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DEVELOPING 4D MALAYSIAN MARINE CADASTRE DATA MODEL BASED ON LADM - PRELIMINARY WORKS

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ABSTRACT:

The complex interactions between terrestrial and aquatic dimensions make effective land management in coastal and marine settings particularly difficult. For thorough spatial data administration, it has been acknowledged that the traditional Land Administration Domain Model (LADM) must incorporate temporal and three-dimensional (3D) elements. The main goal of this work is to develop a 4D Malaysian marine cadastre data model based on LADM that integrates the temporal dimensions (3D + T= 4D) to the current 3D Malaysian marine cadastre data model and to assess how well the extended model handles issues with the representation of 3D marine environment. The depiction and management of temporal data related to shifting coastlines, fluctuating tides, and seasonal fluctuations in the maritime environment are some of the key questions investigated. The findings of this study are expected to provide valuable insights for augmenting land administration methodologies in dynamic marine settings. The outcomes of this research hold significance for sustainable marine development and effective spatial data management in coastal regions.

1. INTRODUCTION

Human and spatial interactions have continued to influence land status change, which involves creating new land or transforming oceans, seas, riverbeds, or lake basins into new land. Land status changes could also result from landfilling, rehabilitation, or land reclamation. These are noticeable almost everywhere in the world, in Malaysia, China, Asia, Africa, the United Kingdom, Dubai, and Singapore. Previous studies (Chen et al., 2017; Duan et al., 2016; Neumann et al., 2015; Sengupta et al., 2018; Tian et al., 2016; Wu et al., 2018) have reported the adverse effects of land reclamation and the non-integration of the temporal elements. In China, human activities have led to increased land change (He et al., 2014) and modification of wetland areas (Ma et al., 2019). Similarly, the influence of land status change has been reported to be due to anthropogenic impacts in Malaysia. Specifically, Wu *et al.* (2018) found a loss of connectivity and fragmentation due to land change status. Furthermore, there are also reports of land change in African countries. According to Aneseyee *et al.* (2020), agricultural expansion has significantly contributed to land change. The cadastre is about spatial object documentation per time; however, these status changes require that the spatial attributes of these spatial objects be captured along their temporal dimensions in the appropriate cadastre register. It must be noted that cadastral property ownership and transactions are crucial, but they are also vulnerable to the whims of time. Cadastre has been defined as a list of the locations, values, and landowners that was initially compiled for taxation purposes (Yomralioglu & Mc Laughlin, 2017),(Binns, 1995).

Information in the land cadastre from marine to land or vice versa necessitates that data about such changes be migrated seamlessly to the relevant new database. There are no provisions in the Land Administrative Domain Model (LADM). Notably, the conflict in Terengganu, Malaysia, came to light as the government tried to implement a new layout for usage, assuming that the land was vacant, but the landowners with their legal papers went to court, made a claim, and were awarded RM5.5 million in damages for breach of contract and statutory duties by denying them access to their plantation after they were moved to another scheme as reported by V Anbalagan of FMT Media Sdn of 12 February 2022, could have been avoided if the temporal(t) elements formed part of the initial cadastre model used in the issue of rights. The nature and dynamic boundaries involved in the numerous transactions and changes in ownership, as well as the legal instrument of right, restriction, and responsibility (RRR), each of these situations has a time component that must be considered and dealt with in its entirety. The government, parties, and stakeholders may face embarrassment if the time element in the cadastre is not included in the documentation of the changing status from land to marine, or vice versa. Utilizing UML class diagrams, the integration process entails the creation of temporal classes. While temporal relationships are used to represent connections between entities that change over time, temporal classes are used to represent entities that change over time, such as ownership or boundaries (Embling et al., 2012; Lisjak et al., 2021). Thus, this research work would investigate these issues and propose the inclusion of the time element in the existing 3D Marine Cadastre Data model for a 4D (3D + T) Marine Cadastre Data Model (Govedarica et al., 2021)(Polat et al., 2020)(Micek et al., 2020). The resulting 4D model could advance more applications and analysis while offering a more thorough and accurate picture of the marine environment.
The remaining sections discuss Methods in Section 2, Results in Section 3, and Section 4 Discussion & Conclusion sections. Finally, Section 4 for Discussion & Conclusion and Future Works.

1.1 Related Works

The integration of spatial and temporal dimensions within land administration has gained increasing attention in recent years (Rakuša et al., 2021) and (Cemellini et al., 2020). As human activities expand into coastal and marine areas, the need to effectively manage and administer land resources in dynamic marine environments becomes crucial. The complex interactions between terrestrial and marine ecosystems coupled with the ever-changing nature of coastlines, tides, and underwater structures, necessitate innovative approaches to land administration (Odli et al., 2020) and (Femenia-ribera et al., 2021). This research responds to this demand by examining the challenges and opportunities posed by the incorporation of temporal and three-dimensional (3D) elements in land administration, for Malaysia LADM (Zamzuri et al., 2022). Coastal regions and marine areas are not only vital for economic and social development but also ecologically sensitive. The accelerated pace of urbanization, infrastructure development, and maritime activities in these areas intensifies the complexities of managing land and marine resources cohesively (Sengupta et al., 2023). Understanding the intricate relationships between natural processes and human interventions is imperative for sustainable development and environmental conservation. This study acknowledges the significance of unravelling these complexities to ensure effective land administration practices that align with the principles of responsible coastal development. (The Land Administration Domain Model (LADM)) is a conceptual framework that underpins land administration systems (Kalogianni et al., 2021). Originally designed to address terrestrial land-related activities, the LADM's extension to encompass marine and temporal aspects holds promise for comprehensively managing land resources in evolving environments (Vranić et al., 2021)(Mehmood et al., 2022). By providing a standardized schema for data representation, the LADM offers a structured approach to integrating various spatial dimensions into a coherent framework(Sun et al., 2021.)(Gürsoy Sürmeneli, Koeva, et al., 2022). This research acknowledges LADM's potential to address challenges in dynamic marine environments (Gürsoy Sürmeneli, Koeva, et al., 2022)(Atazadeh et al., 2021). It enables efficient management of land and marine data, while facilitating data sharing and interoperability. (Kar et al., 2018).
Peter Van Oosterom & Stoter, (2010), proposes five-dimensional data modelling system with scale as the fifth-dimensional scale. It therefore posits geographic information as fully integrated with scale as fifth dimension. This integrated approach ensures scale and time consistency by formalizing geographic data in a conceptual 5D continuum. The study is that of five-dimensional combinations to find the best 5D model applying mathematical multidimensional modelling theories to geo-information multidimensional modelling principles leading to an optimal 5D model. A 5D data model in a Database Management System partition of 3Dspace+time+scale spaces without overlaps or gaps. Thus, the paper presents a novel and challenging approach to geographic data modelling, which may affect data analysis and decision-making in geographic information-using domains but again no specific consideration for marine Georegulation and temporal integration for a holistic data model. The published work of Babalola et al., (2015), on Land Administration Domain Model was a pioneers review focusing on LADM standards for land management, agreed that time should be added to 3D to manage land use complexity, concludes that the design and development process for ISO 19152:2012, temporal schema should be used to achieve research's goal, sadly the work gave no considerations to marine environment on the proposed time integration or addition.

1.1.1 The Land Administration Domain Model (LADM))

The LADM is a conceptual framework that underpins land administration systems. Originally designed to address terrestrial land-related activities, the LADM's extension to encompass marine and temporal aspects holds promise for comprehensively managing land resources in evolving environments. By providing a standardized schema for data representation, the LADM offers a structured approach to integrating various spatial dimensions into a coherent framework. This research recognizes the potential of the LADM as a tool to address the challenges posed by dynamic marine environments, enabling efficient management of land and marine data while facilitating data sharing and interoperability. It tries to harmonize the data model and common worldwide terminology for land administration. As a global norm, it may hasten the implementation of land administration systems that support sustainable goals and encourage the creation of software solutions. LADM encompasses the fundamental information-related elements of land administration, including those across the land, in water, below the surface, and above the earth. Part 1 of the LADM is the general conceptual framework, followed by Parts 2 and 3 on land registration, Part 4 on value information, Part 5 on spatial plan information, and Part 6 on implementation. The focus of this study would be on LADM parts 1 through 3, respectively (Peter van Oosterom, 2023) (Lemmen et al., 2015)(Lemmen, Alattas, et al., 2021)(Flego et al., 2021). The standard is an abstract conceptual model with three packages related to parties (people and organizations), basic administrative units, rights, responsibilities, and restrictions (ownership rights), spatial units (parcels and the legal space of buildings and utility networks), with a sub-package for surveying, and representation (geometry and topology) (Lemmen et al., 2015),(Lemmen et al., 2015),(Athanasiou et al., 2017) and(Lemmen, Abdullah, et al., 2021). LADM can serve as a starting point for modeling certain aspects of dynamic marine environments, it may require significant customization and integration with other domain-specific models (IHO S-121), and standards to effectively address the unique challenges and requirements of marine spatial data management and administration.

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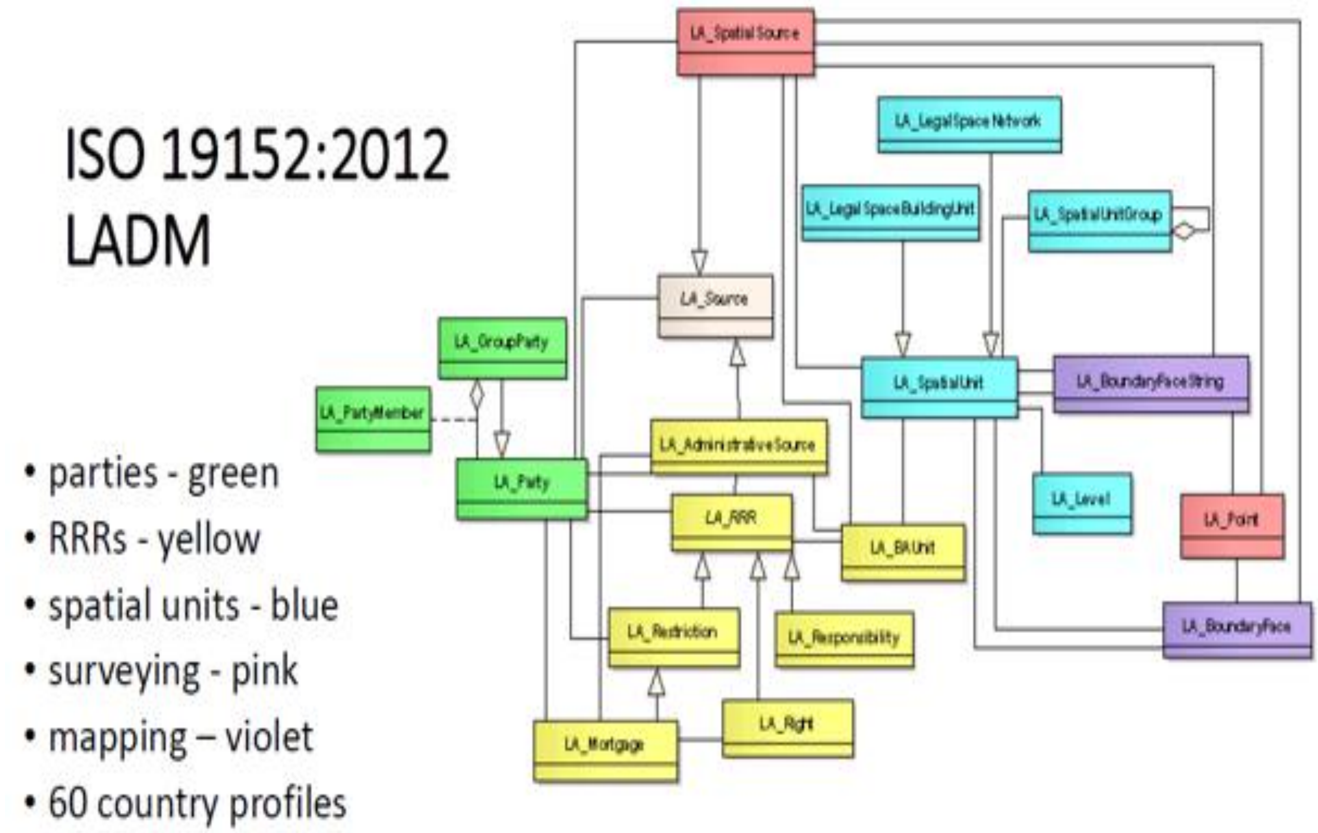


Figure 1. LADM (ISO 19152 2012).

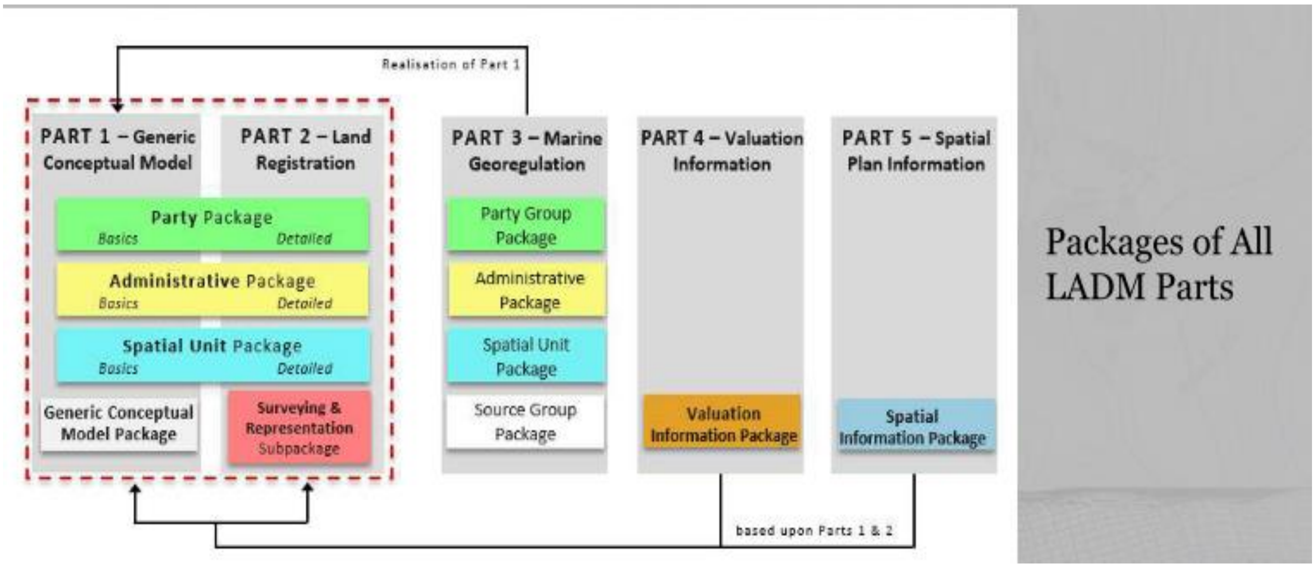


Figure 2. Packages of All LADM Parts. (Peter van Oosterom, 2023)

1.1.2 Marine Georegulation (LADM Edition II)

Georegulation addresses the information structure related to the management of legal spaces such as the international maritime limits and boundaries, marine living and non-living resource management areas, marine conservation areas, and their related rights and obligations. Georegulation provides the concepts and structure for the standardization of georegulation in marine space. IHO S-100 Universal Hydrographic Model, S-121 Marine Limits and Boundaries, and the United Nations Convention on the Law of the Sea are all cited and used in this document. It offers a framework for expressing obligations, limitations, and rights in the context of marine space based on LADM core class realization (Peter van Oosterom, 2023),(Kara et al., 2023)

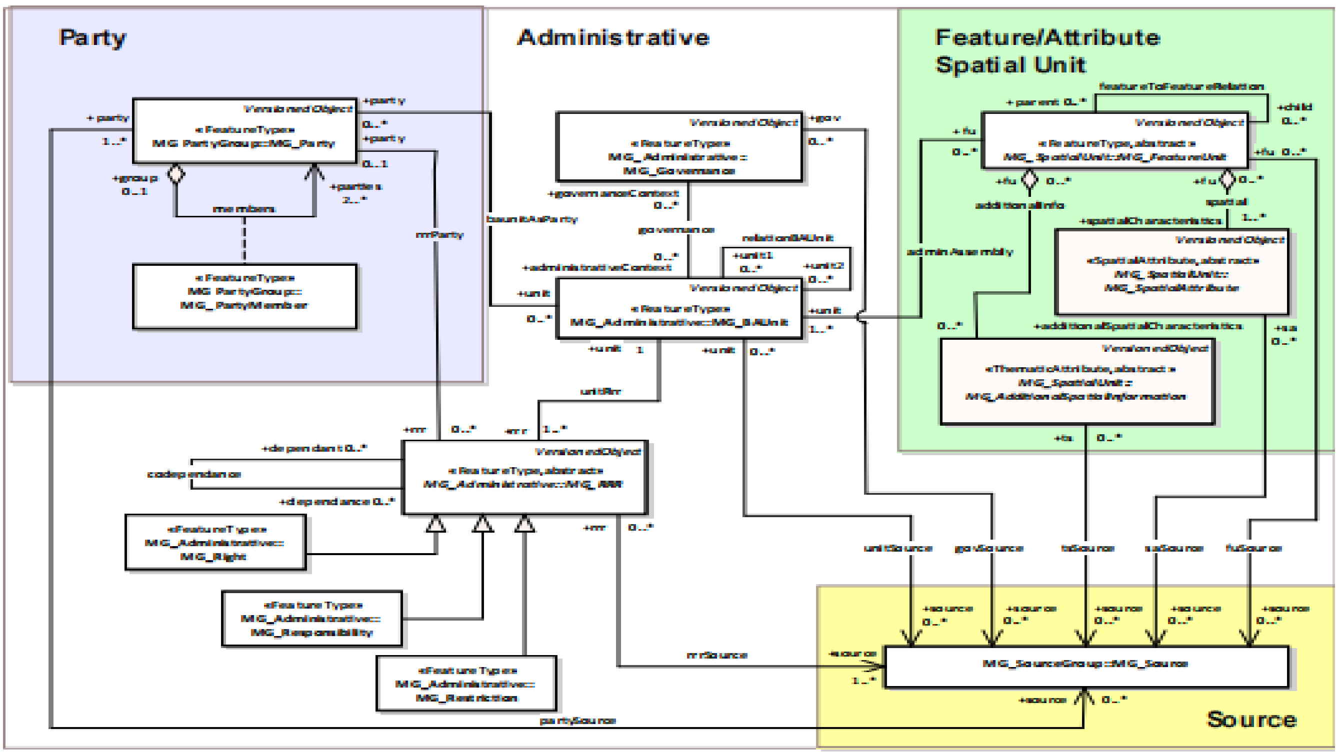


Figure 3. Marine Georegulation (ISO 19152 LADM). (Kara et al., 2023)

1.1.3 Application of Versioned Object

In the context of LADM, a versioned object is a type of object that represents a version of another object in the system. It captures the state of an object at a particular point in time and can be used to track changes to the object over time. It is typically used in situations where it is important to maintain a historical record of changes to an object, such as in land administration systems (Gürsoy Sürmeneli, Alkan, et al., 2022). The LADM Versionobject was introduced in this work and into the various classes to track historical events such as changes to boundaries, and ownership and for a comprehensive audit trail of changes to important objects in the system, which can be useful for the purpose of dispute resolution, legal compliance, and accountability. Versioned systems can also be applied to marine or coastal land and property management, such as in the management of maritime boundaries, marine protected areas, and coastal zones. Here are some examples of how versioned systems can be used in this context (Lemmen, Alattas, et al., 2021). A versioned system can be used to track changes to maritime boundaries between countries or territories. Each version of the boundary object would represent the state of the boundary at a particular point in time (Lemmen et al., 2019), including any changes that have been made to the boundary. This can help to ensure that disputes over maritime boundaries are resolved using accurate and up-to-date information. The system can be used to track changes to the boundaries and management plans of marine protected areas. Each version of the protected area object would represent the state of the area at a particular point in time,
including any changes that have been made to the boundary or management plan. This can help to ensure that marine protected areas are managed effectively and in accordance with legal requirements. Also, the system can be used to track changes to land use and development in coastal zones (Gürsoy Sürmeneli, Koeva, et al., 2022). Each version of the coastal zone object would represent the state of the zone at a particular point in time, including any changes that have been made to land use and development regulations. This can help to ensure that coastal zones are managed sustainably and in accordance with environmental and social considerations (Cemellini et al., 2020) and (Sutherland et al., 2016). In addition to these examples, versioned systems can also be applied to other aspects of marine or coastal land and property management, such as the management of fisheries, aquaculture, and marine infrastructure. By using a versioned system, marine and coastal land and property management can be more transparent, efficient, and effective, which can lead to better environmental and social outcomes.

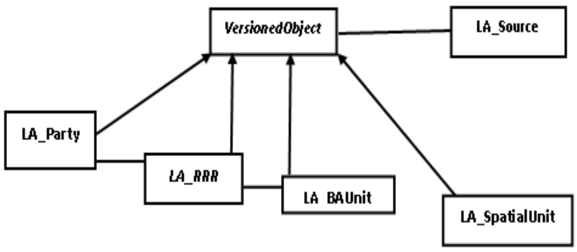


Figure 4. VersionedObject (LADM Edition II) [The Fundamentals package]

Every property item has the potential to change over time, in both 2D and 3D either in spatial or textual data. The alterations include modifications to ownership, rights, and space, among other things. The history would be muddled by partial depictions of the changes and the documentation that accompanied them. To prevent disagreements and fraud, any changes to the spatial representations and ownership of 3D cadastre objects should be thoroughly documented. In this research work, it is important therefore to consider temporal dimension factors while representing cadastre objects particularly in dynamic marine environment (Lemmen, 2012).
The cadastre object's modifications are documented in the history.

Parties, RRR (Rights, Restriction, Responsibility), geographical references (surveying), spatial units (geometry of cadastre objects), and cadastre geospatial data display are the five products that are offered on LADM. Each of these packages represents an essential component of land management and associated duties. The simplified LADM UML is represented by four classes: LA Party, LA RRR, LA Spatial Unit, and LA BA Unit (ISO 19152, 2012). Figure 4 displays the UML diagram that illustrates the relationship between the four classes.
The Fundamentals package defines fundamental classes and ideas that another parts reuse. Figure 4 displays the fundamental classes of LADM Editions I & II. VersionedObject and LA Source are two new classes that are added as base classes in LADM Edition II. The class VersionedObject is linked to the class LA Source, which represents the Land Administration System (LAS) process. Since VersionedObject is a subclass of all other LADM classes, they all inherit this association (Lemmen, Alattas, et al., 2021).

To ensures recording of historical modifications to objects across time, figure 5 VersionedObject below, was designed in this work, incorporating all the created classes with features like beginDateTime, beginLifeSpanVersion, endLifeSpanVersion, and so on. All the created classes inherit the version history from the VersionObject as built in Figure 5, ensuring that changes over time are documented.

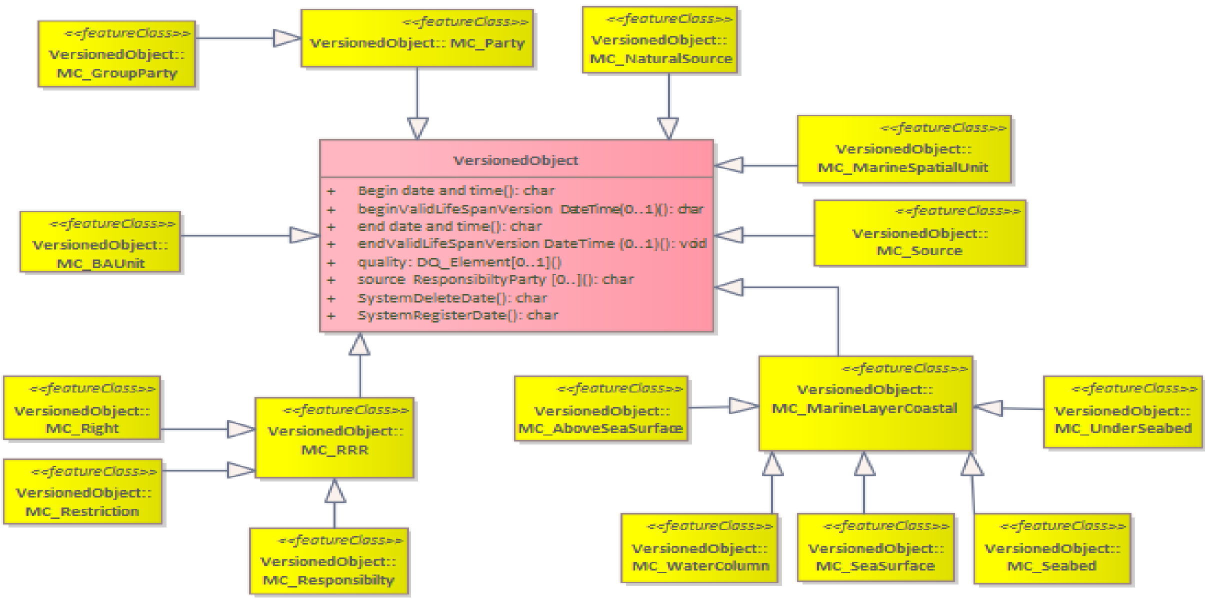


Figure 5. VersionedObject for 4D Malaysia marine cadastre data model

1.1.4 Issues & Challenges

Changing spatial objects and their attributes; land conversion to new definitions, descriptions, new outlook and such as resulting from land transfers, marine area reclamation, and land-to-marine areas, of any kind are vulnerable to time (Gunarso et al., 2013)(Bagheri et al., 2022). Other challenges include property owners with legitimate legal (Right) documents still retaining their paper when the status of their lands changes particularly from land to marine or vice versa, the dynamic boundaries and legal instruments of right, restriction, and responsibility (Pribadi et al., 2021) and the temporal transitions are not captured in the existing 3D Marine Cadastre Data Model and in the Land Administration Domain Model (LADM). Additionally, there is no provision in the existing model for a seamless transfer of cadastral records to the appropriate cadastre based on the occurred changes (Van Oosterom et al., 2006). Also, property ownership history, maintenance records and legal actions remain incomplete due to non-incorporation of time elements in the existing cadastre models. Lack of temporal component hinders property owners from anticipating future situations(Polat et al., 2020), tracing changes in land use patterns, which invariably affects property value and ownership.

The solution to these challenges requires proper cadastral documentation of these changes over time and utilizing ADEs extension tools from the land administration domain model (LADM is the incorporation of the temporal(t)[(3D+T=4D)] component of these spatial objects and their attributes into the LADM and the existing 3D Marine Cadastre Data Model(GÜRSOY SÜRMENELİ et al., 2022)(Kalogianni et al., 2021))(Gürsoy Sürmeneli, Alkan, et al., 2022)(Flego et al., 2021) respectively.

The research aim is to develop a 4D marine cadastre data model based on Malaysia LADM based on LADM Edition II. The methodology explored includes five phases which are the Preliminary research, conceptual Model development phase, model development, validation, and evaluation. In the preliminary research phase, critical review on the concepts of 4D and the existing 3D marine cadastres were carried out. Also, the concept of LADM Edition I & II, LADM Model was examined.

This integration requires adapting LADM's schema(Duncan & Rahman, 2013) to accommodate temporal attributes and 3D geometries, enabling a more holistic representation of land and marine data. The ADEs extensions within the LADM enable extensions of classes to include features and data that are particular to the domain and indicate ownership transaction changes. Methods are next.

2. METHODS

The research explores the following steps for the 4D marine cadastre data model development. The process began with conceptual modeling development using Enterprise Architect software and its UML classes and diagrams. Temporal classes, attributes and their relationships were identified and utilised to create the conceptual model as shown in appendix A. The relationships between the temporal classes were identified and visually represented using UML class diagrams. It is essential that the UML class diagrams faithfully depict the temporal aspect of the cadastre system and are consistent with the existing 3D Malaysian marine cadastre data model which were accomplished by continuously refining and testing UML class diagrams. Temporal classes such as "time slice", "time period", “event” and in this work MC_SeaSurface etc., were added to the 3D model's existing classes. The "time slice" class represents a snapshot of the cadastre system at a certain point in time, whereas the "time period" class indicates a continuous period during which the cadastre system changes. The "event" class denotes a specific action or occurrence that results in a modification to the cadastre system. The created UML temporal classes were utilised to implement the 4D Malaysian Marine cadastre data model within a database management system.

The development of the 4D Malaysian marine cadastre data model involves three iterations as discussed below and as shown in figure 6 respectively.

In the first iteration captioned as (A), a 2D model is established which involves the conceptual modeling, implementation, testing, and validation. This model is represented by x and y coordinates.

In the second iteration (B), three alternative 3D models are created: 2D+time, 3D x, y, z, and 3D and scale. These models are built upon the 2D model from iteration A. The final 4D model is produced from the lower models, i.e., the 2D and 3D models. The resulting 4D Malaysian marine cadastre models are feasible and can be built upon partial models that are already operational. This process provides insights into the behaviors of integrated dimensions.
The third iteration (C) focuses on spatial and temporal or scale concepts only. The aim is to generate concepts for LADM Edition I, which deeply integrates space, time, and scale concepts and is implemented with a 4D data type. The 4D Malaysian marine cadastre model is then produced from the 4D LADM I land cadastre.

The knowledge gained from iterations A, B, and C is used to generate concepts for the 4D Malaysian Marine Cadastre Data Model. This model is derived from the lower models of 2D+time, 3D x, y, z, LADM I, and II.

The fourth iteration (D) involves deeply integrated space, time, and scale concepts along with the LADM implemented with a 4D data type, 4D topological structures and primitives, as well as 4D clustering and indexing.

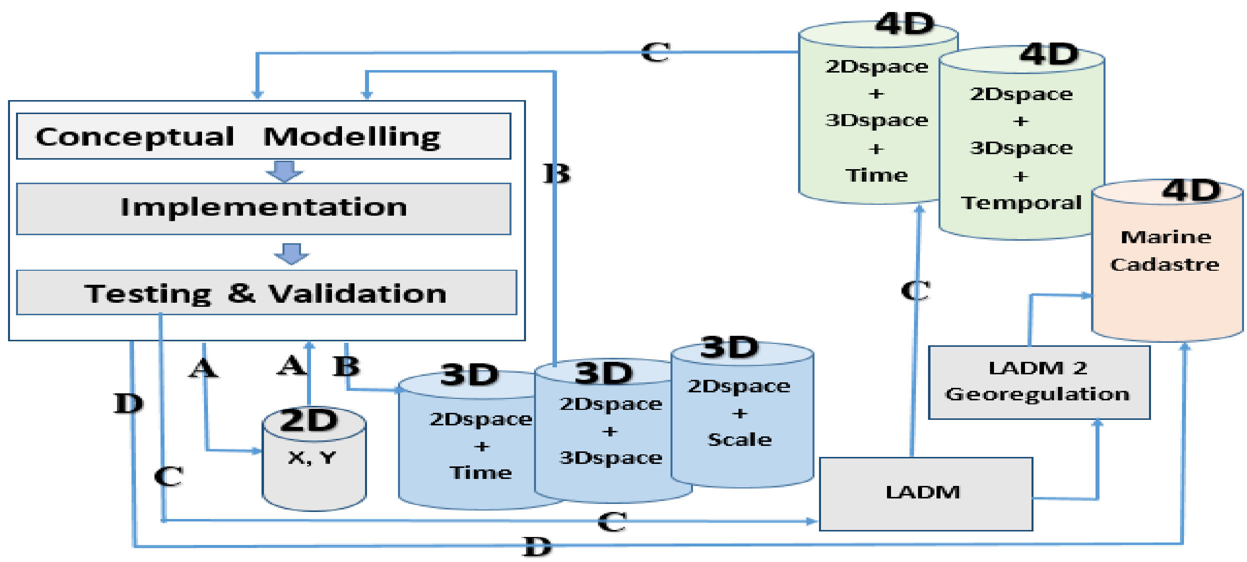


Figure 6. Workflow of Research Methodology

Above methodology is summarized as below.

2D ⟶ X, Y = 2D

3D ⟶ X, Y, Z = SPACE

4D ⟶ 3D + T = 4D

4D ⟶ LADM = (4D) TEMPORAL DIMENSION(MARINE)

3. RESULTS

The resulting 4D Malaysian Marine Cadastre Data Model (Appendix B) is a comprehensive model that integrates all dimensions of space, time, and scale, and can be used for efficient marine cadastre management, as summaries below:

Figure 6, above represent the research flow for the creation of 4D Malaysian Marine cadastre data model. It demonstrates the evolution of cadastre data models to date. Letter A represent two dimensional (2D (X, Y)), B, demonstrate the transition of 2Dspace + Time, 2Dspace +3Dspace, and 2Dspace+ Scale for 3D data model respectively. C Demonstrate the holistic transformation from 3D Model to LADM and subsequently 4Ds = [2Dspace + 3Dspace + Time, 2Dspace + 3Dspace + Temporal], D represents the transformation of LADM Edition I to LADM Edition II[Georegulation]. LADM Edition II to 4D Marine cadastre data model respectively.

In this research, MC is prefix for Malaysia LADM and was used in the coding of the new classes within the marine environment were proposed to both the LADM LA_Spatial unit and Administrative LA_RRR (Right, Restriction Responsibility) unit respectively.

The model consists of the Party unit, the Spatial Unit, and the administrative unit based on LADM standard.

The party unit consist of MC_Party and MC _GroupParty to handle ownership status within the cadastre respectively.

The Spatial unit, consist of MC_SpatialUnit, the MC_MarineLayer, MC_SeaSurface, MC_Seabed and MC_WaterColum respectively. Two news classes; MC AboveSeaSurface, and MC_UnderSeabed were proposed to the Spatial unit, and within the MC_MarineLayer was created making it a total of five classes: MC_SeaSurface, MC_Seabed, MC_WaterColumn, MC_AboveSeaSurface, MC_UnderSeabed respectively. These sub-classes are linked by generalization to the marine layer class while the marine layer class is associated to the marine spatial unit, MC_SpatialUnit. Additional two new classes of MC_BuildingUnit, MC_Point is proposed to the

MC_SpatialUnit under the LA LegalSpaceBuilding Unit of LADM to facilitate the documentation of ownership transactions, historical events, and domain changes respectively. The added MC_Point is to define the coordinates (X, Y, Z) points and other bathymetry data for elevation and contour lines.

In the Administrative unit, one new class were equally proposed and associated to the right party (MC_Rights) as MC_NaturalResourceRight in the administrative RRR unit to document the diverse natural resources beneath the ecosystem, mangrove and other endanger species and the issue bordering on bundle and multiple rights, be it formal or informal and the restrictions on the fishing community and stakeholders respectively. These additions would be accompanied by their various code lists defining the attribute of the added classes in the subsequent works. The added five classes are shown in mixed-white colour.

The developed conceptual model is shown as Appendix A, while the proposed 4D Malaysian marine cadastre data model is shown as Appendix B respectively. Next is Discussions and Conclusion

4. DISCUSSION & CONCLUSION

It is true that prior to the introduction of LADM in 2012, legal papers related to land ownership and rights were based on various models, including 2D, 2.5D, 3D, and 3D space and time, with scale as the fifth dimension. These models were used to define and manage land parcels and rights and were typically designed for terrestrial applications. However, with the transition to LADM, which is a standardized international model for land administration, the focus has broadened beyond just land and now includes marine and other types of spatial data. LADM Edition II, the latest version of the model, includes provisions for the management of marine space, as well as other types of spatial units, such as buildings and structures.

This transition has presented some challenges related to land cover changes, such as the conversion of land to marine, marine to land reclamation areas or vice visa. In some cases, this has rendered existing land ownership and rights documents useless or inaccurate. However, LADM Edition I and LADM Edition II provide mechanisms for addressing these changes and ensuring that property rights are maintained, even as the spatial environment evolves. For example, LADM Edition II includes provisions for managing changes in land cover, such as the conversion of land to marine, marine to land areas, using spatial data models and other tools. In addition, the model includes mechanisms for tracking changes in property rights, such as using time-stamped transaction records and other documentation. Therefore, the transition to LADM Edition I and LADM Edition II has presented some challenges related to land cover changes. These challenges are being addressed using standardized spatial data models and other tools as presented in Figure 6 which enables property owners and administrators to continue to manage and protect their rights, even as the spatial environment evolves over time.

LADM Edition II represents a major advancement in the field of land administration, as it expands the scope of the standard beyond land registration to cover a wider range of information related to land, such as land value and land use. It also includes provisions for managing marine environments and 3D land administration on land and at sea, which are becoming increasingly important as human activity continues to impact these areas.

The new standard is a multipart standard, with six parts covering different aspects of land administration. Part 1 provides an introduction and overview of the model, including definitions and packages, and updates to the LA_Source and VersionedObject classes. Part 2 covers land registration, while Part 3 focuses on marine space(Aien et al., 2011) Georegulation (Okembo et al., 2022). Part 4 covers valuation information, while Part 5 covers spatial plan information. Finally, Part 6 provides implementation guidelines for the standard. The term "georegulation" was introduced as an activity to delimit and assert control over 2D, 3D or 4D represented geographical (and temporal) spaces through regulations, there is also change in the definition of "right" to include both formal and informal entitlements intended to capture a wider range of rights and entitlements related to land and other spatial resources.

Therefore, the LADM Edition II is expected to have a significant impact on the field of land administration, helping to address global issues related to land and marine environments. The standard is also designed to be flexible and adaptable to different contexts, making it a valuable resource for land administration practitioners around the world.

4.1 Conclusion

This research reveals that the integration of the missing temporal component into 3D marine cadastre data model addresses the temporal challenges in cadastral administration in the dynamic marine environment. Related works, issues and challenges bordering on change, seamless data transfer from one cadastre model to another arising from this change were discussed. However, the non-incorporation of the time element into the existing cadastres, has made our cadastre incomplete. The integration of the temporal components into the existing 3D Malaysian marine cadastre data model for a 4D Malaysian marine cadastre data model ensure the completeness of the land-marine, marine to land cadastres data model and invariably solves the inadequacies of the current marine cadastre data model for a holistic data management in both terrestrial and dynamic environments. Also, the incorporated temporal attributes and 3D representations would enable stakeholders to better understand spatial changes in land and marine objects respectively. Additionally, the extended model offers a structured approach to data management, supporting informed decisions that balance economic growth, environmental conservation, and social well-being. As coastal regions face unprecedented challenges of land transformations due to climate change and urbanization, the lessons learned from this study will contribute to the resilience and sustainability of coastal communities. Furthermore, this research exemplifies the potential of integrating cutting-edge spatial technologies and comprehensive data management frameworks in the realm of land and marine cadastral administration. The insights provided by this study pave the way for more effective, adaptive, and sustainable practices at the dynamic interface between land and sea.

Future works include more discussions on versioned object applications, code lists and further improvement on the proposed 4D Malaysian marine cadastre data model and definition of code list, the creation of database using PostgresSQL, validation, testing, evaluation, and visualisation of the 4D cadastre data model in Quantum QGIS environment respectively.

REFERENCES & BIBILIOGRAPHY

Aien, A., Kalantari, M., Rajabifard, A., & Williamson, I. (2011). Advanced Principles of 3D Cadastral Data Modelling. *2nd International Workshop on 3D Cadastres, 2011, November*, 377–396.

Aneseyee, A. B., Noszczyk, T., Soromessa, T., & Elias, E. (2020). The InVEST habitat quality model associated with land use/cover changes: A qualitative case study of the Winike Watershed in the Omo-Gibe Basin, Southwest Ethiopia. *Remote Sensing*, *12*(7), 7–9. https://doi.org/10.3390/rs12071103

Atazadeh, B., Olfat, H., Rajabifard, A., Kalantari, M., Shojaei, D., & Marjani, A. M. (2021). Linking Land Administration Domain Model and BIM environment for 3D digital cadastre in multi-storey buildings. *Land Use Policy*, *104*(March), 1–25. https://doi.org/10.1016/j.landusepol.2021.105367

Athanasiou, K., Sutherland, M., Kastrisios, C., Tsoulos, L., Griffith-Charles, C., Davis, D., & Dimopoulou, E. (2017). Toward the development of a marine administration system based on international standards. *ISPRS International Journal of Geo-Information*, *6*(7), 1–25. https://doi.org/10.3390/ijgi6070194

Babalola, S., Abdul Rahman, A., & Choon, T. (2015). A Brief Review of Land Administration Domain Model and Its Temporal Dimension. *Journal of Advanced Review on Scientific Research*, *6*(1), 1–15.

Bagheri, M., Ibrahim, Z. Z., Manaf, L. A., Akhir, M. F., Wan Talaat, W. I. A., & Wolf, I. D. (2022). Fundamental applications of the Bruun model to project land loss of coastal cities: A case study of Kuala Terengganu, Malaysia. *ResearchSquare*, 1–35. https://doi.org/10.21203/rs.3.rs-1400735

Binns, B. O. (1995). Cadastral surveys and records of rights in land. Based on the 1953 study by Sir Bernard O. Binns. In *Fao Land Tenure Studies*. http://www.fao.org/3/V4860E/V4860E06.htm

Cemellini, B., van Oosterom, P., Thompson, R., & de Vries, M. (2020). Design, development, and usability testing of an LADM compliant 3D Cadastral prototype system. *Land Use Policy*, *98*(April 2019), 104418. https://doi.org/10.1016/j.landusepol.2019.104418

Chen, W., Wang, D., Huang, Y., Chen, L., Zhang, L., Wei, X., Sang, M., Wang, F., Liu, J., & Hu, B. (2017). Monitoring and analysis of coastal reclamation from 1995-2015 in Tianjin Binhai New Area, China. *Scientific Reports*, *7*(1), 1–12. https://doi.org/10.1038/s41598-017-04155-0

Duan, H., Zhang, H., Huang, Q., Zhang, Y., Hu, M., Niu, Y., & Zhu, J. (2016). Characterization and environmental impact analysis of sea land reclamation activities in China. *Ocean and Coastal Management*, *130*, 128–137. https://doi.org/10.1016/j.ocecoaman.2016.06.006

Duncan, E. E., & Rahman, A. A. (2013). A multipurpose cadastral framework for developing countries-concepts. *Electronic Journal of Information Systems in Developing Countries*, *58*(1), 1–16. https://doi.org/10.1002/j.1681-4835.2013.tb00411.x

Embling, C. B., Illian, J., Armstrong, E., van der Kooij, J., Sharples, J., Camphuysen, K. C. J., & Scott, B. E. (2012). Investigating fine-scale spatio-temporal predator-prey patterns in dynamic marine ecosystems: A functional data analysis approach. *Journal of Applied Ecology*, *49*(2), 481–492. https://doi.org/10.1111/j.1365-2664.2012.02114.x

Femenia-ribera, C., Mora-navarro, G., & Martinez-llario, J. C. (2021). *Land Registry*.

Flego, V., Roić, M., & Benasić, I. (2021). LADM extensions to maritime domain in multi-register environment - Case study Croatia. *Land Use Policy*, *102*(June 2020). https://doi.org/10.1016/j.landusepol.2020.105247

Govedarica, M., Radulović, A., & Sladić, D. (2021). Designing and implementing a LADM-based cadastral information system in Serbia, Montenegro, and Republic of Srpska. *Land Use Policy*, *109*(June 2020). https://doi.org/10.1016/j.landusepol.2021.105732

Gunarso, P., Hartoyo, M. E., Agus, F., & Killeen, T. J. (2013). Oil Palm and Land Use Change in Indonesia, Malaysia, and Papua New Guinea. *Reports from the Technical Panels of RSPOs 2nd Greenhouse Gas Working Group*, *November* 29–64. http://www.rspo.org/file/GHGWG2/4_oil_palm_and_land_use_change_Gunarso_et_al.pdf

Gürsoy Sürmeneli, H., Alkan, M., & Koeva, M. (2022). Design and implementation of a 4D cadastral legal model for Turkish land administration infrastructure based on LADM. *Geocarto International*, *37*(26), 12096–12118. https://doi.org/10.1080/10106049.2022.2063410

GÜRSOY SÜRMENELİ, H., Alkan, M., & Koeva Mila. (2022). *Towards Investigation of Integrating LADM, BIM, and CityGMLof3D Condominium Rights for Cadastral Purposes: The Case of Turkish Cadastral System*. *April*.

Gürsoy Sürmeneli, H., Koeva, M., & Alkan, M. (2022). The Application Domain Extension (ADE) 4D Cadastral Data Model and Its Application in Turkey. *Land*, *11*(5). https://doi.org/10.3390/land11050634

He, Q., Bertness, M. D., Bruno, J. F., Li, B., Chen, G., Coverdale, T. C., Altieri, A. H., Bai, J., Sun, T., Pennings, S. C., Liu, J., Ehrlich, P. R., & Cui, B. (2014). Economic development and coastal ecosystem change in China. *Scientific Reports*, *4*, 1–9. https://doi.org/10.1038/srep05995

Kalogianni, E., Janečka, K., Kalantari, M., Dimopoulou, E., Bydłosz, J., Radulović, A., Vučić, N., Sladić, D., Govedarica, M., Lemmen, C., & van Oosterom, P. (2021). Methodology for the development of LADM country profiles. *Land Use Policy*, *105*(July 2020). https://doi.org/10.1016/j.landusepol.2021.105380

Kara, R., Obi Reddy, G. P., Kumar, N., & Singh, S. K. (2018). Monitoring spatio-temporal dynamics of urban and peri-urban landscape using remote sensing and GIS – A case study from Central India. *Egyptian Journal of Remote Sensing and Space Science*, *21*(3), 401–411. https://doi.org/10.1016/j.ejrs.2017.12.006

Kara, A., Lemmen, C., Van Oosterom, P., Kalogianni, E., Alattas, A., & Indrajit, A. (2023). Design of the New Structure and Capabilities of LADM Edition II including 3D Aspects. *Land Use Policy*, *137*(December 2023), 107003. https://doi.org/10.1016/j.landusepol.2023.107003

Lemmen, C., Abdullah, A., Indrajit, A., Eftychia, K., Kara, A., Oosterom, P. Van, & Oukes, P. (2021). The Foundation of Edition II of the Land Administration Domain Model (11163). *FIG E-Working Week 2021: Smart Surveyors for Land and Water Management - Challenges in a New Reality*, *July* 17.

Lemmen, C., Alattas, A., & Agung, S. A. (2021). *The Foundation of Edition II of the Land Administration Domain Model (11163) Christiaan Lemmen, Alattas Abdullah (Saudi Arabia), Agung Indrajit (Indonesia), Kalogianni Eftychia (*. *June* 21–25. https://www.fig.net/resources/proceedings/fig_proceedings/fig2021/papers/ws_03.4/WS_03.4_abdullah_indrajit_et_al_11163.pdf

Lemmen, C., van Oosterom, P., & Bennett, R. (2015). The Land Administration Domain Model. *Land Use Policy*, *49*, 535–545. https://doi.org/10.1016/j.landusepol.2015.01.014

Lemmen, C., Van Oosterom, P., Kara, A., Kalogianni, E., Shnaidman, A., Indrajit, A., & Alattas, A. (2019). The scope of LADM revision is shaping up. *8th International FIG Workshop on the Land Administration Domain Model*, *October* 1–36.

Lisjak, J., Roić, M., Tomić, H., & Ivić, S. M. (2021). Croatian ladm profile extension for state-owned agricultural land management. *Land*, *10*(2), 1–19. https://doi.org/10.3390/land10020222

Ma, T., Li, X., Bai, J., & Cui, B. (2019). Habitat modification in relation to coastal reclamation and its impacts on waterbirds along China's coast. *Global Ecology and Conservation*, *17*, e00585. https://doi.org/10.1016/j.gecco.2019.e00585

Mehmood, H. U., Ujang, U., Azri, S., & Choon, T. L. (2022). Conceptual Domain Model for Maintenance Management of High-Rise Residential Strata. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *48*(4/W3-2022), 77–82. https://doi.org/10.5194/isprs-archives-XLVIII-4-W3-2022-77-2022

Micek, O., Feranec, J., & Stych, P. (2020). Land use/land cover data of the urban atlas and the cadastre of real estate: An evaluation study in the Prague metropolitan region. *Land*, *9*(5). https://doi.org/10.3390/LAND9050153

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding - A global assessment. *PLoS ONE*, *10*(3). https://doi.org/10.1371/journal.pone.0118571

Odli, Z. S. M., Abdullah, A. L., Saad, F. N. M., & Fadzillah, N. S. A. (2020). The relationship between land use and marine litter at Kuala Perlis coastal area. *IOP Conference Series: Earth and Environmental Science*, *476*(1). https://doi.org/10.1088/1755-1315/476/1/012109

Okembo, C., Lemmen, C., Kuria, D., & Zevenbergen, J. (2022). Developing an adapted land administration domain model profile for Kenya. *Land Use Policy*, *117*(January), 106087. https://doi.org/10.1016/j.landusepol.2022.106087

Peter van Oosterom. (2023). *Towards Standards-Based Integrated Land Administration: Land Tenure, Marine Georegulation, Valuation & Spatial Plan Information in the new LADM Edition II* (Issue August).

Polat, Z. A., Alkan, M., van Oosterom, P. J. M., & Lemmen, C. H. J. (2020). A LADM-based temporal cadastral information system for modelling of easement rights–A case study of Turkey. *Survey Review*, *52*(370), 1–12. https://doi.org/10.1080/00396265.2018.1503481

Pribadi, C. B., Budisusanto, Y., & Raniah, W. (2021). Evaluation of Application of RRR (Right, Restriction, and Responsibility) Cadastre Concept for Management of Industrial Marine Space. *IOP Conference Series: Earth and Environmental Science*, *731*(1). https://doi.org/10.1088/1755-1315/731/1/012030

Rakuša, M., Lisec, A., Triglav, J., & Čeh, M. (2021). Integration of Land Cadastre with Spatial Plan Data. *Geodetski Vestnik*, *65*(3), 385–399. https://doi.org/10.15292/geodetski-vestnik.2021.03.385-399

Sengupta, D., Chen, R., & Meadows, M. E. (2018). Building beyond land: An overview of coastal land reclamation in 16 global megacities. *Applied Geography*, *90*(May 2017), 229–238. https://doi.org/10.1016/j.apgeog.2017.12.015

Sengupta, D., Choi, Y. R., Tian, B., Brown, S., Meadows, M., Hackney, C. R., Banerjee, A., Li, Y., Chen, R., & Zhou, Y. (2023). Mapping 21st Century Global Coastal Land Reclamation. *Earth's Future*, *11*(2), 1–13. https://doi.org/10.1029/2022EF002927

Sulistyawati, M. N., Aditya, T., & Santosa, P. B. (2018). The Implementation of LADM Versioned-Object Class for Representing Spatio-Temporal of Cadastre 4D Objects. *BHUMI: Jurnal Agraria Dan Pertanahan*, *4*(2), 249–265. http://dx.doi.org/10.31292/jb.v4i2.281

Sun, J., Mi, S., Olsson, P.-O., Paulsson, J., Harrie, L., Sun, Mi, Olsson, Paulsson, Harrie, Sun, J., Mi, S., Olsson, P.-O., Paulsson, J., & Harrie, L. (2019). Geo-Information Utilizing BIM and GIS for Representation and Visualization of 3D Cadastre. *ISPRS International Journal of Geo-Information*, *8*(11), 503. https://doi.org/10.3390/ijgi8110503

Sutherland, M., Griffith-charles, C., Davis, D., Sutherland, M., Griffith-charles, C., & Davis, D. (2016). *Toward the Development of LADM-based Marine Cadastres: Is LADM Applicable to Marine Cadastres? Toward the Development of LADM-based Marine Cadastres: Is LADM Applicable to Marine Cadastres? October*, 301–316.

Tian, B., Wu, W., Yang, Z., & Zhou, Y. (2016). Drivers, trends, and potential impacts of long-term coastal reclamation in China from 1985 to 2010. *Estuarine, Coastal and Shelf Science*, *170*, 83–90. https://doi.org/10.1016/j.ecss.2016.01.006

Van Oosterom, P., & Stoter, J. (2010). 5D data modelling: Full integration of 2D/3D space, time, and scale dimensions. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *6292 LNCS*, 310–324. https://doi.org/10.1007/978-3-642-15300-6_22

Van Oosterom, P., Stoter, J., Lemmen, C., van Oosterom, P., Ploeger, H., Thompson, R., & Netherlands Rod THOMPSON, the. (2006). *Aspects of a 4D Cadastre: A First Exploration TS 14-3D and 4D Cadastres Aspects of a 4D Cadastre: A First Exploration Aspects of a 4D Cadastre: a first exploration*. 1–23. https://www.researchgate.net/publication/252548375

Vranić, S., Matijević, H., Roić, M., & Vučić, N. (2021). Extending LADM to support workflows and process models. *Land Use Policy*, *104*(February). https://doi.org/10.1016/j.landusepol.2021.105358

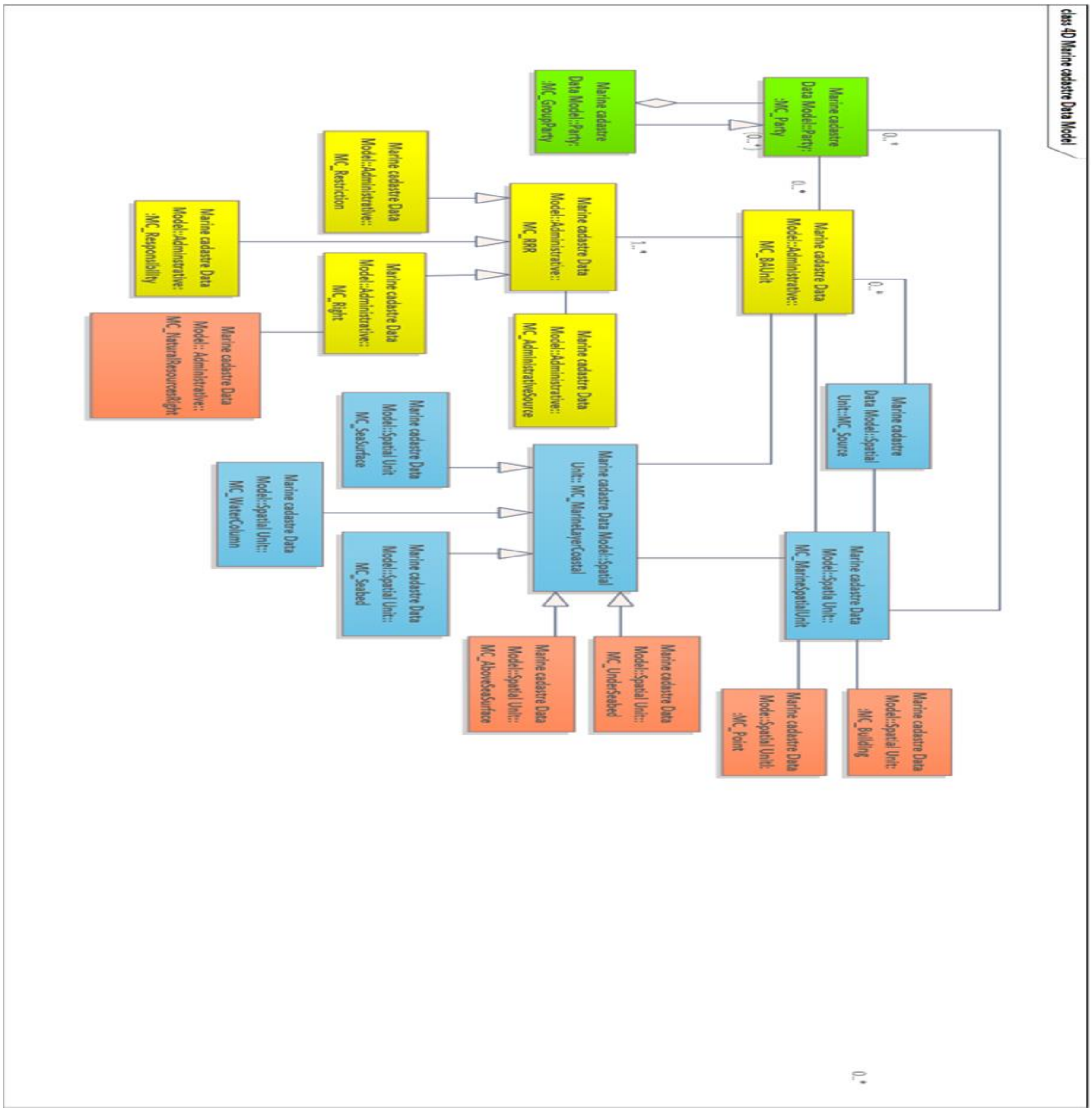
Wu, W., Yang, Z., Tian, B., Huang, Y., Zhou, Y., & Zhang, T. (2018). Impacts of coastal reclamation on wetlands: Loss, resilience, and sustainable management. *Estuarine, Coastal and Shelf Science*, *210*(June), 153–161. https://doi.org/10.1016/j.ecss.2018.06.013

Yomralioglu, T., & Mc Laughlin, J. (2017). Cadastre: Geo-information innovations in land administration. In *Cadastre: Geo-Information Innovations in Land Administration* (Issue January 2018). https://doi.org/10.1007/978-3-319-51216-7

Zamzuri, A., Hassan, I., & Abdul Rahman, A. (2022). Development of 3d marine cadastre data model based on land administration domain model. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *46*(4/W3-2021), 337–345. han, K.L., Qin K., 2017: Biomass burning related pollution and their contributions to the local air quality in Hong Kong. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., XLII-2/W7, 29-36. doi.org/10.5194/isprs-archives-XLII-2-W7-29-2017.

APPENDIX A & B

Appendix A & B are appended below which are both the conceptual model(A), while appendix B is the proposed 4D Malaysia marine cadastral data model.



Appendix A: Conceptual model for 4D Malaysian marine cadastre Data model based on LADM.

Appendix B. Proposed 4D Malaysian Marine Cadastre Data Model Based on LADM