The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-M-6-2025
ISPRS, EARSeL & DGPF Joint Istanbul Workshop "Topographic Mapping from Space" dedicated to Dr. Karsten Jacobsen's 80th Birthday
29–31 January 2025, Istanbul, Türkiye

4D Marine Cadastre Data Models – Turkey & Malaysia

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Keywords: Marine Cadastre, 4D Cadastral Systems, International Standards.

Abstract

In recent years, the demand for data has surged as the importance of sustainability has grown. Both academic and institutional efforts are being made to enhance the efficiency and sustainability of underground, surface, and marine resources. Data management models developed to marine these resources must be capable of operating independently or in an integrated manner. Physical data and legal rights must be represented and managed effectively to manage land and marine areas. Ultimately, it has become inevitable for existing cadastral systems to be improved and advanced into 3D/4D cadastral systems, particularly in land management. While LADM, an ISO standard, plays a key role in modelling legal rights, GIS-based standards (such as OpenGIS, CityGML, IFC, and InfraGML) have emerged for modelling physical data. It develops a more comprehensive land management system, and the modelling of rights related to planning, valuation, and marine areas is being explored in the second version of LADM (Sürmeneli et al., 2022; Zamzuri et al., 2021). In this study, marine cadastre was chosen as one of the key and impactful areas of cadastral work in recent years. The marine cadastre facilitates controlling and managing spatial information related to marine rights, including legal authorities' rights, restrictions, and responsibilities (RRRs) within the marine environment. It also primarily defines marine parcels. The functions of the marine cadastre and the definition of marine parcels should be developed following the cadastral systems of individual countries and relevant international standards (Zamzuri et al., 2022). This study, a collaborative effort, aims to identify the needs of a marine cadastre and to develop a data model based on the LADM standard. The paper is divided into two main sections: the design of data models for Malaysia and Turkey, and the development of corresponding data model schemas. The developed model is expected to facilitate a smooth integration process into existing cadastral systems, a result of the collective efforts of the research community. Initially, studies related to marine cadastre will be discussed, and information will be provided within the framework of international standards on which these studies are based. Next, the specific needs of Turkey and Malaysia will be outlined, reflecting the diverse perspectives and shared responsibilities in the field. After analysing the data model applications, the systems designed by both countries will be presented in sequence. The final output of the study will be a combined 4D (3D + Temporal) data model for land and marine cadastres, represented through UML diagrams. The study will conclude with the presentation of results and discussions, a testament to the collaborative nature of research in this field.

1. Introduction

In recent years, there have been many cadastral studies related to 3D and 4D both academically and institutionally (Gürsoy Sürmeneli and Alkan, 2020; Gürsoy Sürmeneli et all., 2022a; Gürsoy Sürmeneli et all., 2022b; Rajabifard et all., 2021; Trias et all, 2020, Zamzuri et all, 2022; Zulkifli et all, 2021). Because 2D cadastre could not fully present and visualize spatial information regarding record rights, restrictions, and responsibilities (RRRs) on the space usages of complex buildings above and underground. These studies are evaluated based on the needs of countries and the needs for cadastral systems. In this context, the studies are associated with international standards and countries' designs. One of the important points here is to create a database that is compatible with the cadastral standards of the country being studied while revealing originality in the context of international standards (Hassan and Abdul Rahman, 2010; Gürsoy Sürmeneli and Alkan, 2018; Gürsoy Sürmeneli and Alkan, 2020; Gürsoy Sürmeneli et al., 2021; Gürsoy Sürmeneli et al., 2022a; Gürsoy Sürmeneli et al., 2022b; Rajabifard et al., 2021; Zamzuri et al., 2022; Zulkifli et al., 2021).

The Land Administration Domain Model (LADM) is the most widely used among international standards. However, GIS-based standards are also involved in the technological dimension and at the application stage of databases (like openGIS, CityGML, IFC, InfraGML).

Cadastral systems are considered the core of LAS (Land Management Systems). In this context, property is a very important issue worldwide. It is of great importance in terms of defining ownership of the properties, both in two dimensions and in the third dimension. On the other hand, the value of time-dependent functions in cadastral data has revealed the concept of 4D (3D + time) (Hassan and Abdul Rahman, 2010; Gürsoy Sürmeneli and Alkan, 2018; Gürsoy Sürmeneli and Alkan, 2020; Gürsoy Sürmeneli et al., 2021; Gürsoy Sürmeneli et al., 2022a; Gürsoy Sürmeneli et al., 2022b; Rajabifard et al.., 2021; Zamzuri et al., 2022; Zulkifli et al., 2021).

A new Land Administration Domain Model (LADM) version has been discussed and is under further development in ISO/TC 211 on Geographic Information. A cadastre is a parcel-based, current land information system containing a record of land ownership interests related to rights, restrictions, and responsibilities. The relationship between the identification of land parcels, the registration of land rights, the valuation and taxation of land and property, and the current and potential future land usage is included in cadastral systems (Sürmeneli et al., 2022; Zamzuri et al., 2021).

In general, 3D land cadastre deals with 2D and 3D geometries of real estate (land and buildings) with property rights, restrictions and responsibilities. Recent studies by reports and articles such as Zulkifli (2021), Zamzuri (2022), Hanafi (2022), Hashim (2018), Kalogianni (2020), Kara (2021), Kalantari & Kalogianni

(2018), Rajabifard (2021), Thompson (2021), Paasch (2021), Emamgholian (2020), Trias (2020), It has clearly proposed for further 3D cadastral expansion, especially in the areas of 4D data model for land and maritime cadastre, layer web visualization, indoorGML, LADM with spatial planning aspect, BIM and 3D topology for urban land management and cadastre. A suitable system is needed to manage land and maritime properties. Such a system requires various components for land and maritime cadastral objects or properties. Possible components are entities, data types, attributes, constraints, and relationships, which are important in data development. Therefore, this research aims to explore a data model that can accommodate land and maritime cadastre within the LADM international standard (country profile).

Marine cadastre contains ownership, value, and use information regarding a country's marine and coastal areas. It is usually managed by a government agency and used for a variety of purposes, such as maritime boundaries, fisheries management, and marine conservation. A 3D marine cadastre is an extension of the traditional marine cadastre. It is a digital, threedimensional representation of the marine environment and its features, such as the seabed, underwater structures, and marine resources. It also shows 4-dimensional cadastral characteristics by defining the rights at certain time intervals. This technology can be used for maritime spatial planning, managing coastal zones, and building up the ocean floor. Overall, marine cadastre and 3D (+time) marine cadastre are important tools for managing and protecting the marine environment and making smart decisions about how to use and develop coastal and marine resources. LADM, can be utilised to support 3D cadastre by offering a standardised framework for describing and managing land-related data and procedures in three dimensions.

Marine Cadastre has emerged as one of the important and active fields of study in recent years. Marine cadastre enables the spatial information control and management of maritime rights, including the legal authorities' rights, restrictions, and responsibilities (RRRs) in the marine environment. Subsequently, marine cadastre enables the spatial information of maritime rights to be controlled and managed. It includes rights, restrictions and responsibilities (RRR) enforced by legal authorities. The cadastral system should be designed based on the definition of marine cadastre, including the underlying international standards (LADM). The result consists of nonspatial and spatial databases, including temporal attributes. Subsequently, these cadastral systems record, archive, update, analyse, and manage data.

The study aims to determine marine cadastre needs and develop a data model based on LADM. The possible integration process into cadastral systems could be expected to be developed. First, studies related to marine cadastre will be discussed here. Information and examinations will also be made within the scope of international standards on which the studies are carried out or based. Section 2 describes the methodology, followed by data model development (Turkey and Malaysia). Meanwhile, Section 3 is meant for discussions and finally, Section 4 concludes the paper.

2. Design and Development of Data Model Schema of 4D Marine Cadastre

The models of 4D marine cadastre could be developed based on the following procedures, as shown in Figure 1.

a) Explore the existing practices on 4D (3D + Temporal) land and marine cadastre administration and other related information or standards and select the most pertinent data model from each cadastre domain (land and marine).

b) Select the most pertinent data model from each land and marine cadastre domain.

c) Amalgamate the selected pertinent data models for 4D (3D + Temporal) land and marine cadastre based on the international standard, LADM.

d) Using UML diagrams, design and develop an amalgamated 4D (3D + Temporal) data model for land and marine cadaster.

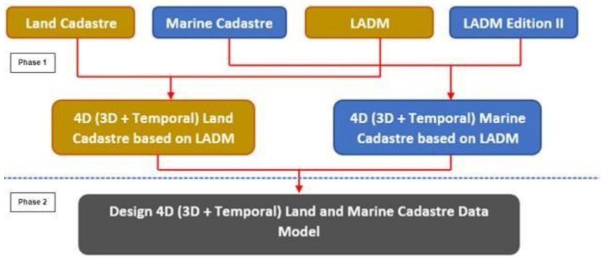

Figure 1. The methodology.

In this section, recent developments, and trends in LADM together with the 4D (3D + Temporal) cadastre for land and sea will be discussed both for Turkey and Malaysia. The literature shows that several works have been conducted, however, specific development need to be addressed accordingly.

2.1 Turkey

When the main issues in the use of coasts and seas in Turkey are examined, it is known that some registrations have been made for aquaculture in the sea, lakes, dams, and rivers. The designated places are recorded in the Fisheries and Fishing Net Registry. Another issue: perhaps the most important point in the process of establishing a fish farming facility is the selection of a suitable location. For this purpose, spatial data (settlement areas, tourism areas, protected areas, etc.) and oceanographic information (sea depth, current speed and direction, water quality, etc.) should be obtained accurately, up-to-date, and quickly from different institutions. For this reason, it is considered necessary to determine and register the boundaries of aquaculture and aquaculture areas such as fish farms, and cadastral activities need to be carried out in marine and coastal areas. In Turkey, new parcels are created by filling sea areas. The ownership of the filled areas belongs to the state and the right to use the structures built on them can be given to other institutions. Turkish General Directorate of Land Registry and Cadastre, which precisely measures the real estate within the borders of our country by determining the rights and obligations and records them using the latest technologies under the assurance of the State, has included marine cadastre among its targets in its 2024 - 2028 Strategic Plan. In this context, it is of great importance to combine the 4D cadastre designed for Turkey with the marine cadastre arguments designed in this study.

In Turkey, Sürmeneli et al. (2022) have designed a 4D legal cadastre model for the Turkish cadastral system and an Application Domain Extension has been developed for a 4D cadastre using LADM and CityGML. The developed model has been enriched with the needs determined for marine cadastre.

Rights and restrictions resulting from mining, hunting activities, and pipeline and transportation routes in marine areas have been determined. Marine parcel determination formed in marine areas has been created under MarineSpatialUnit. TR_building class has been created under MarineSpatialUnit for structures in the filling areas formed on the coastline. Rights holders, users, and data providers are represented in the MarineParty class. The usage of marine areas and the resulting restrictions have been determined in the MarineRRR class. (Appendix 1). The literature review shows some research works and developed database systems for land and marine 3D cadastre, but the database that amalgamates both land and marine is not yet available. This research is conducted to find out whether 3D cadastre for land and marine can be amalgamated in one data model.

2.2 Malaysia

Zulkifli (2014) has proposed an extended LADM country profile for Malaysia (see Figure 2). This country profile defined several classes related to land cadastre. Besides major classes (party, RRRs, BAUnit, SpatialUnit), several other classes have been introduced such as Shared3Dinfo, LegalSpaceBuildingUnit, GenericLot (Lot2D and Lot3D), ParcelUnit, AccessoryUnit and CommonPropertyUnit. The classes were inherited from LADM international standards and expanded according to Malaysian land administration.

To summarise, the 3D cadastre is not only useful for land management but also for marine management, including coastal and offshore areas, as it provides a digital, 3D representation of the marine environment and its features, such as seabed, underwater structures, and marine resources. 3D cadastre for both land and marine can be used for a wide range of things, such as urban planning, real estate development, disaster management, maritime spatial planning, coastal zone management, and offshore development. The S-121 Product Specification for Maritime Limits and Boundaries standard was created by IHO (The International Hydrographic Organization) by deriving LADM classes to provide a suitable format for exchanging numerical vector data on maritime boundaries. LADM and LADM Edition II are essential for 3D Land cadastre and 3D Marine Cadastre. A concept of 3D modelling for 3D cadastre has been initiated and introduced in Malaysia and Turkey (Sürmeneli and Alkan, 2020; Atulukwu et all, 2024) LADM country profile.

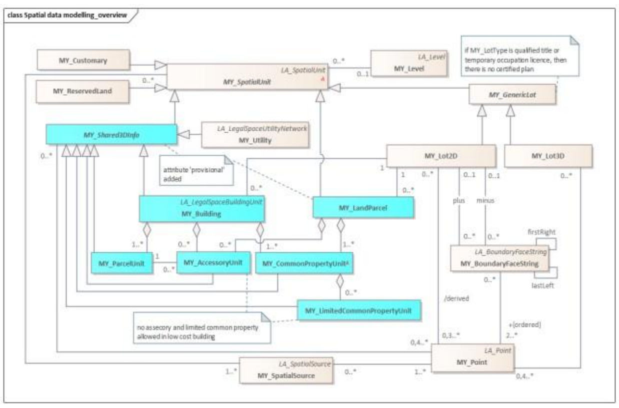

Figure 2. Overview of the spatial part of the Malaysian LADM country profile (Source: Zulkifli et al., 2014).

The Malaysian country profile has been extended with the classes and attributes of marine cadastre as reported by Zamzuri et al., (2022). The classes represented marine administration in Malaysia consists of MC_Party, MC_Administrative and MC_SpatialUnit as shown in Appendix 2. The 3D elements are included in the data model by MC_MarineProperty sub-class – with attributes show the properties information (e.g., including mpID, area, volume) with the marine layer (MC_Seabed, MC_WaterColumn, MC_SeaSurface) presented in the blue colour. However, the data model does not include temporal elements.

The Malaysian marine cadastre model plans to extend with temporal elements representing the bitemporal transaction class and the archived historical record class. It is part of the ongoing research by Atulukwu et al. (2024). Dual-time perspective ensures a comprehensive and accurate record of data changes over time, preserving historical and transaction records. Modifying the current LADM version object may be necessary to accommodate bitemporal data specific to marine environments. Such adjustments are critical for thorough analysis and maintaining continuous data updates, which is essential for effective marine property management. Figure 3 illustrates the ongoing development of the 4D marine data model for Malaysia and describes the transaction of ownership changes, including the situation (marine-to-land / land-to-marine) of cadastre parcel (due to the land erosion at the coastline) as illustrated in Figure 3.

Figure 3. Example of land erosion at Kuala Besut, Terengganu coastline as of 2024 where several cadastral lots virtually affected.

Currently, the Malaysian 4D marine cadastre model proposes classes (MC_Transaction and MC_ArchiveHistoricalRecords) as shown in Figure 4, representing transactionID, transactionType, transactionTime, archiveID, archiveTime, and archiveType. It is an on-going work; thus, the model will be updated accordingly.

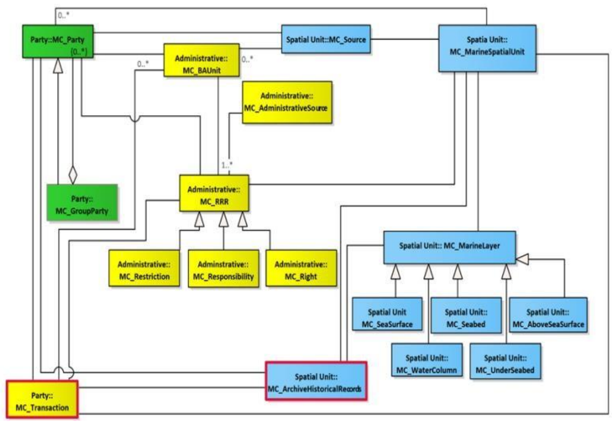

Figure 4. The proposed 4D marine cadastre data model for Malaysia (Atulukwu, et al., 2024).

3. Discussions

Many 3D (or 4D) land cadastre studies in Turkey are mentioned in the article and available in the literature. However, there are no studies on 4D marine cadastre in terms of both legal and technical terms. The priority in Turkey is to finalise the studies that will create this infrastructure for 4D marine cadastre due to the lack of a legal legislation infrastructure. Here, of course, the legal infrastructure is to be established in the context of the 4D spatial database to be presented as a result of academic studies to be conducted in technical terms. Here, the connection between land and marine cadastre should be revealed in technical and legal terms. In this study, the infrastructure has been prepared for the definitions to be made depending on the 4D land cadastre that was previously made to establish the foundations of the technical data infrastructure.

The LADM conceptual model for Malaysia focuses on several aspects: typical cadastral objects, 3D objects (in the form of strata), and marine cadastre. Recently, some researchers at Malaysian academia at Universiti Teknologi Malaysia (UTM) have investigated the temporal associated with those objects. The development of the 3D + time (4D) marine cadastre data model is still ongoing – there are several components related to the transaction of ownership changes to the parcels consisting of bitemporal attributes, representing two types of time-related information (valid and transaction time). This dual-time perspective is crucial for maintaining a comprehensive and accurate record of changes over time. As discussed previously, the concept needs to be tested and validated with a proper prototype (database and visualisation components).

4. Conclusion

Today, despite these advances, land cadastre in many countries is still 2D. However, in recent years, 3D and 4D cadastral studies have been investigated, especially in the domain of LADM. The subject is being discussed and elaborated through seminars, workshops, and conferences in several parts of the world. Recent literature also pointed to the dynamic of the LADM integration with other international standards. The 3D domain also sees the benefits of the integration. Thus, the 4D comes into the "picture". Subsequently, there are active studies on 3D+time (4D) spatial data modelling and realisation for marine cadastre. In Turkey, there is no clear study on both legal and data model infrastructure. However, the current research on the 4D marine cadastre model is being investigated and evaluated for the betterment of the models that are appropriate for the two (2) countries (Turkey and Malaysia).

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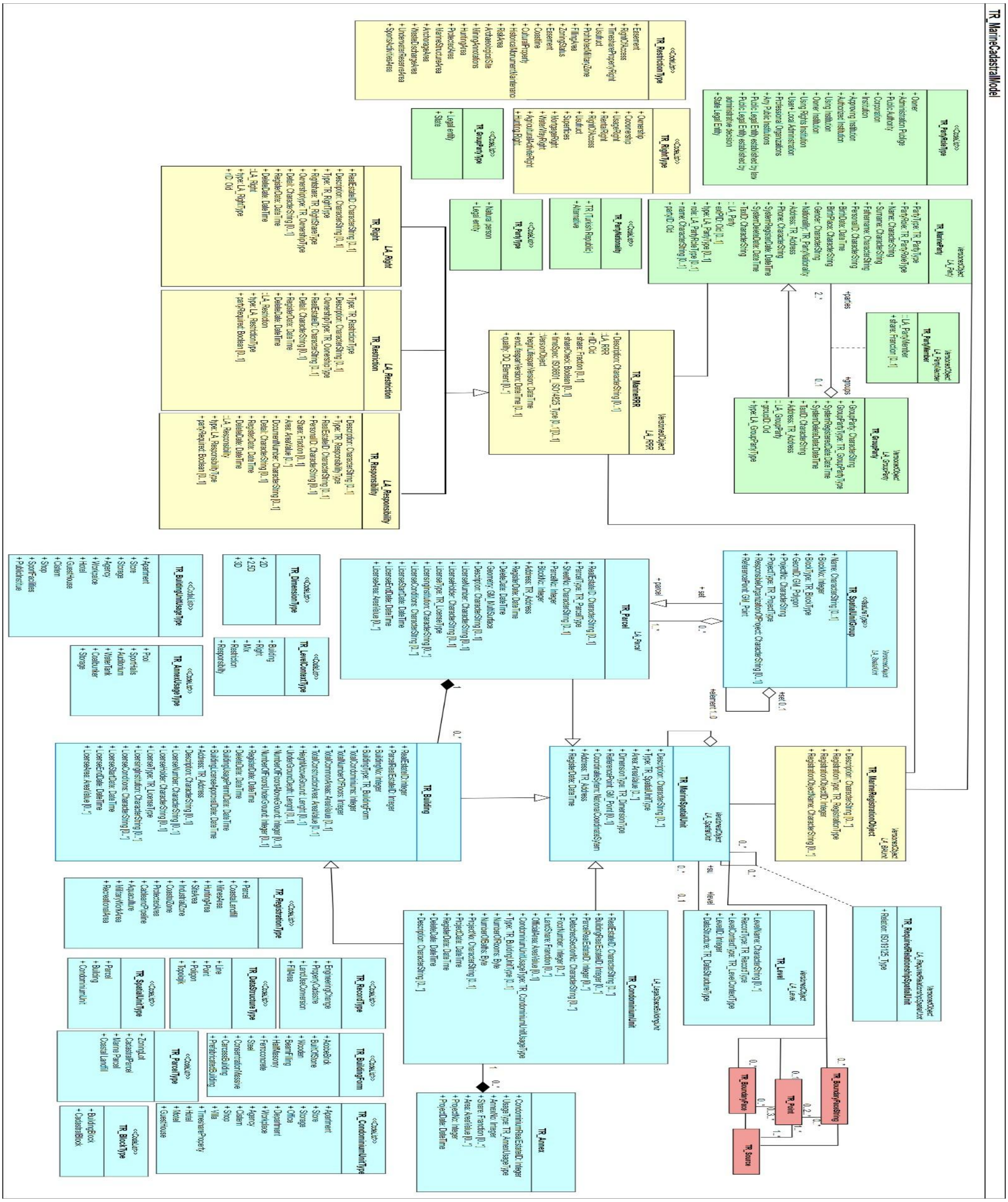
Appendices

Appendix 1. The proposed 4D marine cadastre data model for Turkey



Appendix 2. The 3D marine cadastre data model for Malaysia