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3D Land Administration System within the Spatial Development Lifecycle

Kalogianni Eftychia

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Challenge the future

3D Land Administration System within the Spatial Development Lifecycle

PhD Research Proposal

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October, 2019

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3D LAND **A**DIMINISTRATION **S**YSTEM

WITHIN THE

SPATIAL DEVELOPMENT LIFECYCLE

PhD Research Plan

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ABBREVIATIONS

2D	2-Dimensional
3D	3-Dimensional
AEC	Architecture, Engineering and Construction
BeIM	Built environment Information Modelling
BIM	Building Information Modelling
CE	Circular Economy
CEN	European Committee for Standardization
DCDB	Digital Cadastral Database
DE	Doctoral Education
DMA	Doctoral Monitoring Application
DSRM	Design Science Research Methodology
ELRA	European Land Registry Association
FAO	Food and Agriculture Organization
FIG	International Federation of Surveyors
GII	Geo-Information Infrastructure
GIS	Geographic Information Systems
GLII	Global Land Indicator Initiative
GLTN	Global Land Tool Network
GS	Graduate School
IDBE	Integrated Digital Built Environment
IHO	International Hydrographic Organization
ISO	International Organization for Standardization
IT	Information Technology
LAS	Land Administration System
LADM	Land Administration Domain Model
LGAF	Land Governance Assessment Framework
LoD	Level of Detail
NUA	New Urban Agenda
OGC	Open Geospatial Consortium
RICS	Royal Institution of Chartered Surveyors
RRRs	Rights, Restrictions and Responsibilities
SDG	Sustainable Development Goals
SDI	Spatial Data Infrastructure
STDM	Social Tenure Domain Model
TC211	Technical Committee 211 Geographic Information/ Geomatics
TUDelft	Delft University of Technology
UN	United Nations
UN-GGIM	United Nations Initiative on Global Geospatial Information Management
VGGT	Voluntary Guidelines on the Responsible Governance of Tenure
W3D	Web 3D Consortium

ABSTRACT

Over the last years, the accelerating urbanisation rate in society faces the challenge of sustainability, also including issues relevant to mobility, land administration, taxation, etc. Besides, the increasing awareness of location services - where "*everything happens somewhere*"- spotlights geographic data to be widely used to support decision making, which is also reflected more and more frequently in some of the world leaders' documents. Principally, one of the indicators of the United Nations 2030 Agenda for Sustainable Development (Scott et al., 2017) is to position reliable, disaggregated geographic information to address global challenges aiming at making cities inclusive, smart, resilient and sustainable.

Land is at the basis of society. As cities grow in size and population, harmony among their spatial, social and environmental aspects and between their inhabitants becomes of paramount importance. A healthy land administration ensures security of land tenure, fairness in land markets and efficient land development. In the process it contributes to developing and supporting local economies, while, defining and managing property rights and restrictions (in 3D) is part of making cities liveable. In this context, up-to-date cadastral information provides the basic framework within which development of smart cities can be designed and implemented. Therefore, land administration should not be treated as an isolated field, but as part of the spatial development lifecycle, where all disciplines interrelate and influence each other.

As the world is increasingly migrating towards integration, the need to combine independent systems, methodologies and procedures associated with different disciplines, aspects and scales of the built environment is becoming pertinent. Currently, the disciplines involved in the different phases of this lifecycle are quite autonomous and this leads to duplicates, mistakes, ambiguities and has been proven cost and time-consuming. However, in practice, those disciplines are mutually affected, and their harmonisation and compatibility would be of great benefit for all the involved activities.

Particularly for urbanised areas, administration of land is challenged by unprecedented demand for space use above and below earth's surface, resulting in an increasing spatially complex built environment (including constructions on, above and below earth's surface; utilities, etc.), where relationships in vertical space can no longer be unambiguously represented in 2D. For that reason, cadastral and land administration organisations around the world are taking steps to register multi-level property rights in such a way that the registration provides a clearer insight of the legal situation. Cadastral parcels registered and visualised in 3D provide an answer to the need for clearer, accessible and up-to-date information.

Since the last decade the issue of "3D Cadastre" is being used both as buzzword and technical term to indicate the urgent need of change in the development and management of Rights, Restrictions and Responsibilities (RRRs) and their spatial extend in 3D. There exists not a unique 3D Land Administration System (LAS), while for its establishment, legal, institutional and technical issues need to be addressed. In this scene, weighing the added value of 3D LAS in the full cycle of spatial development and Geo-Information Infrastructure (GII) context is a challenge.

Progress has been made in advancing this concept with the adoption of Land Administration Domain Model (LADM) as ISO standard (ISO, 2012). LADM can support the progressive improvement of LASs and increasingly plays a key role as a lot of research has been carried out since its adoption as ISO standard, with numerous jurisdictions developing LADM-based land information models including both administrative and spatial information. Nowadays, the ground seems to be mature for the LADM revision and the development of its 2nd edition is on its way within ISO and OGC organisations.

This PhD research aims to develop an efficient data flow that can optimally support the entire spatial development lifecycle of the different types of 3D cadastral objects. Among the objectives of the research are: to investigate the different types of 3D cadastral objects; investigate how to close the gap between the conceptual model and the actual implementation of 3D LAS; explore interoperable implementations of LADM-based models; test the applicability and functionality of the proposed developments via a 3D web-based platform; as well as assess the added value of 3D LAS, or the impacts of not adopting it in the spatial development lifecycle in terms of quality/ quantity. The research closely relates to LADM revision, as it is expected that part of it will be included in the second edition of the model, and thus the work will be coordinated in parallel with the LADM revision team work.

KEYWORDS: Land Administration System (LAS), 3D Cadastre, 3D Information Modelling, Geo-information management, Object lifecycle, Standardisation, Land Administration Domain Model (LADM), information re-use, interoperability.

1. SETTING THE SCENE

The current societal demand to improve sustainability performance through collaboration and through a hol life-thinking is driving the need to integrate independent systems associated with different aspects and scales of the spatial development lifecycle to deliver smart solutions and services. Land administration is on the centre of this lifecycle putting on the table issues of environmental sustainability, economic freedom, social justice and equity and political stability. Currently, land administration practices mainly rely on 2D-based systems to define legal and spatial boundaries of interests, however infrastructure density leads to complex interleaving triggering legal, organisational and technical challenges of 3D cadastral systems. In this scene, the LADM plays an instrumental role.

In many global documents (such as the United Nations Agenda for Sustainable Development Goals (SDGs) (World Bank, 2018), the VGGTs initiated by UN FAO (FAO, 2012), the NUA from Habitat III (Habitat, 2016), the 14 global fundamental geospatial data themes by UN-GGIM (UNGGIM, 2019a), etc. land is considered as an issue of utmost importance (Lemmen, 2012) related to many of their indicators and targets. Maximizing the value of fundamental spatial information for policy-making, decisions and actions is going to be critical the next decades and hence, there is the urgent need for the development and adoption of standardised, flexible and transparent approaches in land administration and management (Lemmen et al., 2017).

In this scene, Cadastral Systems are recognized as the core of Land Administration Systems (LASs) containing identication of the individual parcels recording interests above/below/on land and water surface. Land administration is the key asset of any country and is crucial for its sustainable development as it covers both legal aspects (rights, restrictions, responsibilities) and spatial descriptions (parcels forming cadastral maps). The role of LAS in society can be seen as the pivot of a sustainable economic and cultural development and the development of smart cities (ICSM, 2014); while their evolution supports both spatially mature societies and basic fit-for-purpose land administration systems (Kaufmann et al., 1998).

To this end, land administration should not be treated as an isolated sector, but as part of a whole chain of spatial development activities, which should all be well aligned and supported by 3D representation (Figure 1). As also stated by van Oosterom (2013), the naming and order of execution of those activities (spatial planning/zoning, designing, permitting, financing, surveying, registering, constructing, using, maintaining objects) may differ from country to country, however they portray the general process and are related to 3D cadastral registration. Currently, there are isolated/independent and specific phases through the spatial development lifecycle of objects, involving multiple stakeholders (planners, designers, developers, surveyors, financers, etc.) from various domains with different backgrounds, tools and requirements. Land administration is on the centre of this lifecycle facing challenges of sustainability and cumulative space demand. A lifecycle thinking approach should be developed and adopted as part of an integrated development chain; thus, a holistic approach to share and reuse information related to design, construction, legal, administrative, environmental and social issues.

Fashioning AEC (Architecture, Engineering and Construction), geospatial and economic data into an efficient data flow from planning through design and construction to operation and maintenance represents a challenge. The potential for the re-use of information within the spatial development lifecycle is a significant factor in calculating its (economic) value, also because of avoiding inconsistencies/mistakes and by adding real world coordinates, the value and types of data is increased for all stakeholders across the entire lifecycle.

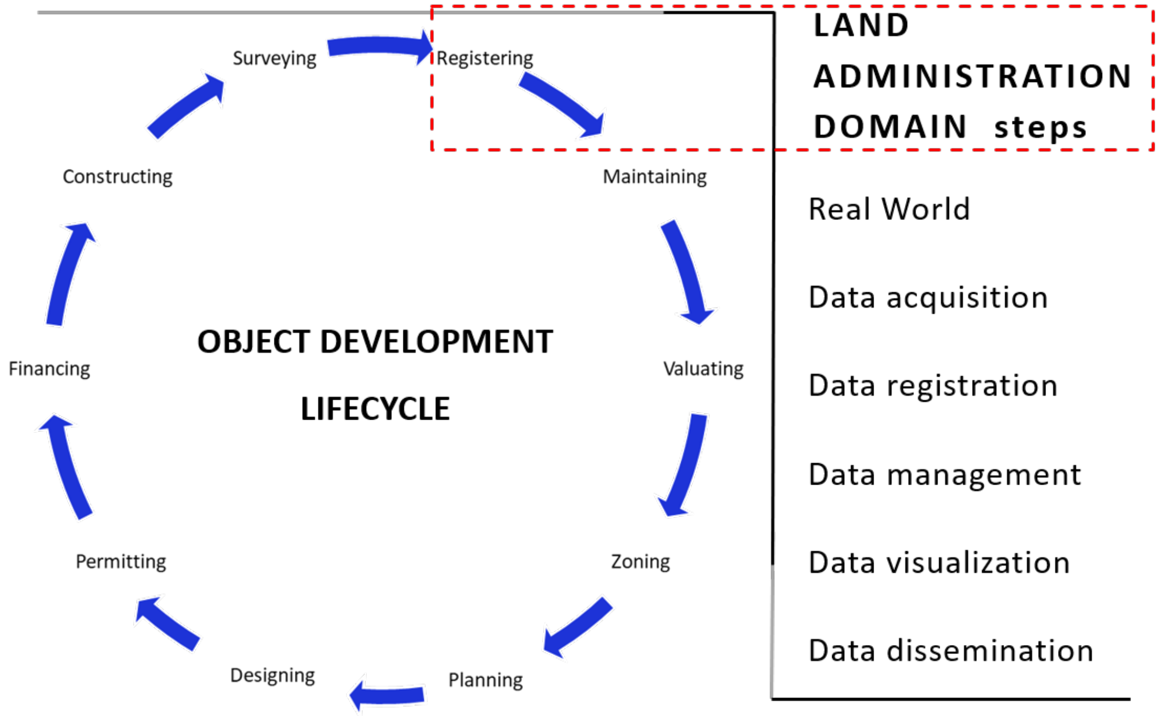

Figure 1. 3D LAS within the spatial development chain

Currently, the disciplines involved in the different phases of this lifecycle are quite autonomous, using custom-made, independent methodologies and workflows. Current situation has proven slow and expensive, with inconsistent datasets and duplicates for the same objects through different phases of its lifecycle, which results in mistakes. Collaboration of different sectors reduces costs of acquisition/design, improves data quality, reduces inconsistencies, minimises data loss, mismatch and overlap between the various stages and enhances data re-use from design phase to end user and registration/operation phase. A common approach to collect, maintain and disseminate 3D data can improve the efficiency of current situation, while data will become suitable for various applications after following a specific workflow.

At the same time, involved parties are becoming data producers themselves and there is need to adopt bottom-up and top-down governance approaches, regarding data acquisition and registration, data processing and sharing from different heterogeneous sources, by working with standards. Efficient, well-organised data gathering is essential for much large-scale reuse.

In this context, the Circular Economy (CE) paradigm, which is among the strategies fostered by the EU to improve the sustainability of state members' economy, focused on applying a closed-loop life cycle instead of a linear one (Stahel et al., 2016), adopting a number of business models; mainly: reduce, reuse, recycle, recover, redesign, remanufacturing. Despite its recognized potential, the application of CE to the design and construction industry is still in its infancy (Biccari et al., 2019), while decision makers in the construction industry (architects, engineers, tenders, etc.) need tools to support them to exploit the value of CE approach with a systemic view of the effects of "circular" business models (Núñez-Cacho et al., 2018).

As the cities grow, they grow both vertically and horizontally, thereby introducing the element of the third dimension (FIG, 2018). Therefore, all the involved experts in the different lifecycle phases would benefit from 3D datasets and procedures, either representing a model of the current real-word or a design of proposed/future scenarios (e.g. architectural plans, spatial plans, etc.), while 3D datasets are becoming ubiquitous for making decisions and for improving the efficiency of governance in different levels.

Despite the technological benefits and the potential economic value of applying a holistic 3D approach, 3D solutions are still not common in applications that could significantly benefit from 3D. One of the bottlenecks is the lack of appropriate 3D data applicable for a wide variety of applications, as well as 3D data capture, which is considered one of the costliest phases of the implementation of 3D LAS and related application. Often 3D data of an area is not readily available (as is in 2D) and if it is available it is either out-dated or it needs significant pre-processing to make the data suitable for a specific application (Stoter et al., 2016). In the context of object lifecycle management and 3D data re-use this can be achieved, as data from 3D survey and design (especially from BIM) are now becoming more and more available. Besides, the value of the 3D (geo)data depends on a range of factors such as the availability, accuracy, amount of detail, whether the data is up-to-date and the consistency with which it is stored relative to similar geo-datasets. These factors contribute to the ease and ability to analyse the data, but also enable the interoperability between applications.

What is more, the increasing complexity of infrastructures requires proper registration of properties' legal status and thus, the 2D-based cadastral systems are facing legal, organisational and technical challenges in recording, managing and visualising the spatial extent of vertically cadastral spaces (Aien et al., 2013; Kalogianni et al., 2017; Atazadeh et al., 2016; Kitsakis et al, 2016 ; van Oosterom, 2013). Currently, cadastral organisations around the world are taking steps to register multi-level property rights in such a way that the registration provides a clearer insight of the legal situation, while it has been concluded (Stoter et al., 2016) that when adopting a 3D approach from the first phases of the object lifecycle, mistakes are avoided, it is less time consuming, less expensive, and only then the advantages of a holistic 3D approach can be fully realized.

So far, no country has a complete operational 3D Cadastral System incorporating 3D aspects, as such: legislation, survey techniques, registration of Rights, Restrictions and Responsibilities (RRRs), management, validation within 3D DCDB and dissemination of 3D parcels, as well as data conversion from 2D to 3D; however, some jurisdictions are quite close to achieve it, namely the city of Shenzhen in China. Nevertheless, the number of partial implementations of 3D parcel registration around the world (some jurisdictions provide legal provisions for the registration of 3D parcels; others show 3D information on cadastral plans such as isometric views, vertical profiles or textual information; etc.) is increasing significantly (Kitsakis et al., 2016; Dimopoulou et al., 2018) taking advantage of contemporary advances in geographic science and technologies enabling the collection, storage, analysis, visualization and dissemination of the third dimension. Applications of 3D GIS to 3D LAS, including smart cities' efforts, virtual and augmented reality, (spatial) decision-making support, disaster management, as well as governance aspects of GII have evolved over the last decade.

In this scene, progress has been made with the adoption of the Land Administration Domain Model (LADM) (ISO 19152, 2012) as one of the first ISO spatial domain standards (ISO 19152, 2012), which outlines the foundations for 3D LAS and increasingly plays a key role, as more and more countries are developing LADM-based 3D registrations (indicatively, countries in Middle East (Israel (Felus et al., 2014), etc.), Asia (the city of Shenzhen in China (Guo et al., 2014), Malaysia (Zulkifli et al., 2014), etc.), Latin America (Colombia (Jenni et al., 2017, etc.), Europe (Croatia (Mađer et al., 2015), Greece (Kalogianni, 2015), etc.)). LADM has gained wide use and interest since its final vote as ISO standard at December 2012 (Figure 2), and now it is currently under revision within ISO and OGC and it is expected to be in line with the relevant UN SDGs.

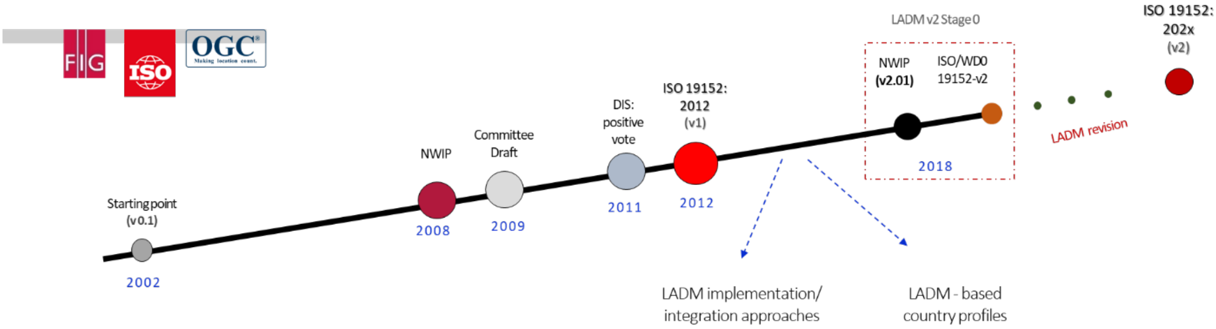

Figure 2. LADM incremental design

In the context of this revision, operationalisation of LADM and interoperability with other standards that represent physical objects (such as BIM models - BIM/IFC, 3D City Models - CityGML, indoor space – IndoorGML, infrastructure utilities -LandXML, LandInfra etc.) are of high priority in order to establish a link with spatial planning and lifecycle management of buildings and other infrastructure facilities. Improved interoperability contributes to reduced deployment time, lower system lifecycle costs, less mistakes, improved flexibility and scalability, improved choice from the IT marketplace, and improved ability to share, exchange and integrate information related to land administration.

Hence, this research aims to investigate and develop an efficient data flow -focusing on the technical aspects- that can optimally support the entire life cycle of spatial objects from initial planning to real estate registration.

2. PROBLEM DEFINITION AND RESEARCH OBJECTIVES

This thesis aims to bring new ideas, improvements, implementations, testing with real data and assessment in the field of 3D LAS. Attention is given in the more efficient integration of 3D LAS registration with the whole lifecycle of an object's spatial development, which involves and affects other activities outside its cadastral registration cycle (Figure 1). When considering the changes required to allow a jurisdiction to register 3D objects, it is important to note the sphere of influence that will have impacts on 3D registration, as well as the data source(s), quality, accuracy and value. These aspects are related and include multiple stakeholders and processes (Figure 1), a fact that generates different user needs and new opportunities, which are being addressed in the context of the LADM revision.

2.1. Motivation

The pressure on space in the built-up area is increasing, and solutions for sustainable land use are therefore more and more found in multiple layers, realized both under and above the surface. However, the registration of land and property rights and related restrictions and responsibilities is still based on a 2D cadastral map combined with registration of rights in deeds, providing information about the spatial dimensions of rights in wordings and 2D drawings per layer. However, experience has shown that cadastral parcels registered and visualised in 3D offer a better answer to the need for clear, accessible and up-to-date information.

Currently, the disciplines involved in the different phases of an object's spatial development lifecycle are quite autonomous, and the experts are using custom-made, independent methodologies and workflows. This situation has proven slow and expensive, with inconsistent datasets and duplicates for the same objects through different phases of its lifecycle.

In this context, in several countries around the world the registration of parcels in 3D is proposed, using in some of them BIM / IFC models as a possible source for the geometry of 3D Cadastral parcels, thus reusing information through disciplines.

Given this background, there is a need to develop and an efficient and well-organised flow of information that supports the full lifecycle of the spatial development chain, enduring legal certainty in real estate and other transactions in align with their spatial counterparts.

2.2. Research questions

Therefore, the **core research question** is:

How to develop efficient data flow that can optimally support the spatial development lifecycle of the different 3D cadastral objects?

The accompanying **research sub questions** will guide the research in achieving the main objective:

1. Which are the different types of 3D cadastral objects (apartments, utility networks, archaeological units, etc.) according to the complexity of their geometry and the spatial development lifecycle phase they occur?
2. How can 3D legal spaces be linked with the physical notion of 3D objects (it may be already built constructions, 3D topography elements, e.g. terrain elevation, etc.), in the context of spatial development chain (from initial planning to real estate registration)? Two aspects can be further observed in this direction:

   a. the design of future physical objects in the real world (CAD, BIM/IFC format) may be considered as input for (future) 3D parcel creation (3D geometry with RRRs attached) and,
   b. the physical objects in the real world can serve as reference/ orientation for the legal spaces (via soft/implicit links or hard/explicit links).
3. Aiming at interoperable implementations of LADM-based models, more functionality is required and in thus, in this scene, two aspects shall be investigated:
   a. Does the development of 3D spatial profiles, at conceptual modelling level, provide the basis for better describing their modelling requirements and facilitate the communication between the different phases of object's lifecycle?
   b. Which encodings, at technical modelling level, can adequately express the implementation of spatial profiles and thus, there is need to establish a link between them and land administration in relation to spatial planning lifecycle?
4. How and according to what criteria the applicability and functionality of the proposed developments can be tested via a 3D web-based platform? A range of use cases will be examined, such as: building's apartment, utility network, natural resources, other infrastructure, etc.
5. Is it possible to assess the added value of the 3D LAS, or the impacts of not adopting it in the spatial development lifecycle in terms of quality/ quantity? Which (globally comparable harmonised) metrics and indicators could be used to achieve it?

Given this context, this research is expected to *facilitate a common understanding of 3D Cadastral Information Systems and their role in object's lifecycle considering interoperability, data sharing and data integration within the whole spatial development chain.*

2.3. Methodological approach

This research is conducted according to the **Design Science Research Methodology (DSRM) process** (Geerts, 2011). In the domain of information systems, DSRM is mainly used to develop an artefact with an embedded solution to address the explicated research problem (Peffers et al. 2007). The artefact can refer to models, constructs, methods, instantiations or any innovative solutions (March and Smith 1995). Over the last decade, Design Science Research Methodology has been implicitly adopted in various doctoral dissertations contributing to the information science aspect of land administration domain (Çağdaş and Stubkjær 2011; Atazadeh, 2017).

In this context, the research approach for this PhD has been developed in accordance with DSRM to enable the research question and the sub questions to be answered in a well-structured and substantiated manner, with feedback loops embedded in the whole process.

The DSRM comprises six activities:

- **A.** Problem definition and motivation,
- **B.** Define the objectives of the solution,
- **C.** Design and development,
- **D.** Demonstration,
- **E.** Evaluation and
- **F.** Communication

In Figure 3 the DSRM activities, as applied in this research are presented and at the following paragraphs are briefly explained.

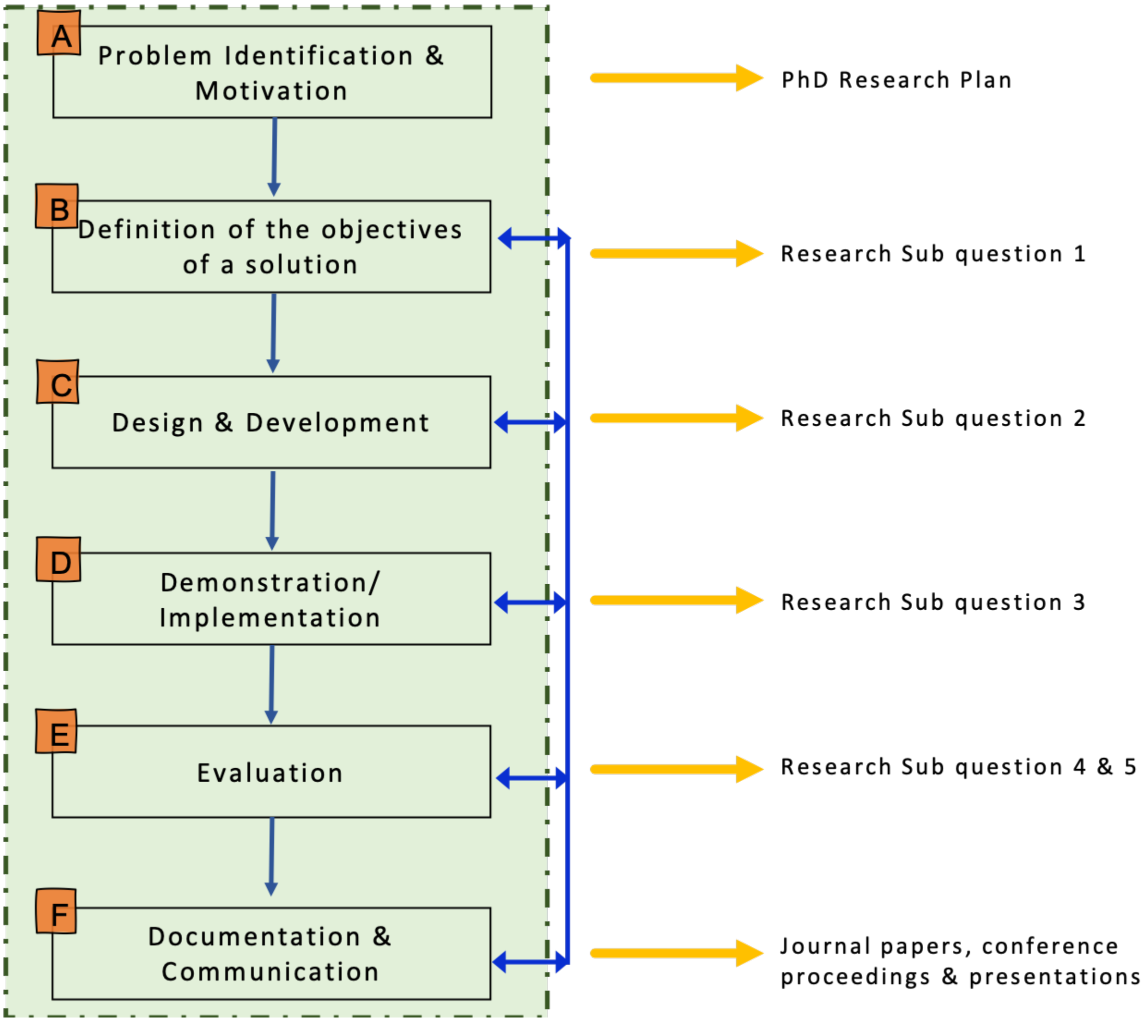

Figure 3. DSRM activities as applied in this PhD research objectives

2.3.1. Problem definition and motivation

This phase includes the explication of the research problem and definition of the requirements for a solution. To define and justify the research problem, relevant literature is thoroughly investigated to identify the state-of-the-art. In the context of this study, a variety of scholarly publications (scientific papers and books) and PhD dissertations are used to review the literature in relevant topics including land administration and 3D LAS, 3D Geospatial Information Systems (GIS), BIM/IFC models, different types of real-world spatial units and interoperability solutions between LAS and the other spatial development lifecycle steps.

Particularly, the analysis of the background focuses on the following aspects:

a. Investigation of the best practices from several countries with operational solutions supporting fully/partly the context of 3D LAS;
b. Requirements' analysis of the different types of 3D spatial units considering the complexity of their actual shape (geometric primitives/topological structure) & reference to other surfaces/objects;
c. requirements analysis of the various technical models/ encodings (i.e. BIM/IFC, CityGML, IndoorGML, LandInfra, INTERLIS, etc.);
d. data harmonisation and interoperability using standardisation approaches;

e. data collection for representative use cases (from Greece and the Netherlands) for various spatial units.

The spatial units that are recognised by (cadastral) authorities in various jurisdictions will be explored in three levels:

a. the development/ update of their taxonomy/categorisation;
b. the design of corresponding spatial profiles at a conceptual level (UML models based on LADM) and
c. the implementation through technical encodings.

Selected use cases will be collected from the relevant authorities (Hellenic Cadastre, Kadaster, Gemeente Delft, etc.) and studied at the evaluation phase of the research to examine the functionality of the artefacts. Specifically, 2D and 3D cadastral data from Greek and Dutch cases studies -including cadastral data (in various formats) attached to apartment complexes/buildings, utility networks and other infrastructures- will be collected.

2.3.2. Define the objectives of the solution

The second phase is closely related with the first one, as the objectives and the requirements of this research are initially identified through relevant literature. Therefore, those requirements are consolidated and finalized through investigating current practices for data exchange, management and communication through objects' lifecycle in the built environment, using standards. It is noted that, an outcome of the literature review is the definition of the research questions, while research sub questions are also addressed through reviewing relevant investigations.

2.3.3. Design and development

The categorisation of the different types of real-world spatial units that have initially been introduced and investigated in phase "Problem definition and motivation" is the first step of this phase. The categorisation, as it has initially been proposed by Thompson et al (2015), will be investigated and reviewed. The requirements of each category will be analysed taking into consideration the ambition and scope of LADM revision.

Based on this analysis and the requirements, conceptual models for the spatial units' categories will be designed to develop the corresponding 3D spatial profiles using different geometrical primitives and/or topological structures for their representation. One of the objectives of this phase is to improve the 3D support of LADM Edition I in terms of: additional classes/attributes (inherited or new ones), semantical enrichment of current elements, code lists, constraints (including those between legal spaces and physical models), data types, validation rules, visualization requirements, etc.

2.3.4. Demonstration/ Implementation

In the implementation phase, the artefact is realized to respond to the problem via case studies. In this research, the proposed profiles are instantiated in a prototype system. Specifically, the investigation of different encoding models concerning the detailed implementation of LADM based on standards (namely: BIM/IFC, GML, CityGML, LandXML, InfraGML, IndoorGML, RDF/linked data, GeoJSON, INTERLIS) will take place. For each spatial profile, the technical model(s)/encoding(s) that can better support its implementation is investigated. It may be the case that there is no encoding that can adequately express the implementation of a spatial profile content, or there is more than one encoding that fits some concepts. A key scientific challenge for this phase, is for instance, to represent non-2-manifold geometries, possibly partly unbounded volumes, involving both planar and curved surfaces (today not present in any other spatial discipline).

Having the artefacts in a (LADM-compatible) database or a data-exchange format is the first step towards implementation. Following, the system architecture of the prototype has to be decided (database schema and 3D web visualisation platform communication and alternative scenario to be tested) in order to develop a complete 3D LAS web-based dissemination system.

In the context of a holistic approach for object lifecycle management, different ways of harmonising and making compatible and integrable datasets which have been collected for different purposes, under different collection regimes, in different phases of the object's lifecycle, using different methodologies, accuracies, levels of detail and standards, will be investigated during this stage of the research. Focus will be given at the registration of legal spaces in 3D through re-using data sources from different lifecycle phases, such as construction and design models. Questions, such as "*what is the potential efficiency/quality benefits when reusing IFC data to 3D cadastral parcels"* will be answered.

2.3.5. Evaluation

The evaluation phase includes the usage of relevant metrics and criteria to measure how well the embedded solution within the artefact can respond to the problem. For this research, the first, "direct" evaluation method to be followed is to test the usability and functionality of 3D spatial profiles and their implementations. Thus, the selected use cases will be loaded in the LADM-compliant database and then visualised via a 3D web-based platform. To achieve this, standardisation techniques will be used to explicitly define data models at both conceptual and technical information model level and to test the performance of advanced technological tools in terms of consistency and integrity.

A second way to evaluate the results of this research, is to submit them to the ISO TC211 nominated experts for LADM v2 project team (and the FIG, OGC, IHO liaisons and RICS), as part of the revised LADM model, to be reviewed and assessed, as this thesis is aligned with the LADM revision process. It is a great opportunity that the quality and applicability of part of the research will be reviewed and evaluated by independent international experts from various countries, driven by the intention that 3D LAS should not be considered in the narrow sense but serve the ambition to realize the full lifecycle support in spatial development. The metrics to assess the results include quality, procedure, speed, cost when comparing the new lifecycle approach to the current one.

In this final stage, also the assessment of the 3D LAS added value in the chain of spatial development will take place, with regards to the artefacts and their evaluation. In this phase, indicators that can be used as quantitative and qualitative metrics for the assessment of the added value of the 3D LAS in the chain of spatial development will be investigated. Today, there are more and more indicators that are available and can be used for this purpose, namely, the Sustainable Development Goals (SDGs), the Land Government Assessment framework by World Bank (World Bank, 2018), the Global Land Indicator Initiative, etc. What is more, indicators that can express the impact from not applying 3D LAS will be also observed across a broad range of activities categorized in three main groups of requirements: legislative, organisational and technical. Lastly, it will be observed whether this fit-for-purpose assessment can be amalgamated with core identifiers.

2.3.6. Documentation and communication

In this phase, the problem and its significance, the artefact and its innovation/novelty, the results and findings of the research are documented and communicated to different audiences in the academia, industry, and governmental bodies. This will be achieved through numerous communication networks, such as scientific journals, conference proceedings, professional industry magazines, workshops, professional social media (e.g. LinkedIn, Research Gate, etc.) and presentations. To name the targeted audience of this research: academic researchers in the area of 3D Geoinformation, 3D Cadastre, Land Administration, GIS and BIM; ISO TC211 and OGC members involved in LADM revision process; experts from the industry in land surveying, land registration, GIS, BIM and 3D modelling.

The methodological diagram of this research is illustrated in Figure 4. The Phases indicated in the diagram are those described in Section 2.3 and presented in Figure 3.

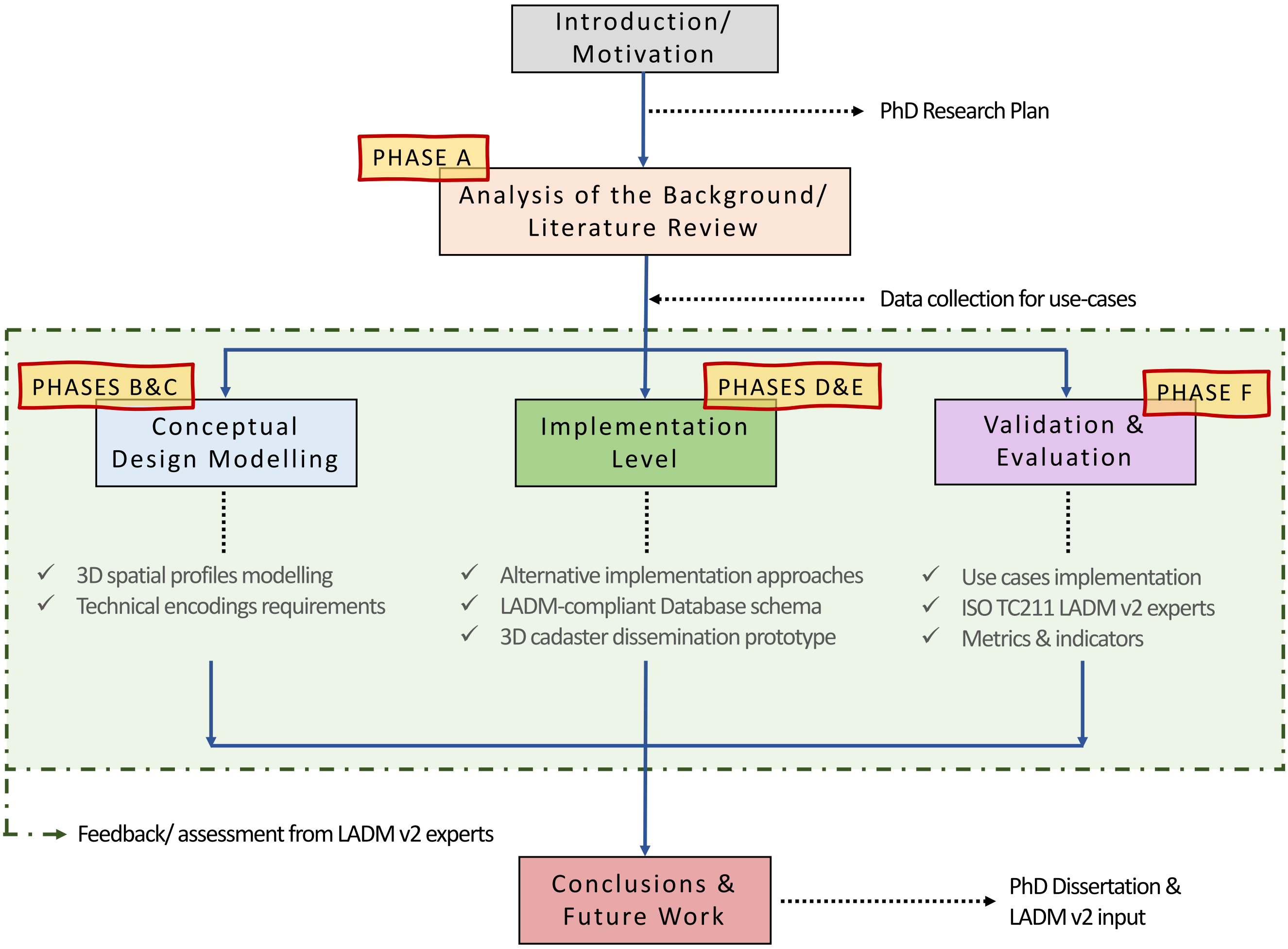

Figure 4. Methodological diagram

3. RELATED WORK & BACKGROUND THEORY

This chapter overviews the background theory and relevant context necessary to understand the scope of the research. Specifically, Subsection 3.1 introduces the issue of interoperability between systems and methodologies within the spatial development lifecycle and the role of standardisation in it. Subsection 3.2 presents the concept and characteristics of the spatial development lifecycle, while subsection 3.3 introduces the topic of 3D Land Administration. The LADM is briefly presented in subsection 3.4 and the land indicators that have been developed to measure progress at international level are presented in subsection 3.6.

3.1. Interoperability and standardisation

Interoperability, data sharing and data integration are required for an efficient spatial development lifecycle of (3D) objects, as well as in the development of land administration. For that reason, there has been a wide consensus in the industry and research community that the use and adoption of vendor-neutral standardised data models and formats constitute the most viable option for interoperability. Standardised data models define common semantics of the data, as well as vendor-neutral file formats to exchange the data in order to meet the diverse requirements of the various disciplines involved in the lifecycle.

Different disciplines working in spatial development lifecycle have their own view and interpretation to its importance, use and application; they have unique vocabularies and are quite autonomous, using custom-made roadmaps. External links to other databases (supporting information infrastructure type of deployment e.g. addresses, population register, business register, building register, utilities register, etc) are needed in all sectors to source input data and/or disseminate results. Data sharing means the data is collected once and used many times through establishing linkages (for example through SDIs) and thus, duplicative efforts in data collection and maintenance can be avoided. Though, effective management of heterogeneous information from different sources can also provide essential support for decision-making based on “common operational picture”.

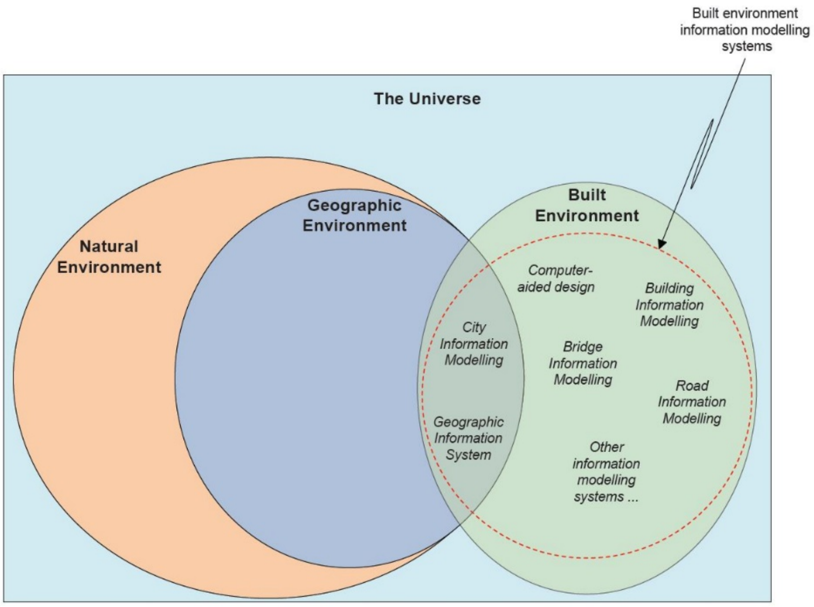

Figure 5. Built Environment Information Modelling systems and the geographic environment (Tah et al., (2017) State-of-the-art review of BeIM)

Towards this direction, significant research has been carried out the last decade, investigating the interoperability and integration between systems and methodologies that are used by various disciplines. Dominant and promising topic in this field has been identified the integration of Building Information Modelling (BIM) and Geographic Information System (GIS); however, still remaining a challenging topic to transform information towards the generation of knowledge and intelligence (Liu et al., 2017). The integration of BIM and GIS enables the effective management of information in various stages of a project's life cycle, namely planning, design, construction, operation, and maintenance. The information at any spatial and temporal scale can be available in such system for different applications.

This is well-expressed, as illustrated in Figure 5, by Tah et al. (2017), who suggested a general term for the integration of GIS and BIM approaches, "*Built environment Information Modelling - BeIM*", to encompass information modelling of all systems used in the built environment to design buildings, infrastructure as well as geospatial and built facilities. It is also underlined that interoperability and integration can be achieved in different levels depending on various aspects.

A 3D LAS covers both built environment and also non-built environment elements (e.g. subsurface natural resources, airspaces, etc.). Nonetheless, the urban environment must address multiple scales of spatial information (Figure 6). From geographic, to civil engineering, to building information models are the basis for accurate and comprehensive spatial modelling for Smart Cities and Spatial Information Infrastructure.

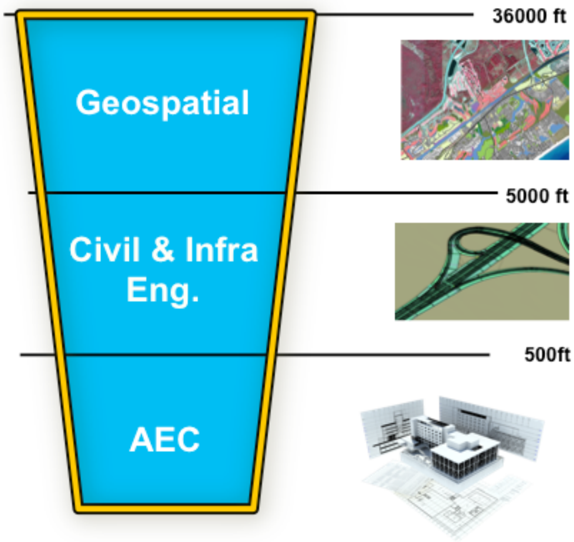

Figure 6. Scales of spatial information (OGC, 2015)

Given that (spatial) information comes from many different sources and is managed by a very large number of different providers, there is an overwhelming requirement to easily discover and share this information. Standards have a key role in this respect and are essential to delivering authoritative geospatial services and products which meet the requirements of the wider community of users. (UNGGIM, 2018). Much effort is made in the AEC and GIS domains to address interoperability issues via standardised approaches and exchange formats.

Several organisations, industry consortiums and communities are involved in standards development activities related to (3D) geoinformation; to name a few: ISO TC/211, Open Geospatial Consortium (OGC), European Committee for Standardisation (CEN), Web 3D Consortium (W3D), BuildingSMART Alliance, 3D Industry Forum (3DIF), Open Design Alliance, Khronos group, etc. ISO TC 211 and OGC are the two dominant ones in the geoinformation field, employing processes and approaches which ensure the development of international standards. Their aim is to ensure the ability to integrate datasets and related services of different types and from different sources, minimising costs and problems, while reducing dependence on implementation specifics (software, etc.).

In this context, there is an established collaboration between BuildingSmart and OGC, the "Integrated Digital Built Environment" approach which has led to the creation of the relevant, joint Integrated Digital Built Environment (IDBE) Working Group within OGC (OGC, 2017) aiming to increase interoperability between the geospatial and built environment domains (Figure 7).

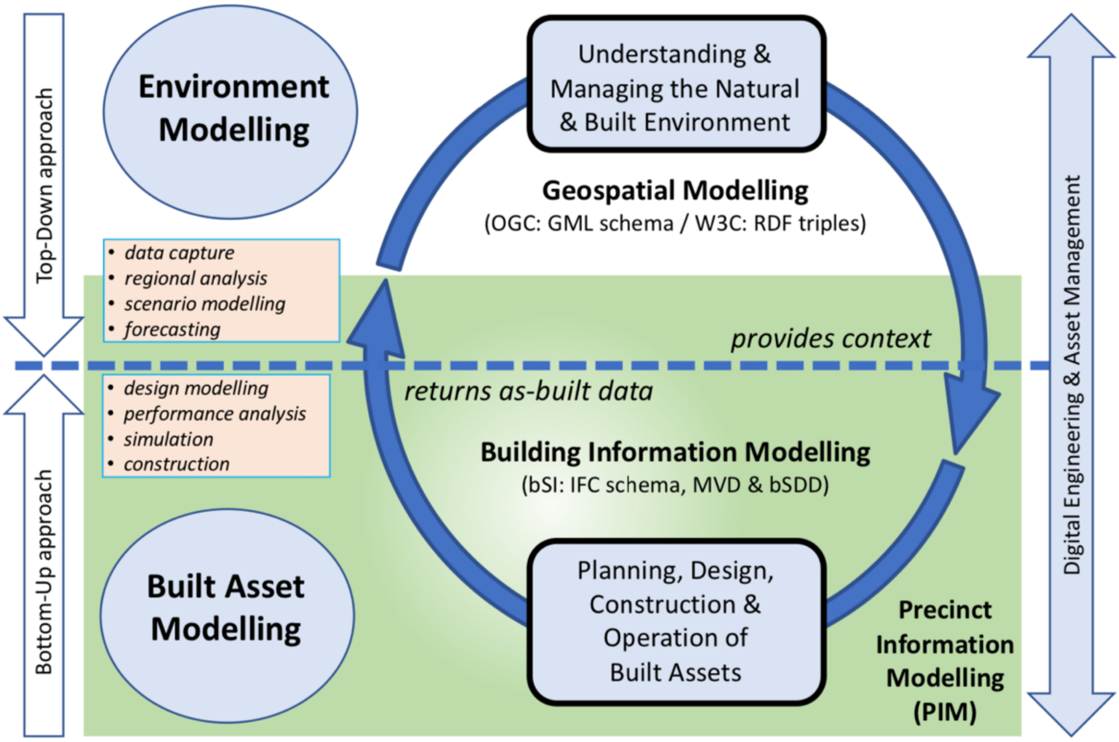

Figure 7. Integrated Digital Built Environment (OGC, 2017)

According to UNGGIM (2018b) "*Geospatial information standards provide a digital encoding to locate and describe features on, above or below the Earth's surface. Geographically related features can be naturally occurring (for example: rivers, rock formations, coastlines), man-made (for example: dams, buildings, radio towers, roads) or intrinsic, implied and transient information (for example: political boundaries, electoral districts, weather systems, distribution of population ethnicity). Technology standards allow different systems and services to work together through standard interfaces. Ideally, when the standards are implemented in products or online services independently, the resulting components 'plug-and-play', that is, they work together seamlessly.*"

Currently, a wide range of standards related to 3D is available and each one has been developed for a specific purpose. Such standards are related to data models, data exchange formats, data storage formats, data dissemination through data formats and/or web services. An extensive comparison of such standards has been performed by Zlatanova et al. (2012) based on selected criteria.

Concluding, although various successful approaches have been developed so far to manage heterogenous information between various systems, limited research has been done on the need for a holistic approach/workflow that will enable the interoperability between the disciplines involved in the spatial development lifecycle in the context of international standards. The research that has been carried out is most close and focused on BIM thinking.

3.2. Spatial Development Lifecycle

The built environment encompasses associated interdisciplinary aspects of design, construction, management and operation of the created surroundings and artefacts. The key industry sectors directly concerned with these interdisciplinary aspects include the Architecture, Engineering and Construction (AEC) industry, as well as the geography and urban planning industry sectors. Although interwoven in certain aspects, these disciplines rely on different systems in the synthesis and management of information associated with the built environment. This does not only apply to the objects of the built environment that already exist, but also to those that are in the design process.

Therefore, in the latter case, a full lifecycle information flow starts with information specification from the owner, the designers and contractors and are usually entered into an existing (BIM) database during design and construction. Such information can then be used to populate the existing building manager's asset management/facilities management system database(s) (including links to the BIM model). Most of the spatial and non-spatial data collected during construction is useful during operations (floor plans and 3D models – both geometry and associated attributes/data).

It should also be considered that financial, permitting, occupancy, maintenance history and other information are considered as vital aspects of an objects' spatial development lifecycle and should be maintained and exchanged between the various phases. At the centre of this lifecycle the registration of the object in a cadastral database can be found; and it is vital to consider workflows to exchange and reuse this information between the phases. Undoubtedly, the utility of 3D modelling is at multiple levels but out of the five core phases in the lifecycle — plan, design, construct, register and operate — the usage varies based on requirements.

3.3. 3D Land Administration Systems

Land Administration Systems have a fundamental role in society supporting connections between the public and across traditional jurisdictional boundaries, contributing to facilitating the delivery of digital economies, fundamental datasets and smart and sustainable cities of the future (Rajabifard, 2014).

As stated by (Aien et al., 2011) "*3D Cadastre should have the capability to capture, store, query, analyse and visualize multi-complex properties and infrastructure objects in a defined and clear legal, institutional and technical framework with a documented set of standards*". Thus, 3D Land Administration Systems is a quite inter-disciplinary field involving experts and knowledge regarding *legal aspects* (how to define and register a 3D parcel), *institutional support* to establish relationships between involved parties and *technical support* to realise it (data acquisition methods, modelling, storage and visualization techniques) (Figure 8). The level of sophistication of the 3D LAS in each jurisdiction will in the end be based on the user needs, land market requirements, legal framework, strategic and planning policies and technical possibilities.

In this scene, the last decade, the number of partial implementation of 3D parcel registrations around the world is increasing significantly (Kitsakis et al., 2016; Dimopoulou et al., 2016; Stoter, 2004) taking advantage of the developments to support the third dimension in the field of GIS Technology.

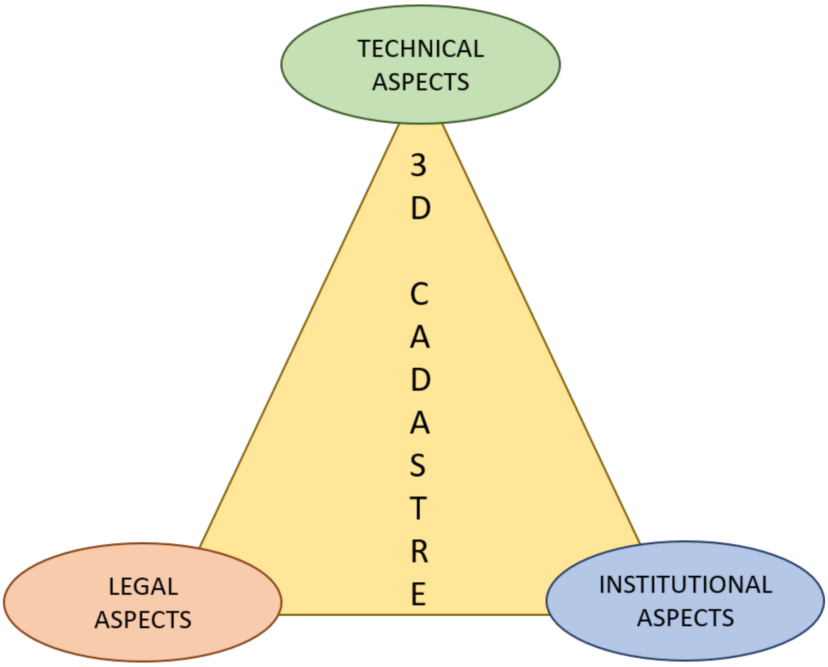

Figure 8. Relationship between different aspects of 3D cadastre (Aien et al., 2011, annotated)

However, less than 50 countries around the world have mature Land Administration Systems (Dimopoulou et al., 2016), whilst currently no country has a complete operational 3D Land Administration System, incorporating all aspects (van Oosterom et al., 2011; van Oosterom et al ,2014), however some jurisdictions are quite close to achieve it, namely the city of Shenzhen in China:

- 3D legislation,
- 3D surveying techniques,
- 3D registration of Rights, Restrictions and Responsibilities (RRRs),
- management, validation and dissemination of 3D parcels,
- correspondence to parcel's physical counterparts.

Although there is no country incorporating all those aspects, there are several jurisdictions, which do have operational solutions supporting at least partly the context of 3D LASs. Those 3D LAS efforts can be mainly categorised as "fully operational" implementations applying a holistic approach achieved in different levels of maturity and "partly-operational" implementations exploring the process of developing a 3D Cadastral Information System focusing on different aspects; e.g. submission of 3D survey plans, prototype stage; link with dominant physical models, implementations that focus on visualisation, implementations that focus on constraints and validation rules (Kalogianni et al., 2018). To this end, the first 3D cadastral registration of multi-level ownerships rights has been accomplished in The Netherlands, in 2016 (Stoter et al., 2017), as a result of many years of research.

3.4. ISO 19152 Land Administration Domain Model

Standardisation in land administration domain concerns the description of key concepts, such as: parcels, documents, persons, transactions, control points and many other issues. It concerns the organisation of tables in the registration and references from those tables to other components, e.g. source documents and maps; this includes efficient access to archives. It concerns coding and use of abbreviations and workflows and it should be observed that all this is valid for both paper-based and for digital LASs (Lemmen et al., 2013).

3.4.1. LADM Edition I (ISO 19152:2012)

The standardisation project of LADM started back in 2008, when the first proposal was submitted as a result of activities within FIG since 2002 and after a series of reviews, comments and updated versions of the standard, it completed its first "cycle" on December 2012 (Kalogianni et al., 2018).

As stated by Lemmen (2012), the basis for the development of the LADM was "*A common denominator, or the pattern can be observed in global land administration systems: legal/administrative data, party/person/organisation data, spatial unit (parcel)/immovable object data, data on surveying or object identification and geometric/topological data are all included*". Subsequently, the initial version of LADM was designed by experts from all over the world, based on the common pattern of 'people–land' relationships, re-using existing international standards (ISO 19107, ISO 19111, ISO 19115, ISO 19108), being as simple as possible to be useful in practice. LADM is currently maintained by ISO TC 211.

LADM is based on user needs and provides standardised terminology enhancing interoperability between information systems. The standard is capable of supporting the progressive improvement of land administration and can potentially be used to support organisational integration (Lemmen et al., 2015), for example, between often disparate land registry and cadastral agencies.

The model provides a conceptual schema with three basic packages and one sub-package (Figure 9):

- **Party Package**: including people and organisations that are involved in transactions,
- **Administrative Package**: including rights, restrictions and responsibilities,
- **Spatial Unit Package**: including parcels and legal spaces of buildings and utility networks.

The **"Surveying and Spatial Representation Subpackage"**: including spatial sources, surveying and spatial representations (geometry and topology).

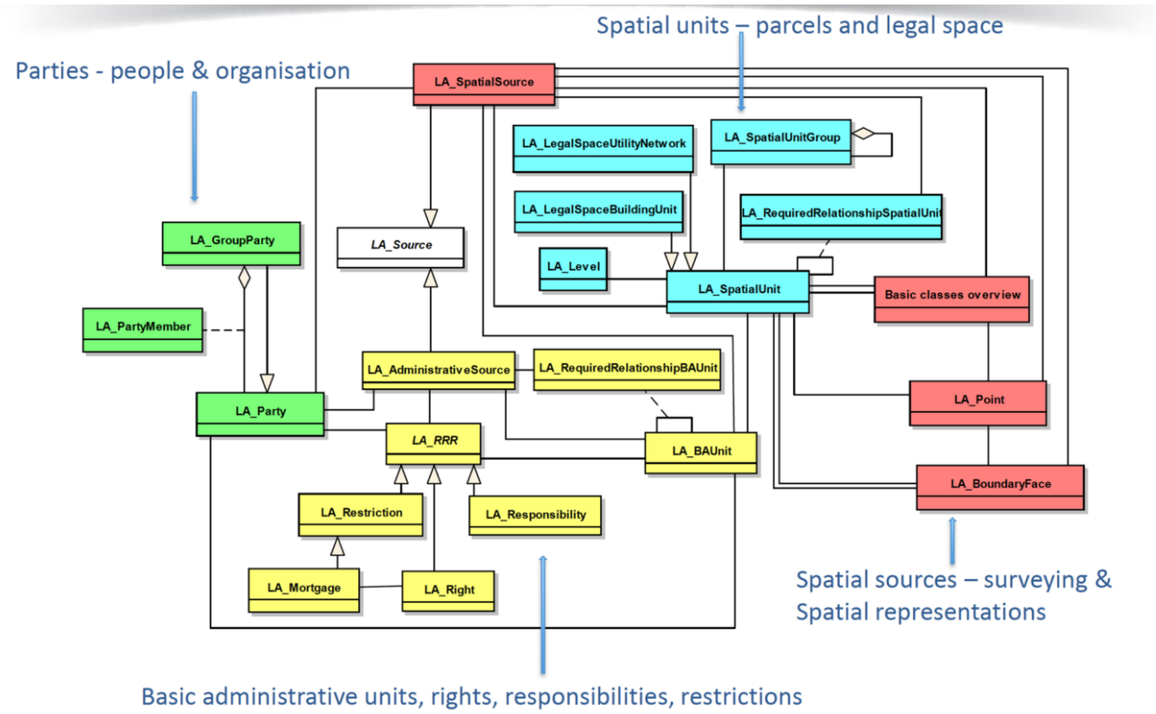

Figure 9. LADM edition I, core classes (ISO19152, annotated)

The continuum of land rights disserves extra attention to understand the possible impact of LADM (Lemmen et al., 2013). In UN-HABITAT (2003) and UN-HABITAT (2008) the various types of land rights are viewed as existing along a continuum, with some settlements being more consistent with law than others.

This view makes it possible to include the people with the weakest tenures in the idea of sufficient legal access, as illustrated in Figure 10.

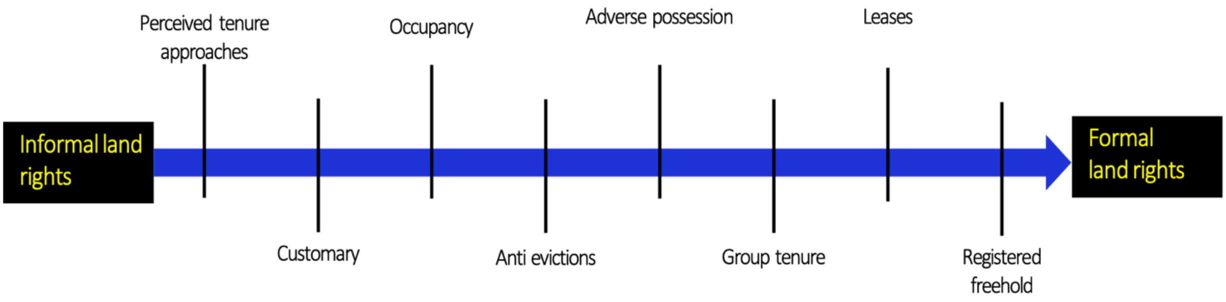

Figure 10. UN Habitat's continuum of land rights (UN Habitat, 2008, annotated)

The major impact of LADM is through its recognition as an ISO standard for the domain of land administration (Lemmen et al., 2015). The growing recognition and influence of the standard is revealed by the multiple country profiles that have been developed; several LADM implementations through technical models and encodings; as well as parallel activities, such as development of land administration domain ontology, support of strata titles, etc. Although LADM at its first edition provides an international framework, conceptually effective to support 3D LAS development (Oldfield et al., 2017) encompassing a wide range of eventualities, it does not stipulate the requisite data format (encodings) for implementation (Janečka and Souček, 2017), which is one of the main goals of its ongoing revision.

3.4.2. LADM Edition II

The ongoing revision will be a joint activity, supported by many organisations and institutions (ISO TC 211, OGC, FIG, World Bank, UN-GGIM, UN-HABITAT, GLTN, IHO, RICS, ELRA, Kadaster, TUDelft, etc.). Each one will be involved and contribute to different aspects of this process, i.e. OGC will provide steps towards implementations in encodings, IHO will contribute to the LADM support to marine spaces, etc. The ambition is to go beyond just a conceptual model by providing steps towards implementations (e.g. more specific profiles, technical model in various encodings, etc.). The intention is that, the first edition of LADM should be upwards compatible with future editions.

The International Federation of Surveyors (FIG) submitted a New Working Item Proposal (NWIP) to ISO on the development of the LADM Edition II in April 2018. This New Working Item Proposal includes the following scheduled main LADM extensions:

- Extended scope of conceptual model. This includes: valuation information, SDG LA indicators, Performance Index, linking legal objects with physical ones, indoor models, support of marine spaces, spatial planning/zoning with legal implications, support of other legal spaces: mining, archaeology, utilities;
- Improvement of the current conceptual model. This includes: formal semantics/ontology for the LADM Code Lists; more explicit 3D+time profiles; an extended survey and legal models;
- Encodings/technical models towards LADM implementation. This includes: further integration with BIM/IFC, GML, CityGML, LandXML, LandInfra, IndoorGML, RDF/linked data, GeoJSON, and
- Process models for survey procedures, map updating, transactions – including blockchain.

At the last ISO TC211 meeting, that took place in Maribor (June 2019), it was concluded that the second Edition of LADM can be organized into multiple parts (either as multiple coherent packages in one standard as available in draft or every part in separate standard). Working Titles of the packages (or parts) are as follows:

- Part 1 - Land Administration Fundamentals
- Part 2 - Land Tenure or Land Registration or Land Interests
- Part 3 - Marine Space or Marine Geo-Regulation (support to marine spaces through IHO S-121)
- Part 4 - Land Valuation
- Part 5 - Spatial Planning
- Part 6 – Implementations (including Link with BIM and other technical encodings (RDF, CityGML, InfraGML, INTERLIS, GeoJSON, etc, processes, etc.)

3.5. BIM models as source in Land Administration domain

Research in the academic community investigates various methods for developing integrated legal-physical 3D data models; nevertheless, the investigation regarding the use of BIM models as input for land administration systems is quite recent.

Emphasis is given on the use of BIM (using IFC, which is the most common publication format for BIM) as input for 3D LAS, as it considered a promising source for semantically enriched spatial data regarding buildings, apartment rights and infrastructure elements and a natural way forward. BIM has revolutionized the design and construction industry around the world the last years; national and governmental BIM councils, roadmaps and even strategies are currently being established in various countries (United Arab Emirates, Ireland, etc.), EU BIM Task Force has been established, while in some of those BIM has already become a government mandate (UK, the Netherlands, etc.) for specific projects (i.e. in Germany for transportation projects). The importance of BIM is recognised, and it is being seen from governmental perspective as a digital reform and transition that will bring together technology, process improvements and digital information to radically improve project outcomes and asset operations. One of the strong characteristics of BIM is that is considered as a strategic enabler for improving decision making and delivery for both buildings and public infrastructure assets across the whole lifecycle.

At the following paragraphs, the most dominant advancements towards the usage of BIM/IFC data as input for Land Administration Systems are briefly presented. To start with, Oldfield et al. (2017) suggested that space objects of IFC model (IfcSpace) and the grouping of these spaces as legal zones (IfcZone) would underpin the basis for utilizing BIM models as input for 3D LAS and thus, boundaries of legal spaces could be modelled by "IfcRelSpaceBoundary". This research also stated two main challenges associated with adopting IFC standard for 3D cadastral purposes, namely the manual extraction of the spatial extent of 3D legal interests from BIM models, and modelling ambulatory boundaries defined by changes in water level of the lake located around the restaurant.

What is more, the same authors -Oldfield et al. (2016)- developed a collaborative BIM-based workflow for cadastral registration using Information Delivery Manual (IDM) approach. The workflow described how cadastral data requirements could be efficiently communicated between project initiators and authorities, which would, in turn, facilitate procedures for obtaining legal spaces from BIM models.

Moreover, in this PhD dissertation, Atazadeh (2017) investigated the feasibility of using BIM models for the 3D digital management and visualisation of legal interests in multi-storey building developments. In the context of the research, it is proposed to extend IFC models with legal data elements and, hence, a prototype BIM model for a multi-story building development was implemented to demonstrate the viability of this proposal with regards to complex legal arrangements.

Atazadeh et al (2018) identified two different approaches for the mapping between LADM classes and IFC entities: a) the attributes of each LADM concept to be modelled as property sets applied to their counterpart IFC entities. The concept of property set definition is used to specialize and extend IFC entities without the need to define new subclasses; and b) Extending LADM with IFC-based physical objects (Figure 11) to cover the case of jurisdictions where building structures are used for boundary delineation and they are also considered as constituent parts of some legal arrangements.

More recent, Meulmeester (2019) proposed a proof of concept of a complete data processing chain for registering new apartment rights in 3D in the Netherlands, by enriching s IFC files with legal information. The legal space is added to the IFC data format with a cadastral information user defined property set, to enable fully automatic extraction of the 3D spaces that belong to one apartment. This is a customised set of attributes that are added to the IfcSpace element, taking into account current guidelines for standardised IFC usage in the Netherlands).

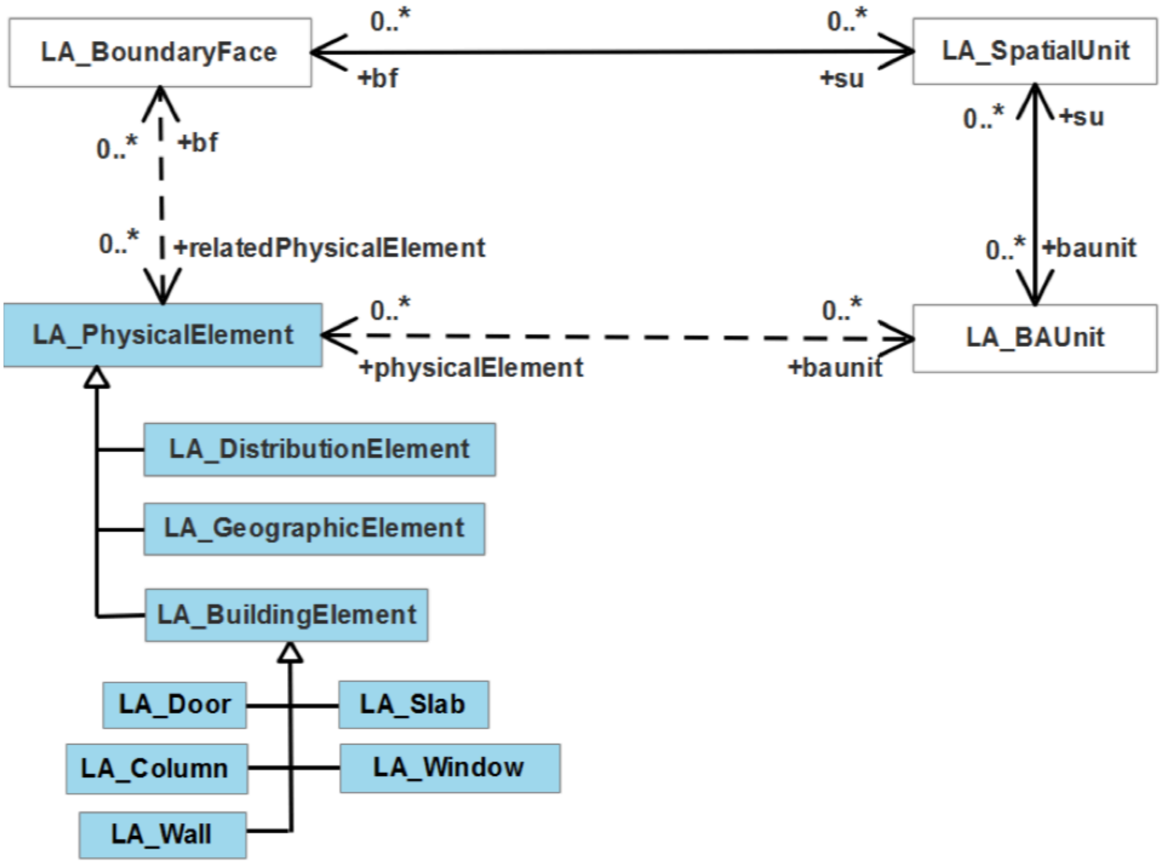

Figure 11. Extending LADM with IFC-based physical objects (Atazadeh et al, 2018)

Last but not least, the most recent approach by Ying et al. (2019), proposes an "easement spatialization" based on building models of IFC standards, to prove that such an approach can optimize the complex presentation of 3D property attributes (Figure 12). The research result shows that BIM can optimize the complex presentation of 3D property attributes and is an effective carrier of easement spatialization, while it underlines similarities and discrepancies of easement modelling in 3D with indoor environment.

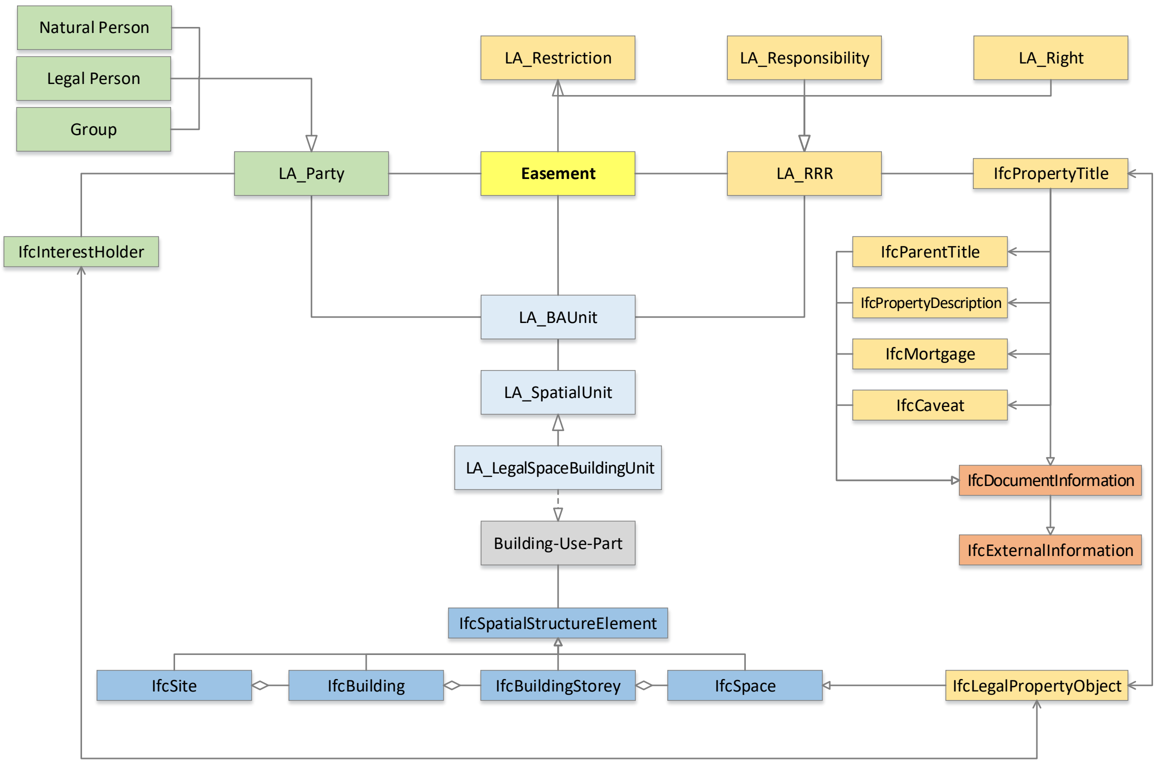

Figure 12. Easement modelling based on BIM model (Ying et al, 2019)

3.6. Metrics and Indicators

Progress needs to be expressed and measured (Lemmen et al., 2017). As also stated by the United Nations Open Working Group (UN-OWG, 2014) "*Sustainable Development Goals are accompanied by targets and will be further elaborated through indicators focused on measurable outcomes.*" Today, indicators are available via the Land Government Assessment framework from the World Bank (World Bank, 2019) and via the Global Land Indicators Initiative (GLII) (GLTN, 2019), and these efforts require data as input for measurements. Standardised approaches allow getting overview quickly and this can be supported by tools, such as the Social Tenure Domain Model (STDM) and LADM compliant databases.

The **United Nations 2030 Agenda for Sustainable Development** includes consideration of the land issue across a number of targets and its indicators to promote a framework for disaggregated and reliable data to link statistics and geospatial data while ensuring national ownership (Habitat III, 2016; UN, 2017; UN, 2018). The Sustainable Development Goals adopted in 2015 by all (193) the United Nations member states and are strongly supported by the UN-World Bank Group partnership. SDGs are an historic global achievement to "*create a future we want in 2030*". These 17 goals (Figure 13), are an integrated, indivisible set of global priorities for sustainable development, focusing on measurable outcomes, in areas such as health, gender, jobs, and poverty reduction, are part of a comprehensive global agenda to end poverty in a single generation.

The 2030 Agenda for Sustainable Development demands the need for new data acquisition and integration approaches and techniques. Land and tenure data is an integral part of this data ecosystem needed to measure, monitor and inform on progress in sustainable development as well as evidence-based policy formulation and informed decisions (Lemmen et al., 2017). For the Agenda, monitoring and accountability will be through the agreed 17 Goals and 169 Targets. Alongside these goals and targets, a global indicator framework currently comprising 230 indicators. The Sustainable Development Solutions Network (SDSN) has compiled a comprehensive list of indicators for the SDGs which consist of 100 “core indicators”, including many related to land (SDSN 2014). SDGs are integrated and indivisible and balance the three dimensions of sustainable development: the economic, social and environmental.

Figure 13. Sustainable Development Goals (World Bank, 2018; UN, 2018)

This list of global indicators is an initial framework to be improved and refined over time, taking into account lessons from implementation, methodological development and technological advances. It is a “practical starting point”, allowing member states and development partners to move forward with implementation of the SDG monitoring framework (United Nations Development Programme, 2017).

Maximizing the value of fundamental geospatial information (including land information) at the national and sub-national levels to capture elements of the 2030 Agenda, for informed policy-making, decisions and actions is going to be critical. Such national bottom up approach can only be achieved within the time frame of the 2030 Agenda when standards are readily available and embraced (Lemmen et al., 2017). In this scene, ISO 19152 LADM plays an important role, while relevance between LADM and some of the SDGs is identified through: SDG 1 “No Poverty”(and more specifically, SDG 1.4 - Target 1.4.2, is about secure tenure rights with legally recognized documentation for all, influencing the way that land is used), SDG 11 “Sustainable Cities and Communities”, SDG 14 “Life Below Water” and SDG 15 “Life on Land”.

The United Nations Economic and Social Council (ECOSOC) established UN-GGIM, the Committee of Experts, as the apex intergovernmental mechanism for making joint decisions and setting directions with regard to the production, availability and use of geospatial information within national, regional and global policy frameworks. UN-GGIM aims to address global challenges regarding the use of geospatial information, including in the development agendas, and to serve as a body for global policymaking in the field of geospatial information management (UN-GGIM, 2019b).

The UN-GGIM recognising “*an urgent need for a set of global fundamental geospatial data themes that could be harmonised in order to enable the measurement, monitoring and management of sustainable development in a consistent way over time and to facilitate evidence-based decision-making and policy-making*” established the **Fundamental Geospatial Data Themes.** Those data themes are 14 themes (Figure 14), from Geographic Names, Addresses to Land Cover, Imagery and Land Parcels (which is related to the spatial part of LADM), designed to bridge the gap between the geospatial data community and other stakeholders, as well as to make a difference in the achievement of the SDGs (UNGGIM, 2019a).

Figure 14. UNGGIM Fundamental Geospatial Data Themes (UNGGIM, 2019a)

Underlying the importance of standardised information, domain independent standards from ISO 19100 series are the basis for describing geospatial information (Østensen, 2018) (Figure 15). An open question is how those themes are related to domain dependent ISO standards, such as ISO 19144, which refers to Land Cover, ISO 19152 LADM, ISO 19160, which refers to address information, etc.

Moreover, the Global Land Indicator Initiative (GLII) was established under the Global Land Tool Network in 2012 with the aim to support efforts to harmonize monitoring efforts around land tenure and governance (GLTN/UN Habitat/Kadaster, 2015). The GLII seeks to derive a list of globally comparable harmonized land indicators, using existing monitoring mechanisms and data collection methods as a foundation (Lemmen et al., 2017).

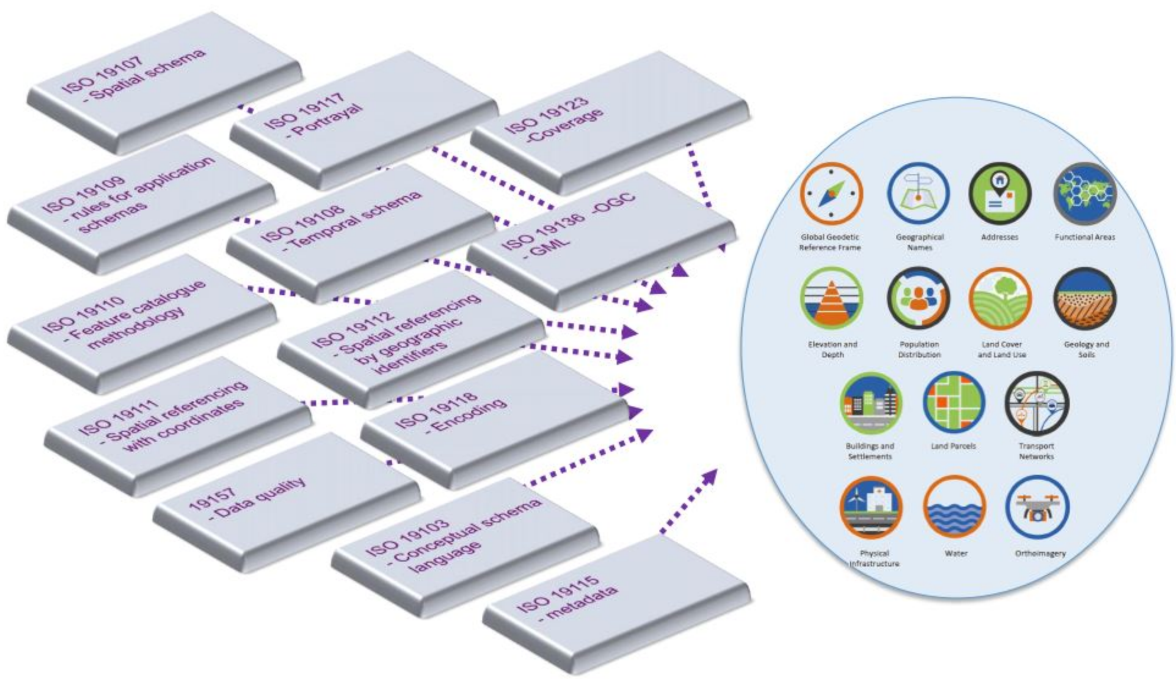

Figure 15. ISO 19100-series: the basis for Fundamental Geospatial Data Themes (Østensen, 2018)

What is more, the Land Governance Assessment Framework (LGAF) can be used for identifying and monitoring sound practise in the land sector (World Bank, 2013; World Bank, 2019). The LGAF is motivated by the fact that land policy analyses and interventions are often fragmented (Lemmen et al., 2017). They are taking a view that focuses only on specific aspects (such as land administration or surveying) and thus, they may miss important synergies to other parts of the system. LGAF is structured in five key thematic areas: (1) how land rights are defined and enforced; (2) how land is managed, used and taxed; (3) how public land is managed; (4) how information on rights are maintained and accessed; and (5) how land disputes are managed and resolved. The tool highlights areas where a country is doing well and where there are deficiencies and does this in a way that builds consensus for land sector reform. LGAF also provides tools to monitor land governance as reform is implemented (World Bank, 2013).

Currently, there are no indicators directly related to 3D, however the GLII and LGAF, use 3D information as input for the collection and management to develop land indicators.

Lastly, the “Globalands” project (funded by the Federal Environment Agency and the German Federal Ministry for the Environment) aimed to identify promising existing land use policies and to develop possible governance tools towards a more resource efficient and sustainable global land use. From the research carried out it was concluded that, currently, no existing set of indicators consistently describes sustainable land use in both the environmental and social domains. The project was completed in 2015 and among its results, was the methodological contribution to the discussion of how to measure sustainable land use. GLOBALANDS developed a new systemic indicators approach for key land use areas (especially agriculture, forestry) as an opportunity for socially inclusive and regionally differentiated implementation. As a methodological contribution to the discussion of how to measure sustainable land use, Globalands developed the new systemic indicators approach for key land use areas (especially agriculture, forestry) as an opportunity for socially inclusive and regionally differentiated implementation (Fritsche et al., 2015)

4. SCIENTIFIC AND SOCIETAL RELEVANCE

4.1. Research Significance

The expected contribution of this PhD is related both to practice and methodology and can be summarised as follows:

1. From a technical perspective, this PhD will contribute to the ongoing research carried out in the field of integrated approaches where the legal and the physical notions of 3D objects may be related. It is expected that technical challenges will be faced mostly at the area of:
    I. transition from conceptual to technical model such as: translate semantically enriched code lists form UML to SQL expressions, define complex constraints in UML and translate them into a database, etc.;
    II. model encodings for the detailed technical specification of LADM based on existing standards, will be addressed at the research and provide useful conclusions in this direction;
    III. data harmonisation and interoperability.
2. It is expected that the research will contribute to the refinement and explicit modelling of the 3D support of current ISO19152 LADM Edition I and investigating the functionality of different encodings for interoperable LADM technical implementations.
3. The outcome is expected to be part of ISO19152 LADM Edition II, while it aims to contribute the ongoing research carried out by FIG Joint Commission 3 and 7 Working Group on 3D Cadastres.
4. Implementing and organising the cadastral registration as an integrated part of the spatial development chain brings potential benefits: data from one stage is reused in next stage, less mistakes/ misunderstandings occur; however, multiple disciplines have to be bridged. Moreover, providing directions for implementing a 3D LAS and experience from the prototypes will result in concrete recommendations for future work. Based on those recommendations decision-makers and industry will be supported to choose and customise 3D Cadastral Information Systems implementations.
5. Currently, there are discrete and specific phases through the spatial development lifecycle of objects, involving multiple stakeholders from various domains with different backgrounds, tools and requirements. All involved parties could benefit from knowledge produced in this PhD research on how to efficiently manage and exchange geo-information within the spatial development lifecycle. An information infrastructure approach is proposed to represent objects together with their legal, administrative and spatial information, through their lifecycle.
6. Emphasis is given on the use of BIM as input for 3D LAS, as it has revolutionized the design and construction industry around the world and it is expected that the proposed system architecture of this research will be an added value towards the reuse of BIM data and models in land administration.
7. The software industry could benefit from the results as, in order to achieve data harmonisation and communication between the stakeholders involved in the various object lifecycle phases, updated or new software tools and formats will be needed and they will be described and/or developed in the context of this research.
8. Setting the scene of 3D Land Administration Systems within the lifecycle of spatial development activities, plays an important role on how both technology and governance aspects of the GII can be

further strengthened to solve complex social and management problems in the built environment. Emphasis will be given on the institutional aspects aiming to establish relationships between the involved parties within the whole chain, from where shared vocabulary and collaborative workflows could be derived. It is expected that this research will gain social profitability, emerging new technologies to facilitate the organisation, sharing, integration and reuse of information sources within the chain of spatial development.

Within the framework of research programmes as spelled out by Faculty's website my PhD research belongs at the "*Geoinformation Technology & Governance*" research programme (https://www.tudelft.nl/en/architecture-and-the-built-environment/research/research-programmes/geoinformation-technology-governance/).

The proposed research is innovative as currently, there is no efficient (by means of: fast and easy, no data loss, etc.) and organised flow of information, in terms of legal, organisational and technical aspects, that can support the entire lifecycle of spatial objects for the sake of better transparency in registered RRR's supporting legal certainty in real estate transactions. Additionally, the concept of re-using source data from design or construction to the registration process is been investigated over the last years, as a stand-alone mechanism and not as an integrated part of the objects' spatial development lifecycle, indicating that parameters that will be taken into account in this research have not been jointly examined.

The deliverables of this research are expected to be related to the modelling of different types of 3D spatial units; structured implementations through encodings that apply from planning/design phase to registration/operation and data reuse between lifecycle phases, accompanied with relevant tools that will be developed as open-source software code; indicators related to the assessment of 3D LAS, etc.

4.2. Societal Relevance

To achieve societal relevance and impact, of this PhD research, early involvement of users is important by sharing their knowledge and expertise and also by providing data to test the research prototypes and tools (and continue to use the results after project). In this context, as this research is closely related to the ISO19152 LADM revision, part of it will be reviewed (in various steps through PhD's lifecycle) by experts around the world and use cases can be collected also in collaboration with them.

What is more, there are some typical owners of objects that can be considered as (indirect) potential users and can benefit from the proposed research (to name a few, Rijkswaterstraat, ProRail, Schiphol Airport, Harbour of Rotterdam, Kadaster, NAMA Consulting Engineers and Planners SA etc.). Similarly, Municipalities, besides owning objects, also provide permits for other object developments, as well as Registrars and Notaries could benefit from the outcome of this research.

Moreover, as this research has international character, it can be a possible user to apply its findings to the countries that provides consultancy services and introduce the outcome to the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), through the revision process of ISO19152 LADM revision process (2018-2022).

Last but not least, at the last stage of the PhD research, SDG's and other relevant indicators will be explored (as mentioned in Section 3.6), in order to assess (qualitative and quantitative) the added value of 3D LAS. In order to achieve the SDG's and to have legal certainty for all citizens in the world, good geospatial information management and sound land administration are important prerequisites. In this context, the investigation of SDGs as a tool to assess land administration, and more specifically 3D LAS in the context of the PhD research indicates the societal relevance of this research. As mentioned earlier, experts around the world will review and assess the research in different stages, among them experts involved in UN-

GGIM (UN-EG-LAM), which plays a leading role, at a policy level, by raising awareness and encouraging the use of geospatial information management for land administration purposes (De Zeeuw, 2016).

Figure 16 illustrates the SDGs that are related to land administration domain.

Figure 16. Land Administration and SDG's (De Zeeuw, 2016)

5. PRACTICAL ASPECTS & PLANNING

This chapter outlines the research plan and the practical aspects of conducting the proposed research outlined in the previous chapters.

5.1. Organisational Aspects

I. General

This PhD research, started in August 2018, continues a wider research activity in the field of land administration and geoinformation technology that commenced in 2012, when I started my MSc in Geoinformatics at the National Technical University of Athens (Greece), where my MSc thesis topic was "*Design of a 3D Multipurpose Land Administration System for Greece, in the context of LADM*". Following, I continued my education by joining the MSc in Geomatics at the Delft University of Technology (the Netherlands), where my MSc thesis topic was "*Linking the legal the physical reality of 3D objects in the context of Land Administration Domain Model*". Both, afore-mentioned MSc Theses are directly related to this PhD research, establishing strong and cognitive foundations in the knowledge and understanding of 3D LAS and standardisation in the field of land administration; topics much relevant with my PhD research.

The research is planned to proceed during the time period of 4 years, as an external PhD research at TUDelft. As I am currently working at an Engineering Company in Greece (NAMA Consulting Engineers and Planners SA), I wish to combine my work with the PhD research. My company undertakes large scale infrastructure works, both in Greece and abroad, as well as cadastral surveys, and thus, NAMA is expected to be involved and support the research by providing real data for representative use cases in Greece. In this scene, it is expected that The Netherlands' Kadaster will support the research and provide relevant data for Dutch use cases.

The timeline of this research involves a series of activities that are not sequential but rather iterative and therefore will be conducted over an extended time period. There are however milestones that I will endeavour to meet in order to remain on track for the timely completion of my PhD. Figure 18 summarises my proposed research timeline.

In addition to the core research there will be other tasks and activities that will make my PhD more robust. These are:

- Research publications in journals and conference proceedings.
- Research visits and collaboration with external partners that may provide case studies, or feedback to the research in various stages.
- Maintaining a continuous and up-to-date literature review.
- Attendance of Graduate School courses, discipline-related courses, workshops, and conferences (in align with Doctoral Education).
- Participation in academic life through assisting with instructing courses or practicals (Geo Lab), and supervising master's students.

II. Supervision

My **Promotor and Supervisor** will be Prof. dr. ir. P.J.M. (Peter) van Oosterom, Chair of GIS-Technology Section, Faculty of Architecture and the Built Environment, Delft University of Technology. Prof. dr. ir. Christiaan Lemmen, University of Twente, Faculty of Geo-Information Science and Earth Observation/ITC will be my **co-supervisor** and as the PhD time will be shared between Delft and Athens, Prof. dr. Efi

Dimopoulou, School of Rural and Surveying Engineering, National Technical University of Athens, will be also my **co-supervisor** of this thesis. Each one of the supervisors that frame my supervisory team, will be involved and supervise the whole life of the PhD research, but also has a distinctive role depending on the phase of the research.

Main supervisor - mentor	Prof. dr. ir. P.J.M. (Peter) van Oosterom	Faculty of Architecture and the Built Environment, Delft University of Technology
Co-supervisor	Prof. dr. ir. Christiaan Lemmen	Faculty of Geo-Information Science and Earth Observation/ITC
Co-supervisor	Prof. dr. Efi Dimopoulou	School of Rural and Surveying Engineering, National Technical University of Athens (NTUA)

III. *ISO 19152 LADM Revision Team*

Part of the PhD research is closely related with the ISO19152 LADM revision process, and therefore proposals will be made for specific components of the updated standard in the context of the research.

These will be tested and validated from experts involved in the revision process with feedback loop in order to arrive at improved versions, before they are submitted to be included in the revised version of LADM (ISO 19152) (Figure 17). Therefore, a team comprising of staff from TUDelft and ITC-University of Twente, supported by the Netherlands' Kadaster, has been shaped to work on the core of this revision. The members of the team are: Prof. dr. ir. Peter van Oosterom (TUDelft), Prof. dr. ir. Christiaan Lemmen (University of Twente), Abdullah Alattas (TUDelft), Agung Indrajit (TUDelft), Abdullah Kara (Yildiz Technical University), Eftychia Kalogianni (TUDelft) and dr. Anna Shnaidman (TUDelft).

Being part of this team, imposes obligations and responsibilities, such as contributing to Working Documents of the new ISO, joining meetings and conferences both virtually and physically, etc. While at the same time it brings many benefits: important feedback and interaction with the team members, validation of the research proposals, shared research interests, challenges and problems that need to be solved, common ground to find robust solutions (e.g. cooperation to code lists approaches, technical encodings, etc.)

There is a distinction between the personal planning and the LADM revision planning, however alignment of personal and LADM revision related activities is necessary to maximize the mutual benefits.

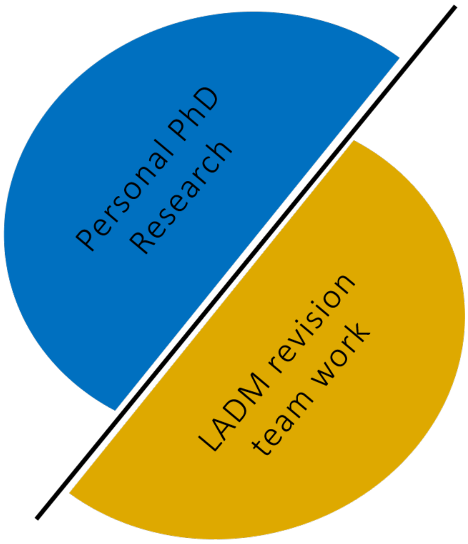

Figure 17. Alignment of personal research with the LADM revision team research

IV. *Monitoring Tools*

Research progress should be monitored and recorded. To better and efficiently organise the PhD research, the monthly progress monitor (Gosling and Noordam, 2011) will be used as a tool to make a realistic plan on a monthly time scale and bring in line expectations and achievements. For this evaluation, each month, a Monthly Progress Report containing 4 questions will be shared with the supervisor and co-supervisor. The questions are the following (Gosling and Noordam, 2011):

- Of the results I obtained last month, which are the most important?
- Did I deviate from last month's planning? If so, why?
- What are my most important goals for the upcoming month?
- How do I overcome potential hurdles on the way?

Additionally, Doctoral Monitoring Application (DMA) will be regularly used in order to trace training and courses for Doctoral Education organised by the Graduate School of TUDelft. By keeping the DMA updated the Graduate School, the supervisor and myself will benefit from it. The arrangements (contact with supervisor, work arrangements, official PhD documentation, educational courses and activities) are also recorded.

Till today, nine (12) Monthly Progress Monitor Reports have been submitted to the supervisory team (October- December 2018 and January – September 2019).

V. *Meetings*

The progress of work will be tracked through meetings with supervisors and presentations (project meetings, lunch seminars, etc.) at TUDelft. Meetings will be scheduled with the supervisor during the annual visits at TUDelft that will last at least a month. Till today, four visits have been scheduled and took place at TUDelft:

- 28 September – 19 October 2019 (PhD visit and GeoDelft 2018 Conferences)
- 25-30 March 2019 (PhD visit and Six-Months meeting with the supervisor)
- 1-5 July 2019 (PhD visit, meeting with the supervisory team and Go/No Go session)
- 23 September – 11 October 2019 (PhD visit and Geospatial Kuala Lumpur international Conference 2019)

The next PhD visit is planned for November 2019 (for 1 week), to be combined with the NCG Symposium 2019, that will be held in ITC, The University of Twente, 21 November 2019.

Moreover, the revision of LADM will be followed by OGC and ISO meetings, while there I will also participate in various conferences and workshops, where meetings with the supervisor will also be scheduled. As the I am expected to be involved in the teamwork introduced above, regular meetings will be scheduled (both in person and teleconferences) with the team members. In this context, regular ISO TC211, OGC meetings will be held among experts from ISO TC211, OGC, industry, government and academia that will be involved in this process and it is planned that I will join selective meetings and dedicate time for discussion with experts from the working group on LADM revision. Till today, I have participated at the following ISO TC211 and OGC meetings:

- ISO TC 211 47th Plenary meeting week, WG7 – Land Administration Domain Model (Stage 0) Meeting, 13 November 2018, Wuhan, China (remotely).
- OGC Land Administration Domain Working Group Meeting in the 109th OGC Technical Committee, 12 December 2018 (remotely).
- ISO TC 211 48th Plenary meeting week, WG7 – Land Administration Domain Model (Stage 0) Meeting, 3-4 June 2019, Maribor, Slovenia (https://committee.iso.org/sites/tc211/home/plenary-meeting/48th-plenary-meeting-maribor-slo.html).
- OGC Land Administration Domain Working Group Meeting in the 111th OGC Technical Committee, 25 & 26 June 2019 (remotely).

What is more, every four weeks (or more often when needed) a Skype meeting will be scheduled with the supervisor and co-supervisor and will be aligned with the progress monitor, while every two months (or more often when needed, especially at the initial phase) Skype meetings will also be scheduled together with the supervisor and the two co-supervisors.

5.2. Tools and technical aspects

Regarding the technological tools that will be used during the PhD research, at this section, some of the most important tools are listed indicatively.

To start with, in order to derive the technical model from the conceptual relevant tools (such as Enterprise Architect, INTERLIS tools, etc.) will be explored during this research. Their capabilities offering semi-automated and automated transformation from conceptual UML models to technical implementations will be assessed and limitations will be observed, in terms of supporting constraints, code list classes, object identity, reference ID integrity, cardinality of associations, inheritance, data types, 2D and 3D spatial data types, etc. Additionally, various database management systems (PostgreSQL with PostGIS spatial extension, Oracle Spatial, MySQL, etc.) will be examined to find out which one serves better the needs of the different technical encodings.

Tools regarding 3D modelling and data exchange and integration that enable interoperability will be used, such as SketchUp Pro and CityEditor plugin, AutoDesk Revit, FME, etc. For the visualization (and evaluation) of the results, 3D viewers both desktop and web-based, such as Adobe 3D PDF, Google Earth, ParaView, FZK viewer, CesiumJS platform, Solibri Model Viewer for the visualization of IFC files, etc. It is planned that the 3D LAS web-visualization prototype that has been developed by TUDelft and tested by Cemellini et al. (2018) will be further developed and tested, namely, to improve the server side/ database with the 3D spatial profiles, etc.

5.2.1. Required skills

The presented research requires the following skills:

- UML modelling
- Spatial databases
- 3D visualisation platforms
- Knowledge and understanding of technical standards: IFC, CityGML, INTERLIS, etc.
- Knowledge and understanding of standardisation approaches in legal domain: LADM, ePan, etc.
- Knowledge and understanding of organisations' role and involvement within GII and collaboration with them to reach optimal results (OGC, ISO TC211, FIG, FAO, UN, IHO, RICS, etc.)
- 3D modelling
- Programming
- Scientific and soft skills (e. g. writing scientific publications, reviewing scientific presentations, presentations on international conferences and workshops)
- Teaching, supervising and coaching (MSc theses, courses' lectures, Synthesis Project's topic, etc.)
- Working as part of a team (networking, collaboration, negotiation)

I already possess most of the afore-mentioned skills, while new ones and the existing will be developed further through the following channels:

- self-study, especially in programming, 3D and UML modelling
- DE courses, especially those related to the supervising and teaching students

5.3. Initial Planning

The first year is planned to be an initial run-over through the whole research process. It starts with an explicit literature research and problem definition as guidance for the design stage which is split into 5 main parts (Phase A of the research), as described in Section 2.3. Following, the research will concentrate in investigating the requirements to model the various spatial units' types in three levels: taxonomy-categorisation, spatial profiles design (Phase B) and implementation through technical models and encodings (Phase C), as presented in Figure 18.

To establish the framework for modelling 3D spatial profiles (paying attention also at the LADM revision) and updating the taxonomy of 3D spatial units, is expected that approximately a year will be dedicated, while their implementation approaches will be investigated through the second year of the research, starting from investigating alternatives to reuse BIM data in LAS. My co-supervisor Prof. dr. Efi Dimopoulou will be mainly supervising those initial phases.

The functionality of those proposals will be tested at the third year, mainly by using selected use cases at a 3D web-based LAS platform that has already been developed by TUDelft and will be further improved (Phases D and E). Enriching the functionalities of the 3D LAS web-visualization prototype and interaction from the server side/ database by using the implementation of the proposed 3D spatial profiles, will be part of the research. My supervisor Prof. dr. Peter van Oosterom will be mainly supervising this stage of the research.

It is mentioned that activities related to the LADM revision (related documentation and models) will be performed in parallel with the personal research steps described above. Specifically, the developed spatial profiles and their implementations will be submitted to the nominated experts for ISO TC211 LADM v2 project team (and the FIG, OGC, IHO liaisons and RICS), as part of the revised model, to be reviewed and evaluated. It is a great opportunity that the quality and applicability of part of the research will be reviewed and evaluated by independent international experts from various countries, driven by the intention that 3D LAS should not be considered in the narrow sense but serve the ambition to realize the full lifecycle support in spatial development. In this scene a challenge raised is the coordination and integration between the research and the LADM revision process, that will need to be taken into consideration. Last but not least, metrics and indicators briefly presenting in Section 3.6. will be used to assess the added value of the 3D LAS within the spatial development lifecycle (Phase F). Experts, such as my co-supervisor, Prof. dr. Chrit Lemmen will be involved in this stage of the research due to his vast expertise in this field, which will be the last one.

While verification of research outputs will be performed on a regular basis throughout the whole design and development process, the higher-level testing on actual data and testing from independent experts involved in the revision will start after the first year and a half. Research made on the above-mentioned topics can result in publications and thus form the backbone for the PhD thesis. Journal paper submissions and Conference presentations are planned after the end of each research period, so that the testing results are fully included.

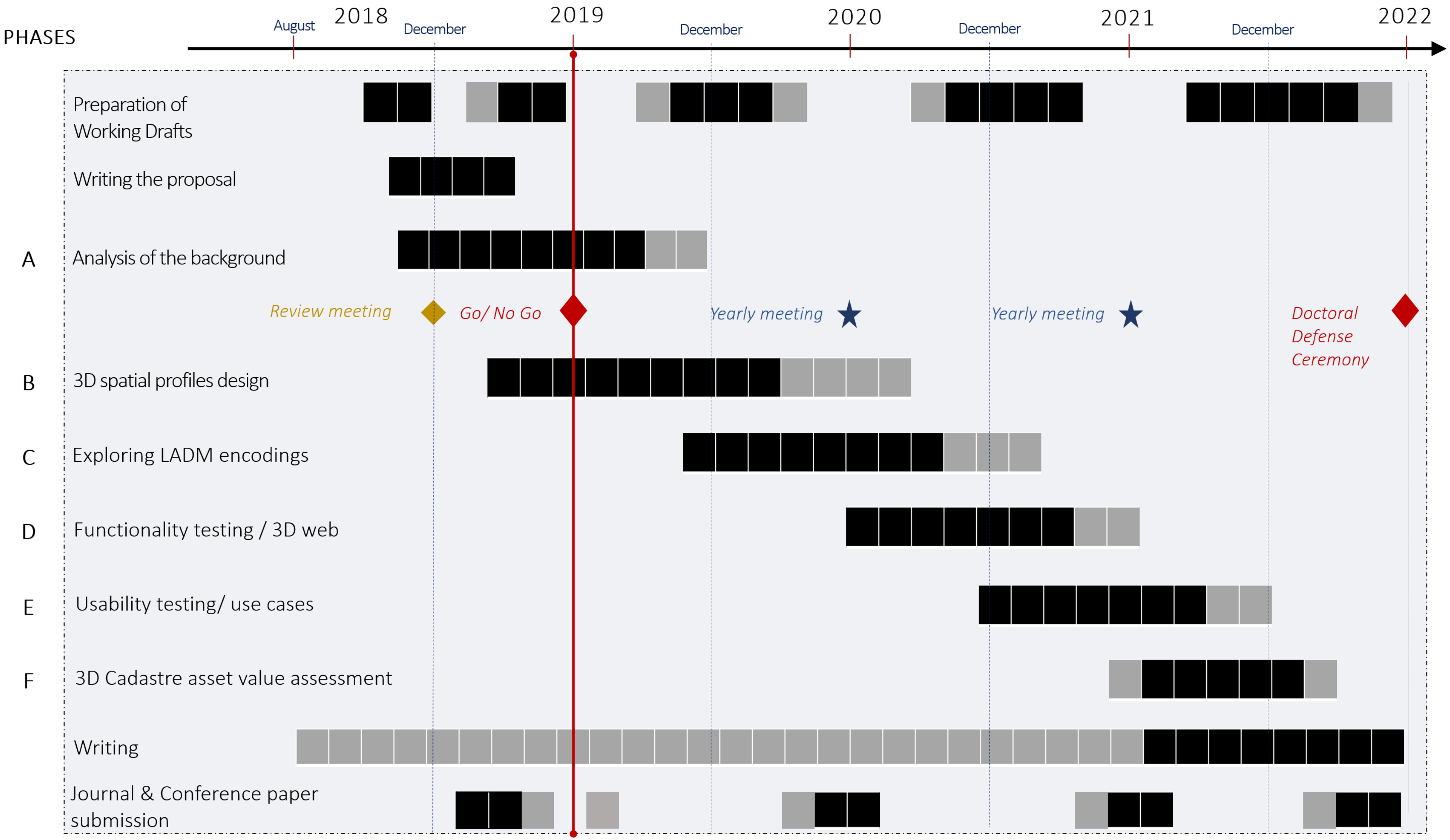

Figure 18. Preliminary PhD research planning

5.4. Reporting of results

5.4.1. Deliverables

The main deliverables that will be published during and after the PhD research are the following:

- This PhD Research Plan - Proposal, as a literature review, planning and agreement of the research (October 2019).
- Publications in journal papers. The list of potential journals is given in Section 5.4.2. Some (extended) parts of this proposal may be submitted for publishing in the next year. It is expected to have a published journal paper for each theme of the research.
- Presentations and papers on conferences, workshops, and symposia. A list of conferences for the coming year is given in Section 5.4.2.
- Datasets, source code (published open source), and examples, case studies.
- MSc thesis topics. During the research, a number of MSc thesis topics will be defined which can accompany and support this research (can be found at: https://wiki.tudelft.nl/bin/view/Organisation/OTB/GISt/MScThesisTopics#A_3D_Cadastre_topics).
- The PhD Dissertation. The main document as the final report of this research with the findings, formalised concepts, and answers to research questions.

5.4.2. Publications' Plan

This Section lists the publications in journal papers and conference proceedings, as well as presentations in conferences and workshops that have been completed till now, and the short-term planned. What is more, lists of relevant journals and magazines are given.

I. Completed

Kalogianni, E.; Dimopoulou, E.; R., Thompson; Lemmen, C.H.J and van Oosterom, P.J.M. (2018). *Investigating 3D spatial unit's as basis for refined 3D spatial profiles in the context of LADM revision.* In: 6th International FIG Workshop on 3D Cadastres Conference Proceedings, pp. 177-200, 2-4 October 2018, Delft, the Netherlands.

Kalantari, M. and Kalogianni, E. (2018). *Towards LADM Victoria country profile – modelling the spatial information.* In: 6th International FIG Workshop on 3D Cadastres Conference Proceedings, pp. 483-498, 2-4 October 2018, Delft, the Netherlands.

Kitsakis, D.; Kalogianni, E.; Dimopoulou, E. and van Oosterom, P.J.M. (2018). *Requirements for Standardised Representation of Public Law Restrictions based on LADM*. In: FIG Commission 3 Workshop and Annual Meeting - Spatial Information in the Era of Data Science: Challenges and Practical Solutions Conference Proceedings, 3-6 December 2018, Naples, Italy.

van Oosterom P.J.M.; Kara A.; Kalogianni E.; Shnaidman A.; Indrajit A.; Alattas A. and Lemmen C.H.J. (2019). "*Joint ISO/TC211 and OGC Revision of the LADM: Valuation Information, Spatial Planning Information, SDG Land Indicators, Refined Survey Model, Links to BIM, Support of LA Processes, Technical Encodings, and Much More on Their Way!*". In: FIG Working Week 2019 – Geospatial Information for a smarter life and environmental resilience. 22-26 April 2019, Hanoi, Vietnam.

Kalogianni, E.; Kalantari, M.; Dimopoulou, E. and van Oosterom, P.J.M. (2019). "*LADM country profiles development: aspects to be reflected and considered*". In: The 8th Land Administration Domain Model Workshop Proceedings, 1-3 October, Malaysia, Kuala Lumpur.

Lemmen C.H.J.; van Oosterom, P.J.M.; Kara A.; Kalogianni, E.; Shnaidman A.; Indrajit A. and Alattas A. (2019). "*The scope of LADM revision is shaping-up*". In: The 8th Land Administration Domain Model Workshop Proceedings, 1-3 October, Malaysia, Kuala Lumpur.

II. *In progress*

Kalogianni, E.; Dimopoulou, E.; Thompson, R.; Lemmen, C.H.J.; Ying, S. and van Oosterom, P.J.M. (2019). "Development of 3D spatial profiles to support the full lifecycle of 3D objects" In: *Special issue "3D Land Administration for 3D Land Uses" "Land Use Policy,* https://doi.org/10.1016/j.landusepol.2019.104177 (accepted, to be published).

Kalogianni, E.; Dimopoulou, E.; Lemmen, C.H.J. and van Oosterom, P.J.M. (2020). The role of 3D LAS within the spatial development lifecycle. In: *IJGI Special Issue on State-of-the-Art in Spatial Information Science* (in progress)

Paper in Special issue in Transactions in GIS on 3D city modelling, BIM, and GIS-based urban analytics (deadline 1 March 2020)

III. *Planned*

- Paper in Conference Proceedings and Journal paper (*at the end of the second year*)
- Paper in Conference Proceedings and Journal paper (*at the end of the third year*)
- Paper in Conference Proceedings and Journal paper (*at the end of the fourth year*)
- Paper at a relevant magazine
- Presentations at an ISO meeting regarding LADM revision process, at an ISO TC211 meeting regarding LADM revision topics and specifically: 3Dspatial profiles, LADM and IHO S-121 and LADM encodings: INTERLIS, as well as an OGC meeting regarding LADM implementation approaches.

Below are listed the relevant journals in this discipline that will be considered when publishing findings:

- Annals of GIS
- Computers & Geosciences (C&G),
- Computers, Environment and Urban Systems (CEUS),
- Geoinformatica
- Geo-spatial Information Science
- International Journal of Geographical Information Science (IJGIS),
- ISPRS International Journal of Geo-Information (IJGI),
- ISPRS Journal of Photogrammetry and Remote Sensing (P&RS),
- International Journal of 3D Information Modelling (IJ3DIM)
- Journal of Spatial Information Science (JOSIS),
- Land Use Policy, Computers Environment,
- Transactions in GIS (TGIS)
- Urban Systems, Survey Review and Transactions in GIS.

What is more, GIS magazines will be considered to publish findings and progress of the research, mainly:

- GIM International
- GIS Professional
- Geospatial World Magazine

- Geo-matching
- Geomatics World
- GeoConnexion

It is noted the list of journals and magazines will be updated during the PhD research, based on the direction of research, the findings, the impact factors and other relevant aspects of the research.

5.5. Conferences, Workshops and Meetings

This Section lists the conference and workshops, where I participated till now, and the short-term planned.

I. Participated

- 6th International FIG Workshop on 3D Cadastres Conference, 2-4 October 2018, Delft, The Netherlands (http://www.gdmc.nl/3DCadastres/workshop2018/)
- 12th 3D GeoInfo Conference, 1-2 October 2018, Delft, The Netherlands (https://3dgeoinfo2018.nl/#invitation)
- ISPRS Technical Commission IV Symposium 2018, 1-5 October 2018, Delft, The Netherlands (http://www.isprs.org/tc4-symposium2018/)
- ISO TC 211 47th Plenary meeting week, WG7 – Land Administration Domain Model (Stage 0) Meeting, 13 November 2018, Wuhan, China (remotely).
- OGC Land Administration Domain Working Group Meeting in the 109th OGC Technical Committee, 12 December 2018 (remotely).
- ISO TC 211 48th Plenary meeting week, WG7 – Land Administration Domain Model (Stage 0) Meeting, 3-4 June 2019, Maribor, Slovenia (https://committee.iso.org/sites/tc211/home/plenary-meeting/48th-plenary-meeting-maribor-slo.html).
- OGC Land Administration Domain Working Group Meeting in the 111th OGC Technical Committee, 25 & 26 June 2019 (remotely).
- 8th Land Administration Domain Model Workshop, 1-3 October 2019, Malaysia, Kuala Lumpur (https://wiki.tudelft.nl/bin/view/Research/ISO19152/LADM2019Workshop)

II. Short-term Planned (one year ahead)

- ISO TC 211 49th Plenary meeting week, 9-13 December 2019, Omiya, Japan (to be decided)
- OGC TC Meeting, 18-22 November 2019, Toulouse, France (to be decided)
- Annual NCG Symposium, 21 November 2019, ITC, The University of Twente, The Netherlands (https://ncgeo.nl/index.php/en/actueelgb/nieuwsgb/item/2802-ncg-symposium-2019)
- FIG WW 2020, 10-14 May 2020, Amsterdam, The Netherlands (http://www.fig.net/fig2020/)
- 15th 3D GeoInfo Conference 2020, September 2019, London, UK

III. Other relevant events

- GeoInfo Conference
- AGILE Conference on Geographic Information Science

- UDMS Conference (Urban Data Management Society)
- FIG Working Week
- FIG Commission 7 Annual Meeting
- FIG 3D Cadastre Workshop
- ISO TC 211 Meetings
- Annual World Bank Land and Poverty Conference
- INTERGEO
- BIM/GIS Workshop
- ISPRS (International Society for Photogrammetry and Remote Sensing) Technical Commission IV Symposium
- FIG LADM Workshop
- FIG Commission 3 Annual Meeting
- Geospatial World Forum
- OGC Meetings
- Meeting of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM)
- FIG Young Surveyors Meeting

It is noted that this list will be updated periodically.

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