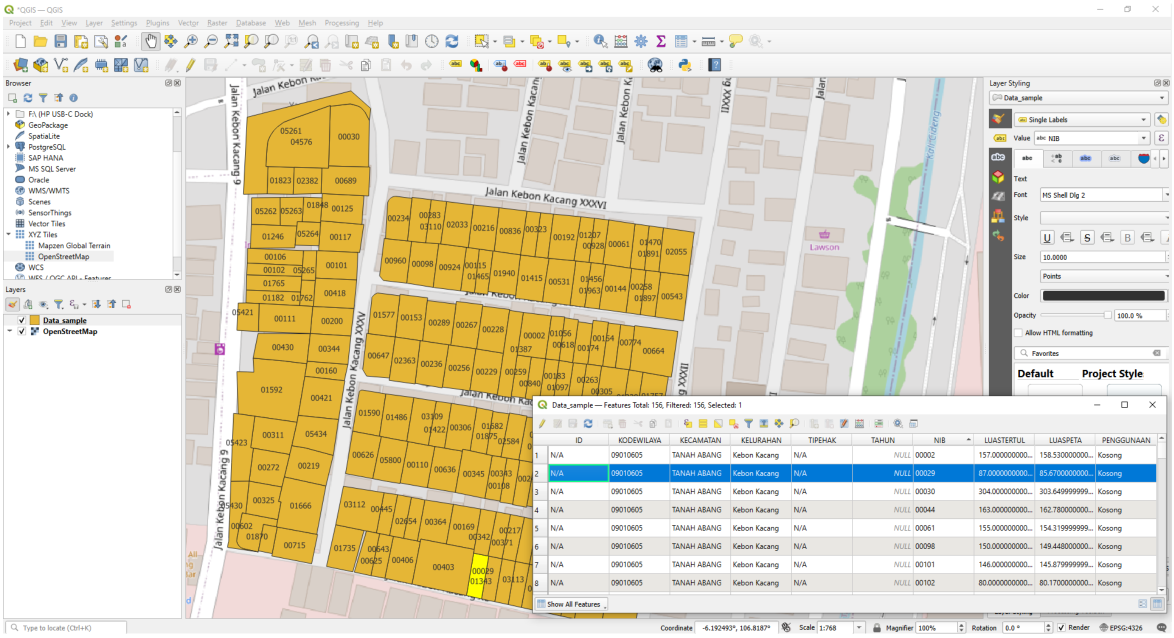

Figure 10. The provided data with related attributes in Bahasa language

4.2.2 Query 1: Identifying Women-Owned Parcels by NIB

Scenario Overview: In this scenario, the goal is to identify parcels owned by women within the study area by retrieving their corresponding NIB numbers. This information is crucial for assessing the distribution of land ownership based on gender and understanding the role of women in land ownership within the Jakarta region.

The earlier version of the LADM lacked the ability to directly answer this query because it did not include specific attributes related to the gender of parcel owners. Without this essential data, it was impossible to distinguish parcels based on ownership by gender, limiting the model's utility in conducting gender-sensitive analyses. This gap posed a significant challenge, especially in contexts where gender equality in land ownership is a critical metric for evaluating the effectiveness of land administration systems. The extended version of LADM, however, addresses this limitation by introducing a "Gender" attribute within the "La_party" class, which records the gender of the parcel owner. This enhancement not only improves the functionality of LADM in supporting local land administration but also aligns with global initiatives such as the United Nations Sustainable Development Goals (SDGs), particularly SDG 5, which emphasizes achieving gender equality and empowering women.

Query Execution: Figure 11 shows the query executed in pgAdmin software, with the result table displayed on the left side. Additionally, a visual representation of the query results, generated in QGIS, is shown on the right side of the figure, illustrating the spatial distribution of women-owned parcels across the study area. This visualization enhances the understanding of gender-based ownership patterns, supporting local policy-making efforts in land governance.

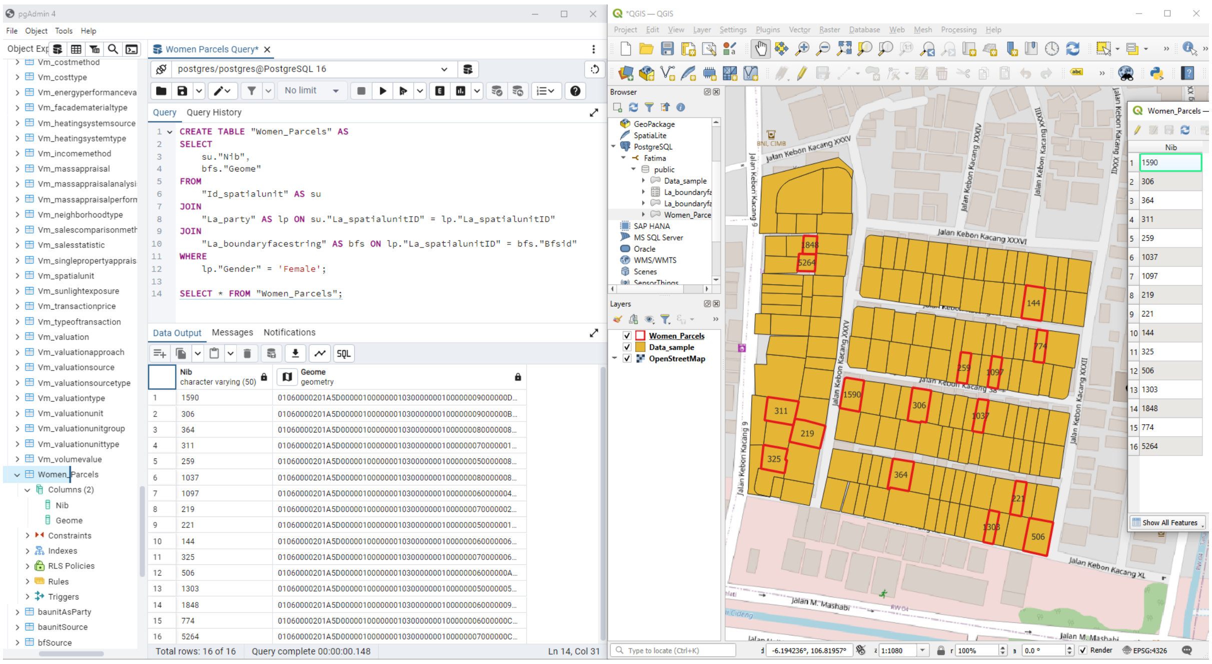

Figure 11. Women-owned parcels query execution in pgAdmin with the distribution displayed in QGIS

4.2.3 Query 2: Identifying Neighboring Parcels Within a 25-Meter Radius

Scenario Overview: In this scenario, the objective is to identify neighboring parcels within a 25-meter radius of a specific parcel (ID: 130) and record their ownership rights. These ownership rights include categories such as Informal, Indigenous, Private, or Public. This query is essential for understanding the spatial relationships between parcels and assessing the distribution of different types of land ownership within a specific area.

The earlier version of the LADM was not equipped to handle this type of spatial query effectively, as it lacked the Indigenous and infomal rights. The extended version of LADM overcomes these limitations by incorporating spatial data capabilities and enhanced classification of right types.

Query Execution: Figure 12 shows the query executed in pgAdmin software, with the resulting neighboring parcels identified within a 25-meter radius of Parcel 130. The ownership rights of these parcels are then recorded in a new table, which is displayed on the left side of the figure. On the right side, a visual representation generated in QGIS illustrates the spatial relationship between Parcel 130 and its neighboring parcels, highlighting the different types of land rights. This visualization aids in understanding the proximity and distribution of various ownership categories, supporting local land management and planning efforts.

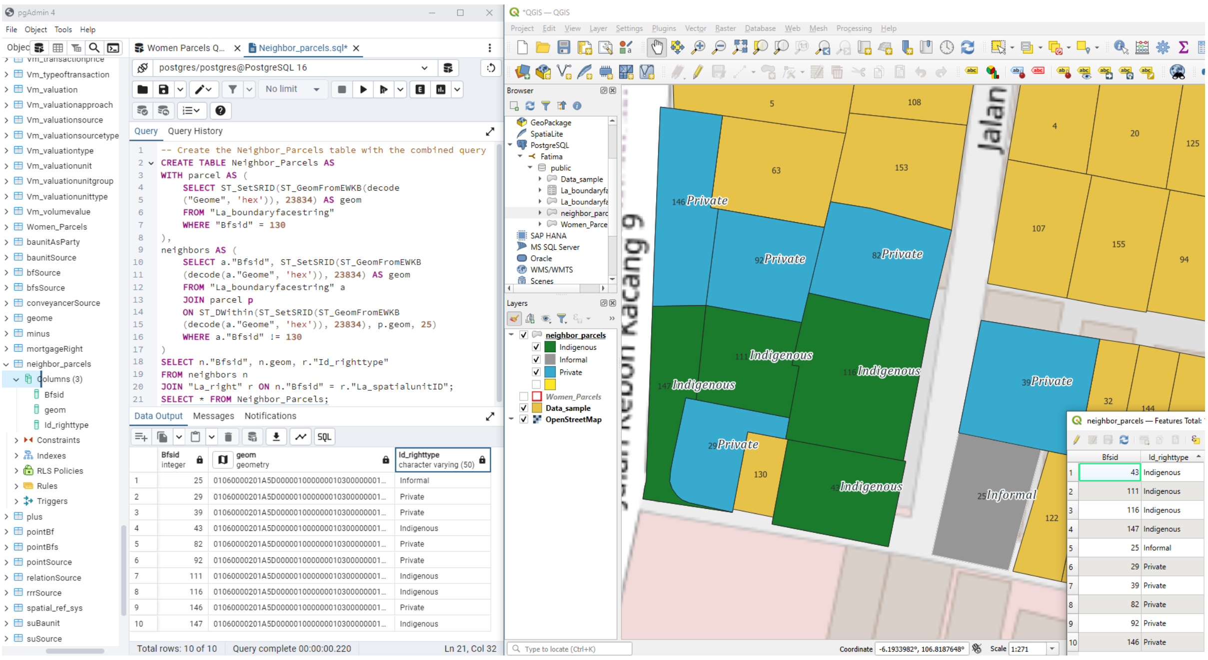

Figure 12. Neighboring parcels query execution in pgAdmin with the distribution and ownership rights displayed in QGIS.

5 CONCLUSION

This study has provided a comprehensive investigation into the enhancement of Land Administration Systems (LASs) by integrating key parameters from global initiatives into the Land Administration Domain Model (LADM). Recognizing that effective LASs are fundamental to economic stability, social equity, and environmental sustainability, this research addresses the pressing need to adapt these systems to meet contemporary global challenges such as population growth, disaster management, and resource scarcity. By extending the LADM to include women rights, indigenous rights, informal rights, and valuation and taxation, the study bridges a critical gap in the current literature, which often overlooks the integration of multiple global trends within a unified framework.

The research was grounded in a systematic methodology that included a continuous review of global initiatives, conceptual and logical model design, and the practical implementation of these extensions within a physical data model. Our study is unique and innovative as it not only presents a conceptual design but also implements a proof of concept through queries and practical application, something that has not been previously implemented in the context of LADM. The findings from this study highlight the significance of addressing spatial and administrative data aspects collectively to align with global sustainability goals, particularly in supporting vulnerable and marginalized communities such as women, Indigenous peoples, and those with informal land rights. The extended LADM framework not only advances theoretical discussions but also offers practical solutions tailored to the unique context of Indonesia, a country facing significant land governance challenges.

A key contribution of this research is the successful implementation of a physical model using PostgreSQL, which effectively operationalizes the extended LADM framework. This step was crucial in demonstrating the feasibility of the proposed extensions and validating their potential to support sustainable land management practices. However, the process of creating the physical model also presented several challenges. For instance, during the conversion of the UML to DDL in Enterprise Architecture (EA) software, extra columns were inadvertently created, requiring additional refinement. Additionally, the software sometimes assigned incorrect primary and foreign keys, leading to issues in establishing accurate relationships between tables. These challenges underscore the complexity of translating a conceptual model into a physical database, highlighting the need for careful validation and modification at each step to ensure the final model accurately reflects the intended design.

The physical implementation also underscores the importance of ongoing enhancement, validation, and integration of LASs to ensure they remain relevant and effective in a rapidly changing global environment. The extended LADM, now capable of addressing complex and nuanced land administration queries, is well-positioned to contribute to more equitable and sustainable land governance practices, both in Indonesia and globally.

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Monitoring Indicators of International Guidance Documents and Frameworks through LADM

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Key words: Land Administration, Land Governance Assessment Framework (LGAF), Global Land Indicators Initiative (GLII), Land Administration Domain Model (LADM).

SUMMARY

Evaluating the performance of a land administration system (LAS) is a critical task as it can provide input for improving the operational system. Through such an evaluation, the strengths and weaknesses of the existing system can be identified, and actions can be taken to improve it. Efforts have been made to develop frameworks and best practices for the assessment and comparison of the performance of LASs. Amongst the most prominent are the ‘Land Governance Assessment Framework’ (LGAF) of the World Bank and the ‘Global Land Indicators’ proposed by the Global Land Tool Network (GLTN) and the United Nations Human Settlements Programme (UN-Habitat) in its Global Land Indicators Initiative (GLII). The GLII indicators are closely related to the UN-Sustainable Development Goals (SDGs) indicators on land tenure security, namely SDGs 1.4.2 (%adults with secure tenure rights), 5.a.1 (%agricultural population with secure rights over agricultural land), and 5.a.2 (women's equal rights to land ownership).

The Land Administration Domain Model (LADM), an International Standard (ISO, 2012), can be used to monitor global indicators proposed by various international organizations and to evaluate the performance of LADM-based LASs, as LADM Edition II now provides full support for all land administration (LA) functions including marine georegulation, valuation information and spatial plan information. Interface classes to the LADM are designed to support the generation and management of products and services, such as the monitoring of global performance indicators for LASs.

This paper is a follow-up on Chen et al. (2024), which was focusing on formalizing SDG land related indicator using LADM. The objective of this study is to explore the extent to which LADM can be used to also monitor the indicators of LGAF and GLII. To this end, the indicators are categorized according to their degree of association with LADM (i.e. full computational association, partial computational association, indirect association, association with other standards and non-association), and interface classes are created based on the results. The results show that LADM can be used to monitor a significant portion of the indicators of LGAF and GLII, although most of the indicators are related to a country's national legislation, its implementation and organizational decisions and capability.

Monitoring Indicators of International Guidance Documents and Frameworks through LADM

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1. INTRODUCTION

The evaluation of the performance of a land administration system (LAS) is an important task, as it may identify the strengths and weaknesses of the existing system and provide the basis for improving it.

The evaluation of LASs is a complex task, initially due to the diversity of perceptions of land within societies (Steudler et al., 2004). Efforts have been made to develop frameworks and best practices for evaluating and comparing the performance of LASs (Williamson and Ting, 2001; Steudler et al., 2004). Global initiatives such as the World Bank, the United Nations (UN) (e.g., UN-Habitat, UN-GGIM, FAO) and the Global Land Tool Network (GLTN) have published agendas, guidelines and frameworks that focus on land administration (LA) beyond 2010. For example, the World Bank published the 'Land Governance Assessment Framework' (LGAF) in 2013, the UN announced the 'Sustainable Development Goals' (SDGs) (UN, 2015), and the UN published the 'New Urban Agenda' (NUA) (UN, 2017). The 'Framework for Effective Land Administration' (FELA) was published by the United Nations Committee of Experts on Global Geospatial Information Management (UNGGIM, 2020); GLTN and UN-Habitat published the 'Assessment of the Uptake of the Set of 15 Indicators by the Global Land Indicators Initiative (GLII) in Global and Regional Frameworks and by Land Actors' (UN Habitat/GLTN, 2021) and the Food and Agriculture Organization of the United Nations (FAO) published the revised version of the 'Voluntary Guidelines on the Responsible Governance of Tenure' (VGGT) (FAO, 2022). This current study will focus on the World Bank's LGAF, and indicators as identified by the GLII.

The LGAF can be used to identify and monitor good practices in the land sector. The LGAF is motivated by the fact that land policy analysis and interventions are often fragmented. They tend to focus only on specific aspects such as land registry or surveying. This not only lacks important synergies with other parts of the system, but may ultimately prove to be ineffective and unsustainable (World Bank, 2013). The LGAF is structured around five key thematic areas: (a) how land rights are defined and enforced; (b) how land is managed, used and taxed; (c) how public land is managed; (d) how information on rights is maintained and accessed; and (e) how land disputes are managed and resolved (World Bank, 2013).

The GLII was established under the GLTN in 2012 with the aim to support efforts to harmonize monitoring efforts around land tenure and governance. The GLII seeks to derive a list of globally comparable harmonized land indicators, using existing monitoring mechanisms and data collection methods as a foundation. The initiative is supporting global and regional frameworks such as the VGGTs, agreed by 193 Member States and supported by civil society (UN-Habitat/GLTN, 2017). In 2021 UN-Habitat and GLTN published an assessment document to '*better understand how GLII land indicators are being used by GLII partner and non-partner organizations, and by extension, to appreciate the impact of GLII indicators on*

the larger regional and global effort to promote monitoring of land tenure security for men, women and youth' (UN-Habitat/GLTN, 2021).
The Land Administration Domain Model (LADM) was published as a standard by the International Organization for Standardization (ISO) in 2012 (ISO, 2012). The focus of the LADM Edition I (ISO, 2012) is on the part of land administration that is interested in rights, responsibilities and restrictions concerning land (or water) and its geometric (geographic) components (Lemmen et al., 2015). The systematic revision of LADM Edition I within ISO has been initiated in 2018, and the domain experts have decided that LADM Edition II should be structured as a multi-part standard. Part 1, ISO 19152-1 *Generic conceptual model*, presents '*the fundamental notions and defines the basic components and relations shared by all objects created by land administration / georegulation*' (ISO, 2024a), is published as an international standard in January 2024. Part 3, ISO 19152-3 *Marine georegulation*, provides '*the concepts and structure for standardization for georegulation in the marine space*' based on the International Hydrographic Organization's (IHO) S-121 (ISO, 2024b), is published as an international standard July 2024. The systematic revision and development processes are ongoing for ISO 19152-2 *Land registration*, ISO 19152-4 *Valuation information* and ISO-19152-5 *Spatial plan information*, all of which are at the Draft International Standard (DIS) stage at the time of writing of this paper (August 2024) (Kara et al., 2024). The LADM can be used to monitor global indicators proposed by various international organizations, including the World Bank's LGAF and indicators identified by the GLII, and to evaluate the performance of LADM-based LASs. Since the LADM Edition II provides full support for all the functions of the LA, it can be used to evaluate the value and use of land-related indicators. For this purpose, interface classes to the LADM can be created to support the generation and management of products and services (ISO, 2012), such as the monitoring performance of global indicators for LASs.
The objective of this study is to explore the extent to which LADM can be used to monitor the indicators of LGAF and GLII. To this end, the indicators are categorized according to their degree of association with LADM (i.e. full computational association, partial computational association, indirect association, association with other standards and non-association) as proposed by Chen et al. (2024), and interface classes are created for the full computational associations. This paper is organized as follows: Section 2 briefly introduces the LADM Edition II, World Bank's LGAF and the GLII's Global Land Indicators. Section 3 analyzes the LGAF indicators and their relationship to LADM. Section 4 examines the GLII and their relationship to LADM. Considering the results of the analyses, interface classes to LADM are created to monitor the indicators in Section 5. The last section concludes this study.

2. BACKGROUND AND RELATED RESEARCH

This section briefly introduces LADM Edition II. This is followed by the main objective and content of LGAF. Lastly, the main objective of GLII and the content of the Global Land Indicators are presented.

2.1 LADM Edition II

LADM Edition I focuses on the land tenure function of LA. The land value and land use functions are not included in detail in the first edition, but external classes ExtValuation and ExtLandUse are proposed, respectively. It is worth noting that the external classes indicate what data content LADM expects from external resources (Lemmen, 2012).

In response to requests from the international LA community, the decision was made to refine the existing content and extend the scope of Edition I of the LADM. This begins with gathering feedback from ISO/TC 211 member states on the need for updated and expanded capabilities of the LADM. In addition, to revise LADM Edition I, several FIG LADM workshops were organized to discuss options for improvements and extensions among experts, see Kara et al. (2024). From those, the integration of valuation information (Part 4) and spatial plan information (Part 5) within the LADM has been considered appropriate, together with the provision of LA in 3D (spatial units below, on and above the surface of the earth) on land (Part 2) as well as at sea (Part 3). In addition, the need for further, refinement of rights, restrictions and responsibilities (RRRs), a refined survey model, new subclasses for spatial units, a set of possible representations of spatial units in 2D, 3D or mixed dimension, identifying legal spaces in buildings, refined legal profiles have been considered. Figure 1 shows the extended scope of LADM Edition II. For the scope and content of the conceptual model of Part 1 (Generic conceptual model), Part 2 (Land registration), Part 4 (Valuation information) and Part 5 (Spatial plan information), see Kara et al., 2024.

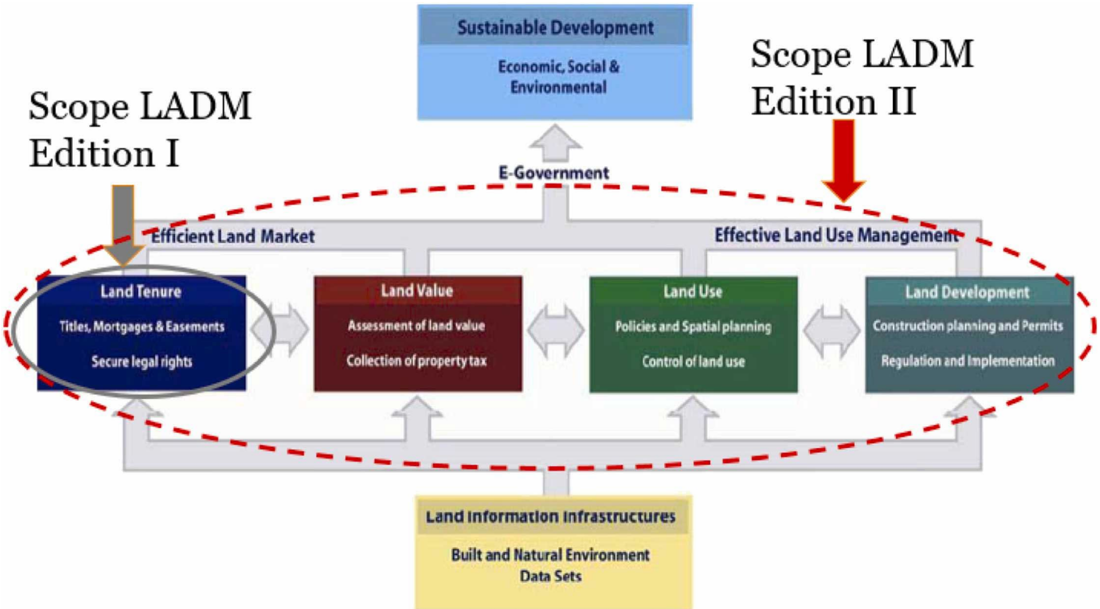

Figure 1. The extended scope of LADM (adapted from Enemark 2006)

LADM Part 2, Part 4 and Part 5 have not yet been published as an ISO standard, but are in one of ISO's mature states: Draft International Standard (DIS). All three parts are expected to be published as an international ISO standard in 2025. The UML of all three parts is available on the GitHub page of the ISO Harmonized Model Maintenance Group (ISO HMMG) at https://github.com/ISO-TC211/HMMG. Since the conceptual models of the mentioned parts are at a mature stage, they can be used to develop interface classes, for example, to monitor the efficiency of LASs in different contexts, including land tenure, value, and use.

2.2 World Bank's LGAF

According to World Bank (2013), the need for a systematic assessment of land governance arises from three factors: (1) land has emerged as a key factor for sustainable growth and poverty reduction, (2) there can be a wide gap between legal provisions and their actual implementation, namely institutional fragmentation, and (3) progress depends on the ability to forge consensus among experts in a participatory and deliberative process based on comprehensive analysis. The LGAF was developed by the World Bank in partnership with FAO, UN-Habitat, International Fund for Agricultural Development (IFAD), International Food Policy Research Institute (IFPRI), the African Union, and bilateral partners (World Bank, 2024). It is worth noting that the LGAF has been revised to take into account the VGGTs and the lessons learned from the implementation of the LGAF (World Bank, 2013).

The LGAF process is coordinated and implemented by country experts. The broad steps of the LGAF are: (1) collection of qualitative and quantitative background information, (2) stakeholder panels to rank dimensions; invitation is based on area of expertise, (3) LGAF report with identification of priority policy areas for follow up, (4) validation of rankings and discussion of actionable policy priorities, and: (5) follow up with work plan (World Bank, 2024). The core approach of the LGAF is to provide scores for each dimension through panels of experts (World Bank, 2024). Each panel discusses a specific thematic area and includes a diverse group of individuals who are subject matter experts on different aspects of the issues in the area under study (e.g., lawyers, academics, experts working for non-governmental organizations, government officials, land professionals, etc.). Between 3 and 8 members can be selected for each panel to bring together a variety of perspectives and substantive expertise needed to provide a meaningful assessment (World Bank, 2024). The dimensions are divided into 9 panels on the following topics: (1) land tenure recognition, (2) rights to forest and common lands & rural land use regulations, (3) urban land use, planning, and development, (4) public land management, (5) transparent process and economic benefit, (6) public provision of land information: registry and cadastre, (7) land valuation and taxation, (8) dispute resolution, and: (9) review of institutional arrangements and policies (World Bank, 2024). The implementation manual of the LGAF (World Bank, 2013) identifies 27 main indicators and associated 108 dimensions. For each dimension, an evaluation consisting of four different levels should be provided. See Table 1 for more details on LGAF indicators. Lastly, 39 countries all around the world, mostly African countries, implemented the LGAF, according to World Bank (2024).

2.3 GLII's Global Land Indicators

The need to step up monitoring of land governance issues drove the establishment of the GLII in 2012 by the Millennium Challenge Corporation, the World Bank, and UN-Habitat. The platform is hosted and facilitated by GLTN/UN-Habitat. GLII includes over 50 institutions around the world ranging from UN Agencies, inter-governmental organizations, international nongovernmental organizations, academia, private sector, researchers and training institutions, and farmer organizations (GLTN, 2024).

One of the mandates of the GLII is to develop nationally applicable and globally comparable land indicators and data protocols for land monitoring (GLTN, 2024). GLII and its partners have built stronger national processes for comparable and comprehensive monitoring of land governance at scale in relation to global and regional land governance frameworks: the VGGTs, the SDGs, the NUA, the African Union Framework and Guidelines for Land Policy in Africa (AU-F&G), and other initiatives. The platform identified a set of 15 land indicators developed and validated by GLII partners, including a number of indicators included in the SDGs monitoring framework under SDGs 1, 2, 5, 11, 15 and their link to SDG 16 (GLTN, 2024). The GLII's 15 nationally applicable and globally comparable land indicators that go beyond the SDGs' land provisions and cover four key areas of land governance: (1) land tenure security for all, (2) land and conflict, (3) land administration services, and: (4) sustainable land use management (GLTN, 2024).

Three main levels of reporting and analysis are envisaged for the 15 GLII indicators: (1) country-level reporting by national governments (GLII indicators with number 1, 2, 6, 7, 8 11, 12), (2) country-level reporting assisted by international data initiatives (GLII indicators with number 3, 4, 8, 9, 10, 13), (3) global monitoring (GLII indicators with number 5, 14, 15) (UN Habitat/GLTN, 2017). It was noted that use of the indicators among partners was highest for the five GLII indicators related to land tenure security (indicators 1.1 to 1.5) (UN Habitat/GLTN, 2021). The GLII indicators are closely related to the SDG indicators on land tenure security, namely SDGs 1.4.2, 5.a.1, and 5.a.2 (UN Habitat/GLTN/GLII, 2022). See Table 2 for more details on GLII indicators.

3. ANALYSIS OF THE INDICATORS AND THEIR RELATIONSHIP TO LADM

3.1 LGAF Indicators and their Relationship to LADM

The World Bank's LGAF includes 107 dimensions associated with 27 indicators grouped under 9 different themes. In the Appendix, Table 1 presents the LGAF themes, land governance indicators, LGAF dimensions and their relationship to LADM. Rows highlighted in green represent *full computational association* with LADM, while turquoise represents *partial computational association*. *Indirect association* is shown in yellow, *association with other standards* is shown in pink, and *non-association* is shown in gray. For the descriptions of associations, see Chen et al. (2024). It should be noted that the first two steps (i.e., keywords extraction and matching with LADM) as proposed by Chen et al. (2024) are not included in this paper, since all indicators of LGAF and GLII are directly related to land management.

A brief explanation of how LADM is related to the related dimensions of LGAF is given in the last column of Table 1. According to the analyses performed, 10 dimensions are found to have a full computational association with LADM, 11 dimensions have a partial computational association. 31 dimensions are found to have an indirect association, while a few dimensions related to actual land use (ISO 19144-3) are found to be partially associated with other standards (which are not included in the statistics given here as they are counted in other categories). On the other hand, 55 dimensions are found to be related to a country's national legislation and its implementation. These dimensions are considered to be in the context of operating a system based LADM. Lastly, it should be noted that these results may not be the final result, the evaluation can be revised considering the feedback given in the workshop, by reviews, and so on.

3.2 GLII Indicators and their Relationship to LADM

The GLII has identified 15 requirements that are grouped into four different themes. In the Appendix, Table 2 shows the GLII themes, the GLII indicators, and their relationship to the LADM. The same color scheme is used to color Table 2.

A brief explanation of how LADM relates to the related indicators identified by the GLII is given in the last column of Table 2. According to the analyses performed, 3 indicators are found to have a full computational association with LADM: 3 indicators have a partial computational association, and 3 indicators have an indirect association. 6 indicators are found to be associated with the national legislation of a country and the implementation of the legislation. These indicators are considered to have no association with LADM.

These results are not final, the evaluation may be revised taking into account the feedback given in the workshop, by reviews, and so on.

4. MONITORING THE INDICATORS THROUGH LADM

After the publication of LADM as an international ISO standard, it is developed to country profiles or really implemented by many countries, academics, companies, etc., see Lemmen et al. (2020). One of the approaches that can be followed to develop a LADM-based product or service is to create interface classes to LADM. Annex L of LADM Edition I indicates that interface classes can be considered as user-defined and outside the scope of LADM (ISO, 2012). Annex L of the LADM Edition I provides three examples of interface classes for party portfolio, spatial unit overview, and mapping spatial units (e.g., cadastral maps). It is expected that the LADM Edition II Part 2 Land registration will include some more interface class examples. Based on the examples used, six interface classes are developed to monitor indicators of LGAF and GLII. These interface classes are presented in this section.

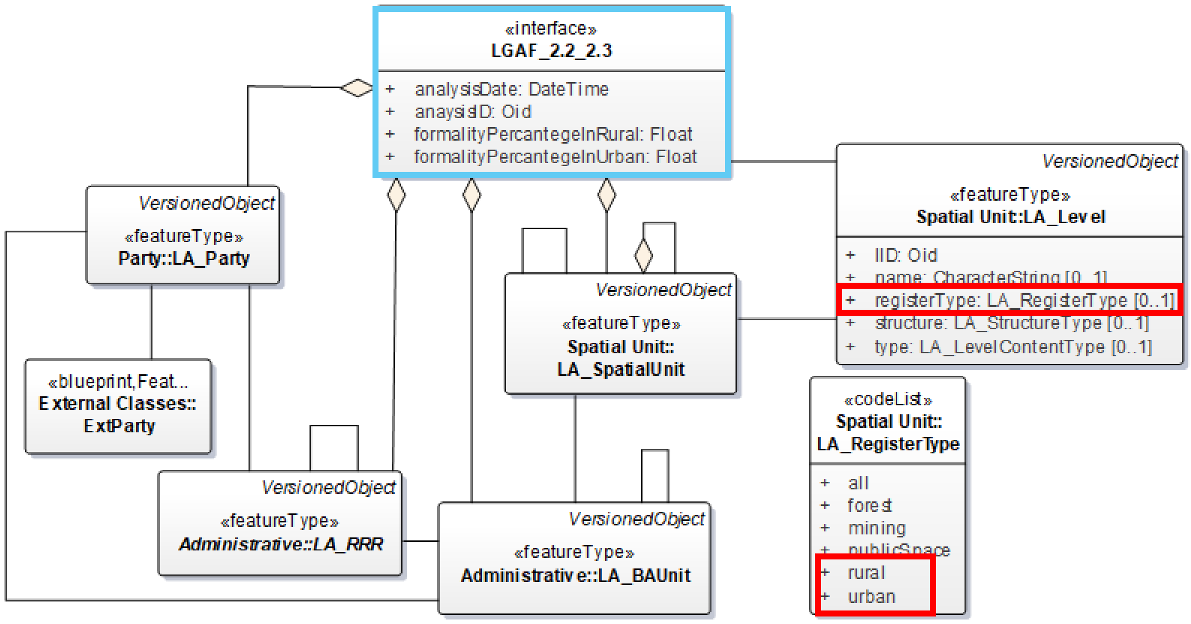

Figure 2. Monitoring LGAF dimensions 2.2 (formally registered land in rural) and 2.3 (formally registered land in urban) via LADM using the interface class approach

Figure 2 shows how LGAF dimensions 2.2 “*Individually held land in rural areas is formally registered*” and 2.3 “*Individually held land in urban areas is formally registered*” can be monitored through LADM using the interface class approach. These dimensions are aligned with ISO 19152-1 and ISO 19152-2. All of the interface classes in this section have analysisDate and analysisID attributes, since the assessment may change over time and a new analysis may be required, for example, every year or so. The registerType attribute of LA_Level can be used to specify whether the land is in an urban or rural area. Therefore, an association relationship is specified between LA_Level and the interface class. The information from LA_Party, LA_RRR, LABAUnit and LA_SpatialUnit is aggregated in the interface class 'LGAF_2.2_2.3' to calculate the formality percentage in rural and urban areas.
The importance of equal rights for women is underlined in several evaluation frameworks. The SDGs also have a few goals that can be related to LA. Chen et al. (2024) developed interface classes, operations and methods to support automatic calculation of the proportion of secure tenure rights (on land and agricultural land) by sex (see SDGs 1.4.2 and 5.a.1).

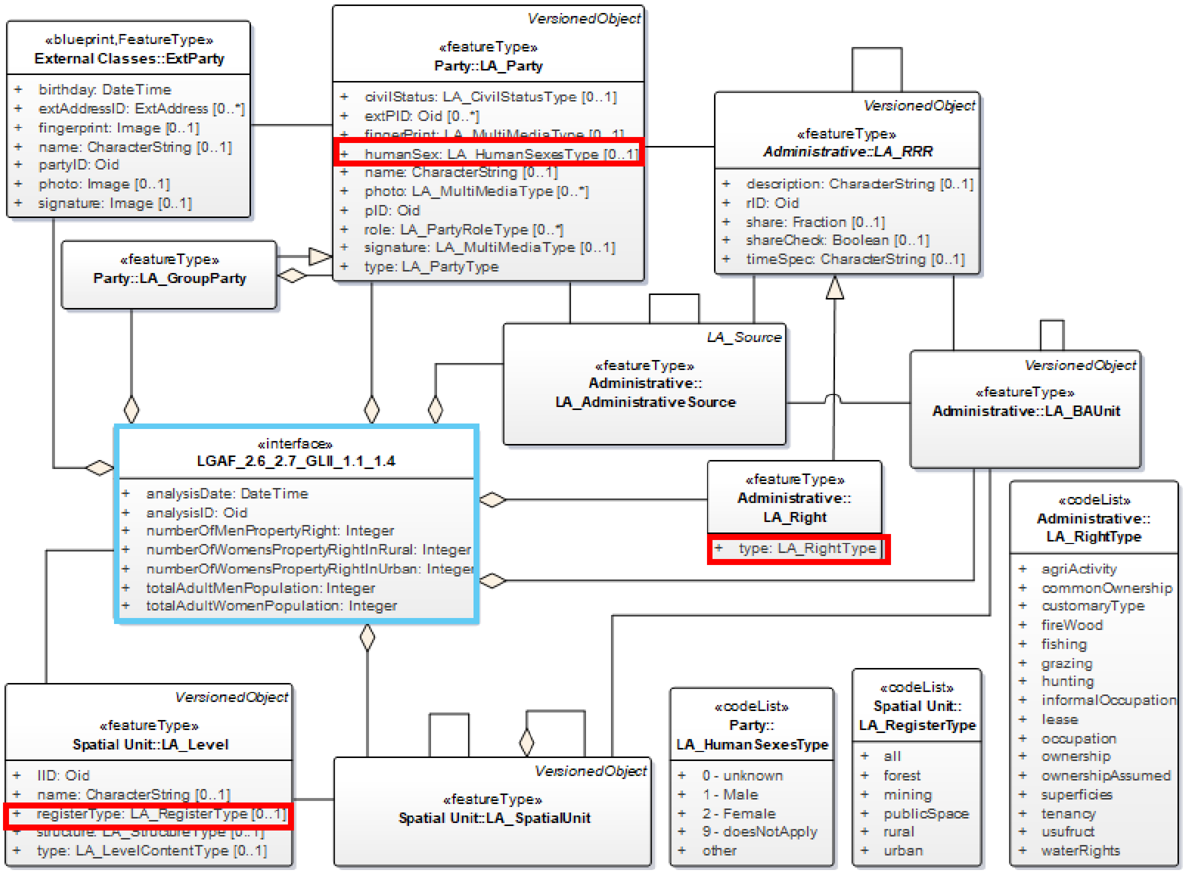

Figure 3. Monitoring LGAF dimensions 2.6 (women’s rights are registered), 2.7 (equal rights to women) and GLII indicators 1.1 (legally recognized documentation to land for women and men), 1.4 (equal rights to women) via LADM using the interface class approach

Figure 3 presents how LGAF dimensions 2.6 “*Women's rights are registered and recognized in practice in both urban and rural areas*” and 2.7 “*Women's property rights to land are equal to those by men*” as well as GLII indicators 1.1 “*Percentage of women and men with legally* *recognized documentation and evidence of secure rights to land*" and 1.4 "*Level to which women and men have equal rights to land, including rights to use, control, own, inherit and transact these rights*" can be monitored through LADM using the interface class approach. These dimensions and indicators are related to ISO 19152-1 and ISO 19152-2. It should be noted that the interface class developed in this paper shares similar attributes (e.g., total population) with the interface class developed in Chen et al. (2024). Similar to the previous interface class (see Figure 2), the interface class "LGAF_2.6_2.7_GLII_1.1_1.4" has an association relationship with LA_Level to specify whether the land is located in an urban or in rural area. Since human sex type (see Unger et al, 2023 for more information) is an important information to monitor these requirements LA_Party and ExtParty are aggregated into the interface class. In addition, information about the type of right and its source is obtained from the LA_Right and LA_AdministrativeSource classes. Lastly, LA_BAUnit and LA_SpatialUnit are aggregated into the interface class to include information about land. The attributes 'number of men's property right', 'number of women's property right in rural' and 'number of women's property right in urban' are added to the "LGAF_2.6_2.7_GLII_1.1_1.4" to monitor the above requirements. Furthermore, it is worth noting that GLII's indicator 1.5 "*Numbers and proportion of indigenous and community groups with land claims that have legally recognized documentation or evidence of secure rights, and percentage of land areas claimed and utilized that have been legally secured*" can also be partially monitored through this interface class, as LADM allows the representation of rights of indigenous and community groups with the LA_GroupParty and LA_Right classes.

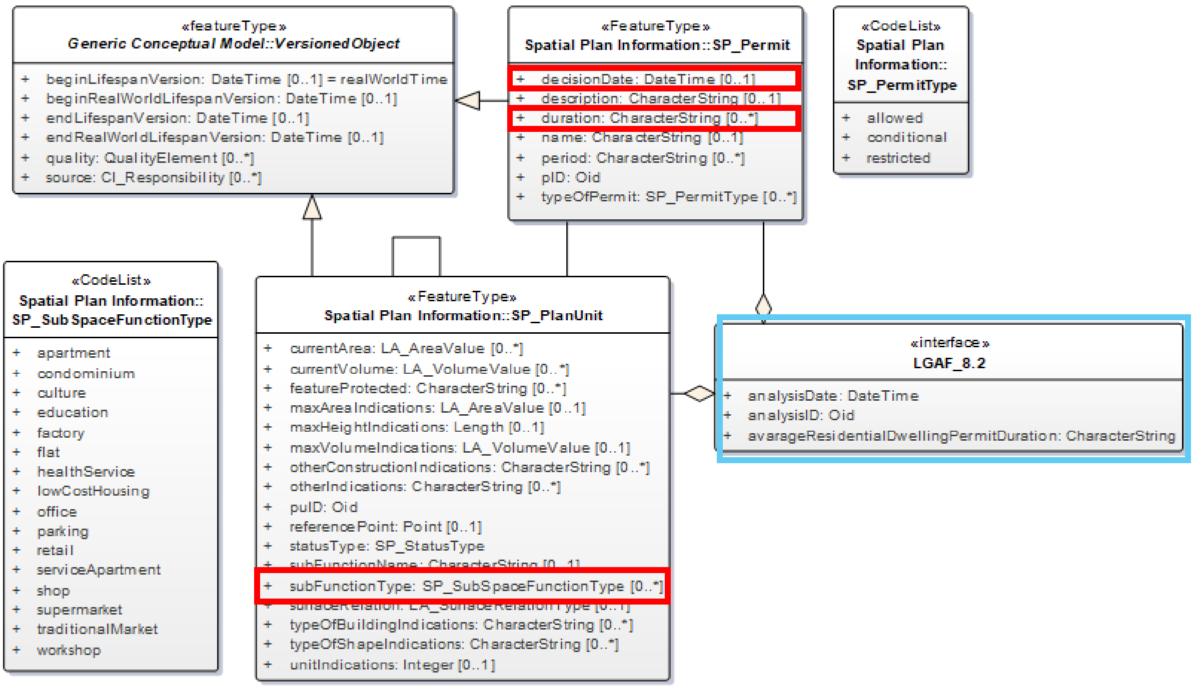

Figure 4. Monitoring LGAF dimension 8.2 (time required for building permit) via LADM using the interface class approach

Figure 4 shows how LGAF dimension 8.2 "*The time required to obtain a building permit for a residential dwelling is short*" can be monitored through LADM using the interface class approach. This dimension is related to ISO 19152-5. The permit duration and decision date of the permit attributes are included in the SP_Permit class, which is also related to the class VersionedObject, which includes real and database time. The LGAF_8.2 interface class has an aggregation relationship with LA_Permit. As this dimension is related to residential dwelling, an aggregation relationship is defined between "LGAF_8.2" and SP_PlanUnit. In order to calculate the average permit duration for residential dwellings, the "avarageResidentialDwellingPermitDuration" attribute is added to the "LGAF_8.2".

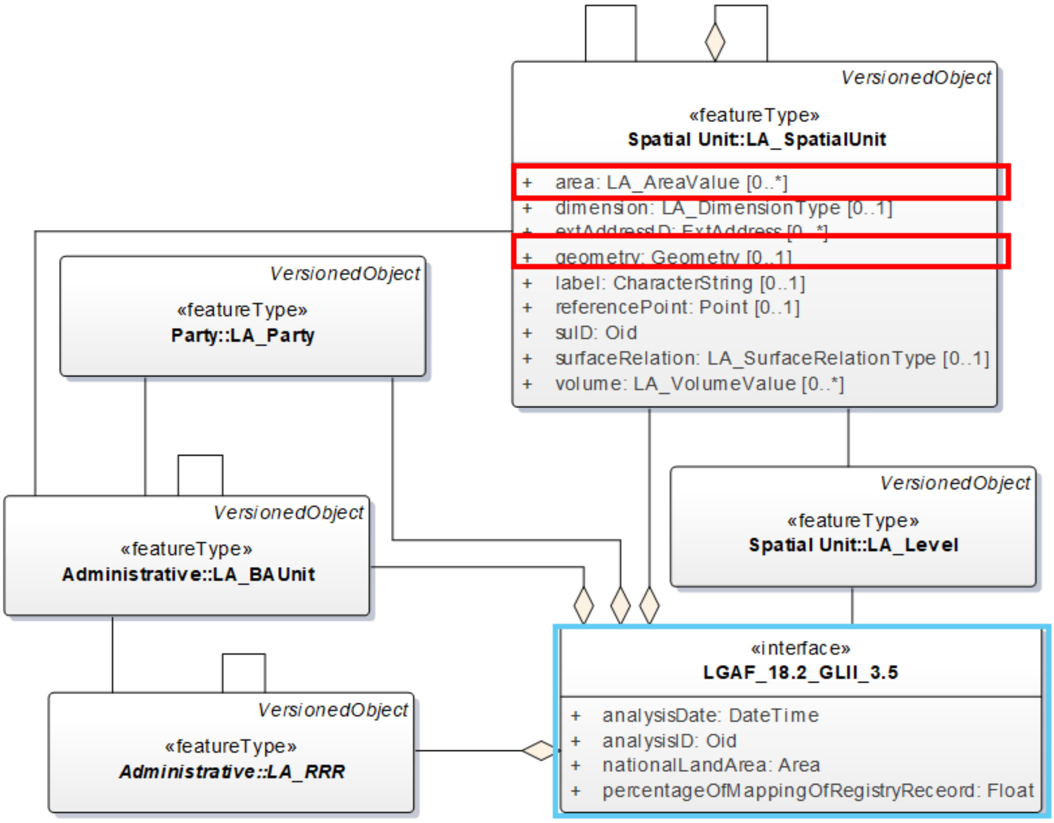

Figure 5. Monitoring LGAF dimension 18.2 (registry records is complete) and GLII indicator 3.5 (rights holders and tenure status are incorporated into cadastral maps) via LADM using the interface class approach

Figure 5 presents how the LGAF dimension 18.2 "*The mapping or charting of registry records is complete*" and the GLII's indicator 3.5 "*Proportion of national land areas with rights holders and tenure status identified that are incorporated into cadastral maps / land information systems*" can be monitored through support by LADM using the interface class approach. This dimension and indicator are related to ISO 19152-1 and ISO 19152-2. The "LGAF_18.2_GLII_3.5" interface class has aggregation relationships with LA_SpatialUnit (for total land area and cadastral maps), LA_Party (for right holders), LA_RRR and LA_BAUnit (for registry records). In addition, LA_Level is linked to the interface class to include all registries into the analysis. The "LGAF_18.2_GLII_3.5" has total "nationalLandArea" and "percentageOfMappingOfRegistryReceord" attributes to monitor the above dimension and indicator.

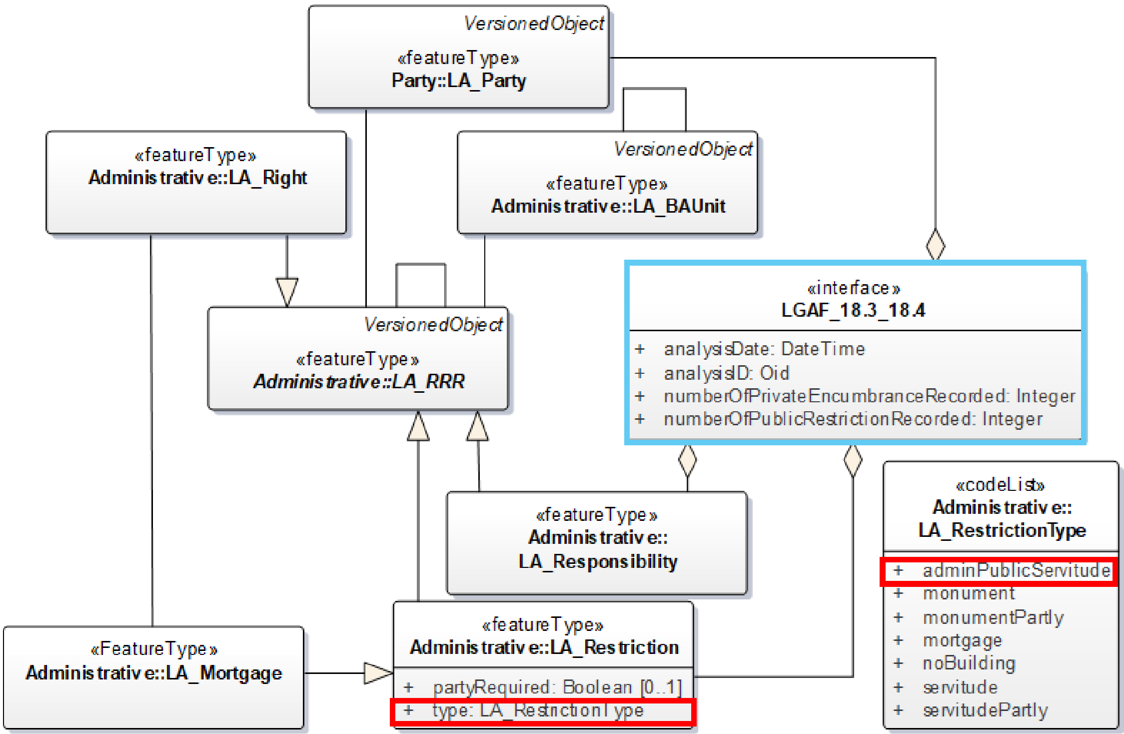

Figure 6. Monitoring LGAF dimensions 18.3 (private encumbrances are recorded) and 18.4 (public restrictions are recorded) via LADM using the interface class approach

Figure 6 shows how the LGAF dimensions 18.3 "*Economically relevant private encumbrances are recorded*" and 18.4 "*Socially and economically relevant public restrictions or charges are recorded*" can be monitored through support by LADM using the interface class approach. This dimension and indicator are related to ISO 19152-1 and ISO 19152-2. "LGAF_18.3_18.4" interface class has aggregation relationships with LA_Party, LA_Responsibility and LA_Restriction to collect all the information to calculate "numberOfPrivateEncumbranceRecorded" and "numberOfPublicRestrictionRecorded".

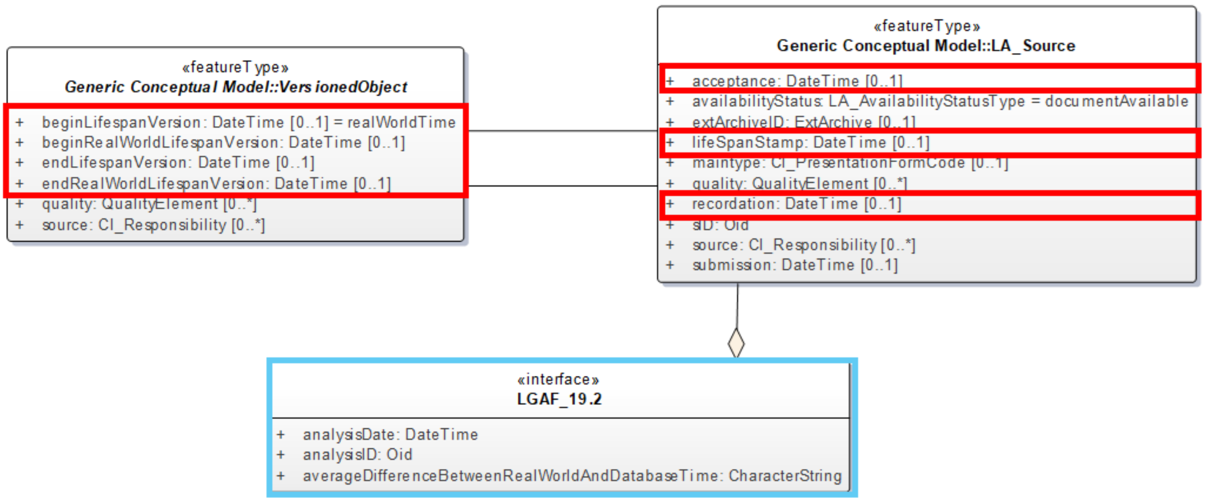

Figure 7. Monitoring LGAF dimension 19.2 (Registry/cadastre information is up-to-date) via LADM using the interface class approach

Figure 7 presents how the LGAF dimension 19.2 “*Registry/cadastre information is up-to-date*” can be monitored through LADM using the interface class approach. “LGAF_19.2” interface class has an aggregation relationship with LA_Source to monitor/search whether registry/cadastre information is up to date via comparing date of source data (LA_Source, VersionedObject) and registration date (real world time, database time, etc).

5. CONCLUSION

This study examines LGAF and GLII indicators considering the conceptual models of LADM Edition II in terms of whether LADM can enable to monitor the performance of LASs through interface class approach using LGAF and GLII frameworks. The findings show that the LADM can be used to monitor a significant portion of the LGAF and GLII indicators, although most of the indicators are related to national legislation, its implementation, and organizational decisions and capacity. A country, for example, may develop a country profile for land disputes based on LADM and effectively manage the disputes. However, indicators related to land disputes are not considered monitorable with LADM Edition II in this paper, as they are not conceptually modeled in LADM. In other words, the evaluation of indicators with LADM depends on many situations (e.g. country implementation, data accuracy, timeliness, etc.). On the other hand, LADM can make it easy to monitor the performance of LA through the indicator. It should be noted that the number of countries reporting to LGAF and GLII is relatively limited. The number of reporting countries should be improved and LADM indicator modeling can facilitate this. Some of the examples in this paper could be added to Annex I (Interface Class) of ISO 19152-2.

Figure 8. LGAF and GLII country reports (Source: World Bank, 2024; GLTN, 2024)

In this paper, interface classes are designed only for LGAF and GLII indicators that have full computational association with LADM. It is also possible to design interface classes for partial computational association and indirect association. Furthermore, it should be noted that the classification of LGAF and GLII indicators still can be changed/revised considering the feedback given in the workshop and so on. In addition, operations and methods can be specified to track the performance of LASs based on the indicators in an automated and formalized manner. Finally, the approach used in this study can be extended in the future with FELA, VGGT and related literature (e.g., Steudler et al., 2004; Dawidowicz and Źróbek, 2018; Chehrehbargh et al., 2024).

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BIOGRAPHICAL NOTES

Abdullah Kara holds a Ph.D. degree (2021) from Yıldız Technical University (YTU) with a thesis on the extension of the Land Administration Domain Model (LADM) with valuation information, which is used as a basis for the development of LADM Part 4 - Valuation information. He worked as a post-doctoral researcher (2021-2024) at the GIS Technology Section, Delft University of Technology. He works as an assistant professor at Gebze Technical University starting from 2024. He has been actively involved in FIG working groups.

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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 database. Since 2000, he is Professor at Delft University of Technology, and head of the 'GIS Technology' Section, 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 LA/LADM' and co-editor of the International Standard for Land Administration Domain, ISO 19152.

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APPENDIX

Table 1. LGAF indicators and their relationships with LADM

Land Governance Indicator	LGAF Dimension	LADM
Land Tenure Recognition		
1. Recognition of a continuum of rights	Individual rural land tenure rights are legally recognized. Customary tenure rights are legally recognized. Indigenous rights to land and natural resources are legally recognized and protected in practice, where relevant according to international treaties. Urban land tenure rights are legally recognized.	This dimension is related to the national legislation of a country and to the implementation of the legislation. LADM supports representing individual tenure rights in rural and urban areas (see LA_Party, LA_RRR, LA_SpatialUnit and LA_Level) as well as customary, informal and Indigenous rights (see also Social Tenure Domain Model (STDM), specialization of LADM) in Annex I of (ISO, 2012) and Annex B in part 2 of edition 2. The result of national legislation may end up in the LA_RightType code list, and by inspecting the code list values and their actual occurrences in the LA_Right records, these dimensions can be assessed.
2. Respect for and enforcement of rights	Accessible opportunities for tenure individualization exist.	A LADM based LAS can enable analyses to check whether tenure individualization exists. Information from different registries (e.g., population, company etc.) can be required to make such analysis.
	Individually held land in rural areas is formally registered. Individually held land in urban areas is formally registered.	A LADM based LAS can be used to monitor these dimensions with LA_Party, LA_SpatialUnit, LA_BAUnit and LA_Level, see Section 4.
	The number of illegal land sales is low. The number of illegal lease transactions is low.	A LADM based LAS can provide total number of transactions, but extra information is required to monitor these dimensions.
	Women's rights are registered and recognized in practice in both urban and rural areas. Women's property rights to land are equal to those by men.	A LADM based LAS can keep track of these dimensions, see Section 4 (LA_Level, LA_Party).
Rights To Forest and Common Lands & Rural Land Use Regulations		
3. Rights to forest and common lands	Rural group rights are formally recognized. Even where ownership is with the state, arrangements to ensure users' rights to key natural resources (incl. fisheries) on land are legally recognized and protected in practice.	This dimension is related to the national legislation of a country and to the implementation of the legislation. The result of national legislation may end up in the LA_RightType code list, and by inspecting the code list values and their actual occurrences in the LA_Right records, these dimensions can be assessed.
	Multiple rights over the same common land and natural resources on these lands can legally coexist.	This dimension is related to the national legislation of a country and to the implementation of the legislation. LADM does support monitoring of this, so by

		checking the actual data, one can see whether or not these types of rights are actually occurring.
	Most communal and/or indigenous land is mapped (demarcated and surveyed) and rights are registered.	A LADM (or STDM) based LAS can help to check how many land parcels are mapped, which rights on that parcel are registered, and who owns the right. Information from different registries (e.g., population etc.) can be required to make such analysis.
4. Transparency of land use rezoning in rural areas	Restrictions regarding rural land ownership are justified.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	Restrictions regarding rural land transferability are justified	
	Rural land use plans and changes in these plans (incl. rezoning) are based on public input and burden sharing.	These dimensions are related to the national legislation of a country and to the implementation of the legislation. With ISO 19152-5 Spatial plan information and related source documents this information could be analyzed.
	Rural land use changes to the assigned land use in a timely manner. use plans/rezoning for specific rural land classes (forest, pastures, wetlands, national parks etc.) are in line with actual use	
	There is a clear public process for rezoning of land use classes that result in changes regarding to environmental protection.	
	Use plans for specific rural land classes (forest, pastures, wetlands, national parks etc.) are in line with actual use.	ISO 19152-5 Spatial plan information is capable of representing land use types originated from zoning plans. Land use types in zoning plans (ISO 19152-5) and cadastral maps (ISO 19152-2) can be overlaid and the result map can be used to check differences. However, land use maps are required for actual use. Therefore, information from ISO 19144-3 Land Use Meta Language (LUML) is required (or other land use standards)
Urban Land Use, Planning, and Development		
5. Restrictions on rights: land rights are not conditional on adherence to unrealistic standards	Restrictions regarding urban land ownership and transferability are justified.	This dimension is related to the national legislation of a country and to the implementation of the legislation.
	Restrictions regarding urban land use are justified and enforced (including risk prone and protected areas).	This dimension can be partially monitored by reviewing the source documents behind spatial plans (from national to local level).
6. Transparency of land use restrictions	There is a clear decision making process for expansion of urban land and associated land use change that respects existing rights and information on change is publicly available.	These dimensions are related to the national legislation of a country and to the implementation of the legislation. Note that ISO 19152-5 Spatial plan information is capable of representing land use types originated from zoning plans. Land use types can be obtained from ISO 19144-3 Land Use Meta Language.
	In urban areas, land use plans and changes in these plans are based on public input.	
	Urban land use changes to the assigned land use in a timely manner.	
7. Efficiency in	A policy is in place and progress is being made	These dimensions are related to the

the urban land use planning process	to ensure delivery of low-cost housing and associated services to those in need.	national legislation of a country and to the implementation of the legislation. If all land use plans are represented as proposed in LADM Part 5 then spatial expansion can be traced by means of temporal characteristics of LADM. Using LADM Part 5 one could check how often plans are updated/replaced and inspect related source documents to analyze the efficiency.
	Land use planning effectively controls urban spatial expansion in the largest city in the country.	
	Land use planning effectively controls urban development in the four largest cities in the country, excluding the largest city.	
	Planning processes are able to cope with urban growth.	
8. Speed and predictability of enforcement of restricted land uses	Applications for building permits for residential dwellings are affordable and effectively processed.	This dimension is related to the national regulations and pricing. The process time of building permit applications can be calculated via SP_Permit and source document.
	The time required to obtain a building permit for a residential dwelling is short.	A LADM based LAS can keep track of this dimension with SP_Permit and VersionedObject classes, see Section 4.
9. Tenure regularization schemes in urban areas	Formalization of urban residential housing is feasible and affordable.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	In cities with high levels of informal tenure, a clear, well-documented process to address tenure security, infrastructure and housing, exists.	
	A condominium regime provides for appropriate management of common property (rules for common property for management of driveways, parking, gardens, stairways, etc.)	Using ISO 19152-2, one can inspect the actual right types, specific for urban areas, e.g. apartment right.
Public Land Management		
10. Identification of public land and clear management	Public land ownership is justified and managed at the appropriate level of government.	These dimensions are related to the national legislation of a country, to the implementation of the legislation. Note that a LADM based LAS can keep track of this dimension (if all public land is recorded) with LA_Party, LA_BAUnit and LA_SpatialUnit.
	There is a complete recording of publicly held land.	
	The inventory of public land is accessible to the public.	
	The management responsibility for public land is unambiguously assigned.	
	Sufficient resources are available to fulfill land management responsibilities.	
	The key information on public land allocations to private interests is accessible to the public.	LADM can be able to check if the associated parties are public organizations (e.g., government).
11. Justification and time-efficiency of expropriation processes	There is minimal transfer of expropriated land to private interests.	Expropriation can be recorded as a source in LA_Source but since it is not explicitly modelled in LADM these dimensions are not considered as monitorable by LADM. By analyzing source documents, the number of transfer amount from expropriated land to private interests and elapsed time for destined use can be detected. See (12).
	Expropriated land is transferred to destined use in a timely manner.	
12. Transparency and fairness of expropriation procedures	Compensation is paid for the expropriation of all rights regardless of the registration status.	LADM can be extended with a country profile to cover expropriation information (e.g., compensation, appeal, etc.). Source document related to expropriation is recorded in LADM
	There is compensation for loss of rights due to land use changes.	
	Expropriated owners are compensated promptly.	

	There are independent and accessible avenues for appeal against expropriation.	
	Timely decisions are made regarding complaints about expropriation.	
13. Transparent process and economic benefit	Public land transactions are conducted in an open transparent manner.	These dimensions relate to a country's national legislation and its implementation. LADM content could be (partially) public to demonstrate transparency and fairness of procedures. If made public, the LADM content can be served, analyzed or visualized.
	Payments for public leases are collected.	
	Public land is leased and/or sold at market prices.	The leased and sold land public lands and their prices can be represented with LADM (LA_Party, LA_BAUnit, VM_TransactionPrice and VM_Valuation), however expert opinion may be required to detect whether land is sold/leased at market price.
	The public captures benefits arising from changes in permitted land use.	A LADM based LAS can enable detection of changes in permitted land use through Part 5 (SP_PlanUnit), Part 2 (LA_BAUnit, LA_SpatialUnit) and their values with Part 4 (VM_Valuation). However, extra information and analyses are required to monitor these dimensions.
Transfer of Large Tracts of Land to Private Investors		
14. Private investment strategy	Policy and regulations are in place to unambiguously and publicly identify public/ communal land that can be made available to investors, in agreement with legitimate land rights holders.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	A policy process is in place to identify and select economically, environmentally, and socially beneficial investments and implement these effectively.	
	Public institutions involved in transfer of large tracts of land to private investors are clearly identified; without institutional and administrative overlap.	
	Public institutions involved in transfer of large tracts of land to private investors share land information and effective inter-ministerial coordination mechanisms are in place to timely identify and solve competing land use assignment (incl. sub-soil).	
	Investors' compliance with business plans is regularly monitored and remedial action is taken if needed.	
	Safeguards are established and applied to prevent that investments involving large tracts of land infringe on or extinguish existing legitimate tenure rights.	
	Cases where resettlement is possible are clearly circumscribed and procedures to carry it out are in place.	LADM could help providing information to analyze this dimension.

15. Policy implementation is effective consistent and transparent and involves local stakeholders	Sufficient information is required from investors for government to assess the cost-benefits of the proposed investments.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	A clearly identified process is in place for approval of investment plans and the time required is reasonable and adhered to.	
	There are free, direct and transparent negotiations between right holders and investors; legitimate rights holders have always access to information.	
	Contractual provisions are publicly available and include benefit sharing mechanisms with legitimate right holders.	
16. Contracts are made public, and agreements are monitored and enforced	Accurate information on spatial extent and duration of approved concessions is publicly available so as to minimize overlap and facilitate transfers.	LADM could help providing information on the spatial extent to analyze this dimension.
	Compliance with safeguards is monitored and enforced effectively.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	Avenues exist for legitimate right holders to air complaints if investors do not meet contractual obligations and decisions are timely and fair.	
Public Provision of Land Information: Registry and Cadastre		
17. Mechanisms for recognition of rights	There is an efficient and transparent process to formalize possession that is in line with local practice and understanding).	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	Non-documentary evidence is effectively used to help establish rights.	
	Long-term unchallenged possession is formally recognized.	
	First-time registration on demand includes proper safeguards and access is not restricted by high formal fees.	
	First-time registration does not entail significant informal fees.	LADM content could support this (transparency), what is actually disclosed is a national decision.
18. Completeness of the land registry	The cost of registering a property transfer is low.	This dimension is related to the national legislation of a country.
	The mapping or charting of registry records is complete.	A LADM based LAS can support checking whether the mapping of registry records is complete via LA_SpatialUnit, LA_BAUnit, LA_RRR and LA_Level, see Section 4.
	Economically relevant private encumbrances are recorded.	A LADM based LAS enables recording private encumbrances via LA_RRR and LA_Party, see Section 4.
	Socially and economically relevant public restrictions or charges are recorded.	It is possible to record public restrictions in LADM via LA_RRR, see ISO 19152-2 Annex E for details.
	There is a timely response to requests for accessing registry records.	Depending on the Land Registry and Cadastre regulations and their implementation, it may change.
	The registry is searchable.	A LADM based LAS enables all kind of

		search (e.g., geometrical, temporal, textual and so no)
	Records in the registry are easily accessed.	Depending on the land registry and cadastre regulations and their implementation, it may change.
19. Reliability: registry information is updated and sufficient to make meaningful inferences on ownership	Information regarding land rights maintained in different registries is routinely synchronized so as to reduce transaction cost for users and ensure integrity of information.	Depending on the land registry and cadastre regulations and their implementation, it may change.
	Registry/cadastre information is up-to-date.	A LADM based LAS can enable to search whether registry/cadastre information is up to date via comparing date of source data (LA_Source, VersionedObject) and registration date (real world time, database time, etc). Informal transactions can't be traced.
20. Cost-effectiveness and sustainability	The registry is financially sustainable through fee collection.	It depends on the financial regulation of national land registry and cadastre.
	Investment is sufficient cope with demand and provide high quality services.	
21. Fees are determined transparently to cover the cost of service provision	The schedule of fees is publicly accessible.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	Informal payments are discouraged.	
	Service standards are published and monitored.	
Land Valuation and Taxation		
22. Transparency of valuations	There is a clear process of property valuation.	A LADM based LAS enables to record all input and output data used and produced in valuation processes, see ISO 19152-4 Valuation information. However, this dimension is related to the national legislation of a country and to the implementation of the legislation.
	Valuation rolls are publicly accessible.	This dimension is related to the national legislation of a country and to the implementation of the legislation.
23. Collection efficiency	Exemptions from property taxes are justified and transparent.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	Property holders liable to pay property tax are listed on the tax roll.	
	Assessed property taxes are collected.	
	Receipts from property taxes exceed the cost of collection.	
Dispute Resolution		
24. Assignment of responsibility	There is clear assignment of responsibility for conflict resolution.	These dimensions are related to the national legislation of a country and to the implementation of the legislation.
	Conflict resolution mechanisms are accessible to the public.	
	Decisions made by informal or community based dispute resolution systems are recognized.	
	There is a process for appealing dispute rulings.	
25. The share	Land disputes constitute a small proportion of	These dimensions are related to the

of land affected by pending conflicts is low and decreasing	cases in the formal legal system.	national legislation of a country and to the implementation of the legislation.
	Conflicts in the formal system are resolved in a timely manner.	
	There are few long-standing land conflicts (greater than 5 years).	
Review of Institutional Arrangements and Policies		
26. Clarity of mandates and practice	Policy formulation, implementation, and arbitration are properly separated.	These dimensions are related to the national legislation of a country and to the implementation of the legislation. Also, organizational structure affects the evaluation of these dimensions.
	The responsibilities of the ministries and agencies dealing with land do not overlap (horizontal overlap).	
	Administrative (vertical) overlap is avoided.	
	Information on land ownership and use is shared among responsible institutions and relevant parts are freely accessible to the public.	
	Overlaps of rights (based on tenure typology) are minimial and do not cause friction.	
	Ambiguety in institutional mandates (based on institutional map) does not cause problems.	
27. Equity and non-discrimination in the decision-making process	Land policies and regulations exist and are developed in a participatory manner.	These dimensions are related to the national legislation of a country and to the implementation of the legislation. Also, organizational structure affects the evaluation of these dimensions.
	There is meaningful incorporation and monitoring of equity goals in land policy.	
	The implementation of land policy is costed, matched with benefits and adequately resourced.	
	There is regular and public reporting indicating progress in policy implementation.	

Table 2. GLII indicators and their relationships with LADM

GLII Indicator		**LADM**
Tenure Security		
Indicator 1.1 Documented land rights	Percentage of women and men with legally recognized documentation and evidence of secure rights to land.	A LADM based LAS enable to specify this indicator using LA_Party, LA_RRR, LA_Source,
Indicator 1.2 Perceived tenure security	Percentage of women and men who perceive that their rights to land are protected against dispossession or eviction.	This indicator is related to the evaluation of right holders.
Indicator 1.3 Tenure security under a plurality of tenure regimes	Level of legal recognition and protection of land rights and uses derived through either statutory or customary regimes	This dimension is related to the national legislation of a country and to the implementation of the legislation. LADM supports representing individual tenure rights in rural and urban areas (see LA_Party, LA_RRR, LA_SpatialUnit and LA_Level) as well as customary, informal and Indigenous rights (see also Social Tenure Domain Model (STDM) (Annex I in Edition 1, Annex B in part 2 of Edition 2), specialization of LADM). Historical source document and current status of land right can be recorded in different levels (LA_Level) in LADM.
Indicator 1.4 Equal rights of women	Level to which women and men have equal rights to land, including rights to use, control, own, inherit and transact these rights	A LADM based LAS can keep track of this dimension, see Section 4 (LA_Level, LA_Party).

Indicator 1.5 Indigenous land rights	Numbers and proportion of indigenous and community groups with land claims that have legally recognized documentation or evidence of secure rights, and percentage of land areas claimed and utilized that have been legally secured.	A LADM based LAS can partially keep track of this dimension, see Section 4 (LA_Party, LA_GroupParty, LA_Source, LA_BAUnit, LA_SpatialUnit).
Land Disputes and Land Conflicts		
Indicator 2.1 Frequency of land disputes and conflicts	Percentage of women and men, Indigenous Peoples and local communities who have experienced land, housing or property disputes or conflicts of different types in the past X years	A LADM based LAS may support the calculations for this indicator. For example, both historic ownership (Level 1), current ownership (Level 2) can be stored in LADM
Indicator 2.2 Availability of dispute-resolution mechanisms	Percentage of women and men, indigenous and local communities that have access to effective dispute resolution mechanisms	This indicator is related to the national legislation of a country and to the implementation of the legislation.
Indicator 2.3 Land dispute-resolution effectiveness	Percentage of women and men, indigenous and local communities who reported a conflict or dispute in the past X years that have had the conflict or dispute resolved.	This indicator is related to the national legislation of a country and to the implementation of the legislation.
Land Administration Services		
Indicator 3.1 Land administration efficiency	Range of times and costs to conduct land transactions	This indicator is related to the national legislation of a country and to the implementation of the legislation.
Indicator 3.2 Transparency of land information	Level to which land information is available for public access	This indicator is related to the national legislation of a country and to the implementation of the legislation.
Indicator 3.3 Land administration availability	Level to which all users, including women and vulnerable groups, have equal access to land administration services	This indicator is related to the national legislation of a country and to the implementation of the legislation.
Indicator 3.4 Mobilization of land-based taxes	Government tax derived from land-based sources as a percentage of total government revenue.	This indicator is related to the national legislation of a country and to the implementation of the legislation. LADM can support taxation via providing information on land (LA_SpatialUnit, LA_BAUnit) and their values (VM_Valuation).
Indicator 3.5 Land area mapped	Proportion of national land areas with rights holders and tenure status identified that are incorporated into cadastral maps / land information systems.	A LADM based LAS enables the calculation the proportion defined in this indicator using LA_Party, LA_SpatialUnit and total national land area.
Sustainable Land Use		
Indicator 4.1 Aggregate national changes in land-use sustainability	Changes in the geographical extent of sustainable land use, measured by: i) land cover/land use change; ii) land productivity change; and iii) soil organic carbon change.	This indicator is related to the national legislation of a country and to the implementation of the legislation. If LADM Part 5 is fully implemented, then changes in planned land use can be specified.
Indicator 4.2 Progress in sustainable land-use planning	Proportions of rural and urban administrative districts or units in which land-use change and land development are governed by sustainable land-use plans that take account of the rights and interests of the local land users and landowners.	LADM part 5 could be used to analyze the actual registered plans (and the dates)

The Conceptual Framework for Implementing eLAS Towards Sustainable Land Administration: Systematic Literature Review

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Key words: electronic Land Administration System (eLAS), Systematic Literature Review (SLR), conceptual framework, sustainable land administration, Sustainable Development Goals (SDGs)

SUMMARY

In the quest for more efficient, transparent, and equitable land management, electronic Land Administration Systems (eLAS) have emerged as a transformative tool, offering the potential to revolutionize traditional land governance processes. However, the successful implementation of eLAS extends beyond technological innovation; it requires a nuanced understanding of the socio-technical landscape and the ability to navigate complex challenges such as institutional readiness, governance frameworks, and stakeholder engagement. This study embarks on a Systematic Literature Review (SLR) in Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to consolidate fragmented research on eLAS, with the aim of developing a robust conceptual framework that can guide its implementation towards sustainable land administration. By critically analyzing a diverse body of literature of academic articles, the study identifies key factors that influence the adoption and scalability of eLAS. The study delves into various dimensions, including technological infrastructure, legal frameworks, capacity building, and stakeholder engagement, to construct a comprehensive conceptual framework that guides the implementation of eLAS. This framework not only addresses the challenges associated with the digitalization of land administration but also ensures that the deployment of eLAS contributes to sustainable outcomes—such as improved land tenure security, enhanced service delivery, and reduced corruption align with global Sustainable Development Goals (SDGs). By integrating sustainability principles into the digital transformation of land administration, the study offers valuable insights for policymakers, practitioners, and researchers aiming to leverage eLAS for broader development goals. Ultimately, this research bridges the gap between theory and practice, providing a roadmap for the effective and sustainable implementation of eLAS, thus supporting the evolution of land administration systems towards greater equity, transparency, and efficiency.

The Conceptual Framework for Implementing eLAS Towards Sustainable Land Administration: Systematic Literature Review

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1. INTRODUCTION

The rapid digital transformation of global economies has profoundly impacted various sectors, including land administration, which is foundational to economic development, social equity, and environmental sustainability. Traditional land administration systems, often characterized by manual, paper-based processes, have struggled to keep pace with the growing complexity and demands of modern governance (Heriz, H., & Boubakeur, Y. 2022). These systems frequently suffer from inefficiencies, corruption, lack of transparency, and slow service delivery, contributing to land tenure insecurity and inequitable access to land resources (Adesola, B. A. 2024). The advent of electronic Land Administration Systems (eLAS) offers a significant opportunity to overcome these challenges by leveraging digital technologies to streamline processes, enhance data accuracy, and improve overall governance (Idris, K. A. 2024). However, the transition to eLAS is not merely a technical upgrade; it is a complex socio-technical endeavor that requires careful planning, integration, and management to ensure it supports sustainable land administration.

An eLAS is a digital platform that manages land-related data, records, and transactions. It facilitates the secure and efficient processing, storage, and retrieval of land information, supporting functions such as land registration, ownership transfers and cadastral mapping (Williamson, I. et al. 2010). Its a tool that can be used to enhances efficiency, transparency, and accessibility in land governance, reducing paperwork and minimizing the risk of errors or fraud. Implementing eLAS involves navigating a multitude of challenges that go beyond technological implementation. It requires rethinking and restructuring institutional frameworks, updating legal and policy environments, and ensuring that the necessary human and technical capacities are in place (Idris, K. A. 2024). Moreover, the success of eLAS depends on its ability to engage a broad range of stakeholders, including government agencies, private sector entities, civil society, and local communities. Without proper engagement and participation, there is a risk that the digital divide could widen, leaving vulnerable populations further marginalized (Ganason, A. 2022). Furthermore, the introduction of eLAS must be aligned with sustainability principles to ensure that it not only improves efficiency but also promotes transparency, equity, and long-term stewardship of land resources (Azadi, H. et al. 2023).

2. LAND ADMINISTRATION SYSTEM (LAS) FRAMEWORK

As reported by Chehrehbargh, F. J. et al. (2024), an efficient Land Administration System (LAS) plays a crucial role in achieving sustainable land administration by providing a structured framework for managing land resources effectively. eLAS are one of tools for advancing Land Administration Systems (LAS) by improving accessibility, efficiency, and transparency. Although eLAS are powerful tools for advancing LAS for archiving sustainable land administration, the implementation of eLAS toward sustainable land administration faces several issues and challenges such as data quality and integration, legal and policy framework, technical challenges and interoperability (Idris, K. A. 2024). Addressing these issues and challenges by having a framework to implement an eLAS is crucial for achieving a sustainable land administration.

Table 1. Frameworks recognize eLAS as a tool for archiving sustainable land administration

Frameworks	Overview
Fit-for-Purpose Land Administration (FFP-LA).	This framework emphasizes the need for land administration systems to be adaptable, affordable, and scalable. It promotes the use of technology to ensure that land administration is efficient and meets the needs of various stakeholders while supporting sustainable land management practices (Bridging, L. A. 2023).
Integrated Geospatial Information Framework (IGIF).	Developed by the United Nations Committee of Experts on Global Geospatial Information Management (UNGGIM), this framework provides guidance on integrating geospatial information into land administration systems, enhancing data accessibility and usability for sustainable development (Calzati, S., & van Loenen, B. 2023).
Land Governance Assessment Framework (LGAF).	While primarily an assessment tool, LGAF can guide the implementation of eLAS by identifying key governance issues and providing recommendations for integrating technology into land administration processes to enhance transparency and accountability (Mukhtarova, A. 2021).
Global Land Tool Network (GLTN).	This initiative promotes the use of innovative land tools, including eLAS, to improve land governance and administration. It focuses on developing tools that are inclusive and sustainable, ensuring that marginalized communities have access to land rights and information (Chigbu, U. E. & Antonio, D. 2020).
Digital Transformation Framework for Land Admin.	This framework outlines the steps and strategies for transitioning from traditional land administration systems to digital platforms, focusing on enhancing efficiency, accessibility, and sustainability in land management (Bennett, R. M. et al. 2024).
Open Data for Land Administration.	This framework promotes the use of open data principles in land administration, encouraging transparency and public access to land information through eLAS, which supports sustainable governance and community engagement (Okembo, C. et al. 2024)
Smart Land Administration (SLA).	This framework focuses on leveraging smart technologies, such as blockchain and artificial intelligence, in land administration systems to enhance efficiency, security, and sustainability in land management (Azadi, H. et. Al. 2023).

Table 1 above show several frameworks specifically noted on supporting the implementation of eLAS toward promoting sustainable land administration. These frameworks collectively support the implementation of eLAS that are efficient, transparent, and sustainable, ultimately contributing to better land governance and management practices. By leveraging these frameworks, countries can enhance their land administration systems, ensuring they are efficient, transparent, and capable of addressing contemporary challenges related to land management and sustainability.

3. METHODOLOGY

Systematic literature review (SLR) method were used to identify relevant research articles that focus on "Electronic Land Administration System". Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol is used to identify, select, and critically appraise research to answer a formulated research question (Moher, D. et al. 2010). With PRISMA protocol, the author can evaluate the validity and quality of existing work against a criterion to reveal weaknesses, inconsistencies, and contradictions (Moher, D. et al. 2010). We can test a specific hypothesis and develop new theories by summarizing, analyzing, and synthesizing a group of related literature. Hence, the researchers conducted a SLR to get the splendid article to answer the question for the research (Moher, D. et al. 2010). The literature review follows 4 distinctive steps which are also closely related to the main features of the PRISMA statement (Moher, D. et al. 2010). The steps are as follows:

- Planning the review that includes identifying key research area, direction and requirement.
- Identifying the inclusion and exclusion criteria.
- Screening and reviewing the articles.
- Data synthesis by investigating, summarizing and visualizing the extracted data.

3.1 Planning the Review

The first step in conducting SLR is a review protocol establishment. The review protocol started with the main research questions to support the steps mentioned above. Scopus, Spinger Link, World of Science (WoS) and IEEEXplore were used as the primary databases for keyword search as they are established, the largest globally used and well-known databases. Google Scholar is used as the secondary databases as its generality, open and free access database. Initially, ‘‘electronic land administration system" were used in the initial search and after the first round the adjustments were made in the search string. The search was not limited by the time frame, application areas, country or journal.

3.2 Study Specification

Inclusion and exclusion criteria are essential for an SLR. These criteria are needed to choose the most relevant papers for future analysis (Table 2). The present study is focused on digitalization by means of land administration system implied electronic system and, therefore, excluded articles containing various modernization or reformation of land administration system or land administration component or theoretical frameworks that are not supported or included by electronic system. Only journal and conference papers were included in the current SLR. Book chapters, notes, short surveys, letters, theses and editorials were not considered.

Table 2. Inclusion and exclusion criteria

Inclusion	Exclusion
Published in the year 2022 to 2024	Published before year 2022
English language	Other than English language
Journals & conference papers	Book, thesis, chapters, notes, letters, editorials, short surveys & proceeding
Contains data and information related to eLAS implementation (Method, Concept, Framework, Techology, etc.), issues, challenges and best practices.	Not containing data and information about eLAS implementation, theoretical without empirical data collection and only engineering aspects about eLAS. General literature review articles.

3.3 Data Selection

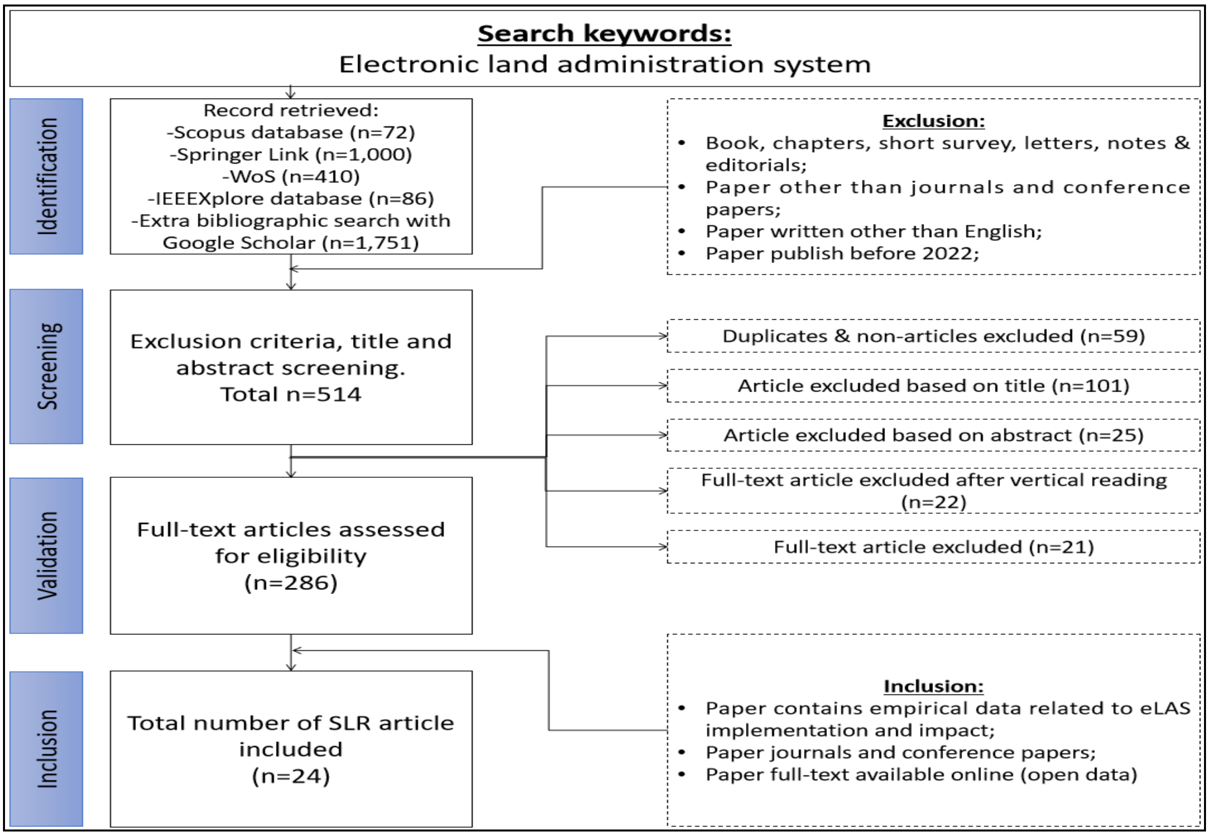

Figure 1. PRISMA protocol model used

The chosen keywords were transformed into a search string by adding Boolean operators such as ‘‘AND’’ and ‘‘OR’’. From the initial search, 72 articles were retrieved from the Scopus database, 1,000 articles from the Springer Link database, 410 articles from the WoS database and 86 from the IEEEXplore. Through the additional Google Scholar keyword search and snowball search in citation chaining, further 1,751 papers were found. There were no restrictions on the timeframe, but the sustainable land administration agenda has caught scholars’ attention mostly from 2022 following The Sustainable Development Goals (SDGs) adopted by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development (UN, 2015). Therefore, selected articles were published from 2022 to 2024 (recent). After that, the inclusion and exclusion criteria (Table 2) were applied, leaving 514 articles for further duplicates and non-articles removal, also titles, abstracts, content and keywords analysis. 59 articles are excluded because of duplication & non-articles, mostly from the Google scholar search engine. After reading the titles and abstracts, 169 articles were eliminated for being out of the research scope. After the full-text assessments, 286 articles were found to be within the research scope. Most research has been excluded due to the fact that its focused predominantly on the theoretical framework, only land administration framework and engineering aspects, comparative analysis of the existing eLAS platforms or its technical architecture and a general literature review on eLAS. After screening the inclusion aspect of the articles, only 24 articles were suitable and selected to be reviewed. The detailed process is shown in Figure 1 above.

3.4 Profile of the Selected Articles

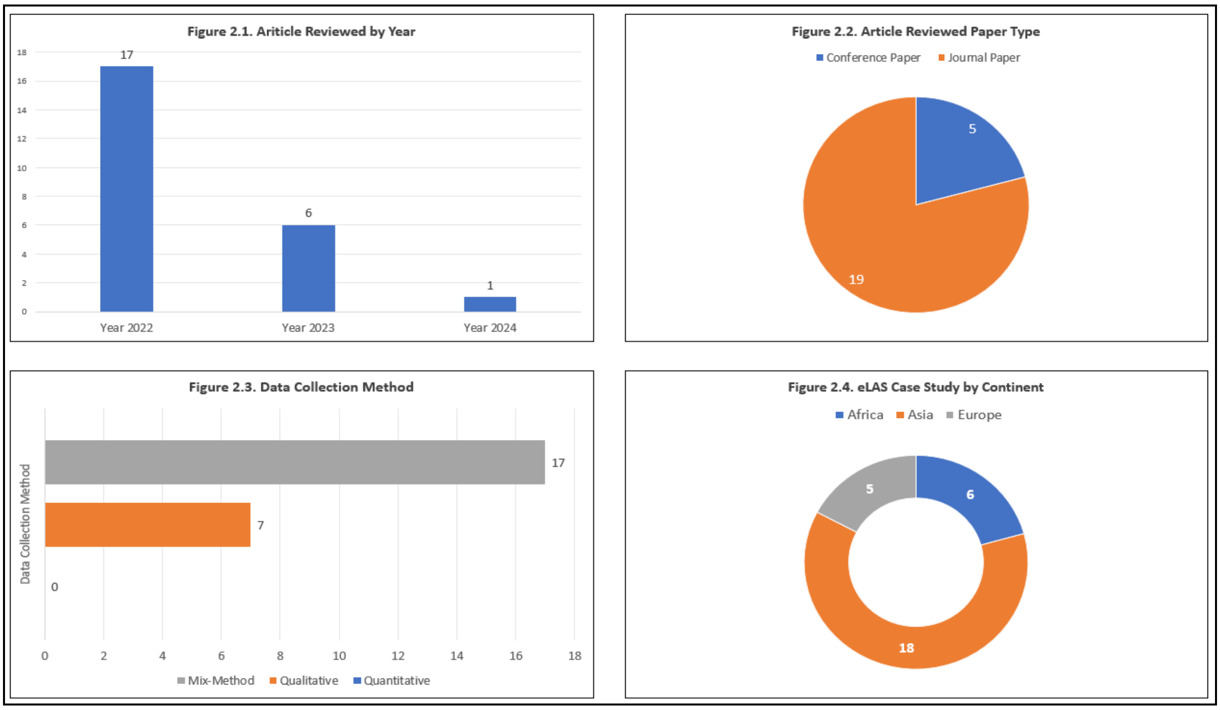

Figure 2. General Reviewed Article Profiling

The yearly publication analysis presented in figure 2.1 above reveals the growing academia's recent interest from 2022 and but the attention substantially decrease in 2023-2024. It is not a final explanation because 2024 is still 6 months away. Majority of the references (Figure 2.2) 79.17% a from journals and balance 20.83% is from conference papers. The methods of data collection in selected articles are interviews, case studies, observations, questionnaires and surveys. Majority are using Mix-Method data collection in 17 of article reviewed and balance 7, are using Qualitative Method in collecting data as figure 2.3. Highlighted also that Asia is the most continent research focus in eLAS (Figure 2.4) to illustrate the momentum of research are globally expend world-wide and direction of research on implementing eLAS toward sustainable land administration to support SDGs can be adopted generally. Nevertheless, eLAS potential is still being scrutinized, and other research has confirmed the eLAS applicability in various land administration functions specially in land tenure, registration and land use planning and also can respond to SDGs demand.

4. DATA ANALYSIS AND FINDINGS

To get the real data to be reviewed, the thematic analysis method is used to analyses the data. This method is a suitable method to sort the qualitative data, which can really help us in the research. The themes were defined and grouped by the two independent authors by grouping the findings based on their similarity or relevance to ensure the reliability of the current work. Not only that, the article also will be analyzed based on the research question to get the theme of the research. The research questions, which are being referred to:

- What are issues and challenges arise when implementing eLAS? (RQ1)
- What is the framework used to implement eLAS? (RQ2)
- How will using framework to implement eLAS help? (RQ3)

4.1 Findings

A total of 24 articles were chosen for the systematic analysis after being screened using the eligibility requirements. This study used three research questions to guide its review of the selected articles. All the paper were summarizes and compares the papers that were chosen, which included the inclusion criterion of a systematic review of the literature, eLAS implementation issues and challenges, framework to implement eLAS with technology and good governance practices, positive or negative impact using framework to implement eLAS and how the impact connect to implement eLAS toward sustainable land administration principles and supporting SDGs global agenda.

4.1.1 Issues and Challenges Implementing eLAS:

All of the reviewed articles raise about data integration, sharing, quality and integrity as a challenge in implementing eLAS. Second most raise issues and challenges is incompatible policies and legal framework and regulatory barriers to implement eLAS optimally. The third most raise issues and challenges is part of governance challenges such as agencies collaboration, system interoperability, stakeholder engagement, public awareness, process bureaucracy and infrastructure limitation. Top three most discusses issues and challenges on implementing eLAS can be refer to table 3 below.

Table 3. Top three issues and challenges implementing eLAS

Issues & Challenges	Number of articles discuss	Percentage (%)
Data	24	100
Policies & Legal Framework	18	75
Governance	17	71

Data quality and integration is a challenge to implement integrated eLAS with other system to improve decision-making processes. For example, the transition from 2D to 3D LAS requires effective integration of existing datasets from various registers, which can be complex and challenging (Tomic, H. et al. 2022). There are also concerns regarding the accuracy and reliability of existing land data, which can hinder the effectiveness of eLAS (Recetin, I. et al. 2022). Data inconsistencies can undermine the trustworthiness of the data. The lack of a standardized methodology for updating and exchanging data contributes to these issues (Bobikova, D. et al. 2022). Most the policies & legislative framework issues discus on harmonization of the legislation to electronic system, need for legislative amendment, regulatory compliance and legal and institutional barriers. These challenges arising from existing legal frameworks and institutional arrangements that may restrict data sharing practices (Hamamurad, Q. et al. 2022). In most country, they are separate stage of land law between federal, state, district and local government such as Malaysia with the National Land Code (NLC) of 1965 and various state laws contain clauses that may not align with the new electronic systems, creating legal and operational hurdles (Heriz, H., & Boubakeur, Y. 2022). Many of the governance issues and challenges arise about structural and organizational issues, inter-agencies collaboration, capacity limitations, bureaucracy, bribery and infrastructure limitation. The urban-rural dichotomy in land administration leads to bifurcated institutions for urban and rural lands, complicating the integration of eLAS across different governance levels (Azadi, H. et al. 2023).

4.1.2 A Framework to implement eLAS:

From this SLR study found that there is no formal specific framework to collaborate how to implement eLAS to archive sustainable land administration. Although there are establish framework for land administration system (LAS) that can be referred to table 1. There are also some eLAS implementation imitate this framework for guidance toward sustainable land administration. From this study, a concept of framework can be categories in two implementations of eLAS with technology-based and good governance-based. The concept of framework that found in this SLR study can be refer to table 4.

The choice of the best conceptual framework for implementing eLAS depends on various factors, including the specific needs, goals and context of the land administration project. The selection of the conceptual framework does not have to be of one type only, it can be combined in its implementation to get the best results based on the goals and projects. Like the study by Nwafor, I. V. et al. (2022), which combines a conceptual framework based on cadaster, LIS and GIS to examine the extent to which eLAS in Nigeria contributes towards the efficiency and effectiveness of service delivery, the challenges of its implementation and the factors considered to formulate improvements to the existing system.

Table 4. Conceptual Framework Implementing eLAS Categories

	Conceptual Framework	Brief Description	SLR Reference
Technology	SDI-Based	Emphasizes the organization, access and sharing of spatial data. Focus on standards, interoperability and development of spatial data infrastructure (SDI) to support land	(Adesola, B. A. 2024), (Hamamurad, Q. H. et al. 2022)

	Conceptual Framework	Brief Description	SLR Reference
		administration.	
	Land Information System (LIS)-Based	Focuses on the collection, storage, processing, and dissemination of land-related information. The concept hovers over data about land parcels, ownership, land use and other related information	(Nwafor, I. V. et al. 2022), (Akumuntu, A. 2022), (Ganason, A. 2022)
	GIS-Based	Uses spatial analysis and mapping tools to manage and analyze geographic data. Useful for integrating various layers of information related to land administration	(Rana, S. K. et al. 2022), (Nwafor, I. V. et al. 2022), (Tomic, H. et al. 2022)
	Blockchain-Based	Exploring the use of blockchain technology to secure and manage land-related transactions. Provide transparency and variability of land records	(Alam, K. M. et al. 2022), (Christine, H. et al. 2022)
	Web-based & Mobile	Emphasizes the development of mobile and web applications for user-friendly access to land information. Supports remote and remote access to land administration services	(Rana, S. K. et al. 2022), (Christine, H. et al. 2022), (Adesola, B. A. 2024), (Pilare, G. et al. 2022)
	Cloud-computing	Leveraging cloud-based infrastructure and services for storage, processing and access to land-related data. Offers scalability and accessibility advantages	(Tomic, H. et al. 2022), (Racetin, I. et al. 2022), (Akumuntu, A. 2022)
Governance	Cadaster-Based/ LADM	Focus around cadastral data, which includes information about land parcels, their boundaries and ownership rights. Usually used for registration and property management	(Rana, S. K. et al. 2022), (Nwafor, I. V. et al. 2022), (Adesola, B. A. 2024), (Abraham, A. G. 2023)
	Enterprise Design	Provides a comprehensive view of the organization, including its business processes, data, applications and technology. Ensure alignment between the land administration system and the overall organizational or business structure	(Racetin, I. et al. 2022), (Permadi, I. 2023), (Bieliatynskyi, A. et al. 2022), (Azadi, H. et al. 2023), (Heriz, H., & Boubakeur, Y. 2022)
	SOA	Service Oriented Architecture (SOA) is focuses on designing the land administration system as a set of interrelated services. Promote modularity, scalability and reusability of system components	(Akumuntu, A. 2022), (Ganason, A. 2022), (Azadi, H. et al. 2023), (Heriz, H., & Boubakeur, Y. 2022)
	Land Governance-Based	Combining legal, institutional and organizational aspects of land administration. Dealing with issues related to land	(Racetin, I. et al. 2022), (Akumuntu, A. 2022), (Permadi, I. 2023),

	Conceptual Framework	Brief Description	SLR Reference
		ownership, land rights and land use planning	(Ganason, A. 2022)
	Risk Management-Based	Focusing on identifying and mitigating risks associated with the implementation of the land administration system. Address issues related to data security, system reliability and legal compliance	(Adesola, B. A. 2024), (Sahni, U. et al. 2022), (Heriz, H., & Boubakeur, Y. 2022)

4.1.3 Expected Impact Toward Sustainable Land Administration Using Conceptual Framework Implementing eLAS:

From the literature review, it was found that all the conceptual frameworks have good characteristics in their application based on the purpose of their use. Implementing an eLAS using a structured framework can have several significant impacts, both positive and negative. Figure 3 below show some of the key impacts.

Positive Impacts

- **Improved Efficiency:** A well-defined framework can streamline land administration processes, reducing the time and resources required for tasks such as land registration, transfer, and management. This leads to faster service delivery for users (Tomic, H. et al. 2022).
- **Enhanced Transparency:** Implementing eLAS within a framework promotes transparency in land transactions and administration. Clear procedures and accessible information help reduce corruption and increase public trust in the system (Alam, K. M. et al. 2022).
- **Better Data Management:** A structured framework facilitates the organization and management of land-related data. This includes the integration of various data sources, leading to more accurate and reliable information for decision-making (Ganason, A. 2022).
- **Stakeholder Engagement:** A framework encourages the involvement of various stakeholders, including government agencies, local communities, and private sector actors. This collaborative approach ensures that the system meets the needs of all parties and fosters a sense of ownership (Sahni, U. et al. 2022).
- **Capacity Building:** Implementing eLAS within a framework often includes training and capacity-building initiatives for personnel involved in land administration. This enhances the skills and knowledge necessary for effective system operation (Permadi, I. 2023).
- **Adaptability and Scalability:** A structured framework allows for the adaptation of the eLAS to local contexts and the scalability of the system to accommodate future growth and changes in land administration needs (Christine, H. et al. 2022).

Negative Impacts

- **Implementation Challenges:** Establishing a framework can be complex and may face resistance from stakeholders who are accustomed to traditional land administration methods. This can lead to delays and complications during the transition (Bieliatynskyl, A. et al. 2022).
- **Resource Intensity:** Developing and implementing a comprehensive framework for eLAS may require significant financial and human resources, which can be a barrier for some regions, especially those with limited budgets (Nyangweso, D. O. & Gede, M. 2022).
- **Technological Dependence:** Relying heavily on technology can create vulnerabilities, particularly in regions with limited infrastructure or technical expertise. System failures or cyber threats can disrupt land administration processes (Bieliatynskyl, A. et al. 2022).
- **Data Privacy Concerns:** The collection and management of land-related data raise concerns about privacy and data security. A framework must address these issues to protect sensitive information from unauthorized access (Yadav, A. S. et al. 2022).
- **Potential for Inequity:** If not carefully designed, the implementation of eLAS may exacerbate existing inequalities in land access and ownership, particularly if certain groups are less able to engage with the technology (Akumuntu, A. 2022).

Figure 3. Key expected impacts on implementing conceptual framework

In summary, using a framework to implement eLAS can lead to significant improvements in efficiency, transparency, and stakeholder engagement, but it also presents challenges that need to be carefully managed to ensure successful outcomes.

5. CONCEPTUAL FRAMEWORK IMPLEMENTING eLAS TOWARD SUSTAINABLE LAND ADMINISTRATION

In general, a conceptual framework is a conceptual structure or model that provides a systematic way to understand and analyze a particular phenomenon. It is a set of guidelines, principles or assumptions that help to organize and structure information, ideas or concepts (Khalid, M. I. et al. 2022). In implementing eLAS, it will involve the development and use of a conceptual framework that provides a structured approach to design and implementation. Various conceptual frameworks can be used, and the choice depends on the needs, context and specific goals of the land administration system to ensure that eLAS can be optimized for use in achieving the specific goals that have been set. Figure 4 below show the drafted conceptual framework develop from the SLR study. This conceptual framework utilizes a four-dimensional framework for implementing the eLAS. This framework includes the following dimensions:

- **Technological Dimension:** Focuses on the technological infrastructure required for eLAS, including the integration of blockchain technology to enhance data security and transparency.
- **Organizational Dimension:** Addresses the organizational structures and processes necessary for effective implementation, including stakeholder engagement and management.
- **Legal and Regulatory Dimension:** Considers the legal frameworks and regulations that need to be established or modified to support the adoption of eLAS and blockchain technology.
- **Socio-Economic Dimension:** Examines the socio-economic factors that influence the acceptance and success of eLAS, including public awareness, education, and the economic implications for users and stakeholders.

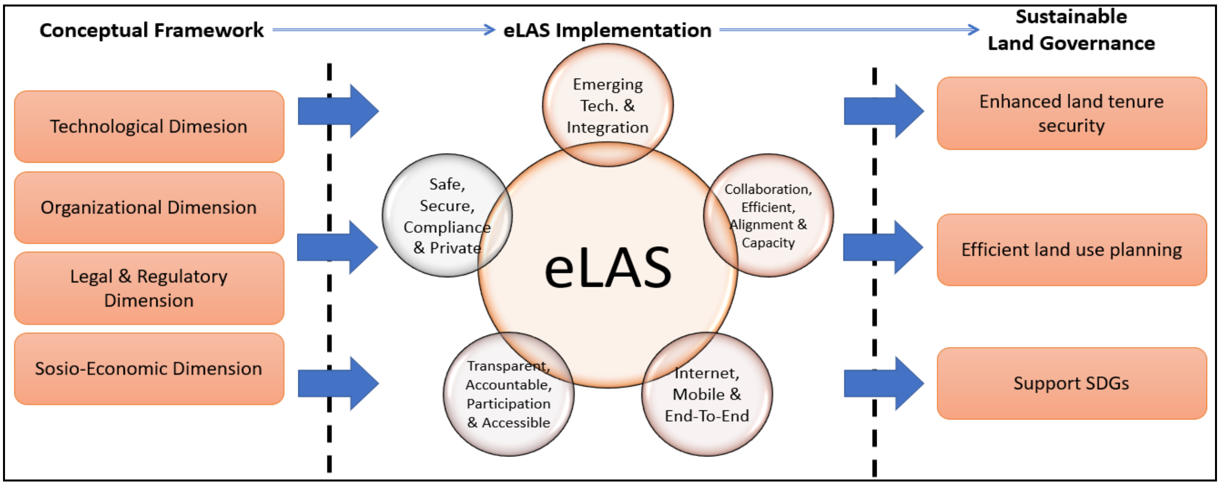

Figure 4. Drafted Conceptual Framework to Implementing eLAS Toward Sustainable Land Administration

Figure 4 above show the drafted conceptual framework. This comprehensive framework aims to ensure that all critical aspects of eLAS implementation are considered for successful integration into land administration practices. By focusing on these components within the Four-Dimensional Dimension, the implementation of eLAS can be more effective, secure, and user-friendly, ultimately leading to better land administration outcomes. The eLAS can be more effectively integrated into existing organizational structures and practices, leading to improved land administration outcomes and greater stakeholder satisfaction. The eLAS also can be conducted in a manner that is legally sound, compliant with regulations, and capable of addressing the complexities of land administration in a digital context. Furthermore, it can contribute to more equitable land administration, promote sustainable development, and enhance the overall quality of life for communities. Figure 5 below show the element for every dimension in the conceptual framework drafted.

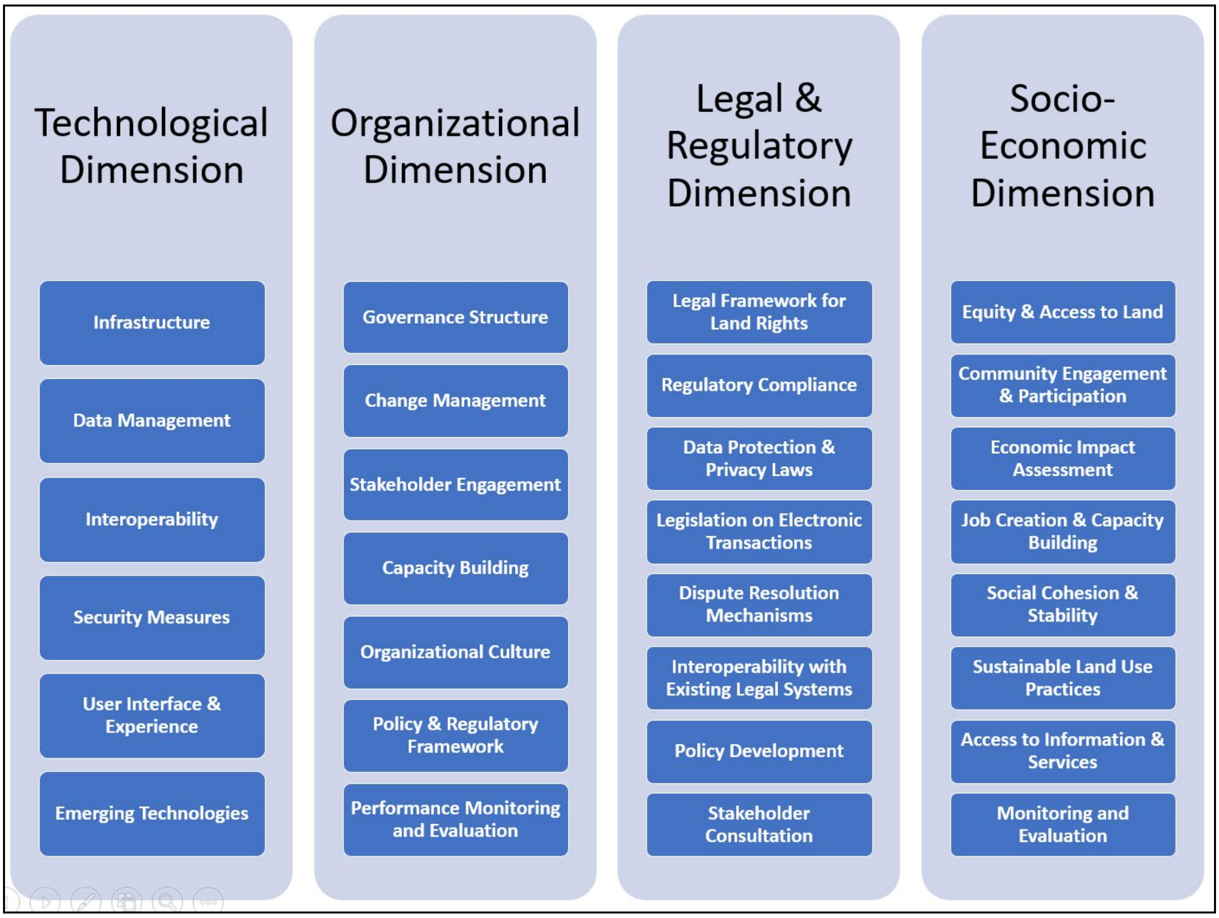

Figure 5. Elements for the four-dimensional dimension conceptual framework

6. CONCLUSION

In conclusion, this SLR study underscores the critical role of digitalization in achieving sustainable land administration. By meticulously applying the PRISMA protocol, the study identifies key challenges such as data integration, policy inconsistencies, and governance issues that hinder the effective deployment of eLAS. The exploration of a conceptual framework for implementing eLAS towards sustainable land administration presents a compelling vision for the future of land governance. By addressing the multifaceted challenges of institutional readiness, stakeholder engagement and technological infrastructure, the framework not only paves the way for innovative solutions but also ensures that marginalized communities are included in the digital transformation journey. This study serves as a vital roadmap for policymakers and practitioners, emphasizing that the successful integration of eLAS is not merely a technological upgrade but a profound shift towards sustainable development that aligns with global aspirations for social equity and environmental stewardship.

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BIOGRAPHICAL NOTES

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Extending NSDI with LADM Valuation Information Model and Expert Opinions to Calculate Score Values of 3D Real Estate

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Key words: Land administration, Real estate valuation, SDI, 3D building, LADM Valuation information, smart city.

SUMMARY

There is a need for high quality, reliable and up-to-date database management systems to determine sustainable property management policies in smart cities. The database management systems capable of storing 2D and 3D spatial information can be effectively used in smart city applications related to many data themes such as buildings, cadastre, transport, land use, etc., considering the needs of applications including property valuation. The property valuation process involves an impartial assessment of the various elements that influence the potential value of a property that is not only rights, restrictions, responsibilities (RRRs), condition of real estate, spatial planning status and constraints but also environmental, geographical, location and socio-cultural information. While traditional cadastral systems provide legal information about properties with 2D geometric information, 3D building and dwelling models can provide more meaningful data for GIS analysis that can be used to increase the accuracy of real estate valuations. If a country has an effective National Spatial Data Infrastructure (SDI) with 3D support, it can be used to link different data themes, such as buildings, cadastre, land use, addresses, etc., that are required in valuation processes. However, to meet today's 3D real estate valuation needs, an extension to NSDI may be required for property valuation registers. ISO/DIS 19152-4 *Valuation information* specifies the characteristics and semantics of valuation registers maintained by public authorities. It covers all administrative valuations and all input and output data within the valuation processes.

The purpose of this study is to extend the NSDI of Türkiye with ISO 19152-4 Valuation information and local value affecting factors to cover all the characteristics required in the 3D real estate valuation, and to implement the developed data model. The developed data model is tested using real 3D dwelling data, and data (value affecting factors) collected through a questionnaire. The scores of each 3D condominium unit are calculated based on the questionnaire answered by the valuation experts.

Extending NSDI with LADM Valuation Information Model and Expert Opinions to Calculate Score Values of 3D Real Estate

Arif Çağdaş AYDINOĞLU, Rabia BOVKIR, Süleyman ŞİŞMAN, and Abdullah KARA, Turkiye

1. INTRODUCTION

Real estate information is intricately connected to multiple facets of urban progress, encompassing economic advancement and quality of life (Geipele et al., 2014; D'Acci, 2019). As the backbone of sustainable urban management, precise and standardised real estate information is essential to ensure successful urban planning, infrastructure development, environmental sustainability, economic development, and real estate valuation (Rajabifard et al., 2013; Dawidowicz et al., 2014; Rogatnev et al., 2020). (Bovkir and Aydinoglu 2018; Janecka, 2019).

Standardizing models in real estate information management is crucial for improving the dependability, uniformity, and usefulness of data, which is vital for making well-informed decisions in urban planning (Aydinoglu and Bovkir, 2017). As a result, application of modern technologies, online platforms, and boosted real estate valuation methodologies can revolutionise the real estate market, offering prospects for more sophisticated management and decision-making in the context of smart cities (Ullah et al., 2018; Apanaviciene et al., 2020; Sisman and Aydinoglu, 2022).

Smart and sustainable urban planning, development and implementations are highly dependent upon the efficient administration and utilisation of three-dimensional (3D) data (Biljecki et al., 2015; Isikdag et al., 2015; Janecka and Karki, 2016; Alavipanah et al., 2017; Apeh and Adbul Rahman, 2023). Regarding the fields of cadastre and real estate, 3D data acquisition, modelling, and visualisation technologies have greatly increased utilization with a particular importance (Kara et al., 2020; Suwardi et al., 2022). Using 3D Geographic Information Systems (GIS) allows for in-depth analysis in evaluating property characteristics and values through advanced geographic analysis such as visibility (Kara et al., 2020).

The real estate valuation process involves an impartial assessment of the various elements that influence the potential value of a property (Bovkir and Aydinoglu, 2018; Aydinoglu et.al., 2022; Yalpir et al., 2021), which include not only rights, restrictions, responsibilities (RRRs), condition of real estate, spatial planning status and constraints but also environmental, geographical, locational and socio-cultural information (Kara et al., 2020; Sisman and Aydinoglu, 2022). For example, access to urban functions, energy performance, solar potential, view characteristics of a real estate, together with local characteristics are of great importance for effective property valuation. A detailed data model is required that clearly organises all the required information. There is a need for high quality, and reliable 2D/3D spatial information that can be effectively used in smart city applications related to many data themes such as buildings, cadastre, transport, land use, etc. If a country has an effective National Spatial Data Infrastructure (SDI) with 3D support, it can be used to link different data themes, such as buildings, cadastre, land use, addresses, etc., that are required in valuation processes. The ISO 19152 Land Administration Domain Model (LADM) is the only

standard that considers links between cadastral, building, land use and property valuation registers, it makes sense to use the LADM when extending an NSDI. The LADM defines a common terminology for land administration and includes both support for 3D representations of spatial units and a seamless integration of 2D and 3D spatial units. One of the new parts of the LADM will most probably be *ISO 19152-4 Valuation information* which specifies the characteristics and semantics of valuation registers maintained by public authorities.
The main objective of this paper is to extend the NSDI of Türkiye with *ISO/DIS 19152-4 Valuation information* and value affecting factors to cover all the characteristics required in the smart city applications and 3D real estate valuation, and to implement the model for calculating the parametric value scores of 3D buildings and condominium units. For the case study, factors affecting real estate value were determined by considering the designed models, literature reviews and existing data content. By using one a Multi-Criteria Decision Analysis (MCDA) method, the parametric value scores were calculated based on GIS for each condominium unit in five different categories and a consolidated parametric value score can be used to support real estate valuation.

2. DESIGNING REAL ESTATE VALUATION INFORMATION MODEL

The management of real estate plays a crucial role in implementing fair, comprehensive, and rational urban policies, which are vital for the sustainability of urban services and the effective administration of properties in a specific area from multiple perspectives (Hely and Antoni, 2019). When examining the current real estate management landscape, it is evident that information regarding parcel details, legal restrictions, zoning regulations, and building characteristics are stored in different data repositories.
Real estate appraisal is an essential aspect of real estate management, serving a wide range of purposes such as expropriation, tax assessment, zoning initiatives, insurance, value-oriented transactions, and urban redevelopment (Kara et al., 2021; Yalpir et al., 2021; Sisman and Aydinoglu, 2022). The accuracy, consistency, and reliability of operations within this wide field of real estate valuation are closely tied to the quality, thoroughness, and timeliness of the data used (Aydinoglu and Bovkir, 2017). Valuation procedures in real estate encompass various essential factors. These factors encompass the geometrical, locational, and physical attributes of the property, as well as the legal aspects related to ownership and formal inventories that impact market prices (Kara, 2021).
In this study, a comprehensive conceptual data model has been developed, which is specifically designed for open data management in the field of Real Estate Management. An initial analysis of requirements was conducted, followed by an assessment of the resultant data components for compatibility with Turkish national Geographic Data Infrastructure (TUCBS). The proposed model enables the inclusion of land and real property data in the TUCBS, which also encompasses other land-related data themes such as buildings, land cover, topography, addresses, and administrative units. The LADM_VM is widely recognised as the primary standard for data management schemas in Real Estate Management. Therefore, the model has been developed as a sub-scheme of the LADM_VM standard for real estate management, specifically adapted to the Türkiye country profile.

In Türkiye, the national SDI initiative, Turkish National GIS (TUCBS), was launched as part of the e-government strategy to foster data interoperability across various administrative levels by establishing data production and sharing standards. TUCBS, aligning with INSPIRE in Europe, utilises the Unified Modelling Language (UML) of model-driven architecture for geographic data modelling with ISO/TC211 standards (Aydinoglu, 2016).

The main model structure of the Real Estate Management (abbreviated as TY) conceptual data model design is structured on LADM Valuation information (LADM_VM) components aligned with the TUCBS data themes. The model fulfils all requirements for land valuation as an extension of TUCBS data themes. The conceptual data models of the proposed model were designed using the basic schemas of ISO/TC211's 19xxx series standards, as well as internationally recognised and applicable technical specification rules such as data encoding, transformation, and service standards of the OGC (GD-GIS, 2019).

2.1 Overview of the Application Schema in Comparison with LADM_VM

In accordance with the structure of the ISO 19152-4 LADM_VM standard, the TY data model was developed with the following eight fundamental feature classes as *TY_TasinmazDegerleme, TY_TopluDegerleme, TY_DegerlemeUnit, TY_DegerlemeUnitGroup, TY_SatisIstatistikleri, TY_IndependentBolum, TY_Building*, and *TY_Parcel* (Fig. 1). The TY model is specifically intended to align with the characteristics of Türkiye and may be regarded as an additional model that is compatible with TUCBS and LADM models. It encompasses all the necessary classes and relationships for real estate management systems in a unified framework. Since the designed TY model was built on the LADM_VM, it maintained its relationship with the LADM Core Model. In addition, it has been defined as directly and indirectly related to several TUCBS data themes. Indirectly related data themes include *Address, Land Use, Public Administration Zones and Protection Zones*. Directly related data themes are *Building (TUCBS_BI)* and *Cadastre (TUCBS_KP*) themes.

TY_TasinmazDegerleme (TY_Valuation) class serves as the fundamental class in the TY data model, similar to the VM_Valuation in the LADM_VM model, for representing valuation information. *TY_TasinmazValuation* is defined as a subclass of the *TK_ParselDeger (Parcel Value)* feature class of the *Cadastre* theme in relation to the TUCBS model. *TY_TasinmazDegerleme* contains attributes such as appraised value (deger), purpose of valuation (degerlemeAmaci), valuation report identifier (degerlemeRaporID), date of valuation (degerlemeTarihi), valuation approach (degerlemeYontemi), type of value (degerTuru), transaction price for the valuation (islemFiyatBilgisi), objection status (itirazDurumu) and valuation identifier (tyDegerleme) (Fig. 2). Data regarding mass valuation is defined with the *TY_TopluDegerleme (TY_MassValuation)* class. It is designated as a subclass of the *TY_TasinmazValuation* class. It contains the attributes mathematical model (matematikModel), statistical analysis method (analizTuru), performance indicators (topluDegerlemePerformansi), and predicted value (predictValue).

TY_DegerlemeBirimi (TY_ValuationUnit) feature class refers to the basic transaction/record units that are subject to valuation. The value unit subject to real estate valuation can be parcel (*TY_Parsel*), building (*TY_Bina*) or condominium unit (*TY_BagimsizBolum*). It is defined with the attributes of infrastructure status (altyapiTesisatOzellikleri), the municipality to which the relevant unit is affiliated (bagliOlunanBelediye) and the type of neighborhood (mahalleTuru), the type of the appraisal unit (turu) and the appraisal unit identifier (tyDegerBirimID). *TY_DegerlemeBirimi* is defined in relation to the LADM's Basic Administrative Unit (LA_BAUnit) class. In this way, the relationship between valuation units and cadastral/zoning plans is established with basic administrative units such as parcels, buildings, and condominium units.

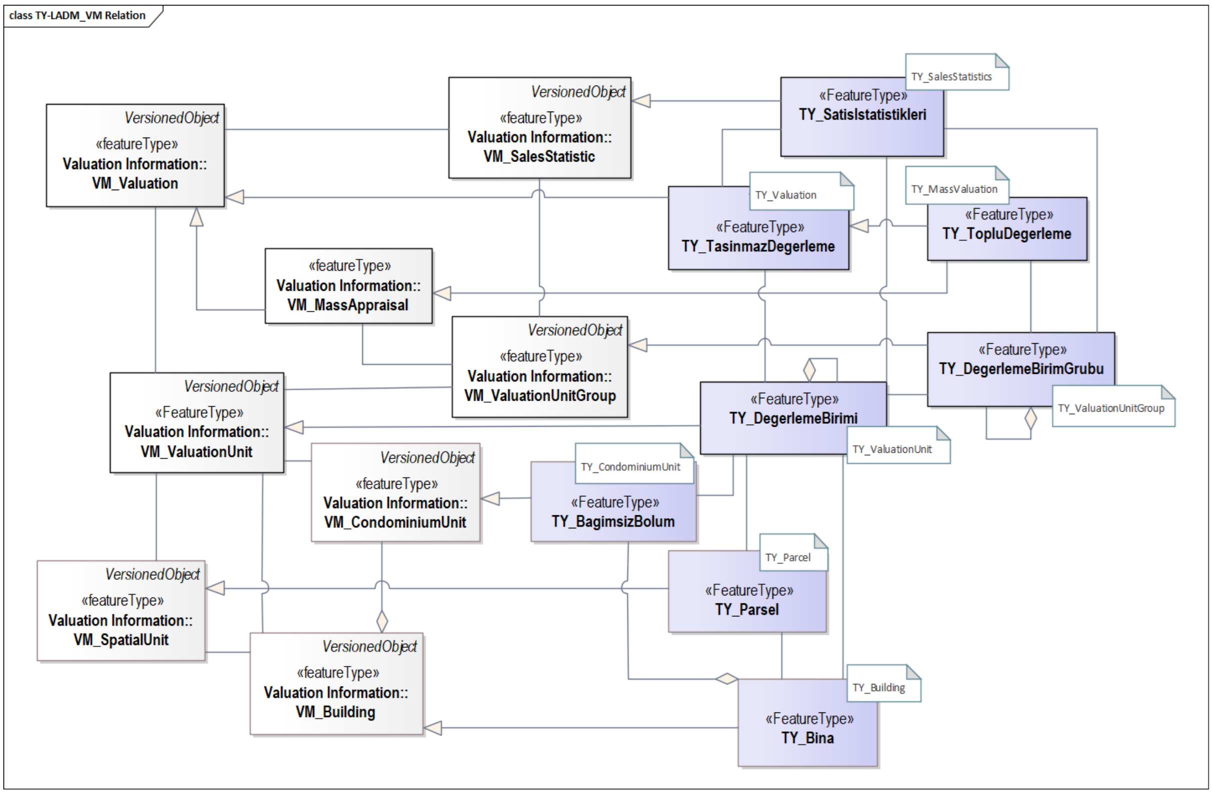

Fig. 1. The relation between TY and LADM_VM Models

Information regarding the valuation unit group subject to real estate valuation is defined with the *TY_DegerlemeBirimGrubu (TY_ValuationUnitGroup)* class. It enables the categorisation of valuation objects in terms of administrative units, use types of real estate or value regions. This class has been specifically designed to represent groups formed for the purpose of evaluating clusters by linking it with LADM's spatial unit group (LA_SpatialUnitGroup) class. It contains the attributes as the valuation unit group name (degerlemeGrupIsmi), group type (grupTuru), and unit group identification (tyDegerBirimGrupID).

TY_Parsel (TY_Parcel) refers to the parcels that are subject to valuation/appraisal. *TY_Parsel* is defined as a subclass of the TUCBS TK_Parsel (TK_Parcel) feature class and is associated with the spatial unit (LA_SpatialUnit) class of LADM. It involves the geometric information and includes the legal information in the cadastral systems related to the parcel. The TK_Parsel class has links with the TK_Tescil (TK_Registration) and HaklarKisitlamalarSorumluluklar (RightsRestrictionsResponsibilities) classes, enabling the execution of essential queries and analyses on cadastral data. These relations enable the recording of changes caused by technical applications on parcels, the registration of spatial easement rights, the management of spatial and legal limits on the parcel, and the integrated evaluation of cadastral/zoning plans. It is crucial to establish these relationships and consolidate the pertinent information in one place for comprehensive real estate management. It is defined with the location of the parcel within the cadastral block (adaIciKonum), current usage information (guncelKullanimTipi), floor area ratio (kaks), ownership information (mulkiyetDurumu), the width of the road facing the front façade of the parcel (onCepheninBaktigiYolGenisligi), and length of the front façade of the parcel (onCepheUzunlugu), parcel area (parselAlani), planned use in the zoning plans (planlananKullanimTipi), building coverage ratio (taks), parcel identifier (tyParselID), the construction order of the parcel determined in the zoning plans (yapiNizami), number of fronts facing the road of the parcel (yolaBakanCepheSayisi), ground condition (zeminDurumu) and slope (zeminEgimi) of the land on which the parcel is located attributes (Fig. 2).

TY_Bina (TY_Building) represents the buildings subject to appraisal. By integrating the architectural structures along with their geometric data, the management of building information may be conducted with a focus on its value. TY_Bina is defined as a subclass of TUCBS Building and LADM_VM building (VM_Building) feature classes and is associated with LADM's spatial unit (LA_SpatialUnit) class, as in the TY_Parsel class (Fig. A.1 and A.2). This class includes area (alan), number of residences (bagimsizBolumSayisi), equipment elements and types of the building (binaDonatiUnsurlari), energy performance (binaEnerjiPerformansi), infrastructure installation of the building (binaTesisati), facade material (disCepheMateryali), volume (hacim), heating source (isitmaKaynagi), heating system (isitmaSistemi), type of use (kullanimTuru), building identifier (tyBinaID), construction quality (yapimKalitesi), building material (yapimMalzemesi), construction date (yapimTarihi), number of floors below ground (zeminAltiKatSayisi) and above ground (zeminUstuKatSayisi) ground attributes.

TY_BagimsizBolum (TY_CondominiumUnit) is an individual unit that is subject to the valuation process and is categorised as a type of valuation unit. This class defines as a subclass of TUCBS Building - Condominium Unit and LADM_VM's VM_CondominiumUnit feature classes, as in TY_Bina, and it is also related to LADM's LA_LegalSpaceBuildingUnit class. It contains attributes as; land share of the independent section (arsaPayi), gross unit area (bagimsizBolumBrutAlani), net unit area (bagimsizBolumNetAlani), type (bagimsizBolumTuru), the floor on which the unit is located (bulunduguKat) and its floor type (bulunduguKatTipi), existing add-on/accessory information (eklenti), usage type of the condominium unit (kullanimTuru), ownership status (mulkiyetDurumu) and individual partition identifier (tyBbolumID).

TY_SatisIstatistikleri (TY_SalesStatistics) provides information on sales statistics derived from real estate transaction prices. This class is developed in collaboration with TY_TasinmazDegerleme, TY_DegerlemeBirimi, and TY_DegerlemeBirimGrubu to provide a comprehensive overview of the registers that contain sales prices and statistics (Fig. 2). It has attributes as; the density of purchases and sales for the relevant real estate valuation unit/unit group (alimSatimYogunlugu), the date of statistical analysis of sales (analizTarihi), mortgaged (anaTasinmazIpotekliSatis) and general real estate sales (anaTasinmazSatis), mortgaged (bagimsizBolumIpotekliSatis) and general independent section sales (bagimsizBolumSatis), price index (fiyatEndeksi) and index calculation date (fiyatEndeksiTarihi), average price per square meter (m2BasiOrtalamaFiyat), base price index (tabanFiyatEndeksi) and index calculation date (tabanFiyatEndeksiTarihi) and sales statistics identifier (tySatisID).The data in the TY_SatisIstatistikleri class is derived from the data recorded for the specific valuation unit within the valuation class, indicating a relationship between these classes. Value maps can be generated using the data stored in the TY_SatisIstatistikleri class.

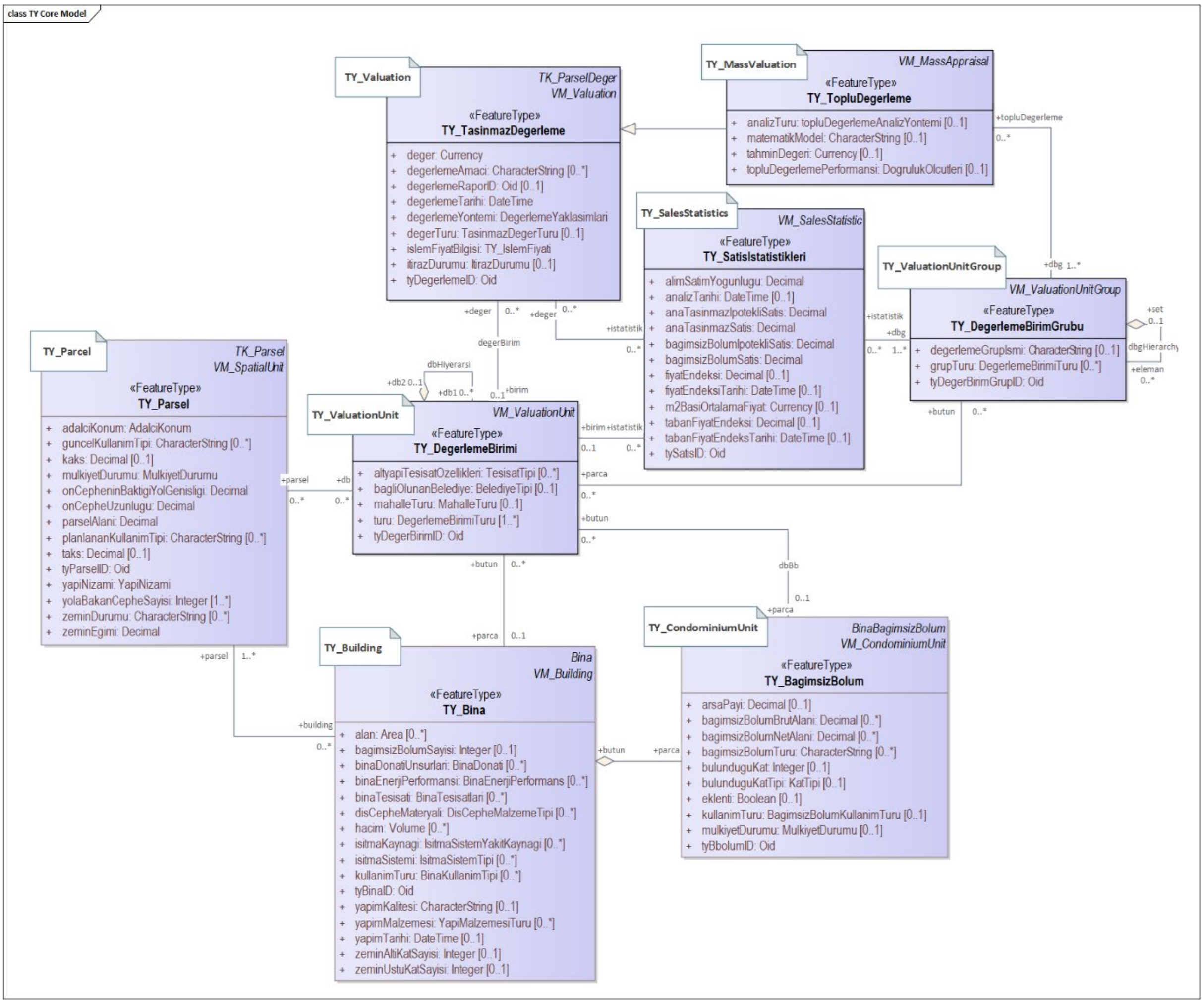

Fig. 2. Detailed core mode of TY

External factors, such as the view, proximity to points of interest (POI), noise levels, and amount of sunshine, are significant considerations in the valuation of real estate. The features derived from geographical analysis can be efficiently computed by documenting the parameters utilised in valuation databases that are integrated with 3D cadastral databases. This profile also incorporates features derived from geographical analyses using 2D and 3D datasets (Fig. 3). The *TY_DegerlemeBirimi3B (TY_ValuationUnit3D)*, *TY_BagimsizBolum3B (TY_CondominiumUnit3D),* and *TY_Kat (TY_Floor)* feature classes in the 3D profile were designed to facilitate data sharing in the construction and facility management industries, aligning with the TUCBS and INSPIRE Building data themes, CityGML, and buildingSMART - ISO 16739-1: Industry Foundation Classes (IFC) standards.

The *TY_DegerlemeBirimi3B* was defined as a subclass of the *TY_DegerlemeUnit* with GM_Object geometry. The 3D geometry allows for the precise definition of parcel, building, and building independent section geometries. In this way, the model design incorporates attributes for urban *functions* (KentFonksiyonOzellikleri) and socio-economic features (mahalliOzellikler) that can be calculated using 3D GIS analysis within the *TY_DegerlemeBirimi* (Fig. 3). *TY_BagimsizBolum3B* is classified as a subclass of the *TY_BagimsizBolum* in compliance with the 3D profile of the TUCBS Building data theme. It is also defined in relation to *TY_Kat (TY_Floor)* which consists of independent sections that are not defined according to the building structure but can also be defined according to logical evaluations (Fig. 3). *TY_BagimsizBolum* class were defined with the attributes that can be calculated/modelled with 3D GIS analysis and modelling of the independent section as the facade direction (bagimsizBolumCepheYonu), number of bathrooms (banyoSayisi), add-ons (eklenti) and their types (eklentiTuru), solar potential (gunesPotansiyeli), exposure to noise (gurultuDurumu), calculated gross (hesaplananBrutAlan) and net (hesaplananNetAlan) area, view status (manzaraDurumu), number of rooms (odaSayisi), kitchen (mutfakSayisi) and toilet (tuvaletSayisi). The *TY_Kat* feature class is a crucial component of 3D Building Information Models (BIM). It contains information such as the number of independent sections (bagimsizBolumSayisi), floor usage type (katKullanimTipi), floor number (katNumarasi), floor ceiling (katTavanYuksekligi) and floor height (katZeminYuksekligi), floor type (katTipi) attributes (Fig. 3).

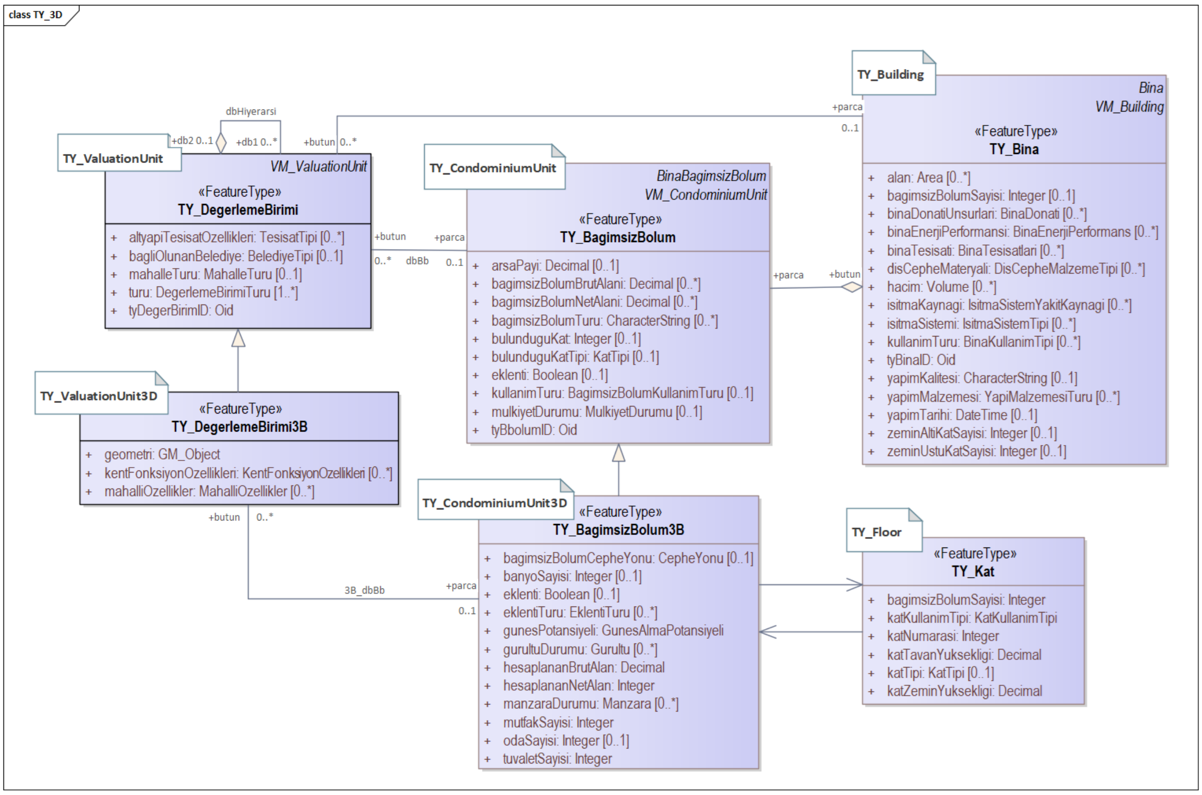

Fig. 3. 3D profile of TY data model

3. CASE STUDY

Within the scope of this study, 2D/3D factors affecting real estate value were defined in five thematic categories, taking into account international standards, literature reviews and existing 3D data model content (Biljecki et al., 2015; El Yamani et al., 2023, IAAO, 2017; IVSC, 2022; Jafary et al., 2022; Kara et al., 2023, 2021; Radulović et al., 2023; RICS, 2017; Sisman and Aydinoglu, 2022; TEGOVA, 2020; TKGM, 2024; Yalpir et al., 2021). Data regarding the factors in the Socio-Demographic Characteristics, Planning Characteristics, Urban Functions categories are generally related to traditional cadastral systems and are represented by 2D geometry. On the other hand, with the developing geographic information technologies, 3D building and condominium unit models at different levels of detail have begun to be produced. By GIS-integrated management of the 3D models produced, datasets related to the 3D factors defined in the building and condominium unit factor categories, as well as the 2D factors affecting the real estate value, may be obtained. In this context, a summary table of these factors that have the potential to affect real estate value.

Study area was determined in Amasya-Merkez district, where the first pilot 3D building models were produced within the scope of the "3D City Models and Cadastre Project" initiated by the General Directorate of Land Registry and Cadastre (GDLRC) in Türkiye (GDLRC, 2024). Relevant datasets were used to produce nominal value scores in the study area. The datasets include related factors were obtained from the Turkish Statistical Institute (TurkStat), the GDLRC-Parcel Query Application and Amasya Municipality city plans, the Disaster and Emergency Management Presidency (AFAD), Amasya Municipality, and Open Street Map (OSM), and GDLRC's 3D City Models and Cadastre Project.

To create parametric value scores for real estate valuation, it is necessary to calculate the weight coefficients representing the importance level of the factors affecting the real estate value (Sisman et al., 2023). Multi-Criteria Decision Analysis (MCDA) methods are effectively utilized to determine the weights of the criteria in decision problems that involve many factors such as real estate valuation. Thus, Best Worst Method (BWM) was used in this study.

In this study, the questionnaires were conducted directly with appraisers working in the public and private sectors and academicians conducting research on real estate appraisal issues. Experts were surveyed and each of the questionnaires was evaluated with BWM. The weights for the calculated factor groups and sub-factors were given in Table 1.

Table 1. Determining the factor weights affecting real estate value

Factor Group	*Factors With Weights*
Socio-demographic characteristics (0.214)	***Population (0.058)*** *(population density, women living in the neighbourhood (%), men living in the neighbourhood (%), children (0-14 age) living in the neighbourhood (%), young (15-24 age) living in the neighbourhood (%), adults (25-65 age) living in the neighbourhood (%), old (65+ age) (%) living in the neighbourhood),* ***Education Level (0.059)*** *(illiterate people (%), uneducated people who can read (%), primary school graduates (%), secondary school graduates (%), high school graduates (%), university graduates (%)),* ***Income Level (0.063)*** *(Number of people with group A+, A, B, C, D, size of income, income per capita),* ***Spending (0.034)*** *(food expenditures, healthcare expenditures, transportation expenditures, education expenditures, sheltering etc.)*

Planning Characteristics (0.163)	***Zoning Characteristics (0.065)*** *(building coverage ratio, floor area ratio,* ***,*** *parcel area, building order form (detached building, attached building), permitted parcel usage type),* ***Parcel Physical Characteristics (0.046)*** *(number of facades facing the road, facade front length, front facade road width, location of parcel in building block, land slope, ground conditions),* ***Property Status (0.052)*** *(condominium, condominium easement, timeshare)*
Urban Functions (0.216)	***Education Facilities (0.041)*** *(kindergarten, primary and secondary school, high school, university),* ***Healthcare Facilities (0.041)*** *(local healthcare facility, hospital, pharmacy, emergency health service station),* ***Transportation (0.063)*** ***(****Rail System Stations, Airport, Sea Transport Stations, Road Transport Station, Proximity to Roads),* ***Points of Interest (0.027)*** *(bazar centre, shopping mall, district bazaar, market, cultural facility, coast, green area, sport facility, restaurant),* ***Public Services (0.020)*** *(administrative facility, courthouse, post office, bank, fire station, security unit),* ***Industrial Facilities (0.008)****, (petrol station, industrial facility, treatment facility),* ***Religious Facilities (0.016)*** *(worship, cemetery)*
Building Characteristics (0.209)	***Building Physical Characteristics (0.127)*** *(age of building, number of total building floors, heating system, existence of heat insulation),* ***Building Installations (0.082)*** *(within housing estate, existence of car parking, existence of pool, existence of elevator, existence of children playground)*
Condominium Unit Characteristics (0.196)	***Condominium Unit Physical Characteristics (0.110)*** *(landscape, direction, floor level)****, Condominium Unit Interior Characteristics (0.086)*** *(floor area, number of rooms, room type, number of balcony, number of bathroom)*

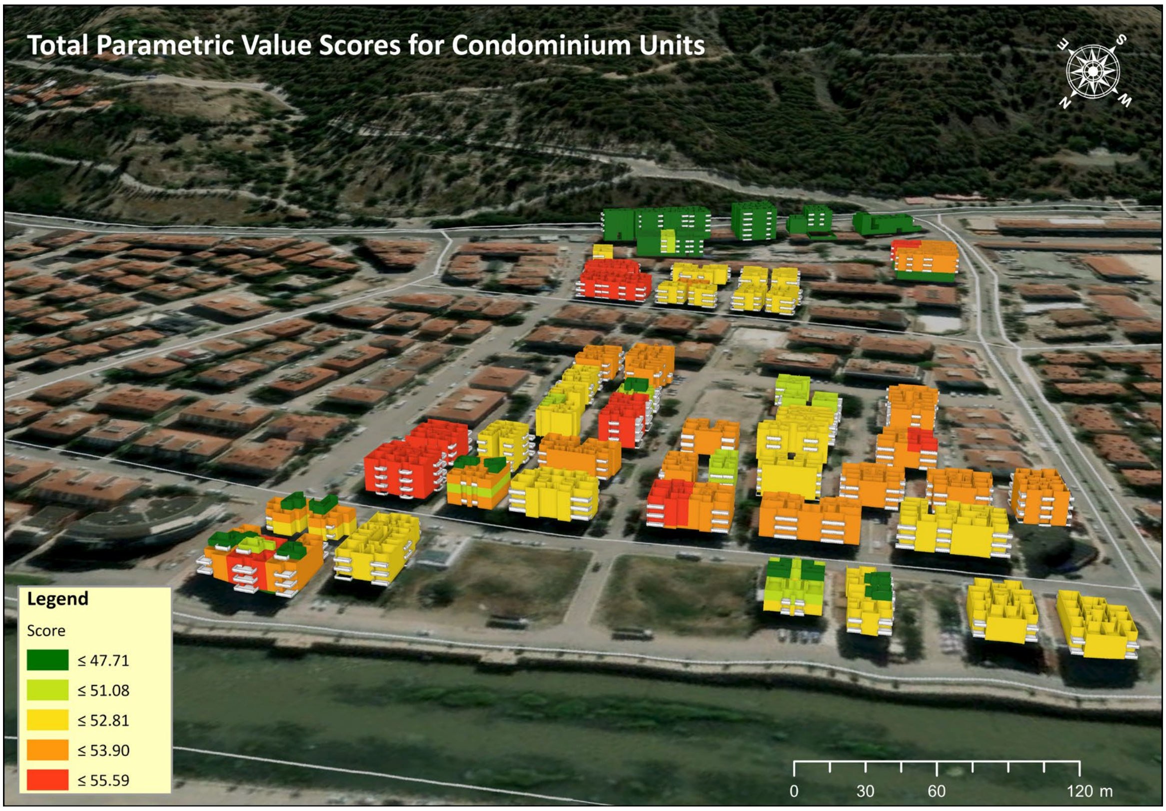

Fig. 4. Total parametric value scores for condominium units

The calculation of the parametric value scores was carried out in a hierarchical structure and a process was followed from the neighbourhood level to the condominium unit level. Geographic data representing the 2D/3D factors defined in Table 1 were analysed in the GIS environment to produce parametric value scores in real estate valuation. Finally, the scores calculated for the five groups were combined and parametric value scores were calculated at the condominium unit level, as shown in Fig. 4.

4. CONCLUSION

While traditional cadastral systems provide legal information about properties with 2D geometric information, 3D building and dwelling models can provide more meaningful data for GIS analysis that can be used to increase the accuracy of real estate valuations. If a country has an effective National Spatial Data Infrastructure (SDI) with 3D support, it can be used to link different data themes, such as buildings, cadastre, land use, addresses, etc., that are required in valuation processes. An extension to NSDI may be required to meet 3D real estate valuation needs. As the ISO 19152 Land Administration Domain Model (LADM) is the standard that considers links between cadastral, building, land use and property valuation registers.

After developing an extension valuation model of Turkey National GIS, compatible with LADM, A case study was conducted in a city, where Türkiye's first 3D building and condominium unit models were produced. Following the calculation of the weights, geographical analyses were performed, and the results were standardised. The developed real estate valuation model, which is structured as a part of NSDI, namely TUCBS, is evaluated with the data collected from the questionnaire. Parametric score values for each real estate are calculated based on the results of the questionnaire for five different group and one aggregated value. The aggregated score value, which can be considered as an approximation of the market value of real estate, is calculated by aggregating the score values of each group. Since it is not possible to obtain real estate values in the area where the case study was conducted, this approach is followed in testing the model. As a future work, it is planned to test the developed model with real data in another case study area. Furthermore, the relationships between indices generated in smart city applications (e.g., quality of life) and real estate values need to be investigated, which is specified as future work.

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Practical Approaches to 3D Cadastre Implementation: Database Schemas and Exchange Formats

Javad SHAHIDINEJAD, Mohsen KALANTARI and Abbas RAJABIFARD, Australia

Key words: 3D Cadastre, Land Administration, LADM, Physical Data Model, Database

SUMMARY

Land administration systems in Victoria currently use 2D cadastral databases to record, manage, and retrieve data, facing various challenges. These databases have been fundamental to land administration for over two decades, primarily focusing on 2D data to manage property rights, restrictions, and responsibilities (RRRs). Despite some progress, a comprehensive database schema for 3D cadastres is still lacking. Developing such a schema involves multiple steps, including creating a conceptual design, selecting a database management system, developing the logical design, and implementing the physical design.

This paper focuses on developing a database and exchange formats at the schema level based on Land Administration Domain Model (LADM) Edition II, aligned with the Victorian cadastral system. The Victorian cadastre is the result of collaborative efforts from various agencies, departments, and projects. Key components like Vicmap, Victorian Online Title System (VOTS), Surveying and Planning through Electronic Applications and Referrals (SPEAR), and ePlan are integral to the system, each corresponding to different parts of LADM II. The current 2D cadastral system in Victoria is based on an XML format, while the Intergovernmental Committee on Surveying and Mapping (ICSM) is working on developing a 3D Cadastral Survey Data Model (3D CSDM) for Australia, which is based on a JSON format. In this paper, we investigate the Victorian cadastral system and different parts of LADM Edition II and identify the similarities between them. An integrated conceptual data model for Parts 1, 2, and 5 will then be created. Since each part of LADM II is a standalone standard, there are redundancy and consistency issues that need to be addressed.

Furthermore, the challenges of transforming the conceptual data model into logical and physical data models will be discussed, and solutions to address these challenges will be analysed. The paper underscores the importance of adhering to database design principles for managing 3D spatial data within relational databases like PostgreSQL/PostGIS, highlighting the necessity of manual interventions during the transformation process. It also examines the creation of exchange formats such as XML and JSON and compares them with databases. The paper emphasises the need for a consistent approach to ensure data integrity, compatibility, and the linking of concepts to maintain consistency and interoperability.

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1. INTRODUCTION

Developing a 3D cadastral system involves several key steps including data acquisition, preparation, and validation, as well as data registration and management, analysis, retrieval, visualisation, and dissemination [1-3]. Victoria, Australia, has successfully implemented both file-based and database systems for 2D cadastre management. Notable examples include ePlan [4], which utilises an XML exchange format for the digital registration of plans, and the Digital Cadastral Database (DCDB) [5], Victorian cadastral map base that provides information about land parcels and property details. However, with the development of high-rise, mixed-use, and modern multi-purpose buildings, traditional 2D systems are inadequate for accurately determining property extents and the associated interests in land. This complexity necessitates advanced data management approaches that incorporate 3D aspects of cadastre to effectively register, record, manipulate, and retrieve RRRs, and other land-related data [6]. Moreover, the importance of implementing technical models like database schemas and exchange formats was emphasised in the International Federation of Surveyors (FIG) Workshop [7].

Conceptual data modelling is a critical step for implementing both databases and exchange formats. The LADM, as an international standard, facilitates interoperability and offers a standardised terminology and formal framework for describing and managing contemporary land administration systems [8]. LADM Edition II has been developed as a multi-part series, consisting of six standards, each one is treated as an individual standard, yet all remain backward compatible with LADM Edition I [9, 10]. The Victorian cadastre shares significant similarities with LADM Edition II, particularly in Part 1 (fundamental concepts and definitions), Part 2 (land registration), and Part 5 (spatial plan information). These parts align closely with the structures and processes of the Victorian cadastral system, making compliance and integration between them feasible.

An important question is how the different parts of LADM can be merged to create an integrated conceptual model for the Victorian cadastre, based on Parts 1, 2, and 5. Once an integrated conceptual data model is designed, it can be directly transformed into exchange formats like XML using Enterprise Architecture (EA) software [11]. However, for database implementation, the model first needs to be converted into a logical data model and then into a physical data model. This process presents challenges such as managing integrity constraints, surrogate keys, operations, inheritance, data types (particularly spatial data types), domains, code lists, indexing and clustering, all of which often require manual modification to resolve [12, 13].

This paper aims to implement a 3D cadastral database for Victorian cadastre based on LADM Edition II. It discusses the alignment of LADM Edition II with the Victorian cadastral system, with a particular focus on Parts 1, 2, and 5, to achieve compliance. The paper explores technical solutions for integrating LADM's various parts and converting the conceptual data

model into a logical and physical data model. Additionally, it explores the implementation of exchange formats like XML and JSON and compares them with database implementation.
The remainder of the paper proceeds as follows. Section 2 reviews related literature and research studies. Section 3 outlines the research methodology employed in this study. Section 4 covers the implementation process, including aligning LADM with the Victorian cadastre, designing the conceptual data model, transforming it into logical and physical data models, and developing databases and exchange formats. A comparison of implementations, along with the challenges and knowledge gaps encountered during the implementation process, will be discussed in Section 5. The paper ends with conclusion and potential directions for future research in Section 6.

2. RELATED WORKS

Most of the literature has implemented and used databases without fully adhering to database design principles, often treating databases as just a component of their work rather than a primary focus of their work [6]. In this section, we review studies that have implemented a cadastral database based on LADM and database design principles.
Alattas et al. developed a technical model for indoor navigation by integrating the LADM Edition I with IndoorGML. They began by creating an integrated conceptual data model, which was then transformed into a logical data model using EA modelling tools. However, they faced challenges during this transformation, particularly with aspects like inheritance, primary key and foreign keys, multiplicity, constraints, data types, spatial data types, code list classes, and indexing. To address many of these issues, they resorted to manual adjustments. Some problems, like the failure to convert attribute multiplicity into tables, remained unresolved. The study highlighted that, despite using data modelling tools like EA, manual interventions are still required to overcome various transformation issues [12]. In another study, Alattas et al. investigated issues related to database implementation and the visualisation of query results. They designed a 3D building in Revit and imported it into the database using Open Database Connectivity (ODBC). Although they transferred semantic data directly from Revit, and linked all attributes, including the 3D geometry, to a unique geometry ID, the tables related to the LADM still required manual data entry [14]. Alattas et al. subsequently used this database to analyse user movements during evacuation exercises in indoor environments [15].
Zulkifli et al. utilised LADM to develop a cadastral registration system for Malaysia that covers both 2D and 3D spatial data. They introduced a Unique Parcel Identifier (UPI) to connect spatial data from the Department of Survey and Mapping Malaysia with non-spatial data from the Land Office. They also suggested new code lists to enhance Malaysian cadastral system. The study demonstrated the use of Oracle Spatial for storing and querying 2D and 3D cadastral data, and Bentley MicroStation for visualisation [16]. Then in another work, they developed a prototype to evaluate the Malaysian LADM country profile. They utilised EA to automatically convert the conceptual model into the technical model. However, it was necessary to make some manual adjustments to the technical model were done. As part of this process, constraints, derived attributes, multiplicity, indexing and clustering were discussed [13]. Several studies, including Zulkifli et al. [17, 18], and Nasorudin et al. [19], have also

utilised LADM and similar methodologies to transform conceptual models into physical models based on the regulations in Malaysia.

There are some studies that have focused on NoSQL databases. As an example, Višnjevac et al. developed a 3D cadastral database based on LAMD using MongoDB [20]. Their system managed 3D cadastral data to some extent but had limitations, particularly in topology rule validation, and lacked options for spatial queries, such as selecting neighbouring objects.

In summary, most studies have utilised LADM Edition I, leaving a gap in discussions regarding the integration of different parts of LADM II, as well as issues of redundancy and inconsistency. Additionally, research has concentrated on the technical model, but there is a subtle difference between technical model in EA and the concepts of logical and physical data models in database development, despite their similar end results. Another gap is the lack of emphasis on database optimisation strategies. For instance, creating separate tables for code lists increases the overall number of tables, which complicates database management and administration. This approach also leads to more frequent use of *JOIN* functions in queries, which can negatively impact performance and require more advanced SQL knowledge to manage them efficiently. Lastly, the literature fails to address the challenges of ensuring semantic consistency and effective data integration when converting LADM entities into database tables, particularly in relation to ontology and linked open data. This oversight could result in difficulties with interoperability, data integrity, and advanced data analysis.

3. RESEARCH METHODOLOGY

As this study emphasises adhering to database design fundamentals, the methodology has been adopted by the database design principles as outlined in [21]. Figure 1 illustrates the methodology and steps of implementation utilised in this research. Firstly, a literature review will be conducted to identify current practices, challenges, and research gaps. Relevant standards will then be explored, leading to the selection of LADM as the most recognised standard in the land administration domain. Victoria was chosen as the case study, and the regulations and standards of Land Victoria were analysed. The compliance of the Victorian cadastral system with LADM Edition II was assessed, and the relevant parts were selected. Based on LADM Parts 1, 2, and 5, an integrated conceptual data model was developed. For physical implementation, two approaches were adopted: a database schema and an exchange file approach. The file format could be generated directly from the conceptual data model, while the database required conversion to logical and physical data models. Finally, a comparison of the database and exchange formats will be conducted at the schema level.

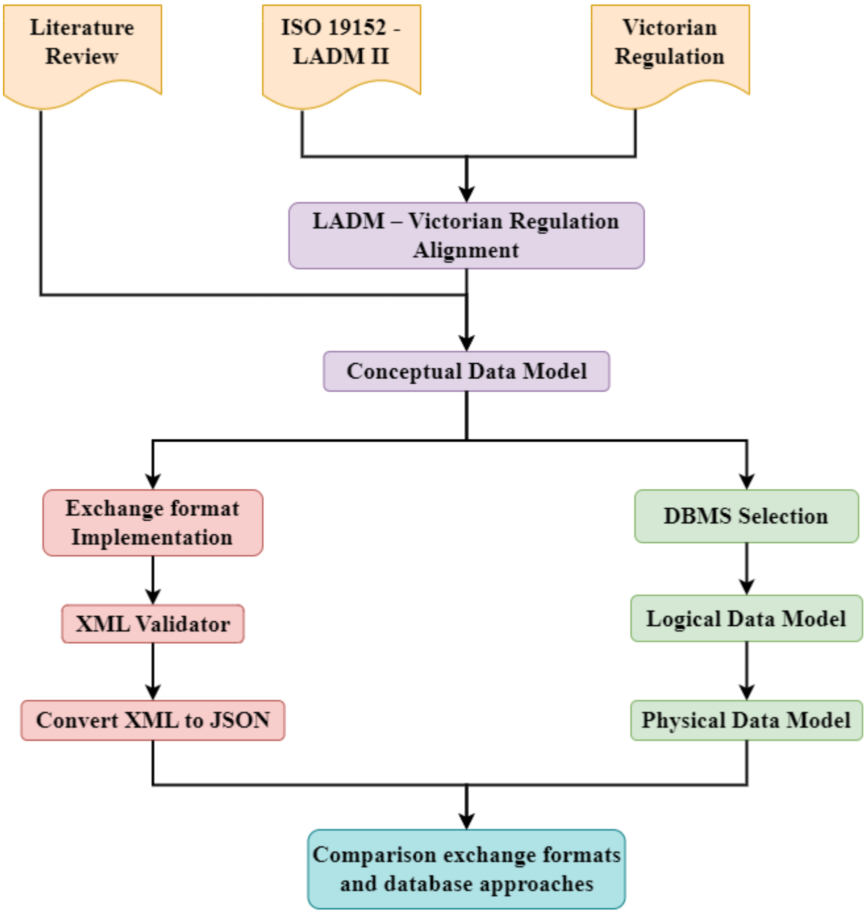

Figure 1. Overview of the research methodology

4. COMPLIANCE OF THE VICTORIAN CADASTRAL SYSTEM WITH LADM II

Prior to the data modelling and implementation, it is essential to determine which parts of LADM II need to be implemented, necessitating an alignment process between LADM II and the Victorian cadastral system. In Victoria, Land Use Victoria (LUV) is responsible for managing land administration activities such as land registration, property information, spatial data services and maps, surveying, land valuation, geographic names, government land policy and advice, and government land transaction oversight. LUV is a key state agency and is currently part of the Department of Transport and Planning (DTP) [22]. Furthermore, LUV is responsible for maintaining the Victorian cadastral system, which currently represents the state's property boundaries in 2D [23]. The Victorian cadastre is the outcome of collaborative efforts from various agencies, departments, and projects. The main components and related activities are summarised below.

Vicmap: Since 1975, Vicmap has played a vital role in Victoria primary mapping system, serving as the state's 2D cadastral map base, also known as the Digital Cadastral Database (DCDB). This database provides comprehensive information on land parcels and properties, including identifiers, standard parcel identifiers (SPI), parcel status (registered or proposed),

distinctions between freehold and Crown land, easements, and unique feature identifiers [5]. Vicmap Property can be aligned with the Spatial Unit package from both Part 1 and Part 2.
The simplified cadastral data model of Vicmap Property links parcel and property attributes to their spatial representations, making it easier to use. However, table *JOINs* are still needed to establish relationships between parcels and properties or to match properties with their addresses using SPI, lot and plan number, and council property number, with reference to the Vicmap Address data model [24]. Vicmap Address is matched with the External package (ExtAddress) of Part 1.
VOTS: land titles are maintained within the Victorian Online Title System (VOTS), a comprehensive database that serves as the authoritative record of land ownership. VOTS is a non-spatial database that not only documents ownership details but also includes information on restrictions such as mortgages, covenants, caveats, and easements that may affect the property [24]. VOTS corresponds to the Administrative and Party packages in both Part 1 and Part 2. Additionally, it can be considered as a source document.
Surveying and Planning through Electronic Applications and Referrals (SPEAR): SPEAR is an online platform that facilitates the process of managing subdivision planning permits, certification applications, and other land administration tasks. It supports the compilation, submission, management, referral, approval, and tracking of applications [25]. SPEAR is aligned with the Party and Generic Conceptual Model packages from Part 1, as well as with Part 5 – Spatial Plan Information. In addition, it is aligned with the external package of the Part 2.
ePlan: ePlan is a digital data file based on LandXML which represents cadastral and administrative information related to a plan. ePlan improves data quality, minimises duplication, and paves the way for end-to-end digital data workflows throughout the plan's lifecycle. This streamlines and automates traditional manual processes, leading to faster, more reliable, and consistent plan registration [4]. ePlan itself is part of the SPEAR process so it is corresponded to Part 1 and Part 5. In addition, it includes survey measurements and parcel dimensions which is in line with Survey and Representation package of Part 2.
Survey Marks Enquiry Service (SMES): SMES is an open-access database of survey control mark information in Victoria [26], which can be matched to the Survey and Representation of Part 2.
Abstract of field record: A document that contains detailed information recorded by a licensed surveyor. The purposes of preparing this abstract include: a) ensuring the preservation and public accessibility of records, b) providing documentary evidence of field conditions that support the chosen re-establishment method, c) offering supplementary information to verify recorded measurements, and d) documenting site conditions, such as traverse lines and instrument positions, which indicate topography and the presence of obstacles [27]. This document aligns with the Spatial Unit package and its subpackage, Surveying and Representation, from Part 2. Additionally, it serves as a valuable source of survey measurements.
Apart from these components, other databases and information are required in the cadastre, such as **Surveyors Registration Board of Victoria**, which is responsible for the registration of licensed surveyors to perform cadastral surveying in Victoria and provides a database of registered licensed surveyors [28]. This aligns with the Party package in Part 1.

Since only Part 1 of LADM II has been officially published at the time of writing this paper, the alignments with the Victorian cadastre are based on existing publications. These alignments may be further refined in the future as more detailed drafts of the other parts become available following their official release. Matching between LADM II and Victorian cadastral system components is demonstrated in Figure 2.

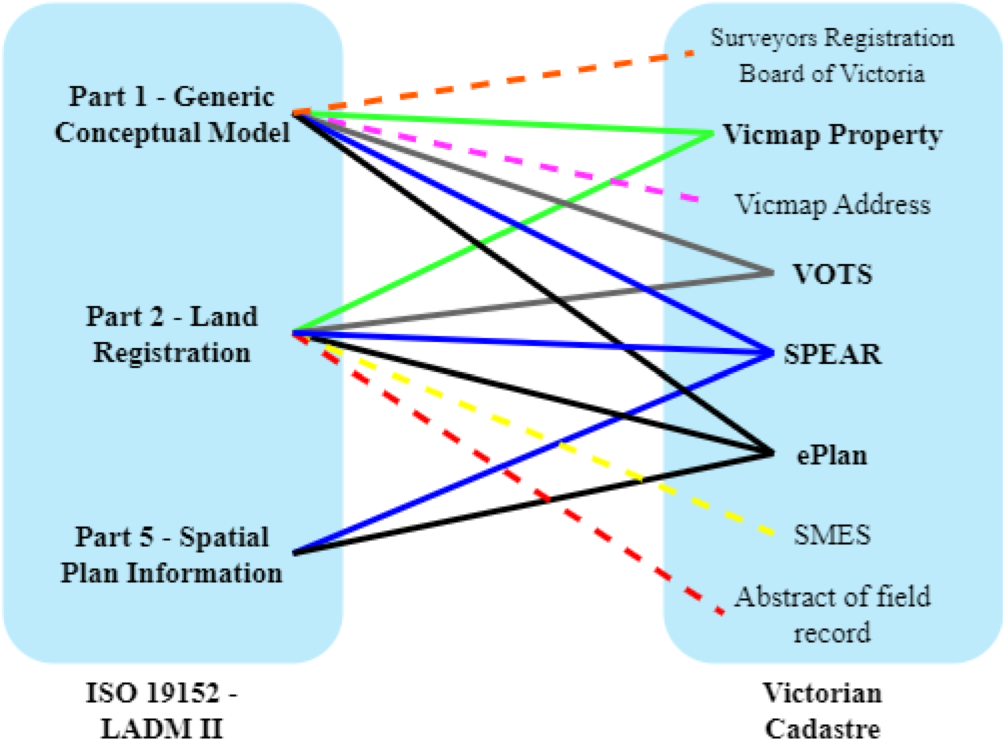

Figure 2. Compliance of LADM II with the Victorian cadastral system

5. IMPLEMENTATION

This section outlines the implementation process and explains each step. It also addresses the challenges encountered and proposes alternative solutions to enhance both execution and problem-solving strategies. The conceptual data model, which serves as the foundation for both the database and exchange formats, will be explained. Following this, the implementation of the database and file formats will be detailed.

5.1. Conceptual data modelling

Conceptual data models represent the most abstract level in data modelling, providing concepts that align with users' perceptions of the data. Based on the alignments conducted in Section 4, implementing parts 1, 2, and 5 of LADM II is beneficial for the Victorian cadastre.
In order to develop the conceptual model, the UML class diagram of ISO 19152 was used, and the model was developed utilising Enterprise Architect version 16.1. During the design of the conceptual model for arts 1, 2, and 5 of LADM, a key challenge arose from the fact that each of these parts is a standalone standard. As a result, overlapping packages and common

classes were identified across these standards, presenting challenges in effectively integrating these packages.

To avoid duplication and ensure data integrity and consistency in modelling process, we used part 1 as the core framework. The relevant packages and classes from parts 2 and 5 were manually incorporated, preserving their full structure. During this process, duplicated classes were removed, and the links between them were meticulously checked to maintain schema consistency and integrity. After integrating these components, the model was organised into 6 packages, as illustrated in Figure 3. After designing the conceptual data model, the subsequent steps vary depending on whether an exchange format or a database is needed. XML files can be directly generated from the conceptual data models; however, for database implementation, the model must be converted into a language that is readable by DBMSs.

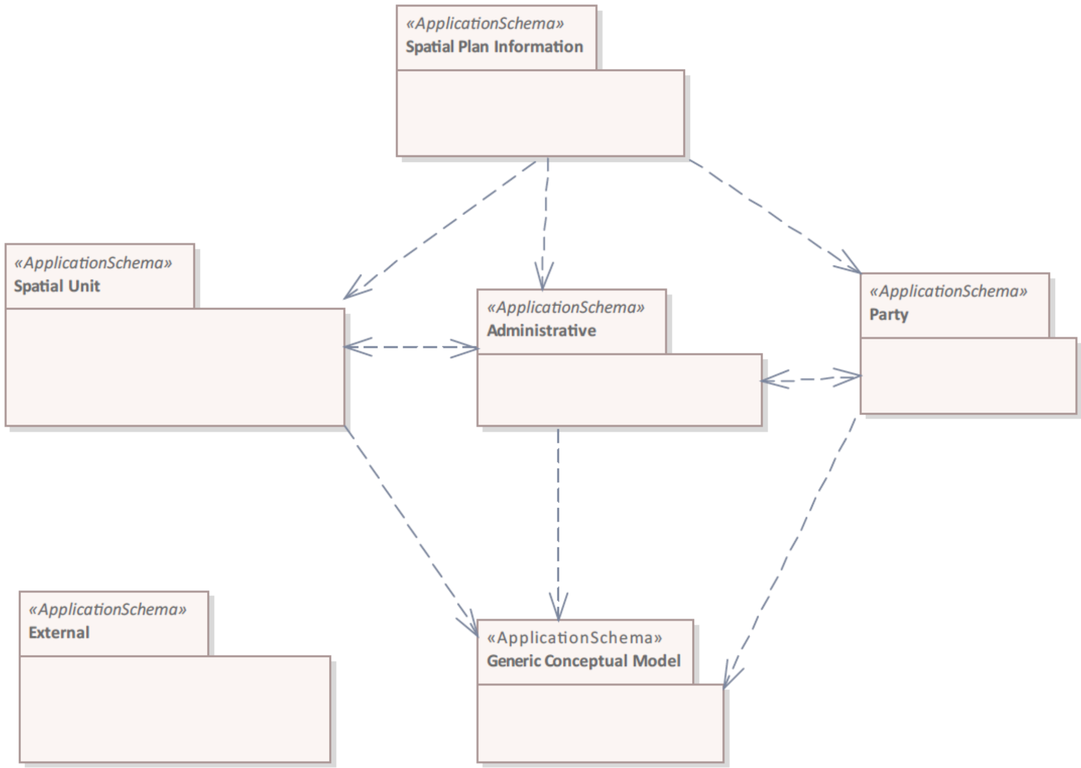

Figure 3. Integrated conceptual data model based on LADM Part 1, 2 and 3

5.2. Database implementation

After designing the conceptual model, the DBMS should be selected. Since cadastral data are mostly structured, a suitable option is to use relational data modelling and relational DBMSs. Among these, PostgreSQL/PostGIS and Oracle Spatial are the two most widely used options. We chose PostgreSQL because it supports spatial applications through its PostGIS extension and is free and open-source. Therefore, the conversion from the conceptual to the logical data model and the generation of Data Definition Language (DDL) codes in EA are based on the structure of PostgreSQL.

5.2.1. Logical design

There are several approaches for designing logical data models. As conceptual data models of ISO standards are implemented in EA, we selected this software for conceptual design. EA leverages transformation models to automatically convert UML class diagrams into DDL table diagrams. However, this process is not entirely automatic and requires some manual adjustments. Below is a step-by-step process for converting a conceptual data model into a logical data model using EA, including the challenges encountered during the transformation and suggested solutions.

- **Formalising Entities (Classes) into Relations (Tables)**: All classes are converted into tables. Association classes, such as *LA_PartyMember*, should be treated like concrete classes and converted into tables accordingly.
- **Converting Attributes to Columns/Tables**: There are three types of attributes including multivalued, composite, and derived attributes. EA does not automatically recognise these attributes, so they must be manually addressed.
    - **Multivalued Attribute:** For example, in the *LA_SpatialUnit* table, attributes like *area* (Figure 4a) may have multiple values, such as surveyed area and official area, which should be split into separate values. Thus, *area* is considered a multivalued attribute, necessitating the creation of a new table, *LA_AreaValue* (Figure 4b). In this case, the data type of FK was changed to integer (Figure 4c) and connected to the PK in *LA_AreaValue* (Figure 4d). The created FK is shown in Figure 4e.
    - **Composite Attribute**: Attributes like *extAddress* that can be divided into smaller parts such as building number, street number, street name, city, state, country, and postal code. These components should either be listed as separate attributes or treated as entities. In this case, *extAddress* should become a separate table to align with the LADM conceptual model. This approach also reflects practices in Victoria, where addresses are stored in a dedicated database like Vicmap Address, which can be considered an external class.
    - **Derived Attributes:** Attributes that can be calculated from other attributes. These attributes are usually not stored in the database because of data redundancy. For example, the *computeArea()* operation (Figure 4) can be used to calculate the area instead of storing it as a separate attribute.
- **Primary Key (PK)**: If a table has a clear primary key, such as *suID* in *LA_SpatialUnit*, it can be set as the PK. Otherwise, a surrogate key can be added. EA generates a default PK for each table, which often needs manual correction. If the table already has a PK, we remove the generated PK and assign the right attribute as the PK. If no PK exists, we retain the generated surrogate key.
- **Resolve Relationships**: Solve associations by adding foreign keys (FK) and associative entities. **Aggregation relationships** such as the relationship between *SP_PlanUnit* and *SP_PlanBlock* or *LA_Party* and *LA_GroupParty* are similar to standard associations when converting a conceptual to logical data model. **Reflexive associations**, like “update” association on *SP_PlanUnit*, are handled similarly (Figure 5).
    - **1:1 Relationships:** Adding an FK to the entity with total participation, if any, or to either side of the relation.
    - **1:M Relationships:** Adding FK to the *many* side of the relation. For example, the relationship between *LA_BAUnit* and *LA_RRR* is 1:M, so the FK is added to the *LA_RRR* table.

- **M:N Relationships:** Creating a new linking table, known as an *associative entity*, with two FKs, each referencing the PK of one of the related tables. In this case, the primary key of the associative table is typically a composite key formed by these two foreign keys, which is often referred to as a Primary Foreign Key (PFK) as illustrated in Figure 6. For instance, the relationship between *LA_BAUnit* and *LA_AdministrativeSource* requires an associative entity. However, some M:N relationships, like the *rrrSource* relationship between *LA_RRR* and *LA_AdministrativeSource*, may not be resolved automatically and need to be handled manually by creating a new table.

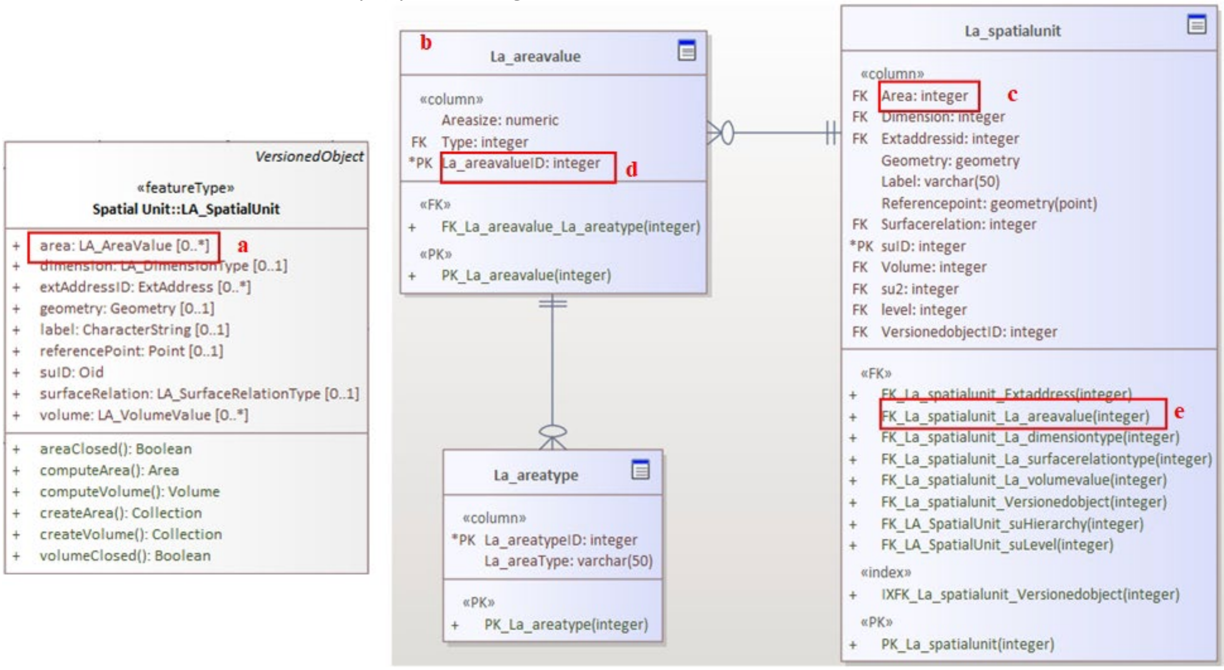

Figure 4. The process of resolving Multivalued attribute

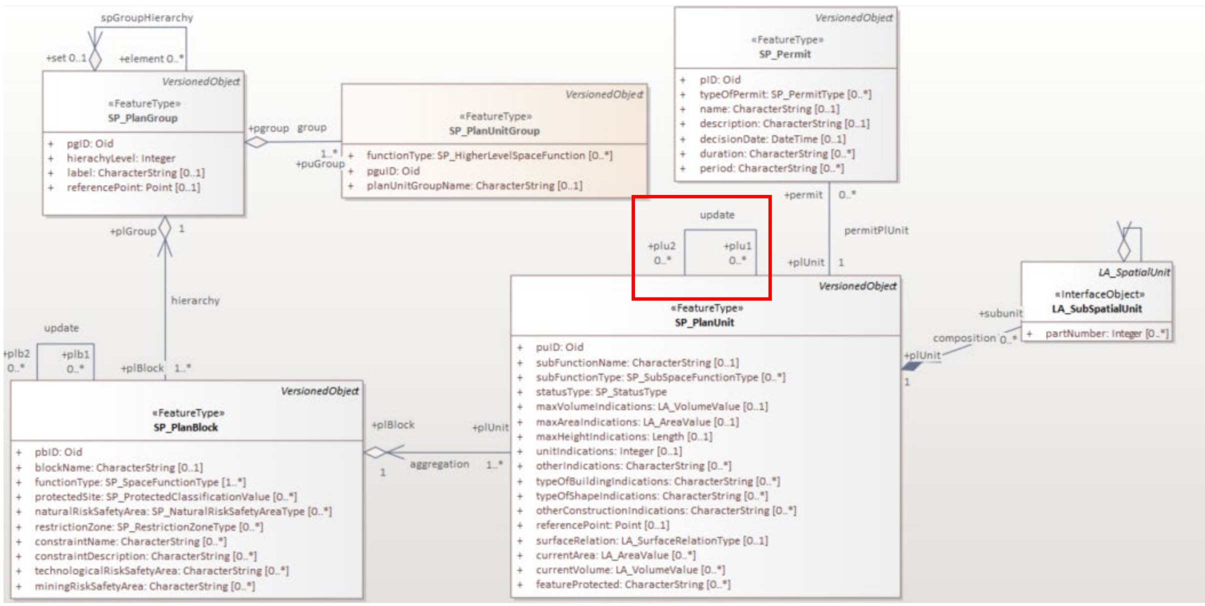

Figure 5. Example of many-to-many and Reflexive associations

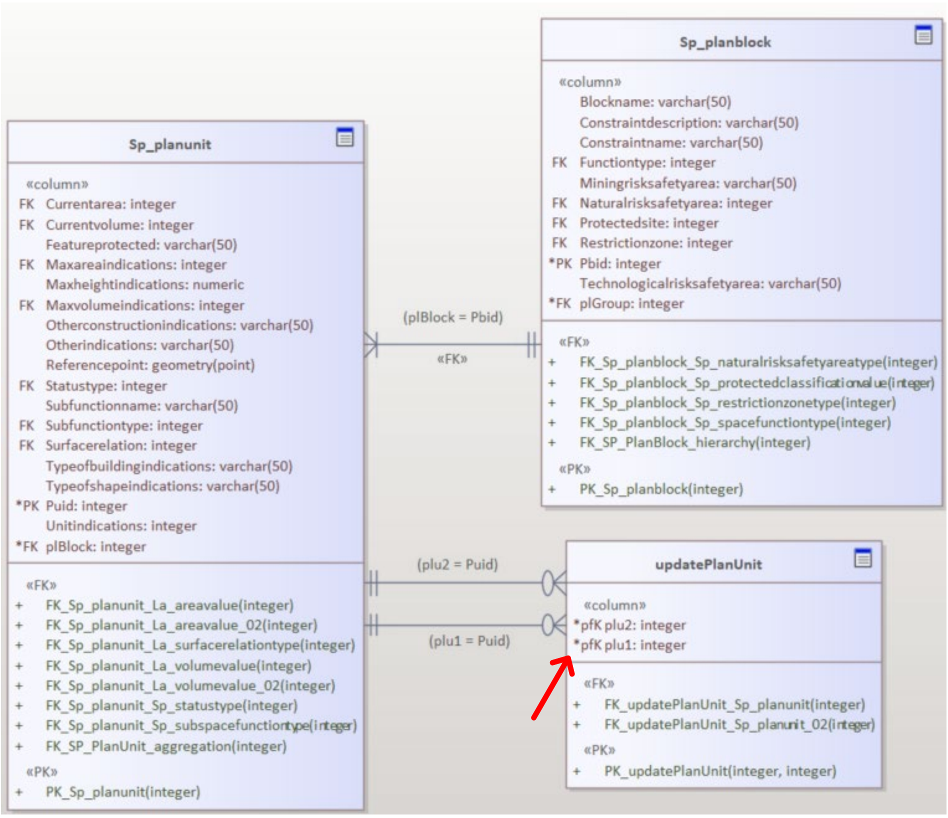

Figure 6. Resolving M:M relationship and the concept of PFK

- **Data Type**: For each attribute, it is essential to assign an appropriate data type. For spatial data, the appropriate geometry data types should be manually corrected, as EA's transformation model can not specify them. Dates and times, typically use the *timestamp* data type. **Generated data types**, such as *LA_VolumeValue*, often represent multiple values that should be stored in a separate table. However, the transformation model defines them as *varchar(50)* by default. The necessary steps are to delete the varchar(50), replace it with an integer, and designate this column as a FK that references the PK of the created table. It is important to ensure that the data type of the FK matches the PK data type of the related table.
- **Domain and Code Lists**: The range of values an attribute can take is known as its domain. There are two types of domains: enumerated and primitive types. Primitive types are similar to *varchar(50)*, which 50 is the default domain in EA. Enumerated types correspond to attributes with a limited set of values. The relevant examples in LADM are code lists. The transformation model creates tables for each code list and incorrectly converts values into columns. The solution is to create a new table with two columns: *ID* and *Type*. Then, insert the code list values into the *Type* column of this table (Figure 7). Alternatively, code lists can be managed in the user interface and limited through programming, or by using functions supported by some DBMSs for enumeration, which allows handling enumeration without creating new tables.

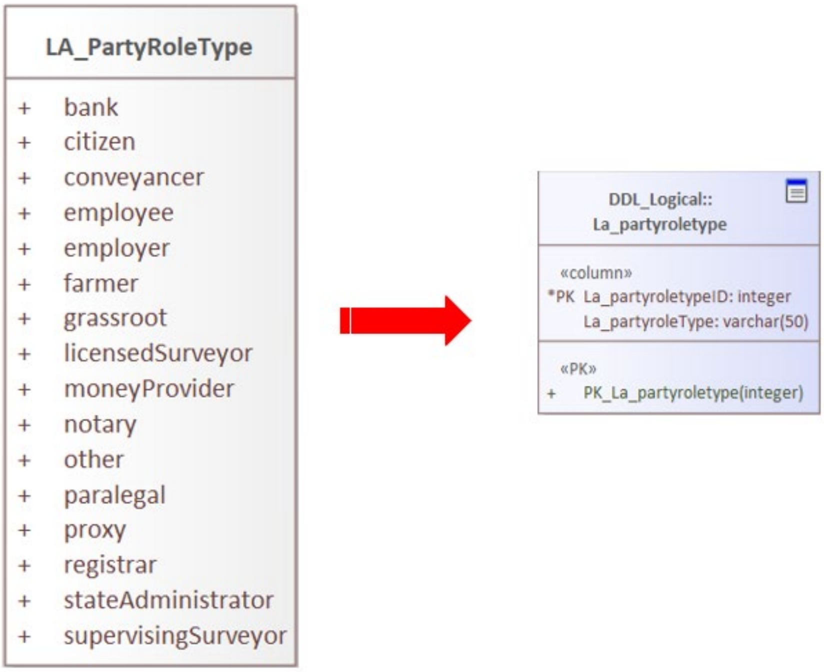

Figure 7. Solution for converting code lists

- **Inheritance/Generalisation relationship:** There are four alternative solutions:
  - **Single Table Inheritance**: All instances of the abstract class and its subclasses can be stored in a single table, with a type field added to distinguish between the different subclasses.
  - **Class Table Inheritance**: A separate table is created for each subclass, including both the fields inherited from the abstract class and those specific to the subclass.
  - **Concrete Table Inheritance**: Create a table for the abstract class to hold common fields, and separate tables for each subclass that include only their specific fields, with foreign keys linking to the abstract class table.
  - **Object-Oriented Inheritance in RDBMSs:** In RDBMSs like PostgreSQL that support object-oriented features, inheritance can be used to create a hierarchical structure of tables.
- **Multiplicity / Cardinality / Participation:** There are limitations in logical and physical data models when implementing these constraints on relationships. The implementation of these constraints varies depending on the DBMS. For instance, MySQL supports participation constraints, whether partial or total. For attribute multiplicity, it is possible to limit them through domain definitions, enumeration, and not-null constraints. For example, multiplicity values like 1 and 1..* can be managed by applying a not-null constraint to attributes that must have more than one value. However, there is not always a direct method to enforce these constraints using standard constraints alone. An alternative is to use SQL coding and triggers to mandate the required values. Another solution for handling attribute multiplicity is to create a new table for attributes which can have multiple values like 0..*. For instance, the multiplicity of the *volume* attribute in *LA_SpatialUnit* is [0..*]. We treat such attributes as multivalued and create a separate table to accommodate them.

- **Operations (Methods / Constraints):** Transformation model does not implement operations such as *areaClosed()* in *LA_SpatialUnit* or "count(part)+count(element)>0" in *LA_SpatialUnitGroup*. These operations must be defined by developing functions and triggers in the DBMS.
- **Normalisation:** Normalisation is a technique used to iteratively improve relations to remove undesired redundancy by decomposing relations and eliminating anomalies such as deletion, insertion and update. In First Normal Form (1NF), multivalued attributes and repeating groups will be resolved. In Second Normal Form (2NF), all the partial dependencies are resolved. The next stage is Third Normal Form (3NF) where all the transitive dependencies will be resolved.
- **Indexing:** Indexes are automatically created when defining PKs and FKs. However, it is necessary to manually implement spatial indexes in a DBMS that supports spatial data by using SQL codes.

5.2.2. Physical design

After resolving all issues in the logical data model, physical model can be implemented into the targeted DBMS. There are two approaches to designing the physical data model. Table 1 illustrates the advantages and disadvantages of each approach.

Table 1. Comparison of approaches for implementing physical data models

Generating SQL Codes	Using Database Builder in EA
Advantages: • **Flexibility and full control over SQL code.** • **Allows precise customisation and correction.** • **Independence from EA.** • **Allowing management in any DBMS.**	**Advantages:** • Automates direct changes in the DBMS. • Seamless integration with DBMS for real-time updates. • Provides additional functionalities like views, functions, and queries, and user-friendly interface. • Requires no advanced database knowledge. • Integrates conceptual, logical, and physical models in a single environment.
Disadvantages • **Requires manual modifications.** • **Time-consuming** • **Higher risk of human error during manual editing.** • **Less efficient for large projects.** • **Required more advanced SQL knowledge**	**Disadvantages:** • Requires manual modifications. • Less control over the SQL code. • Dependency on EA. • Complex initial setup and connection process. • Requires a corporate or higher license for EA, which increases costs.

Generating SQL Codes: The first approach we implemented involves extracting SQL code from the DDL codes generated by EA's transformation model, manually correcting any issues in the SQL code as discussed in section 5.2.1, and then executing it in the PostgreSQL DBMS Query Tool.

Using Database Builder in EA: The second approach utilises the Database Builder in EA, which can be directly connected to the DBMS. Any required changes to tables or data are automatically executed in the DBMS. To connect EA to the database, there are several options including a direct native connection or an ODBC-based connection. We used native connection to link EA to PostgreSQL. Once connected, a database package is created, which includes conceptual, logical, and database packages. It is important to note that the results of converting the conceptual to the logical data model using the transformation models (generated DDL tables) must be moved to database package to allow for manipulation. In addition, there are some functionalities such as views, functions, sequences and queries that facilitate the database management. Figure 8 shows a view of the tables created under the Database Builder in EA.

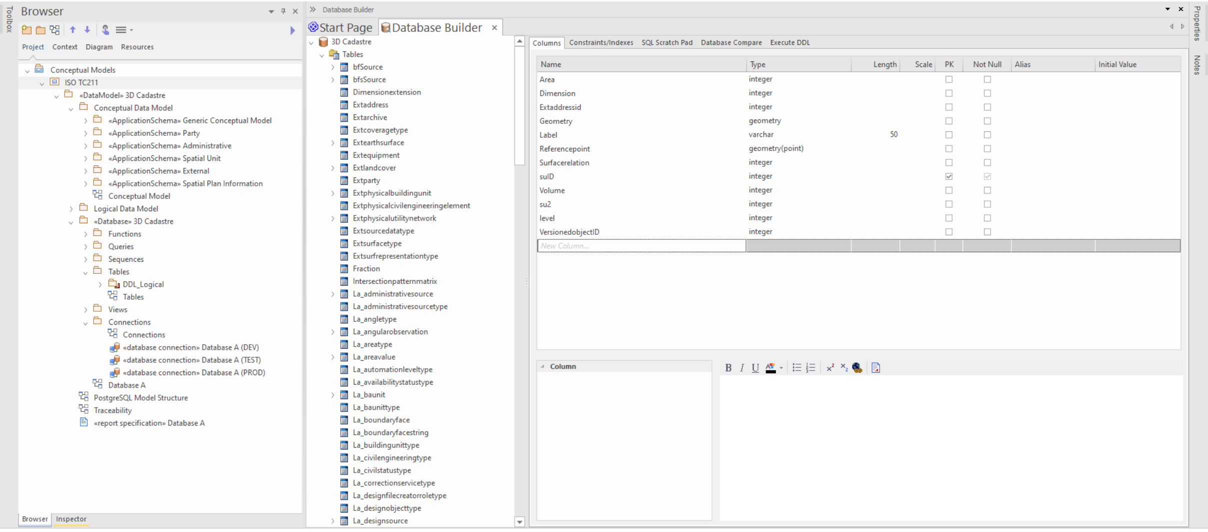

Figure 8. Connecting Enterprise Architect to Database Management System

5.3. Exchange formats – physical data modelling

Implementing exchange formats is crucial for ensuring that cadastral data can be efficiently shared and understood across different systems. For implementing the exchange formats and their physical data models, the first step is having a conceptual data model, which we developed in section 5.1. Then, EA allows us to export this conceptual data model's structure to formats like XSD or XML. These formats provide the foundation for the physical data model and the implementation of exchange formats across different systems. The reason we implemented XML is that ePlan is currently stored in XML format. Moreover, we are interested in implementing JSON because ICSM is developing a 3D conceptual data model for Australia that uses JSON as its format [29]. However, once the project is finalised, this model will need to be customised for use in Victoria.

After exporting the XML, we validated it using an XML validator to ensure its accuracy and consistency. Following validation, there are several options for converting XML to JSON. Since XML is a well-known format supported by most software, it can easily be converted to other formats, such as JSON, and utilised in various projects. The importance of implementing exchange formats like XML and JSON lies in their ability to standardise data, enabling seamless communication and interoperability between various software and platforms. Figure 9 shows a part of the XML and JSON files that were implemented.

```xml
<?xml  version='1.0' encoding='utf-8' ?>
<xs:schema xmlns:xs="http://www.w3.org/2001/XMLSchema">
    <xs:element name="bfSource" type="bfSource"/>
    <xs:complexType name="bfSource">
        <xs:sequence>
            <xs:element name="bf" type="xs:integer" minOccurs="1" maxOccurs="1"/>
            <xs:element name="source" type="xs:integer" minOccurs="1" maxOccurs="1"/>
            <xs:element name="PK_La_boundaryface" type="La_boundaryface" minOccurs="1" maxOccurs="1"/>
            <xs:element name="PK_La_spatialsource" type="La_spatialsource" minOccurs="1" maxOccurs="1"/>
        </xs:sequence>
    </xs:complexType>
    <xs:element name="bfsSource" type="bfsSource"/>
    <xs:complexType name="bfsSource">
        <xs:sequence>
            <xs:element name="bfs" type="xs:integer" minOccurs="1" maxOccurs="1"/>
            <xs:element name="source" type="xs:integer" minOccurs="1" maxOccurs="1"/>
            <xs:element name="PK_La_boundaryfacestring" type="La_boundaryfacestring" minOccurs="1" maxOccurs="1"/>
            <xs:element name="PK_La_spatialsource" type="La_spatialsource" minOccurs="1" maxOccurs="1"/>
        </xs:sequence>
    </xs:complexType>
    <xs:element name="Dimensionextension" type="Dimensionextension"/>
    <xs:complexType name="Dimensionextension">
        <xs:annotation>
            <xs:documentation>The dimension extension type of topology, see ISO 19107:2019</xs:documentation>
        </xs:annotation>
        <xs:sequence>
            <xs:element name="DimensionextensionID" type="xs:integer" minOccurs="1" maxOccurs="1"/>
            <xs:element name="DimensionextensionType" type="xs:string" minOccurs="1" maxOccurs="1"/>
        </xs:sequence>
```

```json
{
  "schema": {
    "element": [
      {
        "_name": "bfSource",
        "_type": "bfSource",
        "__prefix": "xs"
      },
      {
        "_name": "bfsSource",
        "_type": "bfsSource",
        "__prefix": "xs"
      },
      {
        "_name": "Dimensionextension",
        "_type": "Dimensionextension",
        "__prefix": "xs"
      },
      {
        "_name": "Extaddress",
        "_type": "Extaddress",
        "__prefix": "xs"
      },
      {
        "_name": "Extarchive",
        "_type": "Extarchive",
        "__prefix": "xs"
      },
      {
        "_name": "Extcoveragetype",
        "_type": "Extcoveragetype",
        "__prefix": "xs"
      },
      {
        "_name": "Extearthsurface",
        "_type": "Extearthsurface",
        "__prefix": "xs"
      },
```


Figure 9. Implementation of XML and JSON files

6. DISCUSSION

In this section, an assessment of the database implementation and exchange formats (XML and JSON) at the schema level is conducted. Table 2 provides a summary comparison of database schema and exchange format schema (XML, JSON) across various dimensions. Then, the challenges encountered during the implementation will be examined.

- **Conceptual data model integration**

The first step in the process is designing a conceptual data model. Given that LADM II is divided into different parts, each functioning as a separate standard with some overlapping elements, a key challenge is integrating these packages while maintaining consistency and integrity. We addressed this challenge by manually copying the full structure of packages to the core package (in our case, core package is Part 1), ensuring that all connections and links were preserved. However, it is crucial to perform a complete structure copy; otherwise, the integrity and links between the packages could be compromised. Avoiding duplication, maintaining consistency, and ensuring interoperability at the schema level are essential when integrating various standards and data models. However, the challenge of effectively integrating conceptual data models across different systems still remains.

- **Challenges in converting conceptual data model into logical data model.**

Another issue is the challenges in converting a conceptual data model to a logical data model. Currently, there is no fully automated method for this conversion, and many steps still need to be done manually. There are numerous challenges, such as when using software like Enterprise Architect, which automatically creates primary keys and some relationships but struggles with handling certain many-to-many relationships. It can generate indexes but not spatial indexes, and it does not automatically recognise spatial and user-generated data types, constraints, or multivalued and composite attributes.

Table 2. Overview of database schema and exchange format differences

Criteria	Database Schema	Exchange Format Schema (XML, JSON)
Conceptual Model	Both methods share the same conceptual model, ensuring consistency at the conceptual level.	Both methods share the same conceptual model, ensuring consistency at the conceptual level.
User Interface and Ease of Use	Comes with a user-friendly interface that allows easy access and editing of tabular data.	Lacks a native user interface; requires external tools for editing and manipulation
Data Entry	Can be performed manually or automatically using SQL commands or a database interface. Manual entry of geometrical data is particularly challenging.	More challenging without specialised tools; External tools or XML editors are often needed to manage data entry efficiently.
Semantic and Linked Data	Limited. Traditional relational databases are not inherently designed for semantic data or linked data, but they can be extended to support semantic structure. Some DBMSs, such as Oracle, support semantic technologies. Additionally, there are triple stores that support RDF; however, it is necessary to investigate whether they also support 3D spatial data.	XML is naturally compatible with RDF and other semantic web standards. It is easier to convert XML to RDF or import XML to platforms that support semantic formats.
Integrity	Strong data integrity with enforced integrity constraints.	Weaker data integrity.
Flexibility	Changes to schema can be complex, because of constraints	Schemas can be modified more easily

- **Linked data and semantic consistency**

When conceptual model based on LADM is converted into a database, the direct connection with the original model is severed, resulting in a set of tables with independent names that no longer automatically reflect changes made to LADM, particularly when database tables are not linked to the evolving LADM terminology. This can lead to potential inconsistencies or need ongoing updates and alignments. The literature lacks discussion on the semantic implications of converting LADM entities into database tables, which can result in a loss of meaning and alignment with the original standard. To address these issues, the adoption of linked data, ontology, and semantic web principles could enhance semantic consistency, interoperability, and data integration, ensuring that the database and exchange formats remain relevant and connected to evolving standards.

- **Distributed Cadastral Systems in Victoria**

Another issue is that, in Victoria, as in other states or countries, the cadastre is highly distributed across various projects, departments, and agencies. The challenge lies in connecting these disparate systems, especially since there is no centralised database encompassing all of them. An alternative solution is to use the unique identifier in each system. For example, VOTS uses volume and folio method for indexing, which can be linked to spatial cadastral databases through lot and plan numbers and cross referencing with volume and folio numbers [24]. Similarly, the Standard Parcel Identifier (SPI) can be used in the DCDB, and the SPEAR reference number aligns with the SPEAR identifier. Although unique identifiers are accessible in each of these systems that allow us to link and read their data, the problem is that these databases do not connect seamlessly. Integration remains difficult unless a web service from them or access to their online platforms or similar resources is available.

- **Optimisation at schema level**

Another gap is the lack of emphasis on database optimisation strategies. For instance, creating separate tables for code lists increases the overall number of tables, which complicates database management and administration. This approach also leads to more frequent use of *JOIN* functions in queries, which can negatively impact performance and require more advanced SQL knowledge to manage them efficiently. It is essential to consider alternative approaches to improve the quality of database by optimisation strategies.

7. CONCLUSION AND FUTURE WORKS

In this paper, we investigated the Victorian cadastral system and aligned it with LADM II. Then, an integrated data model of LADM Parts 1, 2 and 5 was developed and the challenges in converting the conceptual model to logical and physical models using Enterprise Architect, proposing solutions. We also discussed two approaches for database implementation: using the Database Builder and generating SQL codes. Additionally, we implemented exchange formats based on XML, which is the format used in the current version of ePlan, and JSON, which is a potential future exchange format for Australia. In conclusion, while there are automated tools available for converting conceptual models into logical and implementation models, some issues still require manual intervention. LADM II, particularly Parts 1, 2, and 5, shows some alignment with the Victorian cadastral systems. However, the new version of LADM introduces additional challenges, such as integrating its different parts to avoid data redundancy and maintain consistency and integrity.

There are several gaps in the literature that can be addressed in future works. While our current implementation covers key aspects at the schema level, it is crucial to fully populate all relevant tables to evaluate the database's performance and efficiency at the instance level. Additionally, there is a gap in automatically converting conceptual data models into logical and physical data models. To address this, developing a program that can automate this conversion with less issues is essential. Furthermore, using linked data and semantic web technologies could help connect different conceptual data models more effectively. Storing file formats in both relational and document databases, followed by a comparison of results, is another area that requires exploration.

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BIOGRAPHICAL NOTES

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Determining the semantic similarity of definitions by artificial intelligence for the needs of 3D Land Administration: a case of building units

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Key words: semantic similarity, artificial intelligence, NLP, cosine similarity, LADM

SUMMARY

This article focuses on comparing selected terms connected to the building units across different standards and on testing the possibility of using the calculation of semantic similarity by artificial intelligence in the field of 3D Land Administration.

In the first chapter, the reader is introduced to the issue itself. The second chapter is devoted to determining semantic similarity. First, it is mentioned that it is necessary to use NLP and the related text preprocessing steps. Subsequently, the methods of converting the text into numerical form (vectorization) and then the actual methods of calculation of the semantic similarity between two texts are described. In the third chapter, the reader will learn which standards and the corresponding terms and definitions have been selected. Subsequently, the results of the calculation of semantic similarity using artificial intelligences from OpenAI and Hugging Face are presented here. Finally, the results are compared with each other. In the last chapter, the entire text is summarized and some problems and possibilities for further research are discussed here.

Determining the semantic similarity of definitions by artificial intelligence for the needs of 3D Land Administration: a case of building units

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1. INTRODUCTION

In recent years, artificial intelligence has undergone significant development, and its influence is gradually beginning to manifest itself in an increasing number of different fields. The basic premise of artificial intelligence is that it can understand natural language correctly. In order for this to be possible, it is necessary to use the so-called Natural Language Processing (NLP). NLP is key to converting texts into numerical form and then determining semantic similarity, which is the calculation of a numerical value that determines how similar the texts are in meaning. With such a value, the computer can already work and it is important, in addition to artificial intelligence, for example, in various Internet search engines, in text generation and in a number of other diverse applications.

A problem that also occurs within the 3D Land Administration, for example, is that there are a number of different definitions for individual terms. This can be the cause of a number of misunderstandings, when anyone can understand something different by the given term. The need to talk in a unified language is especially crucial in the case of interconnecting two or more domains together, i.e. BIM/IFC, 3D Land Administration/ISO 19152 and GIS/CityGML. The problem can also occur in the case of various national legislations when each country could use different terms for the same thing/object.

In order to avoid this, it is also possible to use the calculation of semantic similarity, which will help to compare the agreement between individual definitions and allow to find the ones that are the most or, conversely, the least similar. Definitions that have a high semantic similarity are less likely to cause misunderstanding than those that are only minimally similar. Since every artificial intelligence must have some model implemented to calculate semantic similarity, it seems like a good option to use it to solve this problem. In order to calculate the semantic similarity, it is necessary to convert the text into numerical form, so that this is possible, it is necessary to use NLP first. Subsequently, it is already possible to proceed with the conversion of the text into numerical form (into the form of a vector). There are a number of different models that convert text to vector for this purpose. After the text is converted to a vector, the semantic similarity between the two texts (vectors) is calculated. For this purpose, it is possible to use the semantic similarity calculation model used by some of the artificial intelligences.

Artificial intelligence can be used to compare definitions with each other, which can have a significant positive effect on the field of 3D Land Administration as well. This article focuses on comparing selected terms connected to the building units across different standards. Which can help prevent future misunderstandings. There are several publications that focus on the issue of semantic similarity calculation with the use of artificial intelligence, but none of them have yet dealt with this issue for comparing terms and definitions in the field of land administration. The aim of this work is to test the possibility of using the calculation of semantic similarity by artificial intelligence in the field of 3D Land Administration.

2. DETERMINING SEMANTIC SIMILARITY

This chapter deals with the method of calculating the semantic similarity between two texts and the steps that precede the calculation itself. The basic idea is to convert text into a form that a computer can understand. It is necessary to preprocess the text based on NLP and then convert it into numerical (vector) form. In this chapter, the individual steps of preprocessing are described, followed by some models that are used for conversion into vector form and, finally, some options for calculating the textual similarity between two texts.

2.1 Natural Language Processing

To calculate semantic similarity, it is first necessary to convert the text into a form that a computer can understand. The so-called Natural Language Processing (NLP) is used for this purpose. It is a discipline that deals with the conversion of text into a computer-intelligible (usually numerical) form (Xieling et al., 2022). This is particularly advantageous for the automation of certain processes and essential for the correct functionality of artificial intelligence (AI) (Khurana et al., 2023).

In NLP, several basic steps are used during text preprocessing, which enable subsequent easier work with the text when converting it into numerical form (Kadhin, 2018). These are:

- Normalization: This step focuses on editing the text so that it is converted to a basic form. In the resulting form of the text, all letters should be lowercase, there should be no special characters, links, punctuation, numbers, etc. in the text (Pal, 2021).
- Tokenization: The goal of this step is to divide the text into certain continuous sequences of characters that have semantic meaning. This usually involves dividing the text into individual words, so-called tokens (Petrović and Stanković, 2019).
- Stop word removal: This step deals with the removal of so-called stop words. These are words that occur frequently in the text and do not add any new meaning to it. These are mainly conjunctions and prepositions. The word "and" can be an example of such a word (Denny and Spirling, 2018).
- Stemming: This step is aimed at finding the root of words by removing prefixes and suffixes (Hickman et al., 2022).
- Lemmatization: In this case, the corresponding lemma is searched for the word. Unlike stemming, meaning is also considered. Especially if it is a verb, a noun, etc. For example, the word "set" can be a verb in some cases and a noun in others (Chai, 2023).

2.2 Vectorization

Since computers understand numbers best, after preprocessing it is necessary to convert the text into numerical form, preferably into vector form. This process is called text vectorization or text embeddings (Rani et al., 2022). There are several different models used to vectorize text, only some of the most well-known models are described here:

- Bag of Words (BoG): This is the simplest method that is based on word count only. The resulting vector has a length corresponding to the number of different words in the text, and each value of the vector corresponds to the number of occurrences of the given word in the text. This approach does not consider the context in which individual words are found, and therefore the subsequent calculation of semantic similarity can be quite inaccurate (Rani et al., 2022).

- Word2vec: This model already considers the context in which the words are found. It is based on a neural network using a training process. The resulting vectors of semantically similar words will have a strong relationship with each other and will be close to each other in the vector space. It follows that the vectors created by this method also contain semantic information (Yang et al., 2022).
- Global Vector for word representation (GloVe): It is a log-bilinear regression model and unsupervised learning model. Compared to Word2vec, it is faster and provides more accurate results (Pennington et al., 2014). This model is based on the creation of a matrix, the rows of which correspond to individual words and contain their vector representations, the columns of the matrix subsequently correspond to the different contexts in which the words can occur (Rani et al., 2022).

2.3 Computing semantic similarity

After the text is converted to a vector, the semantic similarity between the two texts (vectors) is calculated. This can be calculated in several possible ways. For example, the Euclidean distance calculation can be used, where the distance between two vectors is calculated. The formula for calculating the Euclidean distance is as follows:

$$d(\mathbf{p},\mathbf{q}) = d(\mathbf{q},\mathbf{p}) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \cdots + (q_n - p_n)^2} = \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2},$$

where **p** and **q** are vectors of compared texts and n is the number of vector values (Pal, 2021). A more commonly used and more accurate method is cosine similarity. In this case, the cosine of the angle between two vectors is measured using the following formula:

$$\cos\theta = \frac{\mathbf{p}\cdot\mathbf{q}}{\|\mathbf{p}\|\|\mathbf{q}\|} = \frac{\sum_{i=1}^{n} p_i q_i}{\sqrt{\sum_{i=1}^{n} p_i^2}\sqrt{\sum_{i=1}^{n} q_i^2}},$$

where **p** and **q** are vectors of compared texts and n is the number of vector values (Pal, 2021). The result of this calculation is the angle between the given vectors. If it is zero, the cosine similarity is equal to one, and such two vectors have the highest similarity (100%). Conversely, if the angle between the vectors is 90°, the cosine similarity is zero and such vectors have the lowest similarity (0%) (Pal, 2021).

3. METHODOLOGY

This chapter is devoted to the calculation of semantic similarity using AI on the example of terms and definitions from the field of 3D Land Administration. The results are also compared with each other.

3.1 Selection of terms and definitions

First it was necessary to determine the standards that will be used and then to select from them the terms and corresponding definitions from the area of 3D Land Administration related to building units. Land Administration Domain Model (LADM) was chosen as the

basic standard, the terms of which will be compared with the terms of other standards. Terms and definitions from the Industry Foundation Classes (IFC 4.3), Land and Infrastructure Conceptual Model Standard (LandInfra) and City Geography Markup Language (CityGML 3.0) standards were then selected for comparison.
Terms and definitions related to building units were selected from the above-mentioned standards and these were subsequently recorded in individual tables (see tables 1 – 4). The definitions were selected from part 3 of the IFC 4.3 standard, and from part 4 of the LADM, InfraGML and CityGML 3.0 standards.

Table 1 – terms and definition from LADM (ISO, 2012)

Land Administration Domain Model (LADM)		
1	basic administrative unit	Administrative entity, subject to registration (by law), or recordation [by informal right, or customary right, or another social tenure relationship], consisting of zero or more spatial units against which (one or more) unique and homogeneous rights [e.g. ownership right or land use right], responsibilities or restrictions are associated to the whole entity, as included in a land administration system.
2	boundary	Set that represents the limit of an entity.
3	boundary face	Face that is used in the 3-dimensional representation of a boundary of a spatial unit.
4	boundary face string	Boundary forming part of the outside of a spatial unit.
5	building unit	Component of building (the legal, recorded or informal space of the physical entity).
6	land	The surface of the Earth, the materials beneath, the air above and all things fixed to the soil.
7	spatial unit	Single area (or multiple areas) of land and/or water, or a single volume (or multiple volumes) of space.

Table 2 – terms and definitions from IFC 4.3 (ISO, 2024)

IFC 4.3		
1	building information modelling	Use of a shared digital representation of an asset to facilitate design, construction and operation processes to form a reliable basis for decisions.
2	element	Physical object with a stated function, form and position.
3	entity	Class of information defined by common properties.
4	facility	Physical structure, including the related site, serving one or more main purposes.
5	feature	Conceptualization of certain design or manufacturing functionality to implicitly alter the geometric form of an element to be computed at import.
6	model	Collection of entity data type instances.

7	object	Any part of the perceivable or conceivable world.
8	product	Thing or substance produced by a natural or artificial process.
9	property	Defined characteristic suitable for the description and differentiation of an object.
10	property set	Named set of properties grouped under some characteristics.
11	representation	Organized collection of associated data elements, collected together for one or more specific uses.
12	space	Limited three-dimensional extent defined physically or notionally.

Table 3 – terms and definitions from LandInfra (OGC, 2016)

Land and Infrastructure Conceptual Model Standard (LandInfra)		
1	administrative division	Division of state territory according to political, judicial, or executive points of view.
2	building	Construction works that has the provision of shelter for its occupants or contents as one of its main purposes, usually partially or totally enclosed and designed to stand permanently in one place.
3	building part	Floor-related part of a multi-storage building, subdivided according to management and use by a lawful process.
4	boundary	Set that represents the limit of an entity.
5	condominium	Concurrent ownership of real property that has been divided into private and common portions.
6	construction	Assembled or complete part of construction works that results from work on-site.
7	facility	Improvements of or on the land including buildings and civil engineering works and their associated siteworks.
8	feature	Abstraction of real world phenomena.
9	interest in land	Ownership or security towards real property.
10	land	Area of earth's surface, excluding the oceans, usually marked off by natural or political boundaries, or boundaries of ownership.
11		The surface of the Earth, the materials beneath, the air above and all things fixed to the soil.
12	land parcel	Contiguous part of the surface of the Earth (land and/or water) as specified through lawful process.
13	ownership (in land)	Includes the right to grant a lease, an easement, or a security interest and other lesser rights.
14	physical element	Any component defined within the spatial and functional context of a facility.
15	positioning element	Virtual element used to position, align, or organize physical elements.
16	product	Item manufactured or processed for incorporation in construction works.
17	retaining wall	Wall that provides lateral support to the ground or that resists

		pressure from a mass of other material.
18	site	Area of land or water where construction work or other development is undertaken.
19	spatial unit	Contiguous geometrical entity, which is delimited and located on or close to the surface of the Earth through the bounding elements of its boundary.
20	wall	Vertical construction that bounds or subdivides a space and usually fulfils a loadbearing or retaining function.

Table 4 – terms and definitions from CityGML 3.0 (OGC, 2023)

CityGML 3.0		
1	2D data	Geometry of features is represented in a two-dimensional space.
2	2.5D data	Geometry of features is represented in a three-dimensional space with the constraint that, for each (X,Y) position, there is only one Z.
3	3D data	Geometry of features is represented in a three-dimensional space.
4	city-object relation	Specific relation from the city object in which the relation is included to another city object.
5	feature	Abstraction of real world phenomena.
6	geometry	An ordered set of n-dimensional points in a given coordinate reference system; can be used to model the spatial extent or shape of a feature.
7	life-cycle information	Set of properties of a spatial object that describe the temporal characteristics of a version of a spatial object or the changes between versions.
8	space	Entity of volumetric extent in the real world.
9	space boundary	Entity with areal extent in the real world. Space boundaries are objects that bound a Space. They also realize the contact between adjacent spaces.
10	top-level feature	Feature that represents one of the main components of 3D city models; can be further semantically and spatially decomposed and substructured into parts.

3.2 Computing semantic similarity by artificial intelligence

Subsequently, it was already possible to proceed with the calculation of semantic similarities between the individual definitions of the given terms. The text-embedding-ada-002 model, which uses AI from OpenAI, was used for the calculation. To compare the approaches of different AIs, AI from Hugging Face was also used to calculate semantic similarity.
Individual definitions were passed to these artificial intelligences and the results were semantic similarity values between the given terms. The resulting values were recorded in tables, where each column was coloured separately with a colour transition from red to green, where red indicates the lowest value of semantic similarity in the given column, while green indicates the highest (see tables 5 – 7 for results from OpenAI AI and tables 8 – 10 for results from Hugging Face AI).

Table 5 – semantic similarity results from OpenAI AI between LADM and IFC 4.3 (results are in percentages)

		Land Administration Domain Model (LADM)						
IFC 4.3		1	2	3	4	5	6	7
	1	76,98	70,95	76,28	74,42	79,34	72,99	77,41
	2	77,91	74,00	81,03	80,45	81,16	79,88	80,84
	3	77,92	73,32	73,99	74,63	78,18	72,84	76,09
	4	79,86	70,83	79,30	81,43	85,29	78,98	83,41
	5	73,76	70,19	76,83	76,50	76,62	71,97	74,41
	6	74,57	75,70	71,09	71,81	72,88	69,22	72,61
	7	77,89	72,57	79,43	81,62	82,86	81,65	81,79
	8	75,45	69,25	74,96	75,07	77,44	78,79	78,05
	9	76,64	73,57	77,38	76,24	75,50	73,27	76,86
	10	78,78	75,36	76,78	77,57	77,45	76,13	79,85
	11	80,71	72,27	75,66	76,96	79,06	74,12	81,15
	12	80,21	78,40	84,51	83,64	80,84	79,49	85,41

Table 6 – semantic similarity results from OpenAI AI between LADM and LandInfra (results are in percentages)

		Land Administration Domain Model (LADM)						
LandInfra		1	2	3	4	5	6	7
	1	80,16	72,31	79,65	81,31	77,67	75,75	82,19
	2	77,44	69,45	75,14	78,29	82,65	76,42	80,15
	3	81,72	71,16	77,88	79,57	85,85	76,57	84,27
	4	74,87	100,00	76,71	76,70	74,84	69,55	72,84
	5	80,96	70,39	74,40	76,70	79,59	73,14	80,05
	6	76,58	69,86	77,56	80,17	83,36	77,43	78,70
	7	78,21	68,28	73,88	76,34	81,28	78,40	80,54
	8	75,56	72,39	77,82	77,09	76,46	78,09	77,40
	9	82,35	72,49	75,32	76,14	81,85	76,20	79,81
	10	81,71	73,69	82,03	84,88	81,35	84,38	86,80
	11	75,82	69,55	78,02	78,16	77,42	100,00	82,46
	12	82,06	73,40	82,07	84,58	83,03	84,21	86,72
	13	81,76	70,94	72,63	74,19	77,88	74,33	77,92
	14	80,13	73,03	81,09	83,16	87,04	77,52	82,87
	15	75,47	72,34	80,54	79,30	81,99	75,61	79,84
	16	76,59	70,55	76,85	76,41	80,74	76,66	77,54
	17	75,41	72,74	79,90	80,16	79,37	79,26	79,55
	18	81,19	71,93	78,70	81,67	83,42	78,59	87,24
	19	82,68	77,38	84,94	85,84	82,08	82,46	83,93
	20	77,57	72,28	80,28	81,00	83,76	75,87	81,93

Table 7 – semantic similarity results from OpenAI AI between LADM and CityGML 3.0 (results are in percentages)

		Land Administration Domain Model (LADM)						
		1	2	3	4	5	6	7
CityGML 3.0	1	74,96	71,61	84,21	82,67	78,29	78,37	82,58
	2	76,6	73,87	84,65	80,20	77,27	78,95	82,48
	3	75,01	71,23	86,74	81,97	78,21	78,83	81,88
	4	71,78	73,11	73,07	75,51	73,93	70,06	71,69
	5	75,56	72,39	77,82	77,09	76,46	78,09	77,36
	6	79,06	74,68	84,84	84,53	78,54	76,08	82,53
	7	79,83	74,89	78,98	80,22	80,38	75,04	79,92
	8	80,58	78,94	84,40	82,34	81,74	78,89	84,80
	9	81,21	77,36	83,17	85,15	83,01	78,96	84,02
	10	78,38	72,83	85,52	82,88	82,64	75,16	80,53

Table 8 – semantic similarity results from Hugging Face AI between LADM and IFC 4.3 (results are in percentages)

		Land Administration Domain Model (LADM)						
		1	2	3	4	5	6	7
IFC 4.3	1	22,40	12,30	19,40	13,80	43,10	1,80	18,30
	2	24,60	23,90	39,90	33,00	41,30	24,90	22,80
	3	29,60	38,20	12,80	10,40	31,30	12,10	22,20
	4	22,60	19,70	19,80	27,20	57,50	36,40	38,50
	5	9,00	4,80	32,30	19,70	34,00	14,40	13,30
	6	39,60	47,00	7,10	6,60	26,90	6,20	17,60
	7	11,40	22,20	18,30	25,10	21,40	22,60	32,20
	8	16,40	13,30	9,00	17,40	35,70	25,30	7,50
	9	30,40	31,10	35,80	21,70	34,70	12,30	16,20
	10	29,20	45,90	23,60	23,80	40,10	19,30	27,90
	11	27,40	26,10	13,40	8,30	35,50	14,10	25,90
	12	21,00	27,70	54,40	35,50	31,90	15,10	39,20

Table 9 – semantic similarity results from Hugging Face AI between LADM and InfraGML (results are in percentages)

		Land Administration Domain Model (LADM)						
		1	2	3	4	5	6	7
InfraGML/LandInfra	1	28,30	19,70	28,30	38,00	31,90	14,80	43,00
	2	19,40	11,90	20,40	28,60	55,80	24,10	24,40
	3	33,90	15,70	21,10	28,50	51,80	19,30	39,40
	4	43,70	100,00	20,10	18,00	29,20	8,70	23,10
	5	35,10	25,70	11,10	26,20	38,90	8,00	26,60

6	12,70	4,50	7,70	17,90	47,20	25,50	15,80
7	22,40	12,40	10,00	14,10	36,50	35,40	18,90
8	15,40	8,40	29,60	25,20	28,40	16,10	17,10
9	39,60	23,10	14,70	20,00	38,90	10,30	16,10
10	32,20	20,20	36,40	44,50	28,60	50,70	58,10
11	16,30	8,70	15,20	24,20	25,00	100,00	44,10
12	28,40	23,70	35,70	49,10	36,90	53,20	55,80
13	35,20	15,30	13,90	18,10	28,00	16,30	20,80
14	35,90	33,40	37,70	38,90	63,30	22,90	40,60
15	23,00	19,00	29,80	26,10	50,90	27,50	30,50
16	10,90	10,40	5,70	15,30	51,90	12,40	4,80
17	7,10	11,30	29,80	34,80	37,80	39,00	26,50
18	22,60	9,90	18,30	30,70	46,40	41,00	50,50
19	35,10	34,60	44,30	54,20	38,20	42,70	48,80
20	13,10	23,00	34,20	38,90	38,10	24,00	30,80

Table 10 – semantic similarity results from Hugging Face AI between LADM and CityGML 3.0 (results are in percentages)

		Land Administration Domain Model (LADM)						
		1	2	3	4	5	6	7
CityGML 3.0	1	19,80	16,20	51,80	35,70	30,70	9,30	34,00
	2	13,60	18,70	40,10	16,90	18,40	8,80	28,20
	3	16,00	15,90	59,50	28,40	29,40	13,00	33,50
	4	20,90	25,80	24,50	25,10	32,60	13,40	19,70
	5	15,40	8,40	29,60	25,20	28,40	16,10	17,10
	6	23,10	27,60	44,20	27,90	25,10	17,40	34,20
	7	36,80	34,00	34,90	31,30	43,70	21,20	29,20
	8	20,40	18,20	42,30	37,10	26,50	26,40	50,70
	9	41,20	36,60	42,50	53,90	39,50	27,80	48,80
	10	15,30	12,60	45,60	29,60	44,80	20,40	37,70

3.3 Comparison of results

Thanks to the coloring of the resulting values of semantic similarity, it is possible to estimate at first glance that the results are meaningful and that both artificial intelligences provide similar results. The difference in that the resulting values from the OpenAI AI are in the range of approximately 70 % – 100 % and the resulting values from the Hugging Face AI in the range of 0 % – 100 % is caused by the model that the given AI uses to calculate semantic similarity.

When comparing the numerical values, it turns out that both artificial intelligences determine the same two definitions for 15 out of 21 cases as the definitions with the greatest similarity. This is 71,4 % of cases. An example can be the definitions of the term spatial unit in LADM and space in IFC 4.3, when the similarity between these two definitions reaches 85.41 % in the case of calculation using OpenAI AI and 39.20 % in the case of calculation using Hugging

Face. In both cases, this is the greatest similarity between the individual definitions of terms from IFC 4.3 and the term spatial unit from LADM. Such results can be very interesting, especially when mapping the classes of individual standards to each other and during the subsequent transition from one standard to another. In this case, the result shows that spatial units from LADM, which can be for example rooms or property spaces, will be mapped to a class in IFC 4.3 that supports spaces (i.e. the IfcSpace class) (ISO, 2024).

Otherwise, when determining the definitions with the least similarity, the two AIs agree on only 4 out of 21 terms. This is 19 % of cases. An example can be the definition of boundary face from LADM and city-object relation from CityGML 3.0, where the similarity between these two definitions reaches 73.07 % in the case of calculation using OpenAI AI and 24.50 % in the case of calculation using Hugging Face AI. In both cases, this is the smallest similarity between the individual definitions from CityGML 3.0 and the boundary face definition from LADM. The differences in the resulting values are because the two AIs use a different model to calculate semantic similarity. Overall, when comparing the results of semantic similarity for a specific term, it can be stated that the results of both AIs are similar, since, for example, if the similarity between two specific definitions is low for the first AI it can be expected that the result of semantic similarity between the same definitions will reach a low value also in the case of the second AI.

In some cases, it may happen that even if two different standards define the same terms, it may turn out that their definitions do not have the highest semantic similarity. An example of this can be the term spatial unit, which occurs both in LADM and in InfraGML. The results show that even though both standards use the same term, their definitions do not have the highest similarity. Spatial unit from LADM has greater semantic similarity with terms site and land than with spatial unit from InfraGML.

Furthermore, for some terms, an own calculation of semantic similarity was performed using the BoG method (which is based on word counting and does not consider the context) and the subsequent calculation of cosine similarity. Since the given definitions do not contain many identical words, the results are quite imprecise. For example, for the terms spatial unit from LADM and space from CityGML 3.0, the semantic similarity from our own calculation was only 20.52 %, although according to the results from calculations by AI it should be high. The same case is the terms spatial unit from LADM and space from IFC 4.3, whose semantic similarity is high according to AI, but since the given definitions do not contain any of the same words, the semantic similarity from our own calculation came out to be 0 %. It follows that methods that do not take context into account are highly inaccurate.

By verifying that the semantic similarity calculation is going well, the semantic similarity result can be for the term boundary, which has the same definition in both LADM and LandInfra. As expected, the AI-calculated semantic similarity was 100 % in both cases.

4. DISCUSSION AND CONCLUSION

The method of determining semantic similarity was described within the text. First, it was mentioned that it is necessary to use NLP and the related text preprocessing steps. Subsequently, the methods of converting the text into numerical form (vectorization) and then the actual calculation of the semantic similarity between two texts were described. The next chapter was devoted to the methodology of calculating semantic similarity using AI between selected terms from the field of 3D Land Administration. Finally, the resulting values were compared.

The results show that the calculation of the semantic similarity of the texts was successful in all cases. The differences between individual results are because each AI uses a different model to calculate semantic similarity. For example, even if the results of the AIs do not agree on which two definitions have the least similarity to each other, it can be expected that if one AI comes up with a low similarity value between two definitions, then the other AI will also come out with a low similarity value for these definitions. From the results, it can also be concluded that for determining the semantic similarity of definitions, it is more appropriate to use calculations that also consider the context. Otherwise, two definitions may have a high degree of similarity in meaning, but the resulting value will be zero due to the absence of common words. In conclusion, it is possible to state that artificial intelligence can help with comparing selected terms connected to the building units across different standards. Which can subsequently significantly help when trying to map different classes from different standards onto each other and prevent possible misunderstandings not only in the field of 3D Land Administration.

A problem that can occur when mapping between different standards is that it may happen that the same terms are not the closest in meaning in the two standards and then it is necessary to determine which two terms to use for mutual mapping. Further research would be needed for this. This work was understood as an introduction to the issue of comparing selected terms from the field of 3D Land Administration connected to the building units across different standards using AI. Furthermore, it would be advisable to carry out research that would verify the usability of the calculation of semantic similarity by artificial intelligence for the needs of class mapping between individual standards, which would be useful, for example, during the conversion between IFC 4.3 and CityGML 3.0.

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BIOGRAPHICAL NOTES

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Otakar ČERBA, Ph.D. works at the Department of Geomatics (Faculty of Applied Sciences, University of West Bohemia, Plzeň, Czech Republic). He is focused on web cartography, thematic cartography, Linked Data on the geographic domain and semantic issues of geographic data. He has been involved in many international projects such as Humboldt, SDI4Apps, SmartOpenData, Plan4all or ROSIE. Otakar Čerba is the members of the board of Czech Cartographic Association and the chair of the Commission on Maps and the the Internet of International Cartographic Association.

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The Governance of Semantic Resources for the FIG Community

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Key words: AGROVOC Multilingual Thesaurus (AGROVOC), Cadastre and Land Administration Thesaurus (CaLAThe), FIG's International Office for Cadaster and Land Records (OICRF), The Linked Land Governance Thesaurus (LandVoc), Teaching Essentials for Responsible Land Administration (TERLA)

SUMMARY

Knowledge Organization Systems (KOSs) or controlled vocabularies in terms of taxonomies, thesauri, and ontologies, among others, enable Semantic Web and Linked Data implementations by supporting the publishing of data in a relational, structured way. A number of KOSs are available for the FIG community, as outlined by Çağdaş et al. (2021). Among these, The Linked Land Governance Thesaurus (LandVoc) and Cadastre and Land Administration Thesaurus (CaLAThe) are two thesauri developed specifically for the service of the land related discipline. The former is related to land governance; while the latter is related to the administrative, legal, and geospatial aspects of cadastre and land administration. These thesauri have some commonalities in terms of subject areas, yet are different regarding scope and level of detail; therefore, they support each other.

The LandVoc thesaurus is stored as a subschema of FAO's AGROVOC Multilingual Thesaurus (AGROVOC). Investigation on whether CaLAThe should join the AGROVOC context as a subschema is ongoing. This effort may be adequate but would benefit from being supplemented with support for the explorative development and application of semantic resources, including ontologies, and the application of these in higher education.

The role of the FIG International Office for Cadastre and Land Records (OICRF) in documenting knowledge on land administration may also include the storing of semantic resources. Such semantic resources include FIG- and land-related ontologies, thesauri, taxonomies, as well as code lists and their values specified by ISO Land Administration Domain Model (cf. Kara et al., 2022). We therefore suggest the establishment of a working group with the support of FIG representation, in charge of the integration, maintenance and application of CaLAThe and LandVoc as comprehensive, research-related semantic resources for FIG and the broader land sector. The proposed working group will include representatives of universities, mapping and cadastral agencies, and land and data practitioners working to improve interoperability of semantic resources. The governance of semantic resources related to cadastre, land administration and land governance will contribute to the improved understanding of linked land administration data. Publishing cadastral, land administration and governance data (cf. Stubkjær & Çağdaş, 2015) and LinkedSDG data contribute to better reporting on the land-related Sustainable Development Goals indicators. This underlines the

role that land administration can play in support of sustainable development (cf. Bayer & Meggiolaro, 2024).

The purpose of the paper is to (i) describe the importance of semantic web technology for the recording and the improved discoverability of land administration data and (ii) document the ongoing investigations regarding alignment of CaLAThe and LandVoc for the benefit of FIG and the land administration community as a whole.

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1. INTRODUCTION

The notion of *semantic resources* is introduced to the geospatial community referring to controlled vocabularies, specifically thesauri, which assist in providing interoperability among datasets in the surveying and the construction sector and support a wider e-governance perspective (Çağdaş et al., 2021). Compared to the uptake and application of geospatial tools for solving land-related problems and processes (Hull et al., 2022) the use of semantic resources lags, despite the paramount importance of researchers' and students' shared understanding of terms.

The introduction of thesauri to the largely science and technology-based geospatial domain might be supported by recalling that the zeal of structuring phenomena into hierarchies is as old as Western science: Aristotle (384-322 B.C.) devised a classification scheme for animals, which as Medieval 'Scala Naturae' formed the basis for Carl Linnaeus' Systema Naturæ from 1737, where he divided the physical components of the world into the three familiar kingdoms of minerals, plants and animals. Roget's Thesaurus of English Words and Phrases (1852) provided, according to Roget in his introduction, a "verbal classification . . . the same as that which is employed in the various departments of natural history" (Gilchrist, 2003). This structuring tradition is manifest also within the FIG community: Barry and Roux argue that a more rigorous, formally structured, approach to land tenure information systems theory development is desired. Therefore, they adapt Glazier and Grover's taxonomy, a hierarchy consisting of worldview, paradigm, grand theory, formal theory, substantive theory, hypothesis, research question, proposition, concept, definition, and symbol (2012). However, the following leaves the issue of theory development.

In the present context of research and education, the notion of *semantic resources* also refers to traditional lecturing material as well as to the *knowledge assets* or *intellectual capital* of an organization. The latter includes e.g., guides, standards, and tools mentioned in the Terms of Reference of the C7 Work plan 2023-26, e.g. the Cadastre 2014 (Kaufmann & Steudler, 1998) and ISO 19152:2012 Land Administration Domain Model (LADM) (ISO, 2012). An organization may create value through *knowledge management*, but this issue is not further explored.

This paper is a follow-up of previous work on controlled vocabularies, thesauri, and Knowledge Organization Systems (KOSs) (e.g. Stubkjær & Çağdaş, 2021). Working with thesauri changes the focus from solving problems in society or developing new technology to reflecting on the concepts of the domain of land, the relations among these concepts, and their structuring in various hierarchies. The ISO 19152-1:2024 LADM (ISO, 2024) provides for a normative structure, supplemented by code lists and national profiles. However, worldwide diverse cultures and different languages exist. Translations of terms between languages can result in confusion, especially where terms are already poorly defined (Hull, 2024); therefore, the normative structure is supplemented through thesauri (Stubkjær et al., 2018; Stubkjær et al., 2019) as well as various alternative structures as unfolded in the following.

Linked Data refers to data published on the Web in such a way that it is machine-readable, its meaning is explicitly defined, it is linked to other external data sets and can in turn be linked to external data sets (Bizer et al., 2009). It is built upon a set of standards and specifications published by the World-Wide Web Consortium [1] (W3C) such as Resource Description Framework (RDF), RDF Scheme (RDFS), Simple Knowledge Organization Systems (SKOS), Web Ontology Language (OWL), and SPARQL Query Language for RDF (SPARQL). In Linked Data, a resource is accessed by Uniform Resource Identifiers (URI) over the Web, described by RDF based on standardised RDF vocabularies, connected with other semantically related resources by RDF links (Berners-Lee, 2006), and queried by SPARQL. The meaning of the concepts used in data and relationships between these concepts may be defined by KOSs such as taxonomies, thesauri, or ontologies, which are represented through RDF vocabularies such as OWL or SKOS.

Van den Brink et al. in Best Practices for Publishing, Retrieving, and Using Spatial Data on the Web (2019) notes that the linked data web technology, promoted by the W3C, adds vocabulary management and tooling to the principles, tools, and standards that enabled search engine results for consumer shopping. Authors describe best practices, and note unsolved questions related to representing geometry on the Web, with regard to recommendable serialization forms and formats, and the use of coordinate reference systems. OGC's GeoSPARQL offers a vocabulary that allows serialization of geometries as GML, but the lack of best practices on the consistent use of the existing spatial data vocabularies prevents interoperability. A proposed update of GeoSPARQL, Version: 1.1 [2] has since been achieved.

Other researchers implemented the Linked Data approach to cadastre and land administration domain. For instance, Saavedra et al. (2014) integrated data coming from different cadastral data producers through the Linked Data approach in a Colombian case study. Abd Ghafar & Abu Hanifah (2014) introduce semantic technology supporting knowledge interoperability. Shi et al. (2017) described the publishing and integration of several cross-domain government datasets related to state-owned real estates as Linked Open Data. Ronzhin et al. (2019) presented experiences from building a Knowledge Graph by the Netherlands' Kadaster Land Registry and Mapping Agency and demonstrated the advantages of the Knowledge Graph in three different use cases. Vilches-Blázquez & Saavedra (2019), presented a framework for generating, enriching, and exploiting geospatial Linked Data from multiple and heterogeneous geospatial data sources. They further provided a case study where land administration information from two Colombian agencies were semantically integrated through knowledge graphs and enriched with other data according to Linked Data principles (Vilches-Blázquez & Saavedra, 2022). The above-mentioned research may indicate that we are facing a new (sub-)discipline. The databases of traditional GISs are being replaced by structures (triplestores), which hold concepts that are related through primitive sentences. This implies a new focus on concepts and the corresponding discipline of semantics. Bucher et al. in EuroSDR Knowledge Graph about Geodata Products in Europe (2024) offer an introduction to semantic web

[1] https://www.w3.org/

[2] http://www.opengis.net/doc/IS/geosparql/1.1

technologies (section 1.2) and among others informs on the Dutch National Digital Heritage program (NDE) (cf. Schreiber, 2010).

Concept sets in a domain of interest, their definitions and relationships are specified by KOSs in different levels of complexity, such as term lists, taxonomies, classification schemes, thesauri, and ontologies. Researchers have developed various KOSs in the form of ontology based on ISO LADM, to realise Linked Data implementations in the domain of cadastre and land administration, e.g. Soon (2013), Sladić et al. (2013), Shi et al. (2017), Vilches-Blázquez and Saavedra (2022).

In addition to these ontologies, several land-related thesauri are available for the FIG community, as outlined by Çağdaş et al. (2021). Among these, The Linked Land Governance Thesaurus (LandVoc) and Cadastre and Land Administration Thesaurus (CaLAThe) are two thesauri developed specifically for the service of the land-related disciplines. The former is related to land governance, while the latter is related to cadastre and land administration. These thesauri have some commonalities in terms of subject areas, yet are different regarding scope and level of detail; therefore, they support each other.

The governance of these two complementary semantic resources together with code lists and their values, specified according to the ISO LADM formalism, contribute to the improved understanding of linked land administration data. LinkedSDG[3] data also contribute to better reporting on the land-related SDG indicators. The FIG publication on the Digital Transformation of Land Administration highlights the necessity of clear definitions and uses of terminology referencing specifically LandVoc as well as FAO and FIG glossaries (FAO, UNECE and FIG, 2022). This underlines the role that land administration can play in support of sustainable development (cf. FAO & IFAD, 2022; Bayer & Meggiolaro, 2024). The above-mentioned extension of the focus on concepts suggest to engage and organise colleagues to manage and develop these semantic resources, support their integration into research, and to cooperate with related disciplines in developing courses which introduces next generation of students to the semantic technology (Čeh & Tekavec, 2023; Jovanovik & Spasić, 2019).

The rest of the paper is organised as follows. Section 2 introduces land-related semantic resources in terms of three thesauri: AGROVOC, LandVoc, and CaLAThe, and in terms of FIG Sustained Semantic Resources: OICRF, ISO LADM, the FIG Standards Network, and The Responsible Land Administration Teaching Essentials. In section 3 the use of thesauri in research and (higher) education is reported, to motivate the appropriation of such practices. Section 4 summarises reflections on thesaurus relations and reports on the outcome of the intentions described in the submitted abstract; it is followed by Conclusions.

2. LAND RELATED SEMANTIC RESOURCES

2.1 Land Related Semantic Resources in terms of Thesauri

KOSs or controlled vocabularies are vital for cataloguing and indexing information resources. They also facilitate communication by providing basic terminology for the domain of interest and enable Semantic Web, Linked Data and Knowledge Graph implementations. Several controlled vocabularies focusing on different aspects of land management have been developed by the land-related disciplines including AGROVOC, LandVoc, and CaLAThe. The

[3] https://linkedsdg.officialstatistics.org/#/

content of these controlled vocabularies is described below, as basis for the discussion in Section 4.

2.1.1 AGROVOC Multilingual Thesaurus[4]

AGROVOC is a multilingual thesaurus maintained by the Food and Agriculture Organization of the United Nations (FAO). It includes more than 41.000 concepts and 1.148.000 terms in 42 languages in all areas of interest to the FAO, such as food, nutrition, and agriculture to fisheries, forestry, and the environment. AGROVOC is expressed through the SKOS formalism and published as Linked Open Data. It can be accessed through the SKOSMOS browser[5] and a SPARQL endpoint[6]. AGROVOC concepts are organised under the following top concepts: Activities, Entities, Events, Factors, Features, Groups, Location, Measure, Methods, Objects, Organisms, Phenomena, Processes, Products, Properties, Resources, Site, Stages, State, Strategies, Subjects, Substances, Systems, Technology, Time.
AGROVOC is edited by the web-based platform, VocBench[7], a free and open-source advanced collaboration environment for creating and maintaining KOSs. VocBench also allows the creation and management of domain-specific sub-vocabulary within AGROVOC. Therefore, other expert communities can express their own vocabularies within AGROVOC through a subscheme. This enables enriching AGROVOC with concepts belonging to other controlled vocabularies. However, each concept has to belong to the main AGROVOC scheme and must be located within the AGROVOC hierarchy. Flexibility is achieved by allowing each scheme to have a different concept hierarchy. Furthermore, when a concept is modified (e.g. adding or changing a translation) in a scheme, the data are not only edited for that scheme, because such update will now be seen in all schemes which include this concept. Currently, several sub-vocabularies have been developed within the AGROVOC frame including (i) Land Governance (LandVoc) by the Land Portal Foundation; (ii) Aquatic Sciences and Fisheries Abstracts (ASFA) by the ASFA secretariat at FAO; (iii) Legislative and Policy concepts (FAOLEX) by the Development Law Service (LEGN) of the FAO Legal Office; (iv) FAO Indigenous Peoples; and (v) One CGIAR (Subirats-Coll et al., 2022; FAO, 2023).

2.1.2 The Linked Land Governance Thesaurus – LandVoc[8]

LandVoc is a thesaurus covering concepts related to land governance. It was created as an AGROVOC sub-vocabulary in 2012 by the Land Portal Foundation[9]. LandVoc builds on existing land glossaries, such as the FAO's Land Tenure Thesaurus (Ciparisse, 2003), the LADM, or the Global Land Indicators Initiative glossary. It can be accessed through the SKOSMOS browser[10] and the AGROVOC SPARQL endpoint[11].
LandVoc consists of 310 concepts organised hierarchically under seven top concepts, namely land administration, land equity, land governance, land management, land markets, land

[4] https://www.fao.org/agrovoc/
[5] https://agrovoc.fao.org/browse/agrovoc/en/
[6] https://agrovoc.fao.org/sparql
[7] https://vocbench.uniroma2.it/
[8] https://landvoc.org/
[9] https://landportal.org
[10] https://explore.landvoc.org/landvoc/en/
[11] https://agrovoc.fao.org/sparql

rights, and land stakeholders. It is available in English, French, Spanish, Portuguese, Khmer, Vietnamese, Burmese, Thai, Swahili, Hindi, Italian and Arabic. The content of LandVoc is updated periodically according to recommendations of the Community of Experts and in close coordination with the FAO AGROVOC editorial team. LandVoc thesaurus content is licensed under Creative Commons Attribution 3.0 IGO (CC BY 3.0 IGO).
LandVoc is currently part of FAO's AGROVOC, which is aligned with other vocabularies like EUROVOC, CaLAThe, Chinese Agricultural Thesaurus (CAT), Aquatic Sciences and Fisheries Abstracts (ASFA), Linked Thesaurus fRamework for Environment (LusTRE), National Agricultural Library Thesaurus (NALT), United Nations Bibliographic Information System Thesaurus (UNBIS), General Multilingual Environmental Thesaurus (GEMET), etc. LandVoc can be explored through a SPARQL endpoint and downloaded in Excel, CSW or RDF.

2.1.3 Cadastre and Land Administration Thesaurus - CaLAThe[12]

CaLAThe is a domain thesaurus in the SKOS format. Following reviews of a comprehensive amount of recent PhD theses (Çağdaş & Stubkjær, 2009; Çağdaş & Stubkjær, 2011), it was issued in 2011. The identification and structuring of domain terms, covering legal, administrative, and technical (surveying and information) aspects, was originally intended to support the development of cadastral theory, perhaps a cadastral ontology (Stubkjær, 2001).
CaLAThe's initial version was based on the then draft version of ISO LADM. However, it also included terms from other thesauri, such as the AGROVOC, the GEMET with INSPIRE Spatial Data Themes, the STW Thesaurus for Economics, Cycorp's OpenCyc ontology, and United Kingdom's Integrated Public Sector Vocabulary. Version 2, issued in 2012, was supplemented with terms representing the dynamic aspect of the domain, based on outcomes from the European research activity Modelling Real Property Transactions (ESF/COST G9, 2001–05). Version 3 and Version 4, released in 2019, extended CaLAThe with new terms adopted from the Land Division, Condominium, and Survey parts of the OGC Land and Infrastructure Conceptual Model Standard (LandInfra) (Scarponcini & Stubkjær, 2017). Version 4 also included code lists of the Survey, Land division, and Condominium sections of the LandInfra standard.
From the outset in 2011, CaLAThe was rendered in the English language. However, Version 5 in 2021 started a multi-lingual itinerary by adding terms in Danish and Turkish, the native language of the editors. In Version 6, new and revised concept definitions were provided. The intensional definition (also known as the genus-differentia definition) method recommended by ISO 704:2009 'Terminology work - Principles and methods' was applied in the preparation of definitions. Moreover, the multilingualism of CaLAThe was further improved by Malay terms. Finally, the 2024 revisions complemented CaLAThe with Common law concepts, and Dutch terms were added. The current Version 7 now includes about 250 concepts with their definitions and their equivalences in the Danish, Dutch, Malay, and Turkish languages. The concepts are organised through its top concepts that characterise the domain covered, namely Activity, Information, Land, Law, Party, and Survey.

[12] http://www.cadastralvocabulary.org/

2.2 FIG Sustained Semantic Resources

2.2.1 OICRF - International Office for Cadastre and Land Records[13]

OICRF, Office International du Cadastre et du Régime Foncier, established 1958 (Henssen, 1981), is a study and documentation center for cadaster, land administration and affiliated fields of interest[14]. As of May 31, 2024, the OICRF digital Land Administration Library houses 21.414 publications, encompassing a diverse array of resources such as conference documents, magazine articles, and reports related to land administration. The contents of the library are accessible in multiple languages, incl. Italian, Russian, Spanish, and English.
OICRF is actively engaged in a significant quality enhancement initiative. This improvement focuses on several key areas: standardising country names according to ISO standards, resolving missing links and years in the database (where some of the most valuable resources are found), eliminating duplicate entries, and implementing standardised tags and keywords. With reference to these quality improvements, active promotion of OICRF is paused during 2024 (OICRF, 2024).

2.2.2 ISO 19152:2012 Land Administration Domain Model (LADM)[15]

LADM is a common standard for the land administration domain. It will stimulate the development of software applications and will accelerate the implementation of proper land administration systems that will support sustainable development. The LADM covers basic information-related components of land administration (including those over water and land, and elements above and below the surface of the earth).
The standard provides an abstract, conceptual model with four packages related to:

1. parties (people and organizations);
2. basic administrative units, rights, responsibilities, and restrictions (ownership rights);
3. spatial units (parcels, and the legal space of buildings and utility networks);
4. spatial sources (surveying), and spatial representations (geometry and topology);

The LADM revision process is ongoing. Expanding the scope of the standard motivated organising the standard into multiple parts. The first part focuses on the conceptual model, published as ISO 19152-1:2024 Geographic information, Land Administration Domain Model (LADM), Part 1: Generic conceptual model. Part 1 forms the basis and also provides a global overview of the conceptual models in parts 2 to 5. Part 3: Marine georegulation has been published as ISO 19152-3:2024, and others are following. The development of part 6, Implementation aspects, is planned in collaboration between ISO/TC 211 and the Open Geospatial Consortium. *WG 7.3 – LADM and 3D Land Administration (LADM/3D)* is mentioned, because applications of thesauri support the specification of LADM code lists. These potentials have been addressed in Stubkjær & Çağdaş (2021) and Kara et al. (2024).

2.2.3 FIG Standards Network[16]

The Network sees itself as at the hub of FIG standardisation activity, making the necessary linkages and providing the necessary advice to commissions and others. The following standards are introduced: ISO/TC211 Geographic information/Geomatics, ISO 19152:2012

[13] https://www.oicrf.org/
[14] https://www.fig.net/organisation/perm/index.asp
[15] https://fig.net/organisation/networks/standards_network/ladm.asp
[16] https://fig.net/organisation/networks/standards_network/index.asp

LADM, ISO/TC 172 SC6 Survey Instrument Standards, International Property Measurement Standards Coalition (IPMS), International Land Measurement Standard (ILMS), International Construction Measurement Standards (ICMS), as well as Standards in Hydrography. It maintains the FIG Guide on Standardisation. The Terminology list of the Guide describes Official standards, Legal standards, and De facto standards[17].

2.2.4 The Responsible Land Administration Teaching Essentials

The Responsible Land Administration Teaching Essentials (ReLATE) are motivated by Du Plessis et al. (2020), assessed by Chigbu et al. (2021), and introduced by Enemark (2023a; 2023b). The achievement is described as a structured knowledge base, well designed for combining traditional lecture courses with digital learning material to be used as self-studies (cf. Chigbu et al., 2021). A review of ReLATE or alternatively, Teaching Essentials for Responsible Land Administration (TERLA), is in process (Hull et al., 2024). The core of the Teaching Essentials consists of six modules, each about 70 pages long. They are available on the GLTN e-learning platform in English and French. In the introducing report, they are supplemented with parts relating to the SDGs, providing practical guidance for applying the Teaching Essentials, and offering recommendations for applying the principles of responsible land administration at the country level. Thus, frameworks, approaches, and the LADM are seeking to bring many countries forward.

The ReLATE summary and guidance mentions the development of land administration, where in the 1990s 'the emphasis was on information management, reflecting the computerization of the land information agencies in the 1970s. This focus on information remains, but in recent years the type and quality of information needed has changed, pushing the design of land-administration systems towards an enabling infrastructure for implementing land policies in support of sustainable development.' (Enemark, 2023a). However, the focus in the present paper on semantic resources and technology prompts the observation that the claimed remaining 'focus on information' cannot be confirmed: Key concepts (Box 1) include 'Spatial data infrastructure provides access to and interoperability of cadastral and other land related information on the natural and built environment', but 'interoperability' is not found among learning objectives or elsewhere. The module that according to the title primarily addresses data and information: 4. Responsible land administration and information in practice, includes a lesson 4.4 on Tools to improve land administration effectiveness. 'The lesson presents a range of tools and methods for reorganising land administration with a focus on strategy and strategic planning.' The 'tools' deals with the 'costs of running a land-administration system', and not technologies for land tenure. These are related to in Module 2, titled 'Land tenure security', which includes a lesson 2.4 on Land administration processes with the learning objective: 'Choose and apply appropriate tools from a range of options to improve land tenure security, such as enumeration, social tenure domain model, and pro-poor land registration systems.' (all quotes from Enemark, 2023a). The observation is included in section 3.2 on domain knowledge.

[17] https://fig.net/resources/publications/figpub/pub28a/figpub28a.asp

3. THE USE OF SEMANTIC RESOURCES

To motivate the present proposal for use of semantic resources, it is recalled that semantic resources in terms of thesauri are concept based. This focus on concepts and concept relations has triggered a learning approach called Concept mapping. Therefore, concept mapping is introduced to invite lecturers and students to apply this approach. Next, relations between the semantic resources AGROVOC, LandVoc and potentially CaLAThe are specified through subschemes. Research is referred to which motivates the relevance of more subschemes concerning a shared domain.

3.1 Concept mapping

Thesauri record knowledge; the challenge is to articulate that knowledge in a way that the person can apply it adequately, be it in the role as student, lecturer, or scientist. Concept mapping has been proposed as a learning approach, which gradually has gained wider acknowledgement. A concept map is a graphical representation of concepts (nodes) and relationships (in graph theory: edges) between them. The relationships can be conceptual (such as hierarchical) or empirical (such as cause and effect, influence) (Soergel, 2009). Concept maps display ideas in a hierarchical structure and tie them together with explanatory nodes and links. Two or more concepts can be linked together with words to form propositions (Machado & Carvalho, 2020).

In a concept-map based learning environment, students, individually or in groups, may construct a concept map showing their previous knowledge on a topic, and further develop a knowledge model that reflects their increased understanding (Cañas et al., 2023). A recent review by Machado and Carvalho (2020) motivates the inserting of concept maps into university teaching, as it contributes to developing critical thinking skills, promotes meaningful learning, and facilitates student collaboration. The article further aims to provide educators and researchers with a structured overview of the research on concept mapping as learning and assessment tools implemented with students in higher education. Figure 1 below may introduce the issue. Their review provides a basic introduction to the subject, not repeated here, and among others includes references to several disciplines. Geosciences are not mentioned, but a review by Xiaogang Ma (2022) entitled 'Knowledge graph construction and application in geosciences' details how to build knowledge graphs by designing conceptual models and mentions the CmapTools[18]. Knowledge graph construction requests skills, which are presently lectured primarily by computer scientists. However, like problem-based learning developed from something new and special to become a more general teaching practice, the computer-assisted knowledge construction may similarly become a more general practice.

Some applications of concept mapping have focused on using concept mapping for assessing student learning (Jacson et al., 2023). Others have explored its utilisation in problem-based learning (Alt et al., 2023) and learning technology, e.g. Moodle[19] (Pontes et al., 2012; Chen et al., 2023). From the perspective of improving land administration education, these are all relevant, but for problem-based learning, and Master and PhD. projects, Chakraborty et al.

[18] https://cmap.ihmc.us/
[19] https://moodle.org/

(2023) offer an important addition, as they apply concept mapping for systematising knowledge generated through interviews:

> 'Through 8 Focus Group Discussions (FGD) and concept mapping we identified and systematised the underlying direct and indirect drivers of ecosystem change in the Nakatsu mudflat.' (Abstract). 'Each FGD lasted about two-three hours and started with a brief explanation of the activity at hand and the expected outcome. As the main goal of each FGD was to identify the main drivers of ecosystem change in Nakatsu mudflat and how they intersect (Section 1), we used a research approach borrowing from concept mapping (e.g. Moon et al., 2011) and modelling (Reed et al., 2013)'.

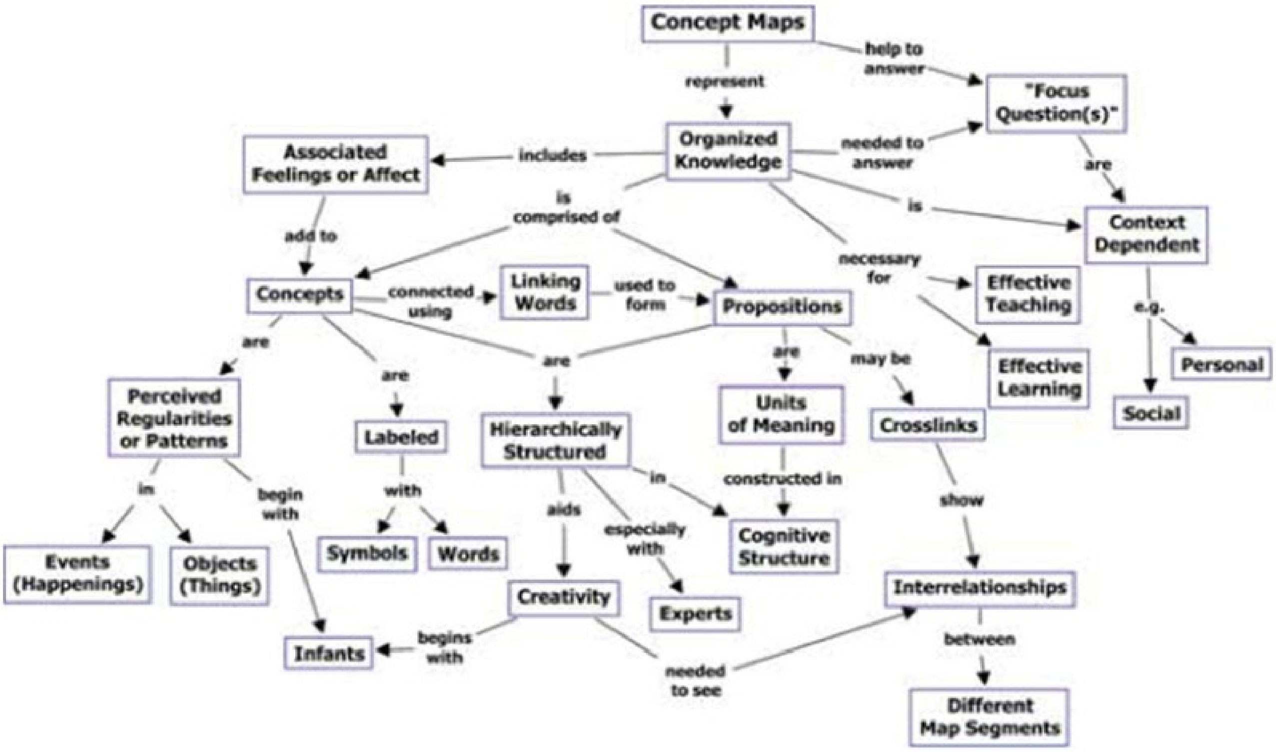

Figure 1. A concept map showing key features of concept maps. Note: Reprinted from Machado and Carvalho (2020)

This brief introduction to concept mapping suggests how the knowledge embodied in thesauri might enrich land administration teaching and learning. Concept maps created by individual students will reflect how students perceive the domain knowledge, e.g. domain concepts and relationships between those concepts as well as enable them to go deeper into the domain knowledge. The creation of concept maps may be based on the concept sets provided by CaLAThe, LandVoc, and AGROVOC, supplemented by other land-related semantic resources. Also, such concept maps will include more relationship types than those provided by a thesaurus (e.g. Broader Terms, Narrower Terms, and Related Terms). Anyway, the concept mapping activity supports students learning by familiarising them with the domain terminology. Exploring the potential of concept maps thus calls for a more specific plan.

3.2 The structuring and presentation of domain knowledge in terms of subschemes

The effort to find an organisational context for CaLAThe triggered attention to AGROVOC and its subschemes[20]. They include LandVoc[21], ASFA[22], FAOLEX[23], and FAO Indigenous Peoples[24], among others. LandVoc and CaLAThe cover shared domains, but the structure of CaLAThe as indicated by top concepts differs from the structure of LandVoc. This raises the question whether it is adequate to have one or more subschemes covering shared domains. Adequate answers to this question are sought by drawing on an analysis of the use of the terms land administration, land management, and land governance (Hull, 2024), a paper on validating knowledge structures (Steiner & Albert, 2017), and a concern of Barry and Roux (2012) and Hull (2024) to maintain creativity while pursuing concept rigor.

Hull performs a bibliometric and qualitative analysis of land-related publications from the past decade and concludes that 'Land governance [LG] is suggested by several respondents as a suitable, all-encompassing descriptor of which land management [LM] and land administration [LA] could be described as sub-domains. Yet the bibliometric analysis highlights the distinctiveness and interconnectedness of the three concepts, suggesting that to favour one of them over the others as a domain identifier may be inappropriate.' The findings of the bibliometric analysis are summarised (p. 9) as follows:

1. LA, LM and LG are distinct terms with their own meanings and applications.
2. LM appears to apply to sustainable management of Earth's resources in the light of current global pressures such as climate change and its impact on food security.
3. LA applies to the conventional topics of cadastre and land registration, supported by innovative technologies.
4. The centrality of LG in the network indicates its importance in bridging the gap between the LA and LM clusters.

LandVoc provides a suitable, all-encompassing scope of LG (cf. Bayer & Meggiolaro, 2022), while CaLAThe reflects the LA with its focus and applications (cf. Çağdaş & Stubkjær, 2015). The cautious assessment by Hull may be supported by asking whether 'innovative technologies' constitute a subdomain of LG? Keywords revealed through the analysis include 'blockchain' and 'gis' (Fig 11), and 'UAV' (unmanned aerial vehicles) and 'digitalization' (p. 9). The Introduction section mentions research on interoperability and ontology, but apparently this research was too scattered to amount to be mentioned. The same holds with terms like linked data, knowledge graph, and semantic web. Also, the observation made in the above presentation of ReLATE, that the 'focus on information' could not be confirmed suggest that LA and thus CaLAThe covers 'innovative technologies' more completely. This may, in part, explain the difficulty in finding an organisational context for CaLAThe.

Steiner & Albert (2017) offer introduction to concept maps and to ontologies. Interesting is their claim that 'For one and the same knowledge domain it is not realistic to assume that only one correct representation of complete consensus exists … [because] there is a range of alternative ways conceivable to describe and conceptualise the same domain'. They discern

[20] https://www.fao.org/agrovoc/multischeme-and-multihierarchy-management
[21] https://landvoc.org/
[22] https://www.fao.org/asfa/en
[23] https://www.fao.org/faolex/en/
[24] https://www.fao.org/agrovoc/multischeme-and-multihierarchy-management

‘Content validity [which] refers to the correct building of the content of a concept map, ... [from] application validity, [which] refers to the practical usability and usefulness of a target concept map.’ [i.e. a concept map to be validated]. Without delving into the theoretical basis of their arguments it appears that application validity refers to the users’ previous knowledge and capacity for making sense of the presented knowledge. LandVoc editors structure their knowledge base to accommodate various user interests, while editors of CaLAThe use resources to improve content validity.

Barry and Roux (2012) refer to Çağdaş & Stubkjær (2009) who motivate the development of standardised definitions as a step towards ‘a coherent and universal core cadastral theory’. They warn that ‘standardisation may stifle critical thinking and innovation, and it may indeed prove impossible to reach consensus over certain terms.’ (2012, p. 305). Research since 2009 demonstrates that this way of expression was not fortunate. The issuing of CaLAThe in 2011 was made precisely because the review of theory and methods published in 2009 (Çağdaş & Stubkjær, 2009) and 2011 (Çağdaş & Stubkjær, 2011) presented a complexity, which made us focus on the concepts only. We applied terms and definitions from the LADM standard, but from alternative sources as well. Rather than heralding standardised definitions, our conception of standards, specifically LADM, is illustrated by our pointing to the supplementing role of code lists and thesauri.

We maintain what was stated in 2009 that ‘To serve their functions effectively, concepts have to be clear, precise, and agreed-upon (Frankfort-Nachmias and Nachmias, 1997, pp. 48–49).’ This is in line with Barry and Roux, contending that ‘a degree of consensus regarding semantics is necessary for modelling [information system] concepts and developing theory.’ Hull et al. (2024) likewise call for a ‘glossary of terms’, also to improve linkage between modules. However, Hull et al (2024) also note that ‘concepts are not static’ and are concerned ‘that some of the frameworks and principles informing TERLA are not working from the existing realities of country contexts in the Global South, but are instead dictating what ‘should be’ according to a particular set of lenses that reflect a generally ‘western’ outlook.’ In the present context of assessing, whether one or more concept structures or subschemes are needed, this call for flexibility may be the strongest support for the latter position. Whether CaLAThe should be the alternative to LandVoc is not the issue here. An alternative concept structure may apply better to the Global South; the point is that one or more alternatives are needed.

The position that it is adequate to have both a LandVoc subscheme and a CaLAThe subscheme is supported by Hull’s (2024) analysis, informing that LA with cadastre constitutes one of the distinct terms and subdomains. Also, Steiner & Albert (2017), open up for various subschemes by discerning content validity from application validity. Finally, the world-wide differences in land tenure realities of countries also calls for the flexibility provided by more subschemes.

4. THE EMBEDDING OF CALATHE WITHIN AGROVOC WITH LANDVOC

The initial abstract of the present paper stated that the role of FIG International Office for Cadastre and Land Records (OICRF) in documenting knowledge on land administration may also include the storing of semantic resources. It proposed a working group in charge of the

integration, maintenance and application of CaLAThe and LandVoc as comprehensive, research-related semantic resources for FIG and the broader land sector, and anticipated a documentation of the ongoing investigations regarding alignment of CaLAThe and LandVoc.
However, OICRF and FIG have recently concluded that it is best not to proceed with the integration of CaLAThe into OICRF. Moreover, the clarifying of interpretations of the notion of semantic resources, cf. sections 1 and 2, and the discussion on the role of these in research and education, cf. section 3, have as consequences that what can be presented is the status of discussions.
The FIG body in charge of curating the thesauri was suggested as a new unit in the submitted abstract. Alternatively, however, objectives and staffing of present WG(s) might be extended. The fact that the *WG 2.4/7.7 Land Administration Education*, a combined C2 / C7 working group, seeks to evaluate, support, and further develop the Teaching Essentials for Responsible Land Administration (TERLA), suggests a close connection to this activity. The *WG 7.8 – Comparative Land Administration* which seeks to demonstrate how FIG can best recommit to creating and disseminate comparative land administration information, as demonstrated through the LandPortal and LandVoc must remain in focus.
The curating activities include:

- The transfer of CaLAThe from its present location to the selected technical solution, to be performed primarily by the present editors.
- The review and addition of terms, and the adding of more languages, for an AGROVOC-based solution for only the CaLAThe terms that are not found in AGROVOC, to be performed by the present and extended circle of language representatives.
- The general development of CaLAThe and LandVoc within the present 2023-26 plans, focusing on the needs of the chosen context.
- Contribute to a long-term curating solution through 2027-30 plan drafting.
- Engage in the further alignment of CaLAThe and LandVoc with other FIG-related semantic resources.

5. CONCLUSION

The notion of *semantic resources* is introduced to the geospatial community referring to controlled vocabularies, specifically thesauri, which assist in providing interoperability among datasets in the surveying and the construction sector and support a wider e-governance perspective. Semantic resources in terms of thesauri are detailed and compared to other FIG-supported semantic resources. Thesauri and the corresponding concern for concepts and concept relations has triggered a learning approach called Concept mapping which is introduced to invite lecturers and students to apply this approach. Finally, the recent efforts to find an organizational context for CaLAThe was documented. A solution including the embedding of CaLAThe in AGROVOC raises the question whether concept relations in terms of subschemes can be sufficiently accounted for in terms of the existing LandVoc subscheme. A number of arguments, including the world-wide differences in land tenure realities of countries, call for the flexibility provided by more subschemes.

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Simon Hull is an associate professor and 2019 PhD graduate at the University of Cape Town (UCT). His doctoral research was in the field of customary land tenure reform. He completed his MSc at UCT in the field of digital close-range photogrammetry in 2000 whereafter he spent two years working as a marine surveyor. He spent a further four years completing his articles and is a registered South African Professional Land Surveyor. In 2006 he changed careers and became a high school Maths and Science teacher in a rural village in northern Zululand. He has held his current position at UCT since 2012, where he lectures in the foundations of land surveying, GISc, and cadastral surveying. His research interests are in land tenure, land administration and cadastral systems, and the use of GIS to address Sustainable Development Goals.

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LADM implementations and developments by Esri (Industry presentation)

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Key words: LADM, Esri

SUMMARY

LADM implementations and developments, state of the art by Esri.

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Brent Jones is President of Nine Three Enterprises LLC since 2024. Before he did oversee Esri's worldwide strategic planning, business development, and marketing activities for land records, cadastre, surveying, and land administration for more than 19 years. As a recognized innovator, Jones specializes in modernizing existing land administration systems and designing new GIS-based cadastral management systems for small and large governments globally. He is past president of URISA; past president of the Geospatial Information and Technology Association; and a current member of the United Nations Committee of Experts on Global Geospatial Information Management, sitting on the Expert Group on Land Administration and Management.

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