ENHANCING THE INTEGRATION OF MARINE AND LAND CADASTRE IN KENYA: A FOCUS ON THE LAND ADMINISTRATION DOMAIN MODEL

SERHAT SARI
AUGUST, 2024

SUPERVISORS:
Dr. M.C. (Malumbo) Chipofya
Msc A. (Andre) Da Silva Mano

ENHANCING THE INTEGRATION OF MARINE AND LAND CADASTRE IN KENYA: A FOCUS ON THE LAND ADMINISTRATION DOMAIN MODEL

SERHAT SARI
ENSCHEDE, THE NETHERLANDS, AUGUST 2024

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geoinformation Management for Land Administration

SUPERVISORS:
Dr. M.C. (Malumbo) Chipofya (First Supervisor)
Msc A. (Andre) Da Silva Mano (Second Supervisor)

THESIS ASSESSMENT BOARD:
Prof. dr. Shuaib Lwasa (Chair)
Prof. dr. David Kuria (External Examiner, Dedan Kimathi University Of Technology Academy)

DISCLAIMER
This document describes work undertaken as part of a programme of study at the Faculty of Geo-Information Science and Earth Observation of the University of Twente. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the Faculty.

ABSTRACT

The increase in population in coastal areas worldwide, the diversification of activities conducted in marine areas, and the significance of these activities to national economies have led countries to place greater importance on marine spatial planning and to prioritize the Integrated Coastal Zone Management (ICZM) approach for better management of coastal areas. Due to the necessity of managing activities in marine areas in a 4D manner and the challenges of border delineations, there has arisen a need to develop marine cadastre to support marine spatial planning. Similarly, to ensure that the developed marine cadastre also contributes to the management of coastal zones, it is crucial that the cadastre systems for land and marine areas are integrated rather than developed separately. This integration is an important step for effective ICZM.

This thesis explores the enhancement of integration between marine and land cadastre systems in Kenya through the application of the Land Administration Domain Model (LADM). To achieve this, it first examines the management of marine and coastal areas in Kenya, including the acts and policies used in this management. Following this, the thesis identifies the necessary marine-specific features and key information required for developing the LADM profile for Kenya's marine cadastre. The LADM Edition 2 Part 3, which addresses marine geo-regulations, will be utilized for developing this profile.

To create the LADM profile for Kenya's marine cadastre, information obtained from literature review, acts, and policies were used, and the first draft of the LADM profile for the Kenya marine cadastre, containing the identified marine-specific features and key information, was developed. After the initial draft was created, fieldwork was conducted in Kenya, and feedback was obtained from experts in both marine and land areas regarding the LADM profile. Adjustments were made to the profile as necessary based on this feedback. In this way, the LADM profile for Kenya's marine cadastre was finalized.

Later, an integrated data model was developed to enhance the integration of marine and land cadastre systems. This was achieved by integrating the Kenya marine cadastre LADM profile, developed as part of this research, with the land cadastre LADM profile created by Okembo et al. (2023), using the realization relationship. As the final step, interviews were conducted with experts regarding how well the developed LADM profile for the Kenya marine cadastre represents Kenya's marine administration and how much the developed integrated LADM profiles can contribute to the integration of marine and land administration.

In conclusion, it has been determined that LADM Edition 2 Part 3 provides a robust data model for marine cadastre and that the marine-specific features required, such as three-dimensional (3D) management, dynamic boundaries, overlapping rights, and dynamic activities (including temporary rights and restrictions), can be incorporated within the LADM framework. Additionally, since LADM was originally developed for land administration and has been validated through numerous academic studies for land administration purposes, it is concluded that the integrated LADM profiles developed in this thesis will enhance the integration of marine and land cadastre systems in Kenya.

Keywords: Land Administration Domain Model, Marine Cadastre, Marine Spatial Planning, Integrated Coastal Zone Management, UNCLOS

ACKNOWLEDGEMENTS

This thesis journey was not easy for me, as it was filled with ups and downs. Without support from many, I would not be able to complete this journey. I would like to thank all parties that have supported and given me guidance throughout this journey.

I am sincerely grateful for the opportunities given by the Republic of Turkey Ministry of National Education of the Turkish Government and the General Directorate of Land Registry and Cadastre. The scholarship opened plenty of chances and support for this study.

My profound gratitude is given to my supervisors, Dr. M.C. Chipofya and Msc A. Da Silva Mano, whose support, time, suggestions, and constructive criticism have significantly contributed to the improvement of my thesis. I sincerely thank Prof. J. Zevenbergen for chairing my proposal and mid-term presentation, as your insightful feedback greatly enhanced the quality of my thesis.

Special thanks to the people I met during my fieldwork in Kenya, both Mombasa and Nairobi. They were very nice and welcoming, and also very open for the interview, which provided important details to support my thesis.

I would like to extend my sincere thanks to the GIMLA family: lecturers and friends. Two years of learning and enriching discussions improved my understanding of land administration. To my friends (people who have traveled with me at least once), I would like to thank you for filling up my days in ITC. It would be an empty and lonely journey without you guys.

I would like to extend my heartfelt gratitude to Salsabila; whenever things started to become overwhelming or a problem arose, she was always there, making all the challenges much easier with her positivity and energy. I feel incredibly lucky to have met you, and the long train and bus journeys we took across Europe on our limited budget will remain some of the fondest memories from this adventure.

On a personal note, I owe my deepest appreciation to my family. Bana her zaman desteğini gösteren sevgili anneme, babama, kardeşlerime ve özellikle bu yolda en büyük desteği veren kuzenim Zeynep Çevik'e sonsuz teşekkürlerimi iletiyorum.

Thank you all for your unwavering support and belief in me.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

BAUnit: Basic Administrative Unit
BIM: Building Information Modeling
CDA: Coast Development Authority
CSC: Coastal Services Center
EEZ: Exclusive Economic Zone
EMODnet: European Marine Observation and Data Network
ESRI: Environmental Systems Research Institute
EU: European Union
FIG: International Federation of Surveyors
GIS: Geographic Information System
IFC: Industry Foundation Classes
IHO: International Hydrographic Organization
ICZM: Integrated Coastal Zone Management
ISA: International Seabed Authority
ISO: International Organization for Standardization
JKP: Jumuiya ya Kaunti za Pwani
KeNODC: Kenya National Oceanographic Data Centre
KMFRI: Kenya Marine and Fisheries Research Institute
KPA: Kenya Ports Authority
KTB: Kenya Tourism Board
KWS: Kenya Wildlife Services
LADM: Land Administration Domain Model
MDA: Model Driven Architecture
MG: Marine Georegulations
MMC: Multipurpose Marine Cadastre
MSP: Marine Spatial Planning
MSPdF: Maritime Spatial Planning Data Framework
MSDI: Marine Spatial Data Infrastructure
MPA: Marine Protected Area
NEMA: National Environment Management Authority
NES: National Environmental Secretariat
NLC: National Land Commission
NM: Nautical Miles
NOAA: National Oceanic and Atmospheric Administration
NSDI: National Spatial Data Infrastructure
RRR: Rights, Restrictions, and Responsibilities
SDI: Spatial Data Infrastructure
S-121: IHO S-121 Maritime Limits and Boundaries
UNCLOS: United Nations Convention on the Law of the Sea
UNEP: United Nations Environment Program
UNESCO: United Nations Educational, Scientific and Cultural Organization
UN: United Nations
UML: Unified Modeling Language

1. INTRODUCTION

The increasing diversity of activities in marine and coastal areas underscores the need for a marine cadastre to effectively manage maritime rights and spatial data. These activities generate significant economic benefits but also exert pressure on coastal ecosystems, necessitating sustainable management through frameworks like Marine Spatial Planning (MSP) and Integrated Coastal Zone Management (ICZM). However, the problem arises from the separate governance structures for land and marine areas, which complicates the integration of administrative and spatial planning efforts. This research addresses the gap by focusing on the development of a unified data model that integrates marine and land cadastres, using an enhanced Land Administration Domain Model (LADM) to improve coastal management. Kenya, with its active ICZM and MSP initiatives and the absence of existing marine cadastre models, serves as an ideal case study. The thesis aims to create a seamless data model that enhances the integration of land and marine cadastre systems, with objectives including developing and validating an LADM profile for Kenya's marine cadastre, and integrating it with existing land cadastre models to better manage marine and coastal areas.

1.1. Motivation and Importance

Life on Earth is fundamentally dependent on the marine environment, which encompasses 71% of the Earth's surface and constitutes 90% of the biosphere (Contarinis et al., 2020). Approximately 37% of the global population resides within 100 kilometers of coasts, resulting in the concentration of population centers and human activities in coastal areas, thereby exerting increasing pressure on natural coastal ecosystem (United Nations, 2023). Furthermore, recent years have witnessed the diversification of activities in marine and coastal areas, encompassing aquaculture, fishing, the development of installations and infrastructures for resource exploration, extraction of minerals and energy resources, as well as the generation of renewable energy, preservation of nature and biodiversity, establishment of protected areas, provision of vital maritime transport routes, submarine cable and pipeline networks, zones for raw material extraction, military training, scientific research, tourism, and conservation of underwater cultural heritage (Longhorn, 2016). This extensive range of utilization collectively contributes to generating a global income estimated at three to six trillion USD annually (Irene et al., 2022). In essence, coastal areas, which are regions where the land meets the sea and include adjacent land and marine environments, remain profoundly appealing to human populations (Ayyam et al., 2019). Similarly, marine areas, which encompass all regions within the ocean environment, remain paramount in the developmental trajectories of nations.

Although developments in coastal and marine areas are of great economic importance, if these activities are not well managed, disruptions can occur in the economic, environmental, and social systems of these areas. To prevent such issues, MSP is considered a sustainable management framework (Philip, 2020). However, two different spatial planning frameworks have emerged for marine and land, typically managed by different institutions and different legislations (Kidd & Ellis, 2012). This situation creates problems in managing coastal zones, which is a geographic area defined by the enabling legislation for coastal management by any country (Ayyam et al., 2019). Therefore, the ICZM approach has emerged. With the ICZM approach, the integration of objectives, policies, sectors, and administration levels for managing coastal zones in both marine and land is aimed (Ministry For Environment And Mineral Resources, 2010).

The recent diversification of the activities in marine and coastal zones has resulted in many institutions, private companies, natural persons, and international organizations claiming rights in these areas. The involvement of many different stakeholders in administration has made the decision-making process in marine and coastal areas complex, prompting discussions since the 1990s about the necessity of marine cadastre for the administration of these areas (Zamzuri & Hassan, 2021). With marine cadastre, interests, the legal limits of these interests, and spatial data can be recorded and managed, thereby effectively managing conflicts in marine areas. However, having different cadastre and spatial planning practices for land and marine areas has led to problems in the management of activities affected by both marine and terrestrial areas and in the management of coastal zones. Increasing the integration of marine and land cadastres constitutes the aim of this thesis, and this issue and its solution are detailed in section 1.2.

Kenya was selected as the case study for this research due to several key reasons. Firstly, significant degradation has been observed in Kenya's coastal ecosystems. Secondly, the country hosts a substantial number of coastal communities that rely on these areas for their livelihoods. In response to these challenges, various ICZM initiatives have been undertaken, including the UN (United Nations)-supported Go Blue project. Furthermore, Kenya is actively engaged in MSP efforts to optimize marine resource use and conservation. These factors collectively make Kenya an ideal case for examining the integration of marine and land cadastres, offering valuable insights for similar regions facing analogous challenges (Philip et al., 2020).

1.2. Problem Statement

A marine cadastre requires information different from that of a land cadastre. While a land cadastre includes title ownership, easements, zoning, and use rights, a marine cadastre includes shipping lanes, oil and gas leases, fisheries data, conservation areas, geophysical information, aquaculture rights, navigation, cable laying, flood control, public access, and various governmental jurisdictions (Philip, 2020). This notion of a marine cadastre can be succinctly defined as a comprehensive framework that documents and organizes spatial information, concurrently delineating maritime rights and interests, including their interactions with neighbouring or underlying boundaries associated with other rights and interests (Robertson et al., 1999). However, if the marine cadastre is developed separately from the land cadastre, it will further deepen the existing issue of land and marine administration integration and make ICZM even more challenging. (Strain et al., 2005). To avoid this issue, integrating the administration of marine and land cadastres is essential. For this study, the LADM is preferred to create a seamless data model, facilitating the integration of marine and land cadastres effectively.

LADM, established in 2012, serves as a guideline for land administration, encompassing the determination, recording, and dissemination of knowledge concerning relationships between individuals and land (Athanasiou et al., 2017). Although this model, as reported by Christiaan Lemmen (2012) offers a comprehensive data model for land administration, incorporating components such as Rights, Restrictions, and Responsibilities (RRR) and spatial unit packages, it lacks the ability to effectively address complex scenarios encountered in marine administration (Zamzuri et al., 2022). Consequently, the development of a new model through the enhancement of existing LADM components was proposed (Alattas et al., 2021). This endeavour included discussions regarding part 3 of LADM Edition 2, referred to as "Marine Space Georegulation," with the goal of ensuring its applicability to marine cadastre.

Although MSP activities have begun in Kenya, no study has been found regarding the data model developed or used for administering marine areas. This thesis seeks to develop an LADM profile tailored to the marine cadastre of Kenya. LADM Edition 2 Part 3 - Marine Georegulation[1] will be utilized to achieve this.

Additionally, although there are studies on ICZM, achieving the desired integration is challenging because marine and land areas are administered separately in Kenya. To enhance the integration of land and marine administration, this study aims to create a seamless data model using LADM. There are academic studies on developing LADM profiles for the land cadastre in Kenya. Okembo et al. (2023), on this topic, have developed an integrated LADM profile for the marine cadastre, aiming to enhance integration in the management of land, marine, and coastal areas, creating a seamless data model.

1.3. Research Gap

Efforts have commenced in Kenya to develop MSP to facilitate the management of marine areas. Regarding the management of coastal areas, Kenya has expressed its commitment to implementing the ICZM approach in its programs. This approach aims to establish multi-sectoral planning for coastal zones, integrating both land and marine spatial planning to achieve holistic management. Furthermore, to effectively and cost-efficiently utilize both land and marine spatial planning, leveraging cadastre systems, including a marine cadastre, is essential to support Marine Spatial Planning initiatives. Moreover, a Spatial Data Infrastructure (SDI) is being developed for marine areas, and the development of standards, which is one of the pillars of SDI, plays a significant role in the development of marine and land cadastre (International Federation of Surveyors, 2003). Kenya developed a LADM profile for the standardization of land cadastre, but no information has been found regarding research conducted on the data model used for marine areas. Figure 1 represents the general approach to managing marine and coastal areas in Kenya. The diagram illustrates the preparation of plans and programs for marine spatial planning within a defined legal framework, serving as guiding documents for the country's marine spatial planning development. As can be understood from the diagram, programs have been developed in Kenya concerning the management of coastal and marine areas, governed by legal frameworks.

The blue box in Figure 1 highlights the importance of coastal zone management, which has led to comprehensive land-marine planning in Kenya. However, despite the ongoing work on ICZM and MSP, there is currently no research or development of a marine cadastre or a data model for it in Kenya. In contrast, as shown in the figure, there have been several studies on data models for the land cadastre using the LADM.

This thesis addresses the research gap indicated by the red boxes in the figure, specifically developing a seamless data model for marine and land cadastre. To achieve this, the first step is to develop a data model for marine cadastre in Kenya using LADM Edition 2 Part 3. Subsequently, the developed model will be integrated with the existing LADM profile developed for land, creating a seamless data model. As a result, this will enhance the integration between marine and land cadastre systems.

[1] https://github.com/ISO-TC211/HMMG

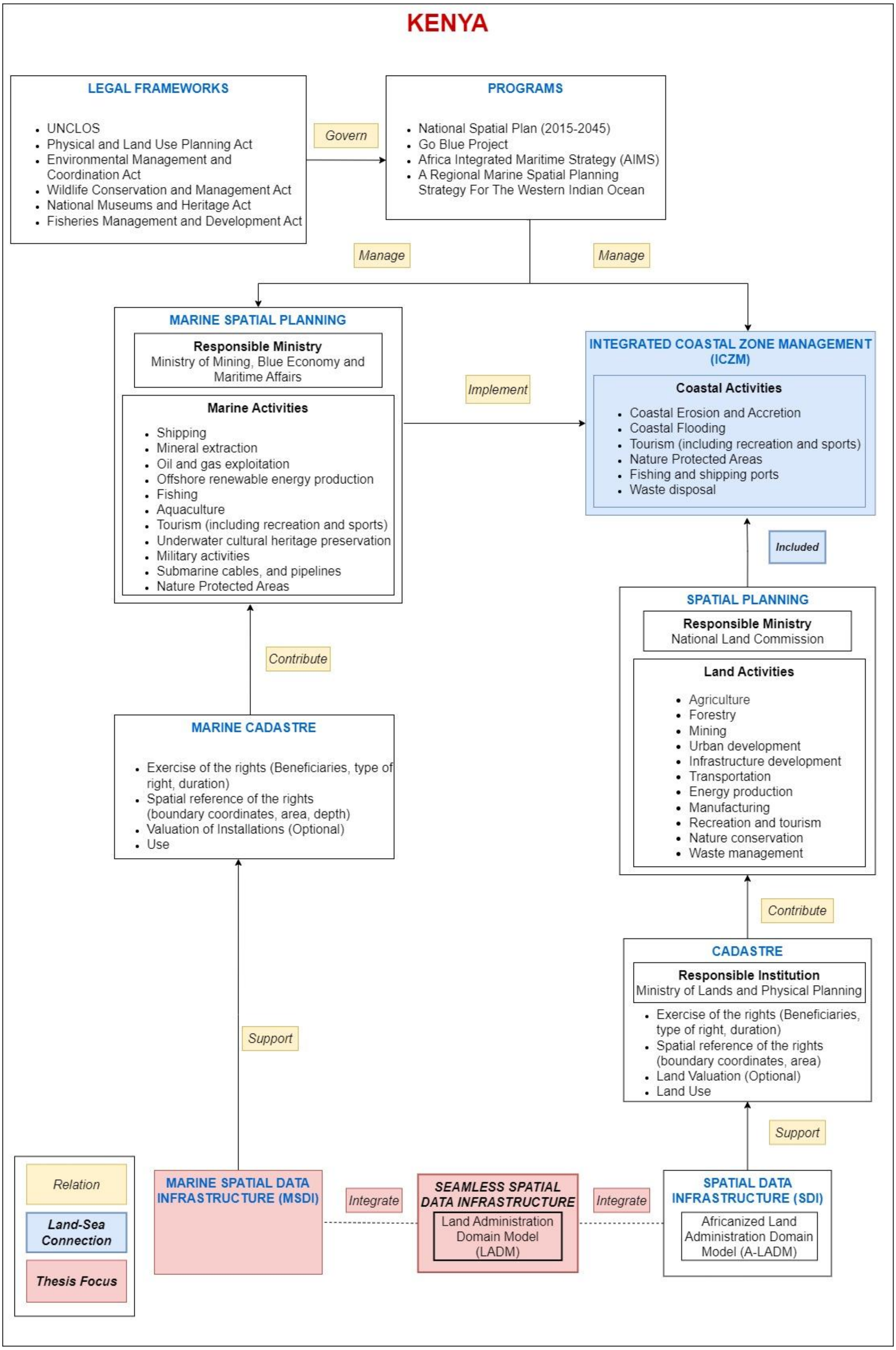


Figure 1. Diagram Summarizing the Research Gap of the Thesis

1.4. Thesis Objectives and Questions

The main objective of this thesis is to develop a seamless data model for marine and land cadastre systems in Kenya by using the LADM. In this thesis, LADM Edition 2 Part 3 is used to develop the data model for marine cadastre in Kenya. Additionally, the realization relationship, as used in LADM Edition 2, is utilized to integrate marine and land data models in Kenya. The specific objectives are:

1. To understand the current state of Kenya's marine and coastal administration strategies, including relevant laws, policies, and spatial planning initiatives for developing a data model for marine cadastre in Kenya.

RQ1: What are the marine and coastal administration strategies, including relevant laws, policies, and spatial planning initiatives in Kenya?

RQ2: What are the marine-specific features and key information that are essential for developing the data model for marine cadastre in Kenya?

2. To justify the selection of the LADM as a suitable data model for integrating marine and land cadastre in Kenya.

RQ3: Why is the LADM considered a suitable data model for integrating marine and land cadastre in Kenya, based on its accessibility, inclusion of marine-specific features, and ability to integrate with existing land administration models?

3. To develop a marine cadastre LADM profile for Kenya, integrate this profile with the existing LADM profile for the land cadastre and validate both the marine cadastre and the integrated LADM profiles.

RQ4: What specific modifications, inclusions, or exclusions are necessary to tailor LADM Edition 2 Part 3 for the Kenyan marine cadastre context based on identified marine-specific features and key information?

RQ5: How does the integration of LADM profiles for marine and land cadastre enhance data interoperability and facilitate seamless administration in Kenya?

RQ6: To what extent does the developed LADM profile represent marine administration in Kenya, and how does the integrated LADM profile contribute to the integration of marine and land administration, according to expert-based interviews?

1.5. Summary of Chapter 1

Integrating land and marine cadastres is vital for effective coastal management, especially in countries like Kenya, where diverse coastal activities require careful planning. The separate governance of land and marine areas poses challenges for sustainable management. This research seeks to address this by creating a unified data model using the LADM. Kenya's ongoing efforts in ICZM and MSP, alongside the lack of a marine cadastre model, make it an ideal case study. This study will review existing literature on marine cadastres, ICZM, MSP, and data models to support the integration of land and marine cadastre systems for improved coastal management.

2. LITERATURE REVIEW

This section delves into essential topics for this thesis, including Marine Cadastre, Integrated Coastal Zone Management (ICZM), Marine Spatial Planning (MSP), and the data models used in marine cadastre. Marine Cadastre is vital for managing complex activities and overlapping rights in marine environments, with definitions provided by researchers such as Hoogsteden & Robertson (1998) and Nichols et al. (2000). This system is crucial for recording maritime boundaries and managing spatial data. Advances in this field have been driven by international agreements and national initiatives, notably the Multipurpose Marine Cadastre (MMC), which enhances the management of marine spaces. MSP addresses the economic impact on marine ecosystems, with support from organizations like the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the European Union (EU). This review emphasizes the significance of data models in marine cadastre, particularly the Land Administration Domain Model (LADM). LADM offers a standardized framework for integrating and managing spatial data related to land and marine environments. It provides a structured approach for recording and managing rights, restrictions, and responsibilities across three-dimensional spaces. The extension of LADM through standards like S-121 enhances its application in maritime contexts, improving the management of maritime boundaries and rights by adapting land-based models to the complexities of marine environments.

2.1. Marine Cadastre

In the marine environment, the need for a specialized cadastre system is highlighted by several factors: the complexity of managing activities by various agencies, stakeholders, and registered owners; the ineffectiveness of traditional boundary demarcation; the dynamic nature of boundaries; the three-dimensional (3D) structure of marine areas allowing multiple overlapping rights in different layers at a single location; and the potential for existing rights to vary over time (Sutherland et al., 2016). Hoogsteden and Robertson (1998) published one of the several studies in which the idea of creating a cadastre for marine areas was first proposed. According to Robertson et al. (1999), marine cadastre is defined as "A system to enable the boundaries of maritime rights and interests to be recorded, spatially managed and physically defined in relationship to the boundaries of neighbouring or underlying rights and interests". Additionally, the marine cadastre is defined from a different perspective by Nichols et al. (2000) as a system of information that includes both the characteristics and spatial scope of property rights and interests concerning ownership, diverse rights, and restrictions within the marine jurisdiction.

Due to increasing maritime conflicts between nations, the international treaty known as the United Nations Convention on the Law of the Sea (1982) came into force in 1982, defining the rights and responsibilities of nations in marine areas. Many nations adhere to this treaty to govern their marine areas. United Nations Convention on the Law of the Sea (UNCLOS) has had a significant impact on the creation of marine cadastres by defining the rights of states in marine areas, including the breadth and depth to which these rights apply (Cockburn et al., 2003).

The MMC represents a pivotal advancement in the realm of marine cadastre, developed collaboratively by the National Oceanic and Atmospheric Administration (NOAA), Coastal Services Center (CSC) and the United States Minerals Management Service. Introduced in 2010 as a Geographic Information System (GIS)-based online marine information system, the MMC encompasses comprehensive marine cadastral data, including geographical boundaries, usage, rights, restrictions, and responsibilities associated with marine areas. Moreover, it integrates essential foundational data that facilitates the planning, management, and conservation of submerged lands and marine spaces (Calado & Gil, 2010).

Concurrently, significant contributions to the field of marine cadastre have been made by Working Group 4.4 of the International Federation of Surveyors (FIG), which is dedicated to Marine Development and Administration. A critical area of focus within these studies is the development of a three-dimensional (3D) marine cadastre data model. This model aims to enhance the administration and management of both land and marine environments, addressing the complex spatial challenges associated with marine territories (Zamzuri et al., 2021).

The United States (2001), Canada (2010), Australia (2014), New Zealand (1999), and the Netherlands (2003) are pioneers in the field of marine cadastre with their studies conducted at national and regional scales. Although there is no marine cadastre study specific to Kenya, it is observed that there has been an increase in national-level studies on marine cadastre in recent years (Daria et al., 2012; Dawidowicz & Źróbek, 2014; Erbas et al., 2014; Hernandi et al., 2014; Kaminskis et al., 2022; Lee, 2009; Reddy, 2015; Ying et al., 2022).

2.2. Integrated Coastal Zone Management

The coastal area can be defined as a geographic area bounded by limits extending both towards land and sea (National Environment Management Authority, 2007). These areas encompass diverse and productive ecosystems, habitats, and resources such as coral reefs, coastal forests, mangrove swamps, seagrasses, beaches, and dunes. Additionally, coastal areas play a crucial role in hosting diverse tourism and recreational activities, serving as vital zones for ports, maritime transportation, commerce, and trade. This makes them economically, politically, and socially significant for numerous countries (Sutherland & Nichols, 2006).

However, the influence of landward and seaward activities on these areas complicates their management and planning. To better manage inter-sectoral activities in coastal zones, the ICZM approach emerged in the early 1980s (Post & Lundin, 1996). ICZM entails establishing objectives, incorporating various policies and sectors, and coordinating administrative efforts to integrate land and marine dimensions across time and space, to achieve sustainable and equitable long-term benefits from coastal and marine resources (Ministry For Environment And Mineral Resources, 2010).

Several projects have been carried out to manage coastal zones in Kenya (Mwanguni et al., 2023). The country's first ICZM process effort was conducted in 1984 by the National Environmental Secretariat (NES) with contributions from the United Nations Environment Program (UNEP). Another project, sponsored by UNEP, focused on establishing a Geographic Information System (GIS)-based database of Kenyan coastal resources in 1993. Additionally, a project related to another database was the development of the Kenya National Oceanographic Data Centre (KeNODC) in 1998, sponsored by UNESCO and led by the Kenya Marine and Fisheries Research Institute (KMFRI). The data center aimed to consolidate data related to marine and coastal zones, but the project did not conclude successfully. In addition to these projects, in 1990, the Coast Development Authority (CDA) was established in Kenya to coordinate and plan developments in the coastal zone and ensure the sustainability of resources in the region (Coast Development Authority, 2012).

The Nairobi Convention, which came into effect in 1996, is one of the legal developments governing the protection, management, and development of the Western Indian Ocean and coastal areas (United Nation, 1985). Additionally, in 2007, the ICZM Policy was published in Kenya to guide actions and policies related to the utilization and management of Kenya's coastal resources, including their protection and restoration (National Environment Management Authority, 2007). Currently, the Go Blue[2] project, planned to be implemented between 2021 and 2024, is ongoing. Led by UN-Habitat, UNEP, and the Jumuiya ya Kaunti za Pwani (JKP) from Kenya, this project aims to achieve a sustainable blue economy in the coastal zone of Kenya, establish an integrated approach in land-marine planning, ensure security in the coastal zone, and attain healthy and resilient marine and coastal ecosystems through these developments (United Nations, 2023).

2.3. Marine Spatial Planning

As mentioned in previous sections, the increase in potential revenue from marine areas due to various new activities conducted in these areas, coupled with the threat posed by these activities to the rich and vital ecosystems in marine areas, has led to the emergence of the idea of MSP. MSP is defined by UNESCO (2009) as "*a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process.*"

Many organizations worldwide are working on the development of MSP. In order to establish a framework for Marine Spatial Planning, a directive was issued by the EU in 2014 (European Union, 2014). Additionally, in 2009, UNESCO published a guide titled "A Step-by-Step Approach for Marine Spatial Planning" to define the MSP establishment framework (UNESCO, 2009). Another significant step in the development of Marine Spatial Planning is the European Marine Observation and Data Network (EMODnet) platform, which was initiated in 2009 and facilitates open access to marine data from European countries (Míguez et al., 2019).

Currently, the MSP project is being developed within the Ministry of Mining, Blue Economy and Maritime Affairs in Kenya. For this purpose, they are utilizing the guide "A Step-by-Step Approach for Marine Spatial Planning" published by UNESCO. Additionally, there is an ongoing data collection phase from ministries responsible for activities in Kenya's marine areas to consolidate all marine area data onto a single platform.

2.4. Data Models for Marine Cadastre

To ensure the administration and dissemination of spatial data related to marine areas, developing a Marine Spatial Data Infrastructure (MSDI) is essential. MSDI refers to the essential framework of policies, institutional arrangements, standards, and technologies that enable the availability and accessibility of spatial data (UK Hydrographic Office, 2019). There have been initiatives to develop standardization models for marine areas. One such initiative is the Maritime Spatial Planning Data Framework (MSPdF), published in 2023 to address data management issues in MSP. This data framework focuses on defining the necessary data structure for MSP development (Abramic et al., 2023).

Another Marine Cadastre data model is the S-121 data model, developed by the International Hydrographic Organization (IHO) and published in 2019, which can store legal entities holding states' sovereignty and sovereign rights within marine boundaries and limits defined by UNCLOS (Beaupré et al., 2022). In the development process of S-121, instead of creating a model from scratch, an existing model was initially identified and modified to suit marine areas. During this process, the S-121 data model was built upon the LADM, which allows for the storage and interrelation of geospatial, administrative, parties, sources of

[2] http://jkpnodes.rcmrd.org/#/

information, and temporal attributes required by the S-121 model (Athanasiou et al., 2017). LADM, developed in 2012, is a parcel-based data model that encompasses Persons and organizations (Parties), Rights, restrictions, and responsibilities (RRR), Parcels, buildings and construction works (Spatial Unit), surveying, geometry, mapping, and transactional history (VersionedObject) (Lemmen & Oosterom, 2011). The S-121 data model extends these existing standards from the LADM framework, originally designed for land administration, to meet the requirements specified by UNCLOS for marine limits and boundaries.

Numerous academic studies have been published regarding the suitability of LADM Edition 1 for marine cadastre. These studies have concluded that an LADM-based marine cadastre is feasible (Athanasiou et al., 2017; Griffith-Charles & Sutherland, 2014; Lemmen et al., 2019; Sutherland et al., 2016). Some academic studies have also focused on creating a marine cadastre data model specific to certain countries using LADM. These studies have been conducted in Malaysia, Croatia, Greece, Trinidad & Tobago, and Canada (Abdul-Rahman, 2017; Flego et al., 2018; Griffith-Charles et al., 2018; Sutherland et al., 2016; 2022; Zamzuri & Hassan, 2021b).

In the Land Administration community, there is a consensus that LADM Edition 1, which focuses on land tenure, is not sufficiently adequate in some areas of land administration (Kara et al., 2024). Therefore, it has been agreed that the scope of LADM needs to be revised and extended to include conceptual models for cadastral acquisition techniques, marine boundaries, valuation information, spatial plan information, and more 3D support (BIM (Building Information Modeling)/IFC (Industry Foundation Classes) input) (Alattas et al., 2021). As a result, work on developing LADM Edition 2 began in 2018. LADM Edition 2 Part 3, also used in this thesis, is shared under the name "Marine Georegulation." The IHO S-121 Maritime Limits and Boundaries standard was used as the basis for developing this part (Kara et al., 2024). In LADM Edition 2 Part 3, the surveying and representation sub-package from Edition 1 was not included, as it was unsuitable for marine areas. Instead, the Spatial Unit package was adapted to fit marine regulations. While the documentation for LADM Edition 2 parts 1, 2, and 4 has been shared, the documentation for LADM Edition 2 part 3 has not yet been released but is expected to be available in 2024.

2.4.1. Land Administration Domain Model Edition 2 Part 3 – Marine Georegulation

It was previously mentioned in an earlier section that class diagrams created for the "Marine Georegulations" section of LADM Edition 2 Part 3 are shared on the ISO-TC211 (Geographic information/Geomatics) GitHub page[3], as shown in Figure 2. However, while documentation for LADM Edition 2 Parts 1, 2, and 4 has been published by the International Organization for Standardization (ISO), documentation for Part 3 had not been released at the time of writing this thesis. Therefore, although the model can be accessed on the GitHub page, information regarding the meanings of the classes, attributes, and associations it contains cannot be obtained. To understand these aspects in LADM Edition 2 – Part 3, documentation from the S-121 data model, which served as the basis for its development, has been reviewed. These documents were accessed on the IHO website for S-121 Version 1.0.0 documentation[4]. Below, each package contained in LADM Edition 2 Part 3 is explained based on information obtained from the S-121 data model documentation. MG prefixes in the class names represent marine regulations.

[3] https://github.com/ISO-TC211/HMMG

[4] https://registry.iho.int/productspec/view.do?idx=177&product_ID=S-121&statusS=5&domainS=ALL&category=product_ID&searchValue=

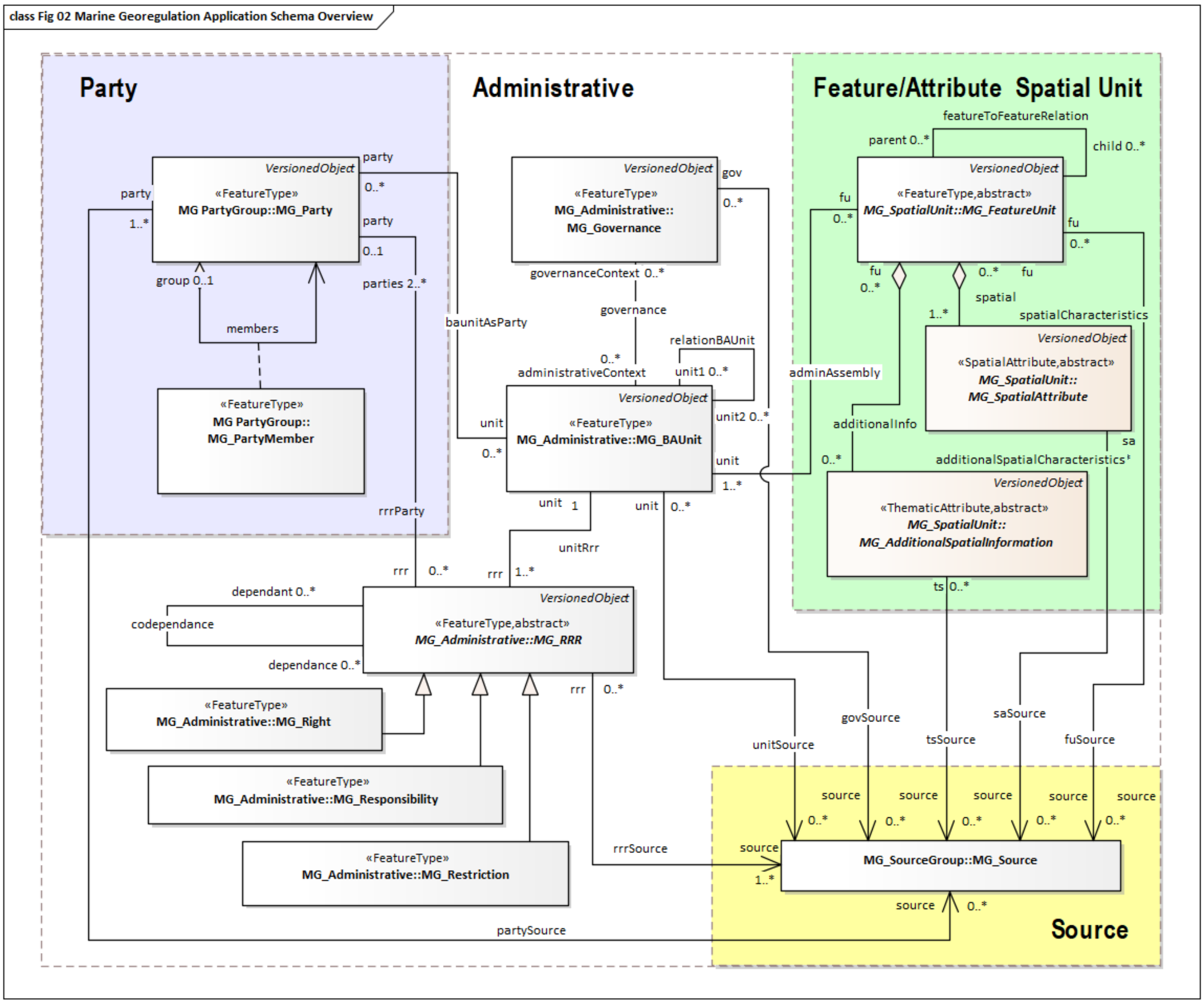


Figure 2. LADM Edition 2 Part 3 – Marine Georegulation Overview.

2.4.1.1. Source

The Source class maintains descriptive documentation that supports, complements, or describes the associated object (International Hydrographic Organization, 2019b). In marine cadastre, the Source class can hold license information for activities conducted by parties in the marine environment. As seen in Figure 3 of the LADM profile, all information elements may originate from a source. The Sid attribute in the Source class identifies the source, the SourceSubmissionDate attribute indicates when the source was submitted by a party, the SourceRecordationDate attribute denotes when the source was registered by a registering authority, and the SourceAuthoritativeDate attribute records the date of the source's legal authority (International Hydrographic Organization, 2019a).

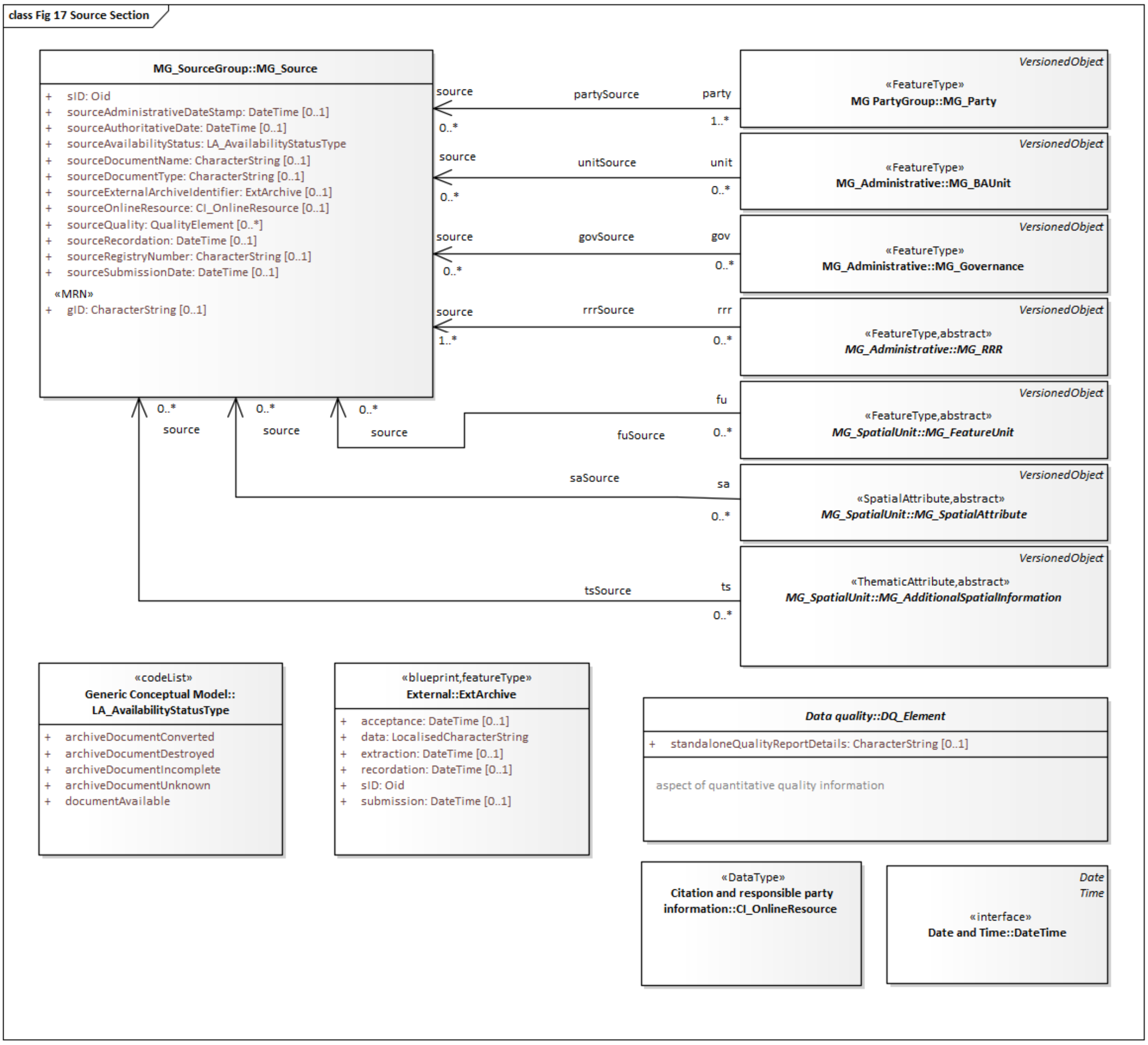


Figure 3. LADM Edition 2 Part 3 - Source Class

2.4.1.2. VersionedObject

The VersionedObject class is responsible for storing and managing the historical data of the database (International Hydrographic Organization, 2019b). As shown in Figure 4, the Party, RRR, BaUnit, FeatureUnit, and Governance classes inherit from the VersionedObject class. Within the VersionedObject class, the beginLifespanVersion attribute records the start time of a specific instance version, while the beginRealWorldLifespanVersion attribute captures the real-world time when that specific instance version began to be applied. Similarly, the endLifespanVersion and endRealWorldLifespanVersion attributes serve analogous purposes for recording the end times of instance versions.

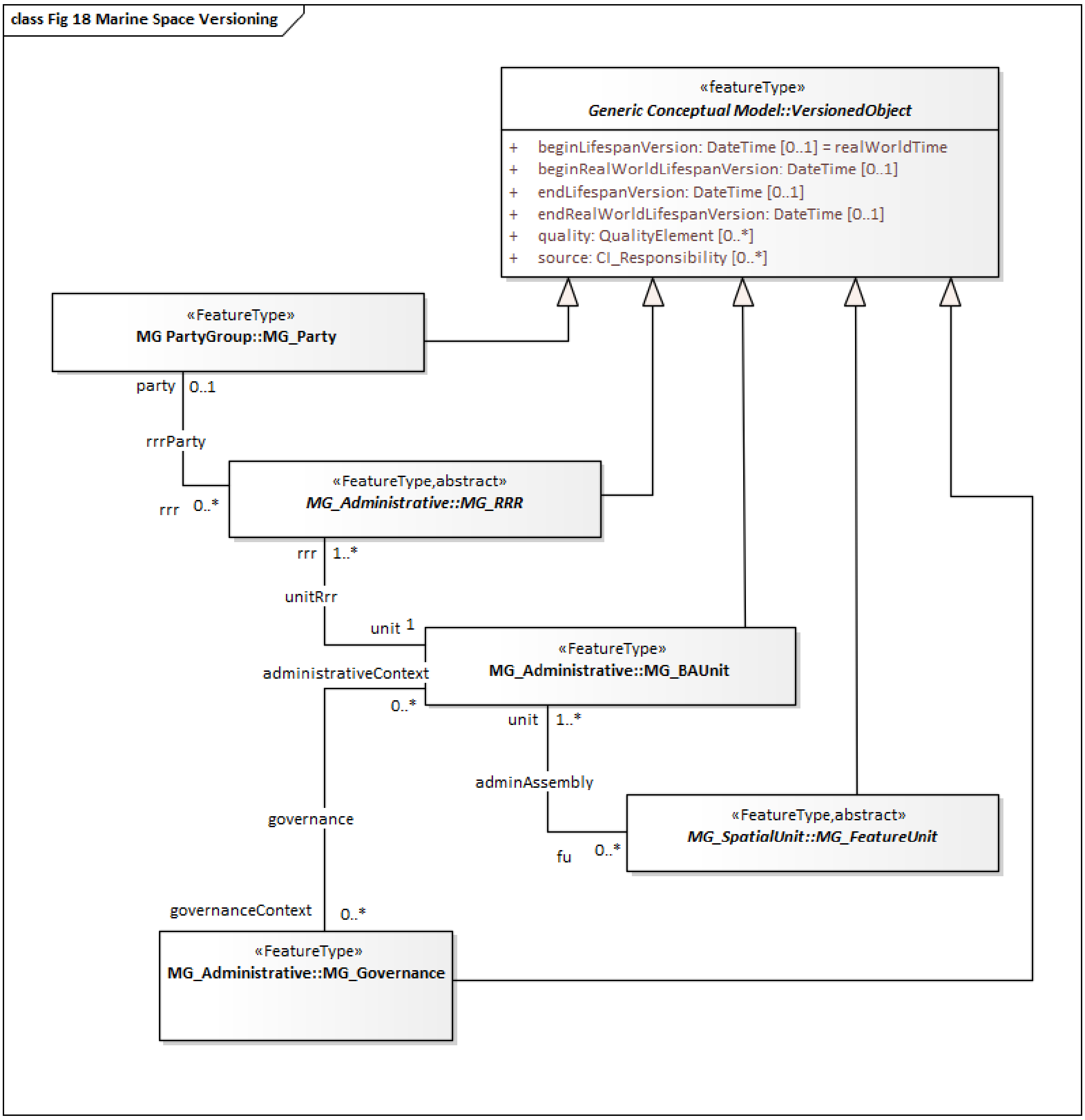


Figure 4. LADM Edition 2 Part 3 VersionedObject Class

2.4.1.3. Party

As can be seen in Figure 5, the Party package stores information about actors associated with rights, restrictions, or responsibilities (International Hydrographic Organization, 2016). It consists of two classes: MG_Party and MG_PartyMember. MG_Party includes attributes such as the party ID (pID), name (partyName), role (partyRole), and type (partyType) of the party responsible for rights, restrictions, or responsibilities. Additionally, a code list is created for party types, listing the possible values that the partyType attribute can take. If multiple parties are responsible for a single right, restriction, or responsibility, these parties are classified as group parties. The PartyMember association class allows group parties to specify their shares within the group as fractions. Furthermore, the MG_GroupPartyTypeList code list provides a list of types that a group party can assume.

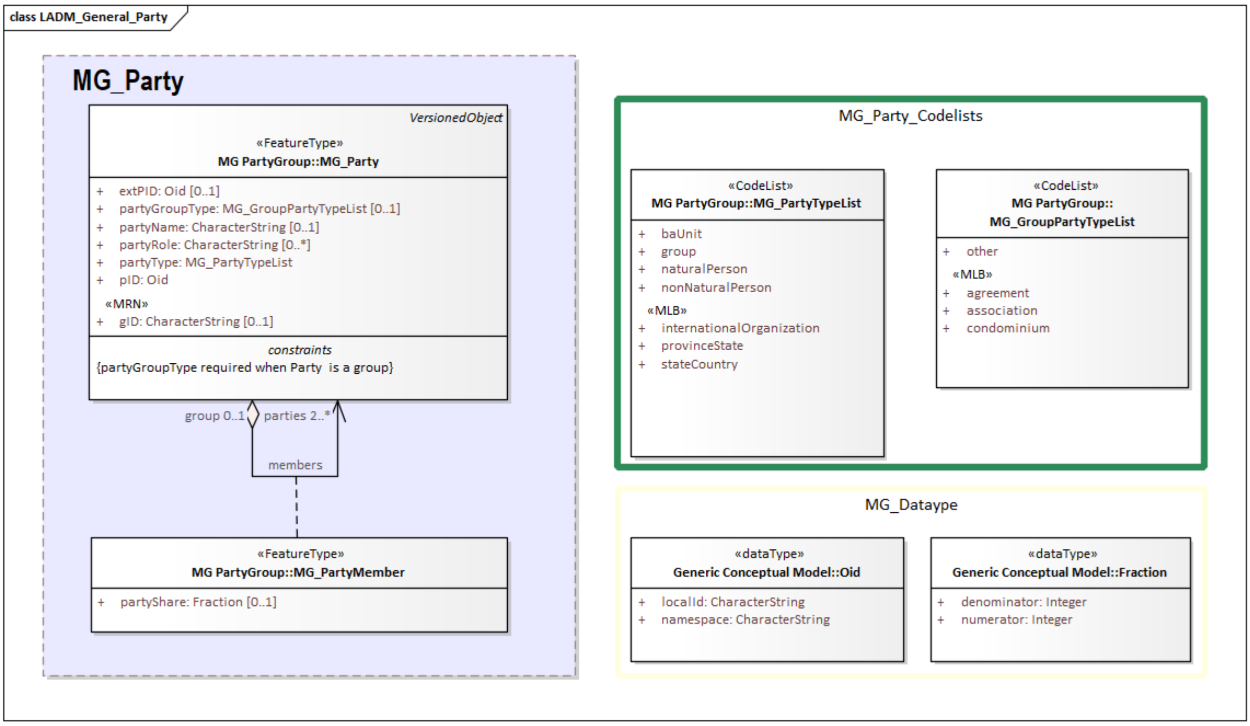


Figure 5. LADM Edition 2 Part 3 Party Package

2.4.1.4. Administrative unit

As can be seen in Figure 6, Administrative Unit package represents the representation of rights, restrictions, and responsibilities (RRRs) applied by a party on a spatial unit or a group of spatial units (International Hydrographic Organization, 2017). Technically, it provides a link between spatial units, RRRs and parties.

The Administrative Unit comprises Basic Administrative Unit (BAUnit), governance, and RRR classes. MG_Governance provides contextual information derived from proclamations, laws, or treaties, including title, reference number, and date, to support specific descriptions or interpretations relevant to selected features (International Hydrographic Organization, 2019a). The BAUnit class represents the extent of a volume of space composed of zero or more spatial units associated with a single, uniform right, restriction, or responsibility. The MG_RRR class defines the legal aspects, while MG_Right, MG_Responsibility, and MG_Restriction classes inherit from MG_RRR. MG_Right pertains to actions or activities that a party can perform, MG_Restriction involves actions that a party must refrain from, and MG_Responsibility denotes formal or informal obligations to perform certain actions.

When it comes to the relationships between the classes, it is shown that a BAUnit can be associated with zero or many governance context information, and similarly, one governance context information can be associated with multiple BAUnits. Additionally, it is seen that a BAUnit can have multiple RRR values. On the other hand, the BAUnit class performs a relationBAUnit relationship with itself. This relationship is established for 'A BAUnit may be related to other instances of BAUnit.' The RRR class, in turn, performs a codependence relationship with itself, which shows the 'Dependency relationship between a Right, Restriction, or Responsibility and another Right, Restriction, or Responsibility.'

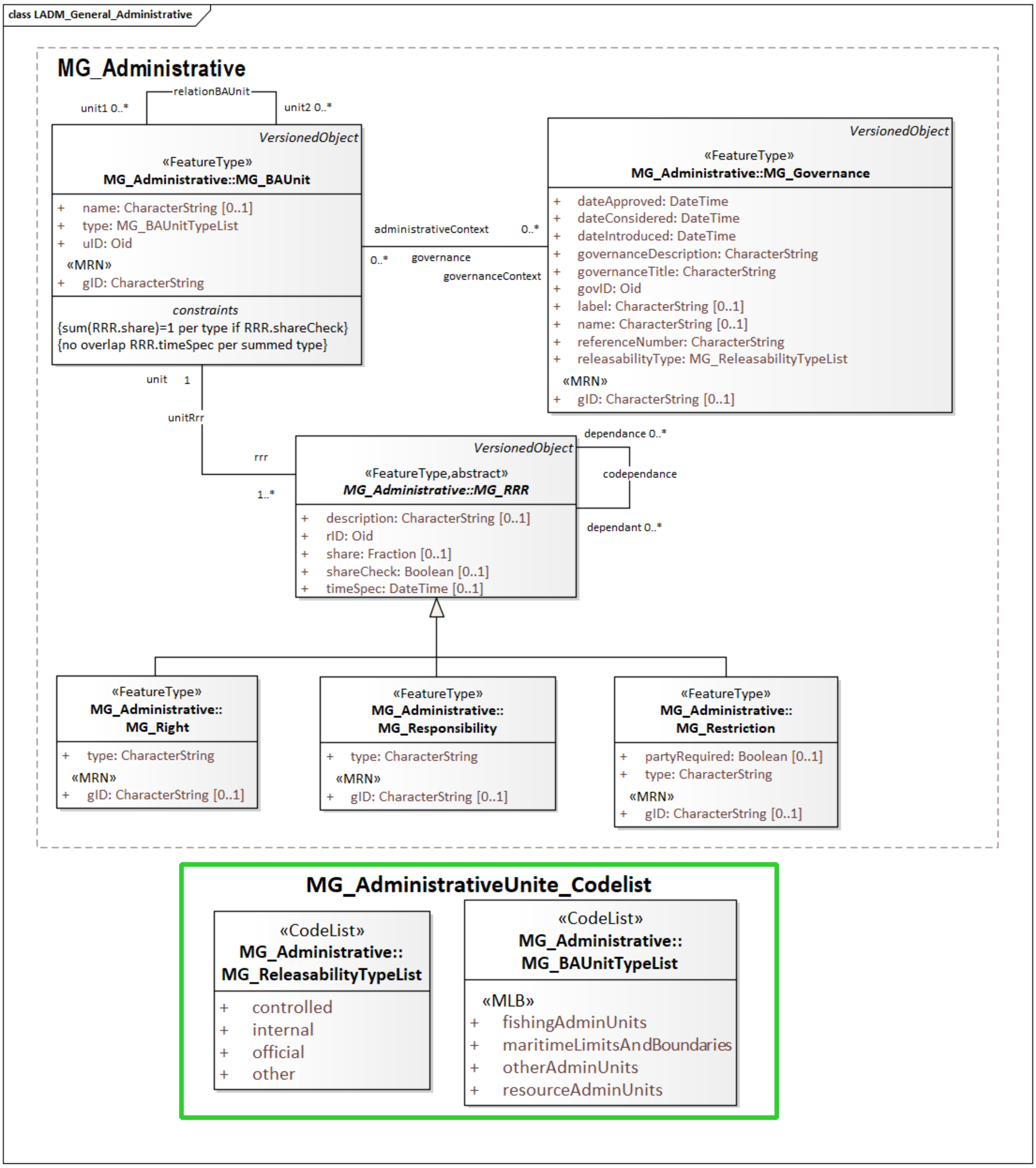


Figure 6. LADM Edition 2 Part 3 Administrative Unit Package

2.4.1.5. Spatial unit

As can be seen in Figure 7, Spatial Unit defines the geospatial characteristics of spatial entities (International Hydrographic Organization, 2017). The MG_SpatialUnit package includes the Feature Unit, Location (0D), Limit (1D), Zone (2D), and Space (3D) classes. This facilitates the association of specific treaties or control points to define curve boundaries and assign curves to enclose zones. In summary, to create the geometry in the MG_SpatialAttribute abstract class, MG_Point, MG_Curve, and MG_Surface geometries are overwritten to the geometry attribute in the MG_SpatialAttribute class.

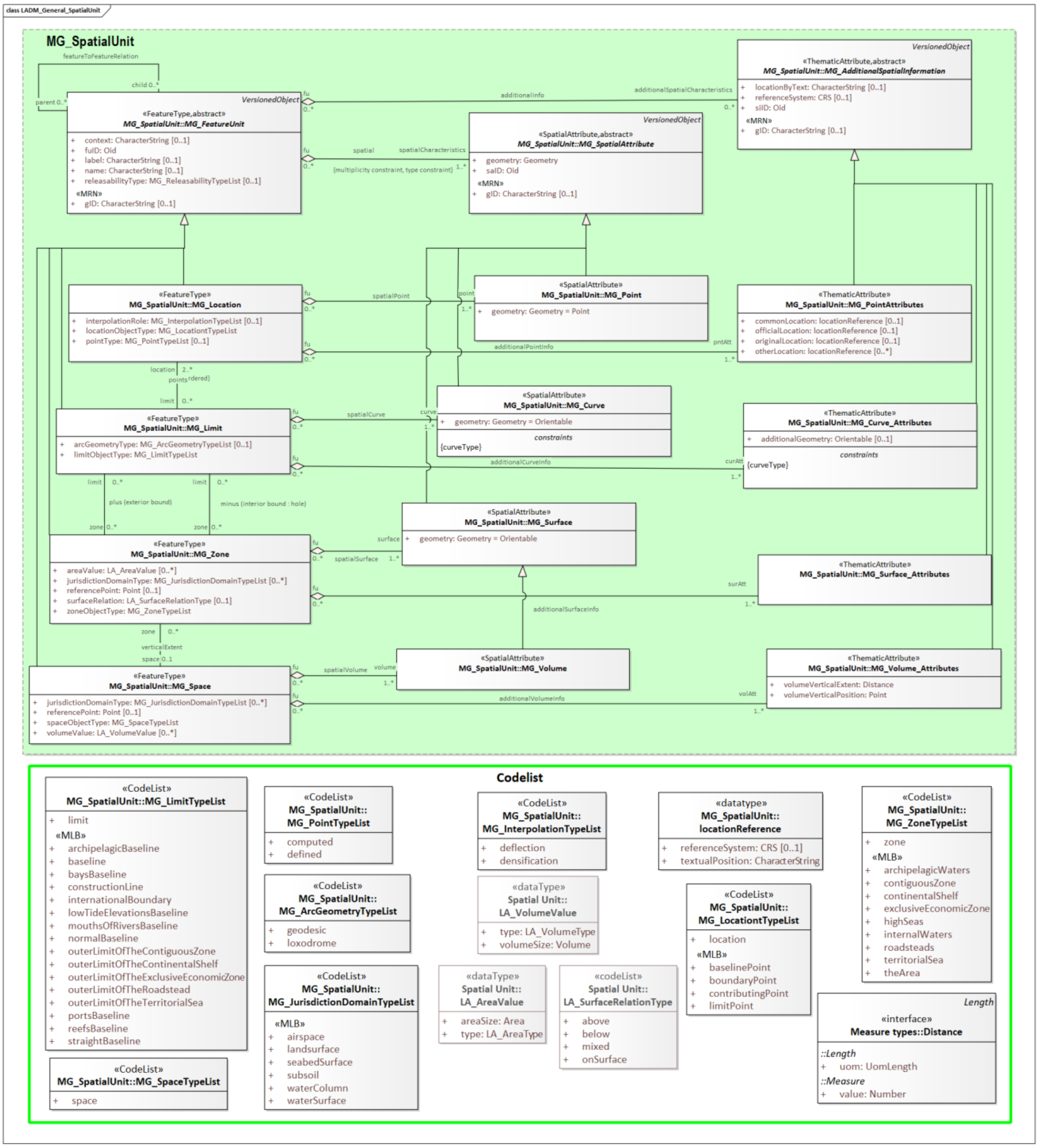


Figure 7. LADM Edition 2 Part 3 Spatial Unit Package

Key attributes within the spatial unit packages include: MG_ZoneTypeList for defining UNCLOS boundaries, MG_JurisdictionTypeList for specifying the vertical jurisdictional domain of an object, and the Space class for defining the third dimension of the Feature Unit. Specifically, in the MG_Volume_Attributes class, the volumeVerticalPosition attribute records the vertices of the Feature Unit, while the volumeVerticalExtent attribute captures their distances from the seabed.

In the MG_SpatialUnit package, the MG_SpatialUnit abstract class also establishes a featureToFeatureRelation relationship with itself. This relationship allows the creation of compound or complex features that include multiple feature units. Additionally, the MG_FeatureUnit abstract class, which holds feature types, the MG_SpatialUnit abstract class, which holds spatial attributes, and the MG_AdditionalSpatialInformation abstract class, which holds thematic attributes, form generalization relationships with other subclasses.

2.5. Summary of Chapter 2

The literature review has highlighted the necessity of integrating land and marine cadastres to support effective coastal management in Kenya. It has also shown how the LADM can serve as a foundational framework for this integration, addressing the unique spatial challenges and governance issues inherent in managing marine and land areas. Building on these insights, the methodology of this research employs a structured approach to develop and validate a unified data model.

3. RESEARCH METHODS

The methodology of this thesis follows the guidelines outlined in the article "Methodology for the Development of Land Administration Domain Model (LADM) Country Profiles" by Kalogianni et al. (2021) and is structured into three phases. Initially, marine-specific features and key information for the development of the LADM profile tailored to Kenya are identified. In the second phase, the selection of the LADM as the marine cadastre data model is justified. In the next stage, the LADM profile for marine cadastre in Kenya is developed and integrated with the existing LADM profile for Kenyan land administration to develop integrated LADM profiles between marine and land cadastre in Kenya. As the final step, expert-based interviews were conducted regarding the validation of the developed Kenya marine cadastre LADM profile's suitability for the Kenya marine cadastre and the contribution of the integrated LADM profiles to the integration of marine and land cadastre (Workplan is provided in Annex 3). The methodology process applied during the thesis process is provided in Figure 9.

3.1. Study Area

Kenya is a country located on the western coast of the Indian Ocean, sharing maritime boundaries with Comoros, France, Kenya, Madagascar, Mauritius, Mozambique, Seychelles, Somalia, South Africa, and Tanzania, with a population of about 56 million (Obura, 2017). With approximately 600 km of coastline stretching from Somalia to Tanzania, Kenya possesses an area of about 142,000 km^2 of exclusive economic zone (EEZ) (Ruwa, 2011). The location of Kenya and its EEZ can be seen in Figure 8.

The administration of coastal and marine zones is critical because these regions host numerous resources and communities, making them a significant source of income for Kenya. The Kenyan coast features ecological areas such as mangrove forests, coastal forests, coral reefs, and seagrass beds, which support many endangered species and provide ecosystem protection through carbon sequestration and shoreline protection. Additionally, these areas are home to nearly 2.7 million coastal community residents (Uku et al., 2023). Activities such as fishing, tourism, transportation, oil and gas exploration, agriculture, and mining contribute to Kenya's blue economy. These activities generate over US$4.1 billion annually, with tourism being the highest revenue-generating activity at 45% (Philip et al., 2020).

In 2017, Kenya experienced a calculated decline of nearly 30% in its existing coral reefs (Philip et al., 2020). Additionally, pollution, over-exploitation, declining biodiversity, and climate change adversely affect Kenya's coastal areas. This situation poses a threat to Kenya's blue economy, as well as the ecosystem and communities living in coastal areas. To address this issue, Kenya has implemented institutional and legal changes.

In line with this, in 2010, Kenya enacted the Constitution of Kenya, which includes provisions for coastal and marine zones. This constitution categorizes the land-sea interface as public land, encompassing the territorial sea, EEZ, seabed, continental shelf, and all the land between the high and low watermarks (National Council for Law, 2010). Additionally, the Constitution established the National Land Commission (NLC) to oversee and manage land use planning across the nation. Other laws relevant to the land-sea interface include the Wildlife Conservation and Management Act, Fisheries Management and Development Act, Kenya Maritime Authority Act, Kenya Ports Authority Act, Environmental Management & Coordination Act, Forest Conservation and Management Act, Tourism Act, and Coast Development

Authority Act. Table 1 details the key institutions responsible for managing coastal and marine zones in Kenya and their respective roles.

Table 1. Key Institutions Responsible for the Management of Coastal and Marine Areas in Kenya and Their Visions

AUTHORITIES	RESPONSIBILITIES
Coast Development Authority (CDA)	Empower coastal communities in fisheries, agriculture, and tourism.
Kenya Wildlife Services (KWS)	Protect marine species and manage Marine Parks.
National Museums of Kenya	Oversee Kenyan museums to promote cultural and environmental awareness.
Kenya Tourism Board (KTB)	Promote sustainable marine tourism activities like diving and snorkeling.
Kenya Ports Authority (KPA)	Manage seaports for efficient maritime trade.
National Environment Management Authority (NEMA)	Enforce environmental regulations and promote sustainable development.
Kenya Forest Service	Manage Kenyan forests, including vital mangroves.
Climate Change Directorate	Adapt to climate change impacts on coastal communities.
Fisheries, Aquaculture and Blue Economy Department	Supporting sustainable growth in fisheries, aquaculture, and the Blue Economy.
Kenya Marine and Fisheries Research Institute (KMFRI)	Researching Kenya's marine and freshwater resources.
Mining Department	Managing responsible mineral exploration and exploitation in Kenya.
National Oil Corporation of Kenya	Overseeing Kenya's oil and gas exploration and production endeavors
Kenya Maritime Authority	Protecting Kenyan waters through enforcement and pollution prevention.

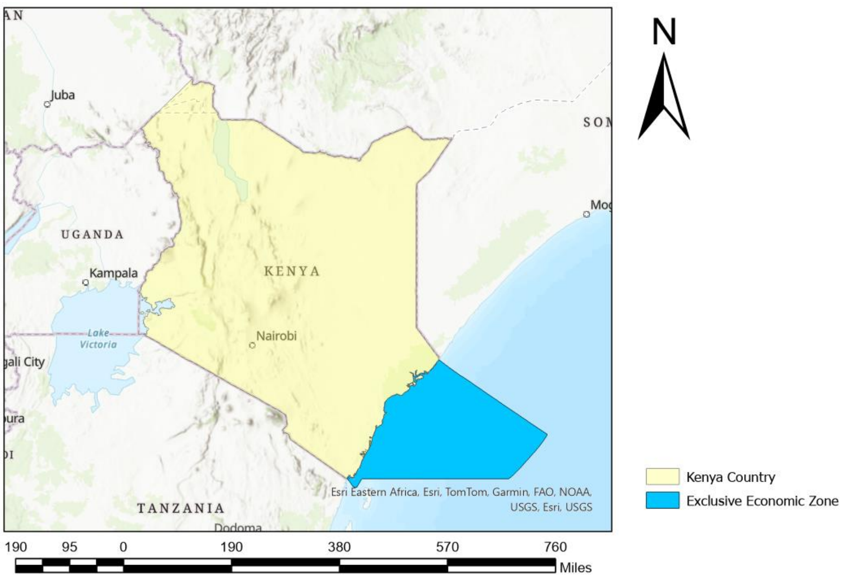


Figure 8. Exclusive Economic Zone of Kenya

3.2. Methodology Flowchart

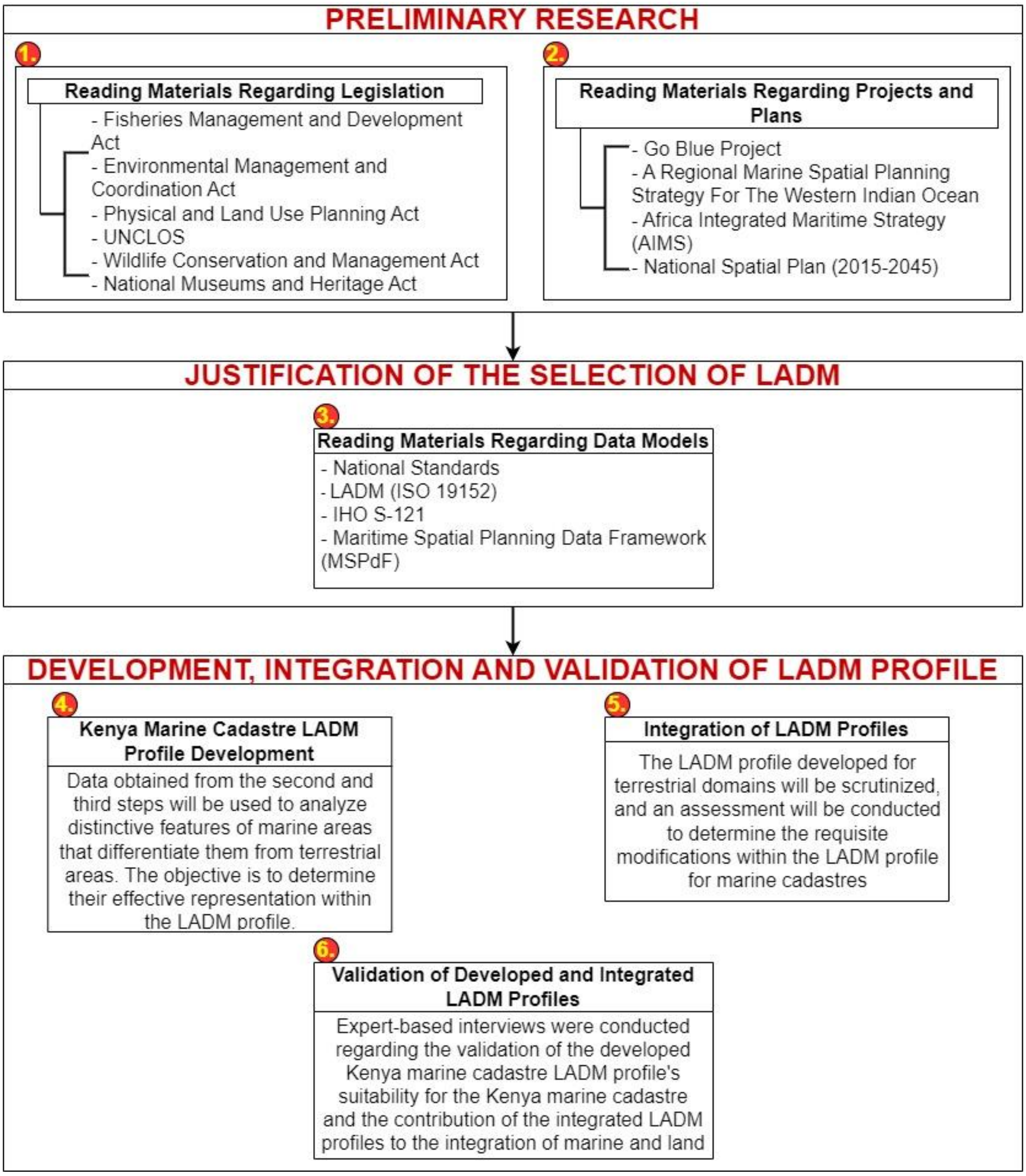


Figure 9. Methodology Flowchart.

The methodology workflow consists of three sections, each representing research objectives. First, it focuses on understanding the current state of Kenya's marine and coastal administration strategies. Through documentation analysis, marine-specific features and key information for Kenya are listed. Next, the justification for developing the LADM (Land Administration Domain Model) for Kenya's marine cadastre data model is provided. Finally, the Kenya marine cadastre LADM profile is developed and then integrated with the Kenya land cadastre LADM profile developed by Okembo et al. (2023). In the final stage, the validation of these LADM profiles is conducted through expert-based interviews (Annex 5 research matrix).

3.3. Preliminary Research and Literature Review

The focus of this part is on identifying marine-specific features and key information essential for developing the LADM profile for marine cadastre in Kenya. Marine-specific features include the need for three-dimensional (3D) management, dynamic boundaries, overlapping rights, and dynamic activities (temporary rights and restrictions). Key information encompasses types of parties, rights, restrictions, responsibilities, and spatial and administrative source types.

To identify these features and information, the study first examined the United Nations Convention on the Law of the Sea (UNCLOS). This international agreement provides a legal framework for marine and maritime activities and is used by Kenya for managing marine areas (Kibiwot, 2008). UNCLOS clearly outlines the rights, restrictions, and responsibilities of a ratifying country regarding offshore areas, and also specifies the rights of other nations (Cockburn et al., 2003). Additionally, the maritime zones defined in UNCLOS are incorporated into the LADM profile.

Additionally, to identify marine-specific features, a search was conducted on Google Scholar using keywords such as "MSP," "Marine Spatial Planning," "Coastal Zone Management," "ICZM," and "Kenya." The reason for choosing these keywords is that, to find marine-specific features and key information specific to Kenya, it is first necessary to understand Kenya's Marine Spatial Planning and Integrated Coastal Zone Management efforts. After reading these academic studies, the marine-specific features that should be included in the developed LADM profile were identified. Subsequently, to extract key information, the acts and policies shown in Figures 10 and 11, used for the management of marine and coastal areas in Kenya, were analysed in detail. These documents have facilitated a better understanding of the main activities in Kenya's marine and coastal areas and their management methods, providing key information for the development of the LADM profile specific to Kenya. These acts and policies are shared by Kenya through an official website[5] on the internet.

Figure 10. Acts for Marine and Coastal Management in Kenya

[5] http://kenyalaw.org:8181/exist/kenyalex/index.xql

Figure 11. Policies for Marine and Coastal Management in Kenya

3.4. Justification of the Selection of the LADM

In this section, the focus is on the justification for choosing LADM as the data model to be developed for marine cadastres, specifically in Kenya. To do this, studies on data models that can be used for marine cadastres worldwide have been examined. It has been observed that alongside LADM, the S-121 data model published by the International Hydrographic Organization (IHO) is also a data model released at the international level. Another study related to the data structure to be developed for marine cadastres is the Maritime Spatial Planning Data Framework (MSPdF) published by the European Commission in 2023. Apart from these studies, many countries have worked on developing their own national data models for marine cadastre.

To determine the data model to be used in this thesis, a data model must meet the requirements that are considered to achieve the purpose of creating a seamless data model. These requirements include (1) Accessibility of the data model, (2) Inclusion of marine-specific features and key information needed for Kenya's marine cadastre operations, and (3) Integration with the data model used for land administration. The first requirement is necessary for developing a data model as explained in Section 4.3. The second focuses on whether the data model can represent the determined marine-specific features and key information in Kenya (explained in the next paragraph). The final requirement is important for creating a seamless data model (explained in Section 4.4).

3.5. Development of the Kenya Marine Cadastre LADM Profile and Integrated LADM Profile

3.5.1. Development of the Kenya-Specified LADM Profile for Marine Cadastre

In this phase of the methodology, the LADM profile for marine cadastre in Kenya was developed. The development and validation of this model were carried out in three stages. First, the initial LADM profile was created using the marine-specific features and key information obtained in section 4.1. Next, fieldwork was conducted in Kenya, where interviews with domain experts were held to gather information on unclear aspects of marine and coastal management in Kenya and to obtain feedback on the developed initial LADM profile. In the final stage, the LADM profile, revised based on the feedback, was validated by reconvening with the experts, asking questions about the model, and ensuring its validation for Kenya's marine cadastre.

First, in developing the initial draft of the LADM profile specific to Kenya, the LADM Edition 2 Part 3, detailed in Section 2.4.1, was utilized. This part of the LADM, published by International Organization for Standardization (ISO), is designed for marine geo-regulations. To adapt this model for Kenya, it was necessary to integrate the marine-specific features and key information identified in the previous section. The process began by examining LADM Edition 2 Part 3 classes, attributes, codelists, and relationships to identify which elements were unnecessary or needed modification for Kenya's marine administration. Subsequently, the marine-specific features and key information that are not yet represented in the LADM profile were added to the model by creating, deleting, or modifying the necessary classes, attributes, code lists, or relationships. This comprehensive integration resulted in the initial draft of the LADM profile tailored to Kenya's marine cadastre.

To implement all of these changes on LADM Edition 2 – Part 3 as shared by ISO, the Enterprise Architect program was utilized. This commercial software was chosen because it facilitates the easy creation of Unified Modeling Language (UML) models and, with Model Driven Architecture (MDA), allows these models to be automatically converted into technical models (Psomadaki et al., 2016). Additionally, understanding LADM requires comprehension of the UML class diagrams used in its creation. The following section provides a brief overview of UML class diagrams.

3.5.1.1. Unified Modeling Language (UML) class diagrams

UML is a standardized object visual modeling language and is used for the analysis, design, and implementation of software-based systems (OMG, 2009). UML contains a variety of diagrams, such as object diagrams, class diagrams, use case diagrams, and activity diagrams, each serving different purposes. In the development of LADM, class diagrams are utilized. Class diagrams are used to model the static structure of systems, created by describing the elements within the system and illustrating the relationships between these elements (Seidl et al., 2015).

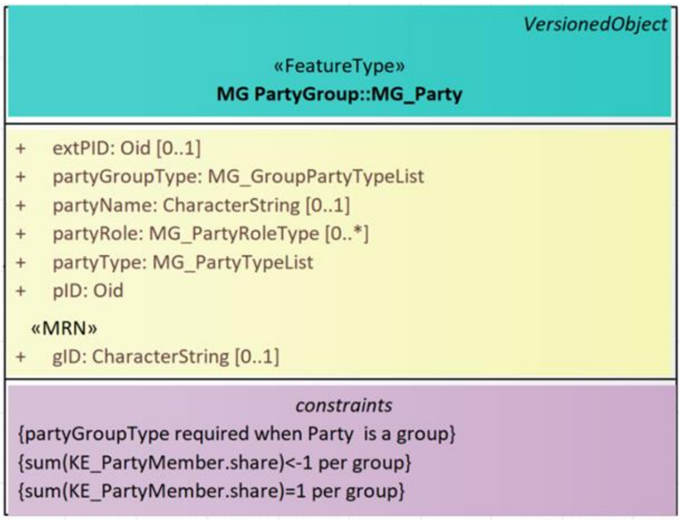


Figure 12. Representation of a Class.

As can be seen in Figure 12, A class is a group of objects that have common attributes, operations, relationships, behaviors, and constraints (International Hydrographic Organization, 2015). In a class, the section shown in green contains the name of the class diagram, the section shown in yellow contains the attributes, and the section shown in purple contains the operations of the class. An attribute holds information that is present in all instances but varies for each instance. As seen in Figure 13 with partyName, attributes can take data types such as integer, string, or character string. Alternatively, as shown with partyType, attributes can use code lists that predefine allowable values Code lists help ensure data consistency by listing acceptable inputs, preventing mistyping or varying responses for the same data.

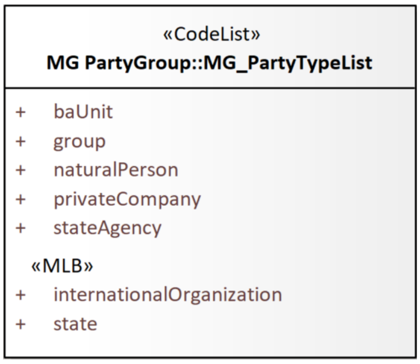


Figure 13. Example of a Code List

Each attribute has multiplicities that indicate how many instances of that attribute can be associated with a given class, represented as an interval enclosed in square brackets [minimum .. maximum]. For example, [0..*] indicates that an attribute may have zero or more instances. If no multiplicity is specified for an attribute, it defaults to [1], meaning it can hold exactly one instance. Finally, one of the important components of class diagrams is associations, and some of the association types used are provided in Table 2. Associations are used in a class diagram to represent relationships between each class. Below, some associations commonly used in class diagrams and their meanings are illustrated.

Table 2. Associations in UML Class Diagrams

Association Type	Description	Example Notation
Association	A general relation between two class	
Generalization	An inheritance relationship where one class is a specialized version of another.	
Aggregation	A whole-part relationship where the part can exist independently of the whole	
Composition	A stronger form of aggregation where the part cannot exist independently of the whole	
Realization	Implementation of an interface by a class	

3.5.1.2. Interviews for the development of the Kenya Marine Cadastre LADM profile

This interview was conducted after the initial draft of the Kenya Marine Cadastre LADM profile was developed using a literature review, acts and policies utilized in Kenya's marine and land administration. The interview process employed a semi-structured interview method. A semi-structured interview is a qualitative research method where the interviewer asks open-ended questions to the interviewee (Sheppard, 2021).

During the interview process, questions were initially posed about unclear areas related to the management of Kenya's marine and coastal areas, despite the acts, policies, and literature review. Subsequently, the LADM profile developed for Kenya's marine cadastre was presented and explained in detail. Feedback was solicited on each package of the LADM profile that needed improvement or modification. After obtaining feedback from experts on the first draft of the developed Kenya marine cadastre LADM profile, necessary changes were made based on the feedback, and the final version of the LADM profile was prepared. The questions asked during the semi-structured interviews are listed in Annex 1. The semi-structured interview was conducted with each expert listed in Table 3 during the interview process.

Table 3. List of Interviewees

WORKPLACE		ROLE
1	Survey of Kenya	*Hydrography*
2	University of Nairobi	*Environmental Geoinformatics*
3	University of Nairobi	*Land Information Management Systems*
4	Environmental Systems Research Institute (ESRI)	*Director/Chief Consultant*
5	Kenya Marine and Fisheries Institute	*Research Scientist*
6	Kenya Maritime Authority	*Officer*
7	UN-Habitat	*National Programme Officer*
8	Kenya Marine and Fisheries Institute	*Research Scientist*

3.5.2. Integration of LADM Profiles

In this stage of the thesis, aiming to achieve a seamless data model, the LADM profile developed for marine cadastre during this research will be integrated with the LADM profile for land cadastre published earlier this year by Okembo et al. (2023). The integration process will consist of two phases. In the first phase, the integration of the LADM profiles will be accomplished using the "realization" relationship. In the second phase, an interview with experts will be conducted to evaluate the practical applicability of the integrated LADM profile in real-world scenarios.

In the development of a LADM profile for land cadastre and marine cadastre, the realization relationship is employed to integrate these distinct domains within a unified modeling framework. This relationship denotes that one class implements another class, illustrating a type of dependency (OMG, 2009). In the integrated LADM profile developed, the decision to utilize the realization relationship for integration stems from the need for classes in the Marine cadastre LADM profile to inherit from the Land cadastre LADM profile, while also accommodating different code lists tailored to marine environments.

The reason for choosing the " realization " relationship is that it allows the marine and land LADM profiles to be used independently, even though they are integrated. This flexibility enables institutions responsible for land administration to use only the land administration portion of the integrated LADM profile in projects that do not require land-sea integration. Similarly, this applies to marine administration projects that do not require integration. However, when data exchange between the two domains is required, such as in coastal zone management, the commonly "realized" parent facilitates a mapping between classes in the two domains. This integration will significantly enhance interdisciplinarity due to the institutions' familiarity with the LADM structures.

An example of the use of the "realization" relationship is found between LADM Edition 2 Part 3 and Part 1. In LADM Edition 2, the " realization " relationship is employed to indicate that the classes in Part 3 are based on the classes in Part 1. LADM Edition 2 Part 1 is referred to as a generic conceptual model and serves as a high-level umbrella standard that supports all other parts of LADM Edition 2 (Body et al., 2022). LADM Edition 2 Part 1 provides an abstract conceptual model comprising four packages: party, basic administrative units, spatial units, and surveying and representations.

3.5.3. Validation of LADM profiles through expert-based Interviews

At this stage, expert-based interviews were conducted for the Kenya Marine Cadastre LADM Profile and the Kenya Integrated LADM Profile developed in this phase, and efforts were made to validate the models. At this stage, due to the unavailability of some experts listed in Table 3 because of their busy schedules, interviews were conducted with the top five experts. Upon examining the table, it is evident that the experts specialize in different fields, which results in some experts not having much knowledge about the marine cadastre or some not being very familiar with LADM. Therefore, special attention was given to preparing the questions for the experts during the interview process, and efforts were made to ensure that the questions were understandable by all experts.

To facilitate this understanding, key components of the LADM profile relevant to a marine cadastre were illustrated through the creation of imaginary scenarios (Data management plan is provided in Annex 4). To develop imaginary scenarios, activities and locations within Kenya’s EEZ were modeled in the 3D environment using the ArcGIS Pro. ArcGIS Pro was selected for this purpose due to its capabilities in both database management and 3D visualization (Bar-Maor, 2022). The imaginary plan for Kenya’s EEZ is illustrated in Figure 14. This plan was subsequently used in interviews to validate both the accuracy of the developed Kenya marine cadastre LADM profiles and the applicability of the integrated LADM profiles within Kenya.

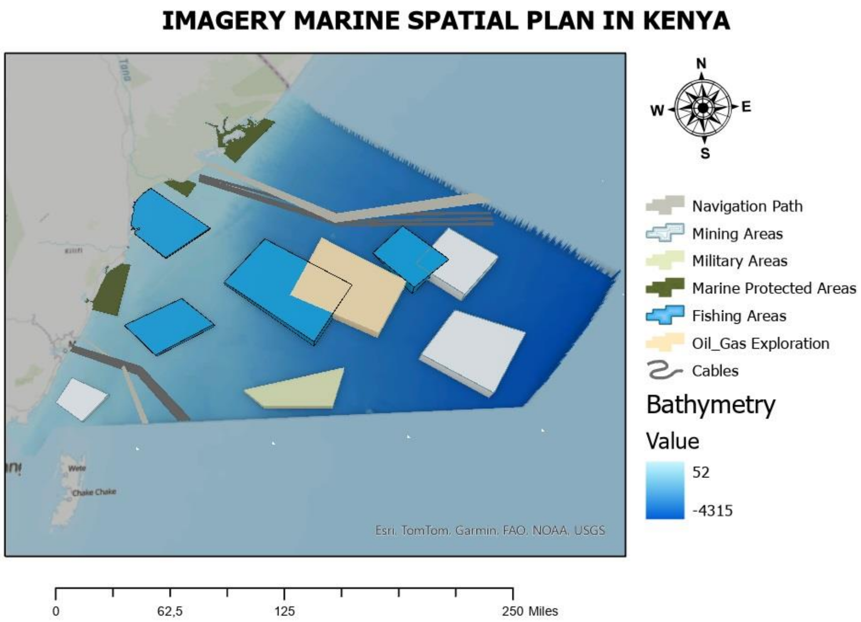


Figure 14. Representation of an Imaginary Plan for the Kenyan EEZ

3.5.3.1. Interviews for the validation of the Kenya Marine Cadastre LADM profile

The validation of the final LADM profile, obtained after incorporating feedback, was conducted through a second interview with experts. In this interview, the method described in Antonia Bertolino's study "Is my model right? Let me ask the expert" (2011) was employed for the validation of the LADM profile. This method aims to reduce the knowledge gap between model experts and domain experts. It uses criteria to explore and query the model, where a criterion implements a question by composing patterns. Deductive questions are created based on criteria that derive true statements from the input domain model, while questions that correspond to false statements in the input domain model are referred to as distractors in the study. For each question posed, the interviewee was provided with a multiple-choice answer format, offering five possible and exclusive options: (1) Yes, (2) Somewhat, (3) No, (4) "I'm not an expert of this particular subject" (NE), and (5) "I'm an expert of the subject but I'm not sure what to answer" (DK).

To implement this validation method (Bertolino et al., 2011) for the expert validation step in this thesis, the classes, attributes, relationships, and codelists within the LADM profile that required expert validation were identified, and criteria were established for each. Google Forms was utilized to convey the questions to the interviewees and collect their responses. Each deductive and distractor question was presented to the interviewees as multiple-choice questions and checkboxes. Multiple-choice questions were employed to validate the classes, attributes, and relationships in the LADM profile, with one distractor included. For the validation of codelists, checkboxes were used, and each codelist included one or two distractors. The interviewees were unaware of the presence of these distractors. Finally, the responses provided by the experts were compared to the expected answers. If an expert's response matched the expected answer, the result was marked as "pass"; if not, it was marked as "failed." The greater the number of questions yielding a "pass" result, the higher the accuracy of the model. The questions used for validation are provided in Annex 2.

The interviews concerning the suitability and accuracy of the LADM profiles for Kenya focused on how the developed Kenya marine cadastre LADM profiles, as depicted in the imaginary scenarios, encompassed the marine-specific scenarios and key information outlined in Table 6. This evaluation aimed to verify their appropriateness for the Kenya marine cadastre. These scenarios were supported by class diagrams derived from the LADM profiles, and animations developed using PowerPoint, in addition to the imaginary marine plan illustrated in Figure 14. This presentation aimed to enhance the experts' understanding of the developed work and to increase the accuracy of the feedback received. The developed scenarios can be seen in Section 5, from Figure 29 to Figure 34.

3.5.3.2. Interviews for the validation of the integrated LADM profile

After developing the integrated LADM profile for land and marine cadastre, the next step is to validate its applicability in Kenya. For this purpose, an interview method with experts was employed. The interview included two multiple-choice questions and one semi-structured question, and the validation method (section 3.5.3.1) was not utilized at this stage. Support questions and imaginary scenarios were used to facilitate understanding for the interviewees and enhance the comprehensibility of the integrated LADM profiles. The imaginary plan shown in Figure 14 was utilized again, and this interview discussed the applicability of the developed integrated LADM profiles in Kenya's marine spatial planning and Integrated Coastal Zone Management. The developed imaginary scenarios can be seen in Section 5, from Figure 35 to Figure 37. The experts interviewed are the first five individuals listed in Table 3.

3.6. Ethical Considerations and Risk

Ethical concerns may arise during the collection of spatial data or expert participation in semi-structured and validation interviews. Throughout the thesis process, only publicly accessible data from Kenya's EEZ were used to create imaginary scenarios. Other spatial data used in the imaginary scenarios were not obtained from any source; they were created by the author, based on information obtained in the literature and fieldwork, solely to test the LADM profile on Kenya. For the interview part, the content of the interview was clearly explained beforehand, and the consent form prepared by the University of Twente was completed by the interviewed experts before the interview. Additionally, expert feedback within the thesis was anonymized. To correct language and grammar errors during the thesis process, ChatGPT was used. Following the use of this tool, the author carefully reviewed and revised the content as necessary and takes full responsibility for the final work.

3.7. Summary of Chapter 3

The methodology section of this thesis describes the steps taken to create a LADM profile for Kenya's marine cadastre. This involved analyzing marine and coastal management practices, legal frameworks, and institutions in Kenya. The approach focused on incorporating marine-specific features and key information into the LADM framework, ensuring it fits Kenya's maritime context. The results section presents findings in a clear order, starting with an overview of marine and coastal management in Kenya. It then explains how specific marine features were identified and added to the LADM framework. This process led to the development of a customized LADM profile that can easily integrate with existing land administration models, like the one developed by Okembo et al. (2023). In the end, the developed LADM profile was validated through expert interviews to ensure its effectiveness and practicality.

4. RESULTS

This section follows the structure of the methodology. The first subsection addresses marine and coastal management activities in Kenya. After understanding marine and coastal management in Kenya, marine-specific features and key information are identified in the next subsection and the rationale for choosing Land Administration Domain Model (LADM) is presented. The third subsection involves the development of an LADM profile for Kenya's marine cadastre using the identified marine-specific features and key information. In the final subsection, the LADM profile developed for marine areas is integrated with the LADM profile developed by Okembo et al. (2023). This integration creates a seamless data model for marine and coastal area management in Kenya using LADM.

4.1. Institutional Framework and Legislation in Marine and Coastal Areas Management in Kenya

To establish an LADM profile specifically for a marine cadastre in Kenya, it is first necessary to understand the activities conducted in marine and coastal areas and how these activities are managed. As shown in Figure 15, the current management method for marine spatial planning in Kenya involves each institution conducting planning and maintaining data independently related to its own domain. However, in the future, it is planned to develop marine spatial planning applications on a common platform with participatory planning. Efforts have already begun at the Ministry of Mining, Blue Economy, and Maritime Affairs, utilizing UNESCO's (United Nations Educational, Scientific and Cultural Organization) "Marine Spatial Planning: A Step-by-Step Approach toward Ecosystem-based Management" as a guideline for countries to develop their Marine Spatial Planning (MSP) (UNESCO, 2009).

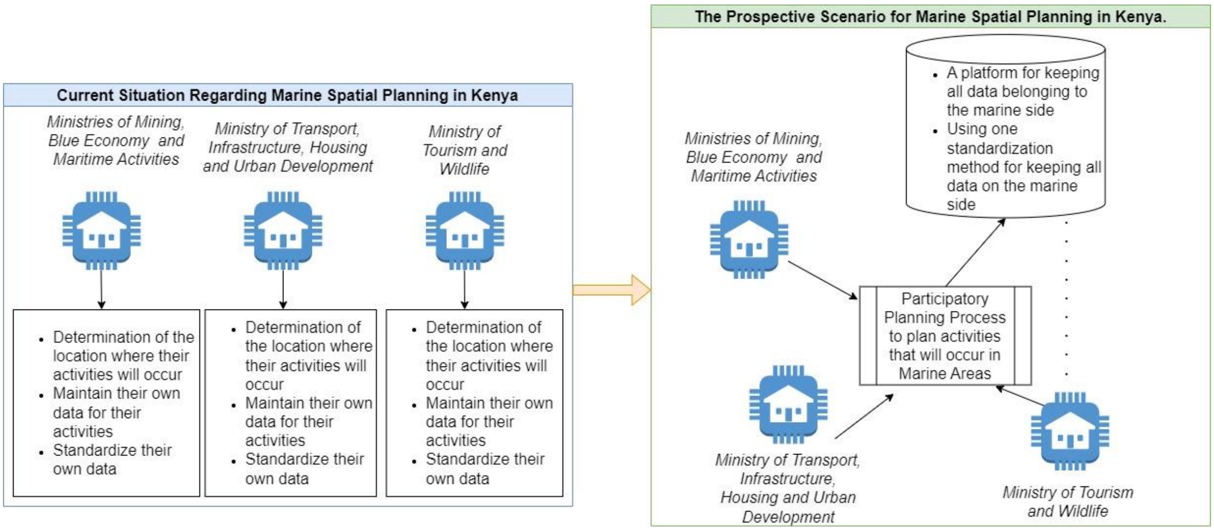


Figure 15. Marine Spatial Planning Process in KENYA

Additionally, the diagram shown in Figure 16 was created based on the analysis of acts and policies used in the management of marine and coastal areas in Kenya, as well as feedback obtained during the fieldwork process. As can be seen from Figure 16, the diagram is divided into three sections to better understand the management of Kenya's coastal and marine areas. These three sections are focused areas in planning, institutions, acts and policies.

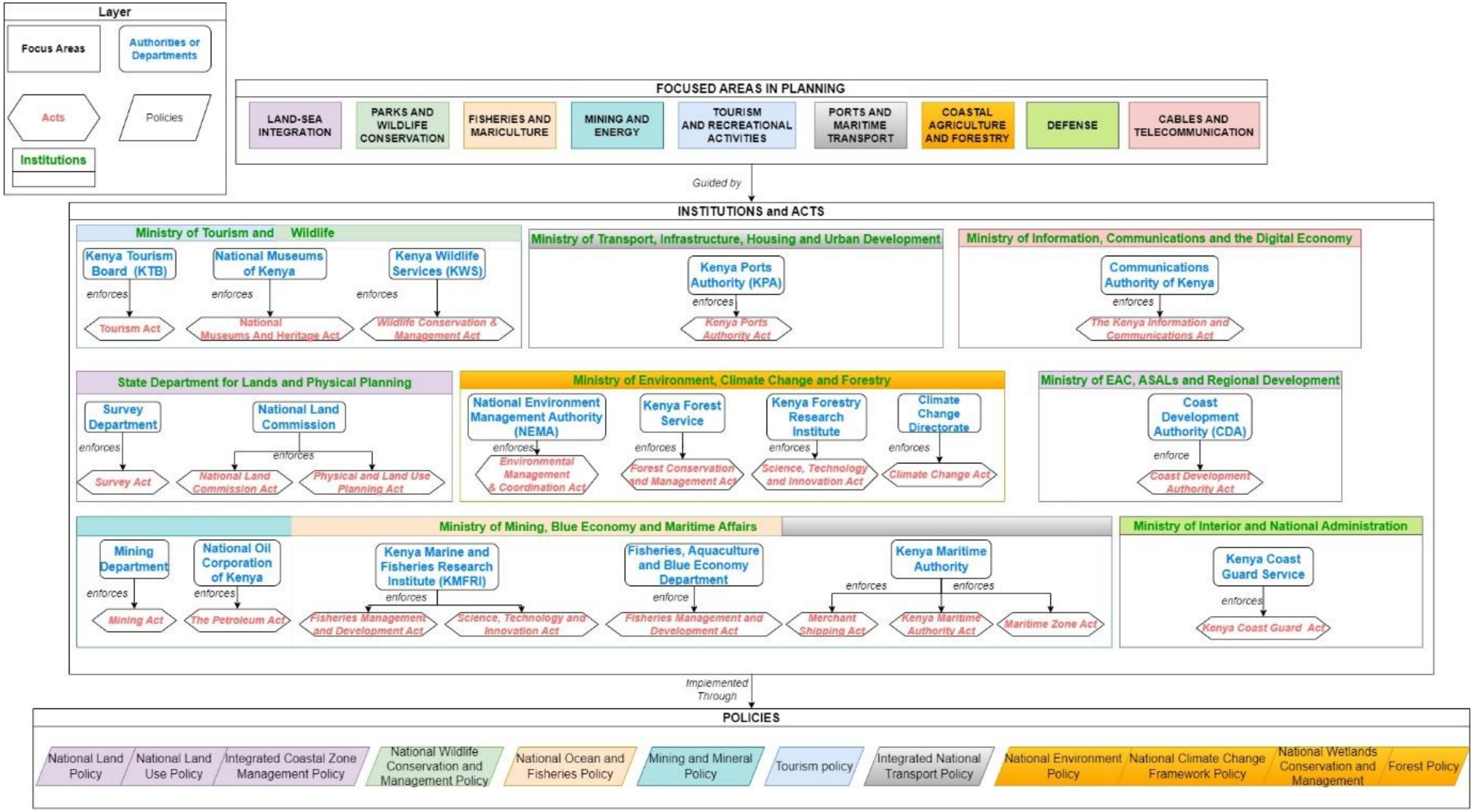


Figure 16. Diagram for the Management of Marine and Coastal Areas in Kenya

In the focused areas in planning section, the activities conducted in Kenya's coastal and marine areas are included, and each activity is assigned a color code to relate the activities to the corresponding institutions and policies. Following this, the institutions and acts section of the diagram illustrates which ministry manages each activity, which departments each ministry has, and which acts these departments enforce to manage the activities. In the final section of the diagram, the policies followed by the institutions for implementation are listed, and a color code is used to indicate which policies are related to which activities.

After summarizing the management of marine and coastal areas in Kenya, the legal framework utilized for managing Kenya's marine and maritime activities—the United Nations Convention on the Law of the Sea (UNCLOS)—was examined. Initially, the maritime zones established by UNCLOS for improved management of marine areas, as depicted in Figure 17, were analyzed. The limits of these zones, their vertical dimensions, and the governing authorities are detailed in Table 4. As indicated in the table, marine areas up to the high seas are governed by the coastal state. In the continental shelf area, the coastal state has jurisdiction only over seabed and subsoil activities, while the water body and sea surface remain international waters. The continental shelf area is delineated according to UNCLOS Article 76, resulting in different limit values for each country. In areas up to the exclusive economic zone (EEZ), all layers of marine areas are managed by the coastal state.

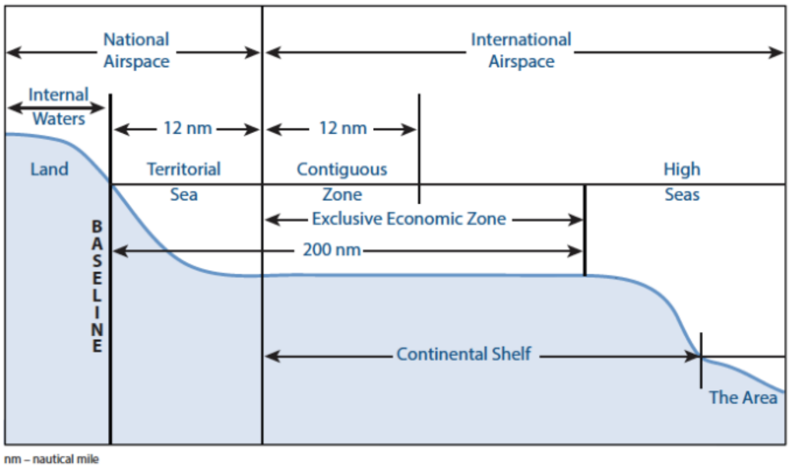


Figure 17. Marine Zones Defined by UNCLOS (Source: The Fletcher School, 2017).

Table 4. Maritime Zones and Jurisdictional Governance from UNCLOS

ZONES	LIMIT	LAYER	GOVERNED BY
Internal Waters	all water on the landward side of the baselines.	All layers Including airspace	Coastal State
Territorial Sea	12 nautical miles (nm) from normal baseline (the low water line along the coast)	All layers Including airspace	Coastal State
Contiguous zone	12nm from the limit of territorial sea	All layers doesn't include airspace	Coastal State
Exclusive Economic Zone	200nm from normal baseline	All layers doesn't include airspace	Coastal State
Continental Shelf	not exceed 350nm from normal baseline (Art. 76)	Seabed and subsoil	Coastal State
The High Seas	beyond the limits of national jurisdiction (beyond EEZ)	All layers Including airspace	International
The Area	beyond the limits of national jurisdiction (beyond continental shelf)	Seabed and subsoil (resource exploration)	International Seabed Authority (ISA)

Table 5 lists the rights of the coastal state and other states for each zone as specified in UNCLOS. Upon examining the table, it is evident that up to the contiguous zone, the coastal state has full control over all activities, while other states have the right of innocent passage only. In the EEZ and continental shelf areas, the coastal state holds the right to explore and exploit non-living resources. Additionally, in the EEZ other states can engage in fishing and scientific research with the consent of the coastal state.

Table 5. Rights of Coastal States and Other States from UNCLOS

ZONES	Coastal State Rights	Other State Rights
Internal Waters	Full control over all activities	Generally no permission for passage or other activities
Territorial Sea	Full control over all activities	Innocent passage (navigation, overflight)
Contiguous zone	Enforcement of customs, immigration, sanitation, and pollution laws and regulations	Passage (not necessarily innocent passage)
Exclusive Economic Zone	* Exploration and exploitation of living and non-living resources * Marine pollution control * Construction and operation of artificial islands and installations * Regulation of certain activities (e.g., scientific research)	* Navigation, overflight, laying of submarine cables and pipelines * Fishing (with permission from the coastal state) * Scientific research (with consent of the coastal state)
Continental Shelf	* Exploration and exploitation of non-living resources of the seabed and subsoil	
The High Seas	* Freedom of navigation, overflight, fishing (with regulations by Regional Fisheries Management Organizations) * Laying of submarine cables and pipelines * Scientific research (with due regard to the rights of others)	* Freedom of navigation, overflight, fishing (with regulations by Regional Fisheries Management Organizations) * Laying of submarine cables and pipelines * Scientific research (with due regard to the rights of others)
The Area	* Exploration and exploitation of seabed mineral resources (through ISA permits)	* Exploration and exploitation of seabed mineral resources (through ISA permits)

After reviewing all legislation and sources related to the management of marine and coastal areas in Kenya, Table 6 lists the marine-specific features and key information that the LADM profile for Kenya should include. These features and information will be incorporated into the LADM profile specifically developed for Kenya. The integration of marine-specific features and key information into the Kenya marine cadastre LADM profile is presented in Section 4.3, and how each marine-specific feature is addressed in the developed LADM profile is detailed in Section 5.

Table 6. Marine-Specific Features and Key Information for Kenya

	KEY INFORMATION	MARINE SPECIFIC FEATURES
1	Administrative Source Type	Group Party Registration
2	Spatial Source Type	Dynamic Activities
3	Party Type	Temporary Restrictions
4	Party Role Type	3D Spatial Data Recording
5	Group Party Type	Recordation of UNCLOS Zones
6	Right Type	3D Right And Restriction Management
7	Restriction Type	
8	Responsibilities Type	
9	Utility Network Type	
10	Use type	
11	Cover type	

4.2. Justification for the Selection of LADM as a Suitable Data Model for Kenya Marine Cadastre

At this stage, the reasons why LADM was chosen as the data model for the marine cadastre in Kenya will be explained. First, international data models that could be used for marine cadastre were examined. Among these data models, IHO S-121 (Maritime Limits and Boundaries) and LADM are the most well-known international data models for marine cadastre. It was mentioned in the literature review section that IHO S-121 was used as a basis in LADM's Edition 2 Part 3, which deals with marine georegulations. Another initiative related to data models for marine cadastre is the Maritime Spatial Planning Data Framework (MSPdF), published in 2023 to address data management issues in MSP. This framework can be used to develop a data model.

In addition to international studies, some countries have developed national MSP geospatial data information platforms for marine cadastre. Some of these countries include the United States[6], Canada[7], Austuralia[8], United Kingdom[9]. Additionally, there is the European Marine Observation and Data Network (EMODnet)[10] platform, which belongs to European countries. All these national and regional marine geodata platforms share marine data and information networks.

In this thesis, the reasons for choosing LADM as the data model for the development of the Kenya marine cadastre are considered according to the comparison among the other data models. According to the author's observation, the parameters for the comparison are accessibility, inclusion of marine-specific features, and ability to integrate with existing land administration models. The result of the comparison is shown in Table 7.

While data models are accessible for some, but not all, national and regional platforms, these platforms are primarily designed to support a wide range of marine and coastal management activities at a national level rather than providing legal clarity on marine limits and boundaries. Therefore, they do not encompass the marine-specific features and key information needed for the Kenya marine cadastre. LADM Edition 2 Part

[6] https://marinecadastre.gov/
[7] Canada Marine Planning Atlas (dfo-mpo.gc.ca)
[8] Australian Marine Spatial Information System | Geoscience Australia (ga.gov.au)
[9] Marine Environmental Data and Information Network | Working together to improve access to and stewardship of marine data (medin.org.uk)
[10] Home | European Marine Observation and Data Network (EMODnet) (europa.eu)

3 and IHO S-121 data models focus on the desired legal clarity over marine limits and boundaries. However, there are scientific studies in Kenya that develop data profiles for land administration using LADM Edition 1 (Lemmen, 2012). This makes LADM more preferable for this thesis compared to IHO S-121 for the integration of land and marine cadastre.

Table 7. Comparison of the Data Models

	Accessibility of the data model	Inclusion of marine-specific features and key information needed for Kenya's marine cadastre operations	Integration with the data model used for land administration
LADM Edition 2 Part 3	Yes	Yes	Yes
IHO S-121	Yes	Yes	No
National Data Model	Some of them	No	No

4.3. Develepment of LADM Profile for Marine Cadastre in Kenya

At this stage, the LADM profile developed for the Kenya marine cadastre will be presented, with reference to the Unified Modeling Language (UML) class diagrams for LADM Edition 2 Part 3 available on the ISO-TC211 (Geographic information/Geomatics) GitHub page[11], as detailed in Section 2.4.1. This section will outline the Kenya-specific LADM profile and illustrate the modifications made to the basic LADM Edition 2 Part 3 to tailor it for Kenya. Table 6 lists the marine-specific information and key information required for the Kenya LADM profile. The overview of this profile is shown in Figure 2, and modifications to each package were made to integrate the listed key information and marine-specific features. The subsequent figures detail these changes, with additions highlighted in green to adapt LADM Edition 2 Part 3 to the Kenya marine cadastre and deletions highlighted in red.

4.3.1. Source class

Initially, a Source class was created for the Kenya marine cadastre LADM profile, as illustrated in Figure 18. This class is crucial for storing license information related to activities conducted by parties in Kenya and is included in the Kenya-specific LADM profile without modifications to the attributes from LADM Edition 2 Part 3. Additionally, the administrativesourcetype attribute, which provides the type of document used for the administrative source, has been incorporated, with the types listed as domestic administrative, domestic legislative instrument, and international agreement.

[11] https://github.com/ISO-TC211/HMMG

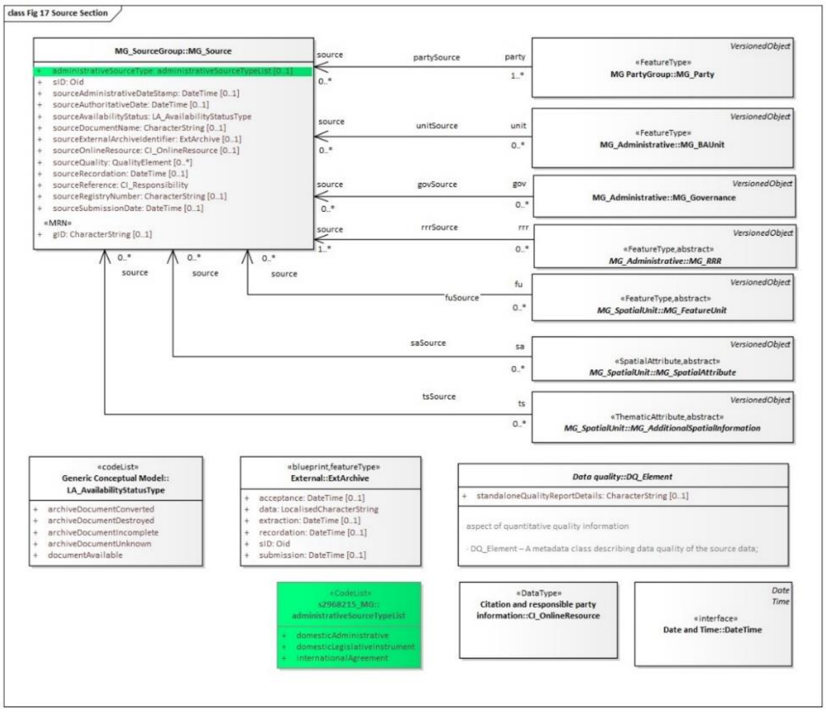


Figure 18. Kenya Marine Cadastre LADM Profile Source Class

4.3.2. VersionedObject class

For Kenya, storing and managing historical data is also crucial for the marine cadastre. To address this, the VersionedObject class from LADM Edition 2 Part 3 has been included in the Kenya marine cadastre LADM profile, as shown in Figure 19. No modifications have been made to this class from the original LADM Edition 2 Part 3; the relationships and classes have been used as they are in the Kenya Marine Cadastre LADM Profile.

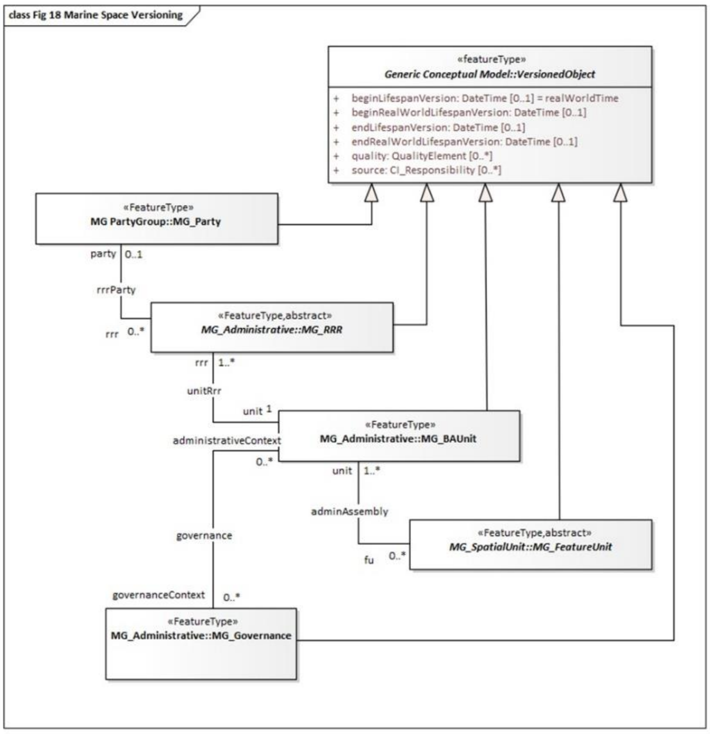


Figure 19. Kenya Marine Cadastre LADM Profile VersionedObject Class

4.3.3. Party package

Another important package for the Kenya marine cadastre LADM profile is the party package, which holds information about actors with rights, restrictions, and responsibilities in marine areas. As shown in Figure 20, this package includes details such as party name, party type, and party role. Although LADM Edition 2 Part 3 provides a list of party types, the list has been adjusted for the Kenya Marine Administration by adding "private company" and "state agency" party types. Consequently, the "non-natural person" type from the original LADM Edition 2 Part 3 list has been removed. For the party role type attributes, the original CharacterString value in LADM Edition 2 Part 3 has been replaced with a party role type code list. This new code list includes the role types of parties involved in marine activities in Kenya.

In marine administration, a group party is formed when multiple parties have rights to a feature unit, and the type of this group party is listed in the group party type code list. The LADM profile created for Kenya includes both communities with rights recognized and legally recorded in the system, as well as communities not recorded in the system. Additionally, if multiple parties share rights in a specific area, the sharing is recorded with the share attribute in the party member class. All parties hold a certain share in that area, with the total sum of shares equaling 1. Another scenario in Kenya's marine administration involves cases where multiple parties have rights to an area, but the rights are not distributed among the parties. For example, multiple parties may hold licenses for fishing activities in a fishing area in Kenyan waters, but the area is not shared among the parties, allowing each party to benefit from the entire fishing area. For such cases, the share attribute takes a value of -1, and the total share values in these areas are less than -1.

Figure 20. Kenya Marine Cadastre LADM Profile Party Package

4.3.4. Administrative Unit package

In the next phase, an administrative unit package was created for the Kenya marine cadastre LADM profile, which includes the Basic Administrative Unit (BAUnit), governance, and RRR classes, as shown in Figure 21. The necessity of including the Basic Administrative Unit and governance classes for the Kenya marine cadastre was determined during the fieldwork process. The first modification made in the Administrative Unit package was the addition of marine protected areas (MPA) and navigation administration units to the code list for BAUnit type. Subsequently, code lists were created for the right, restriction, and responsibility types that were originally defined as CharacterString in LADM Edition 2 Part 3. The values and meanings of these codes are illustrated in Table 8.

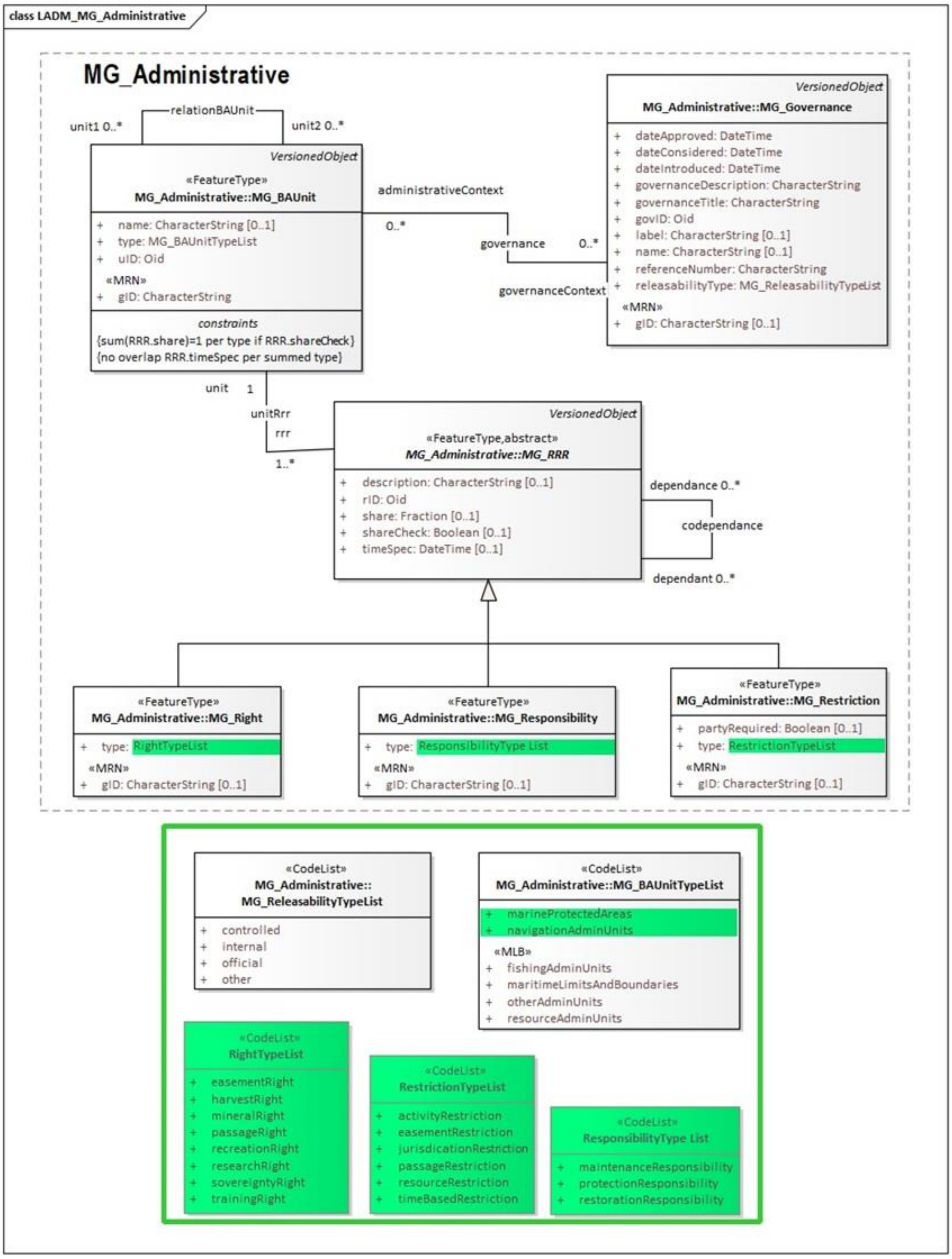


Figure 21. Kenya Marine Cadastre LADM Profile Administrative Unit Package

Table 8. RRR Types and Meanings

RRR Types	Meaning
EasementRight	The right to establish infrastructure (e.g. lay a cable)
HarvestRight	The right to harvest a marine resource such as fishing, seagrass
MineralRight	the right to extract minerals
PassageRight	The right of access including passage
ResearchRight	The right to conduct scientific research
RecreationRight	The right to engage in recreational activities
SovereigntyRight	The right of an exclusivity of jurisdiction
TrainingRight	The right to conduct training activities
ActivityRestriction	Restriction on performing certain activities (e.g. recreational or research)
EasementRestriction	Restriction on establishing infrastructure
JurisdicationRestriction	Restriction on jurisdiction (e.g. limits on sovereign right)
PassageRestriction	Restriction on the right of access
ResourceRestriction	Restriction on the right to harvest of a resource
TimeBasedRestriction	Restriction on any right based on time
MaintenanceResponsibility	Responsibility to maintain a facility or other entity
ProtectionResponsibility	Responsibility to protect a facility, resource, or entity
RestorationResponsibility	Responsibility to restore a facility, resource, or entity to its original state

4.3.5. Feature Unit package

In another phase, the feature unit package, which holds the geospatial characteristics of spatial features in LADM Edition 2 Part 3, was modified for the Kenya marine cadastre LADM profile as shown in Figure 22. This package includes three abstract classes: the MG_FeatureUnit abstract class, which holds feature types; the MG_SpatialUnit abstract class, which holds spatial attributes; and the MG_AdditionalSpatialInformation abstract class, which holds thematic attributes. These three abstract classes establish an inheritance relationship with spatial data information for Location (0D), Limit (1D), Zone (2D), and Space (3D). The method for storing spatial unit data in LADM Edition 2 Part 3 was discussed with domain experts during the fieldwork process, and feedback indicated that the method is suitable for the Kenya marine cadastre LADM profile.

The Feature Unit Package also includes limit and zone type lists and stores marine boundaries and limits defined by UNCLOS. This allows for the storage of legal entities holding states' sovereignty and sovereign rights within the marine boundaries and limits defined by UNCLOS. Additionally, the jurisdictionDomainType attributes in the Zone and Space classes can specify the layer of the 3D marine environment where the spatial unit is located with textual information.

The modifications made to the package for developing the Kenya marine cadastre LADM profile include the creation of the MG_legalSpaceUtilityNetwork class and the addition of the spatialSourceType attribute to the MG_AdditionalSpatialInformation class. The creation of the MG_legalSpaceUtilityNetwork class is intended to store information about utility network types and utility network status types. The spatialSourceType attribute aims to record the method used to measure spatial data in the LADM profile.

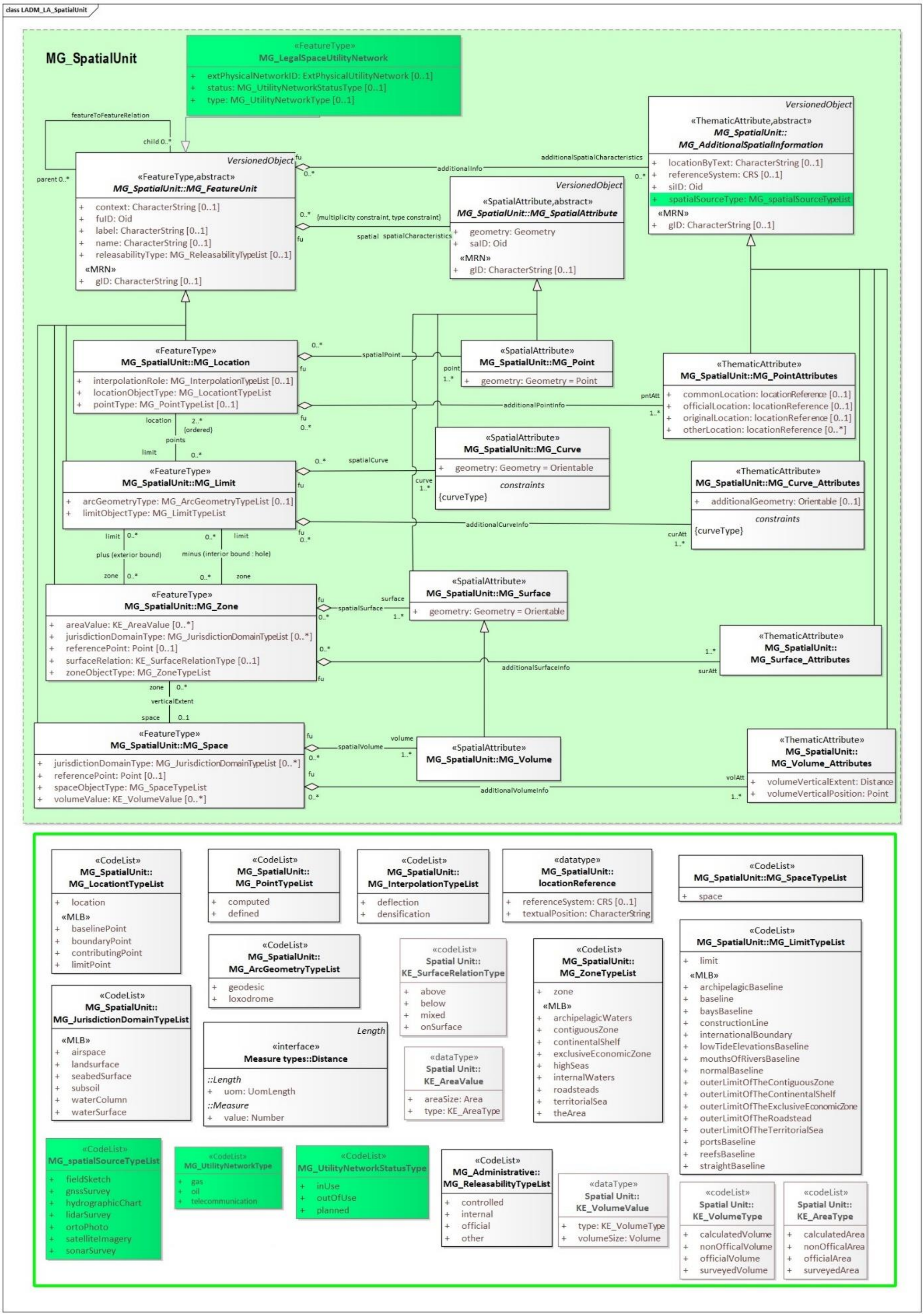


Figure 22. Kenya Marine Cadastre LADM Profile Feature Unit Package

4.3.6. External classes

Finally, Figure 23 shows the external classes that were incorporated into the LADM profile for the Kenya marine cadastre, including information not present in LADM Edition 2 Part 3 but required for the Kenya marine cadastre LADM profile. These classes are the use type and cover type. Kenya has recently placed significant emphasis on MPA and the protection of regional ecology, which is why the ExtCoverType class has been added to the LADM profile. The ExtUsetype class was also added to meet the needs of marine spatial planning activities in Kenya.

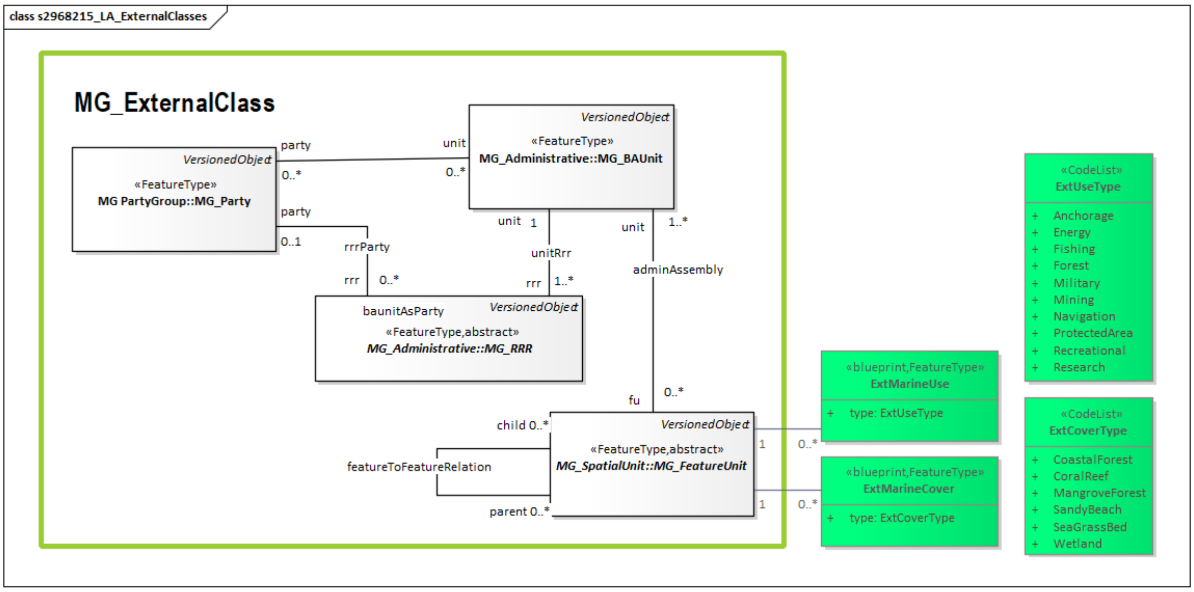


Figure 23. Kenya Marine Cadastre LADM Profile External Classes

4.4. Integration of Marine and Land LADM Profiles

In this section, the Kenya marine cadastre LADM profile was integrated with the LADM profile developed by Okembo et al. for the Kenya land cadastre, which he published as an academic study (Okembo et al., 2023). The purpose of this integration is to create a seamless data model for both land and marine cadastres in Kenya, thereby increasing interdisciplinarity among institutions in projects that require the integration of land and marine administration. Although the LADM profile developed by Okembo et al. (2023) was based on LADM Edition 1, and LADM Edition 2 Part 3 was used for the marine data model, the core structures of both profiles are the same, and both contain the basic classes. Therefore, the realization relationship, used to show the dependency of Part 3 on Part 1 in LADM Edition 2, was employed for the integration in this thesis. Classes that serve the same purpose and do not generalize to another class in both the marine cadastre LADM profile and the land cadastre LADM profile were chosen for the realization relationship. Since subclasses inheriting from the main classes also apply the relationships of the main classes, the classes for the realization relationship were selected from the main classes.

In the following figures, the LADM profile developed for the land cadastre is shown with a cream-colored background, while the LADM profile developed for the marine cadastre is shown in blue. Each package was addressed separately for the integration of the LADM profiles. In Figure 24, it is shown that the source class developed for the marine cadastre is implemented by the source class developed for the land cadastre through a realization relationship. Additionally, Figure 24 also shows that the same VersionedObject class is used in both the land and marine cadastre LADM profiles. Furthermore, the LA_AvailabilityStatusType codelist is used by both source classes.

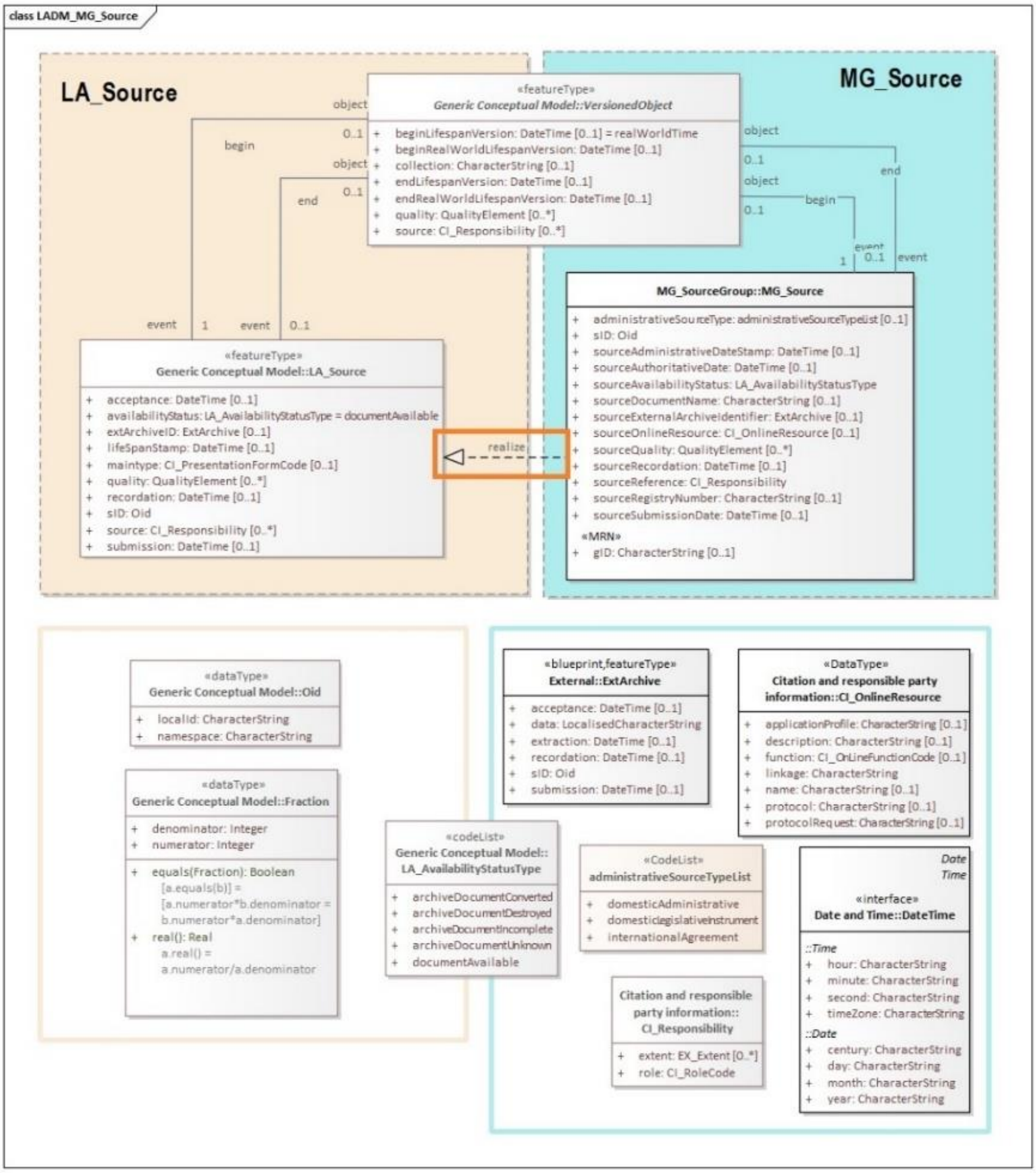


Figure 24. Integration of Source Classes

In Figure 25, it is shown that the party package developed for the marine cadastre is implemented by the party package developed for the land cadastre through a realization relationship. In this package, the party and partymember classes, which are used for the same purpose in both the land and marine LADM profiles, are related through a realization relationship. As seen in Figure 25, although these classes are used for the same function, the attributes and codelists used within the classes differ.

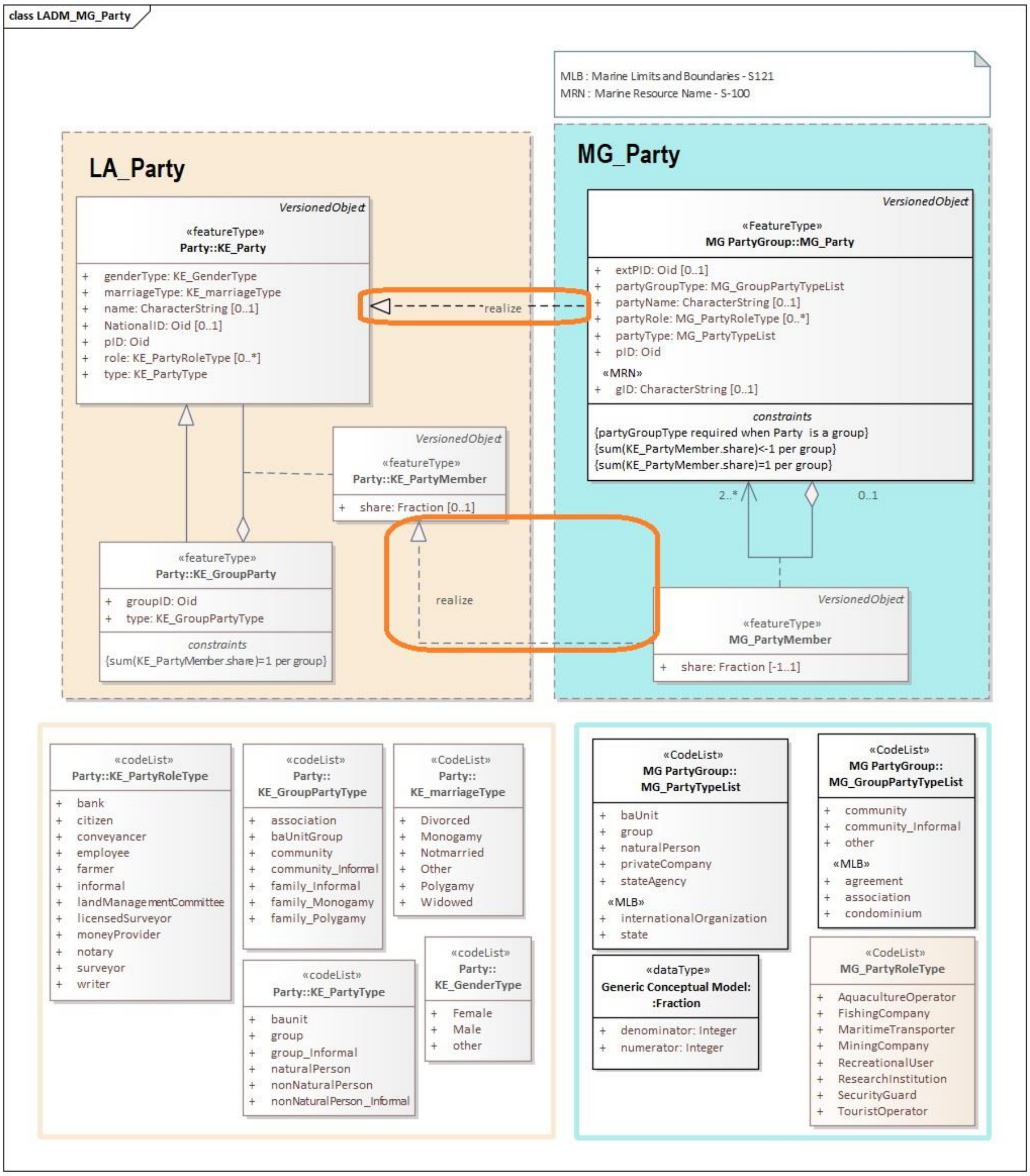


Figure 25. Integration of Party Packages

In Figure 26, the integrated state of the administrative unit packages developed for the land and marine cadastre LADM profiles is shown. In the land cadastre LADM profile, represented in cream color, and the marine cadastre LADM profile, represented in blue, the only common classes are the BAUnit and RRR classes. There is no equivalent class for the Governance class, which is present in the marine cadastre LADM profile, in the land cadastre LADM profile. Since the Rights, Restrictions, and Responsibilities classes inherit the RRR class through a generalization relationship, the realization relationship is also inherited.

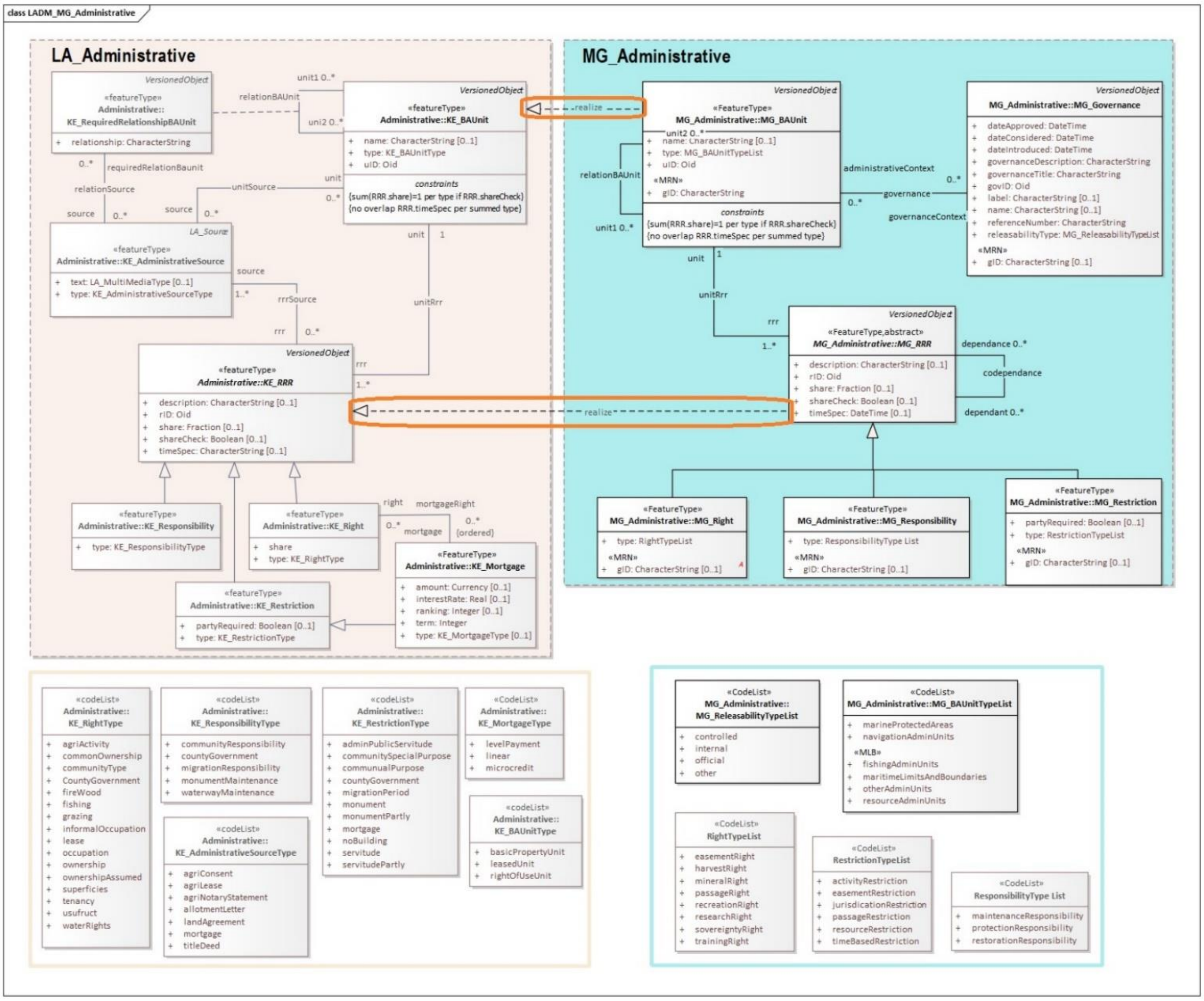


Figure 26. Integration of Administrative Unit Package

As shown in Figure 27, the LA_SpatialUnit, Surveying, and Representation packages used for recording spatial data in the land cadastre LADM profile are integrated with the MG_SpatialUnit package, which records spatial data in the marine cadastre LADM profile. Upon examining the LADM profile developed for the marine cadastre, it is observed that all classes are related to the abstract class MG_FeatureUnit through generalization or aggregation relationships. Therefore, to achieve integration with the land cadastre LADM profile developed by Okembo et al. (2023), the KE_SpatialUnit class, serving the same purpose as the MG_FeatureUnit class, was used. Additionally, the AreaType, VolumeType, and SurfaceRelationType codelists are used in both spatial unit packages.

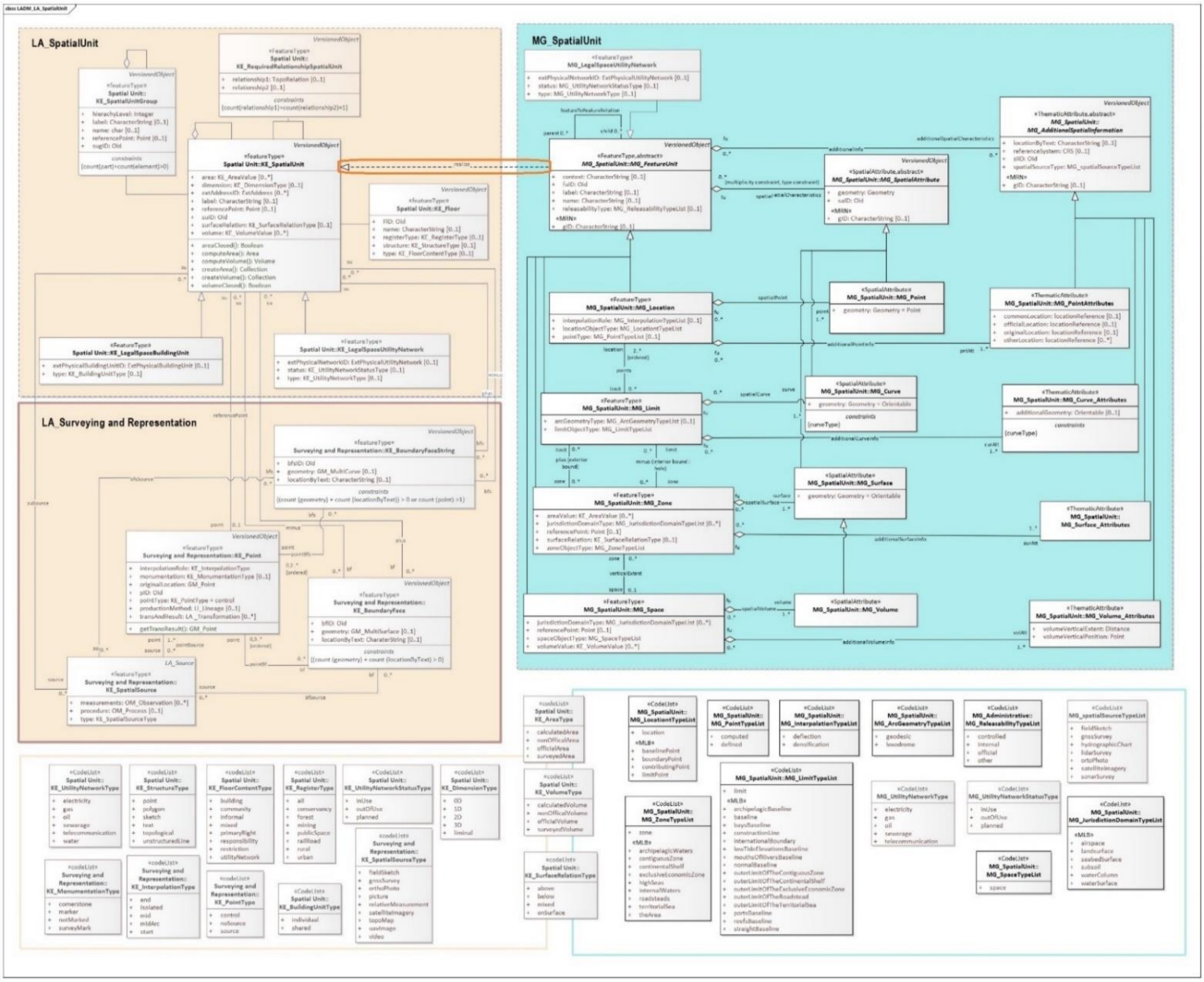


Figure 27. Integration of Spatial Unit Package

Finally, Figure 28 illustrates the integration of external classes. The classes created for storing use type and cover type data in the marine cadastre LADM profile are also present in the land cadastre LADM profile developed by Okembo et al. (2023). These two classes in the marine cadastre LADM profile are implemented in the land cadastre LADM profile through a realization relationship.

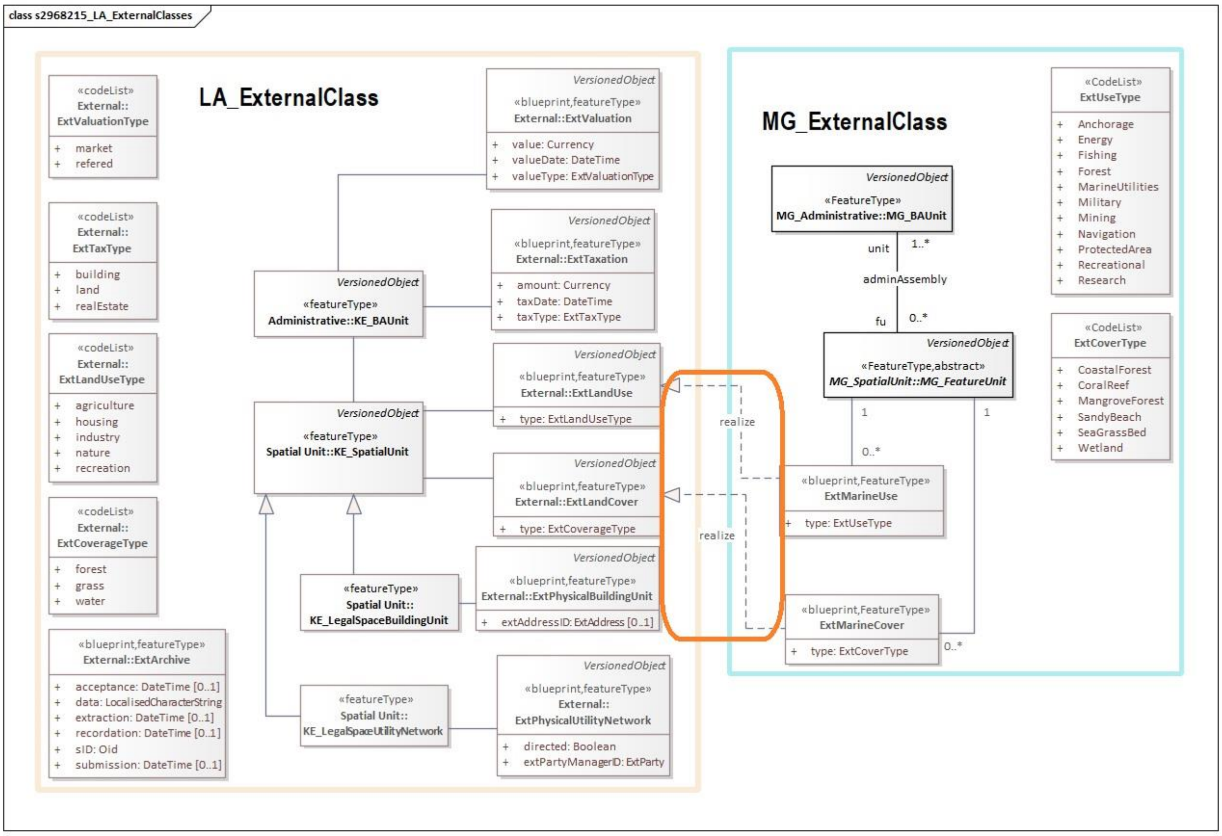


Figure 28. Integration of External Classes

4.5. Validation of Developed Kenya Marine Cadastre LADM Profile and Integrated LADM Profile Through Expert-Based Interviews

This section discusses the results of expert-based interviews of the Kenya Marine Cadastre LADM Profile and the integrated Kenya marine and land cadastre LADM profiles.

4.5.1. Validation of developed LADM profile

In this thesis, expert-based interviews were chosen for the validation of the LADM profiles. The validation method used in Bertolino et al. (2011) was used in the interviews, and multiple-choice and checkbox questions prepared for validation were sent to experts via Google Forms. These questions included deductive questions, true statements from the input domain model, and distractors, false statements in the input domain model. Expected answers were created for each question, and the experts' responses were compared with these expected answers. If the experts' responses matched the expected answers, the result was marked as "pass"; otherwise, it was marked as "fail." A total of five experts were interviewed for the validation of the developed LADM profiles, and 12 multiple-choice questions and 10 checkbox questions were asked. Table 9 contains the experts' answers to the multiple-choice questions used for validating the classes, attributes, and relationships in the developed LADM profile. Table 10 shows the experts' answers to the checkbox questions used for validating the codelists. In the table, deductive questions are marked with a checkmark (✓), while distractors are marked with a cross (×). Additionally, (NE) indicates "I'm not an expert in this particular subject," and (DK) means "I'm an expert in the subject but I'm not sure what to answer."

Table 9. Comparison of Expert Responses to Multiple-Choice Questions with Expected Answers

QUESTIONNAIRE	#PASS	#FAIL	#NE	#DK
1 (√)	5	0	0	0
2 (√)	5	0	0	0
3 (√)	5	0	0	0
4 (√)	3	2	0	0
5 (√)	5	0	0	0
6 (√)	5	0	0	0
7 (√)	5	0	0	0
8 (√)	5	0	0	0
9 (√)	4	1	0	0
10 (√)	3	2	0	0
11 (√)	4	1	0	0
12 (×)	3	2	0	0

As shown in Table 9, expected answers were received from experts up to question 10; however, unexpected responses were obtained for questions 10, 11, and 12. For questions 10 and 11, the answers were given as "somehow," and since the expected answer was "yes," these were considered as failures. Question 12 was used as a distractor, and despite the expected answer being "no," experts provided a "yes" response.

Table 10. Comparison of Expert Responses to Checkbox Questions with Expected Answers

CODELIST TYPE	NUMBER OF COMPONENT	#PASS	#FAIL
Party Type	8	35	5
Group Party Type	6	26	4
Party Role Type	10	44	6
Right Type	9	42	3
Responsibility Type	3	15	0
Restriction Type	8	38	2
Utility Type	5	21	4
Spatial Source Type	7	33	2
Use Type	10	49	1
Cover Type	6	30	0

In Table 10, the questions are in checkbox format, with each codelist having a separate checkbox question. As shown in the table, the majority of codelist components were correctly accepted by the respondents, although some failures were observed in distractor questions and some in deductive questions.

Based on the results of the interviews conducted using the validation method, the model appears valid regarding its current classes, attributes, and relationships, as indicated by the answers to multiple-choice questions. Although there are some failures in the checkbox questions for codelists, the majority of responses indicate a pass. This suggests that the developed LADM profile is valid for the codelists as well.

4.5.2. Validation of integrated LADM profile

After creating the integrated LADM profile for Kenya, interviews were conducted with experts to validate the applicability of this LADM profile in Kenya. For this interview, Google Forms was again used, but this time the validation method (section 3.5.3.1) was not utilized. Imaginary scenarios using ArcGIS were prepared to demonstrate how the integrated LADM profile would be used and how it could contribute to projects requiring land-sea integration in Kenya. Following the presentation of these scenarios, the experts were asked three questions. The first question was about the scenarios provided and the method of using the integrated LADM profile within these scenarios. The second question concerned whether the presented integrated LADM profile would contribute to marine and land management. Both of these first two questions were set up as multiple-choice questions. The final question was open-ended, asking about the importance of having integrated data models for marine and land management in Kenya. All three questions received positive responses from the interviewed experts, and they all emphasized the importance of having an integrated data model in Kenya.

4.6. Summary of Chapter 4

The results section provided a detailed account of the development and validation of the LADM profiles for Kenya's marine cadastre. It described the process of integrating marine-specific features into the existing LADM framework, the validation of these profiles through expert interviews, and the creation of a cohesive data model. With this comprehensive overview in place, the discussion section will now delve into interpreting these results in the context of the research objectives. This includes evaluating the effectiveness of the developed LADM profiles, comparing them with existing literature, and exploring their practical applications. By examining the insights gained from the results and aligning them with broader theoretical and practical considerations, the discussion will provide a deeper understanding of the implications for marine and land administration in Kenya.

5. DISCUSSIONS

In this chapter, the results obtained will be discussed along with the research objectives. As a result of this discussion, all results will be examined and interpreted as a whole. Finally, the obtained results will be compared with the existing literature, and the practical applications of the developed integrated Land Administration Domain Model (LADM) profiles will be discussed.

Three objectives were initially determined in this study. The first objective is to understand Kenya's current marine administration strategies. The methodology used to achieve this objective is explained in section 3.3, and the obtained result is provided in section 4.1. The second of these three objectives is to determine a suitable data model. For this objective, the preliminary research and literature review method described in section 3.4 was used, and the obtained result is explained in section 4.2. The final objective is to develop the LADM profile for the marine cadastre in Kenya, integrate it with the existing LADM profile for land cadastre in Kenya and validate both of these LADM profiles through expert-based interviews. The methodology used to achieve this objective is explained in section 3.5, and the obtained result is provided in sections 4.3, 4.4, and 4.5.

5.1. Discussion for Kenya's Marine and Coastal Administration Strategies

The first objective involves addressing two research questions. The second research question aims to identify marine-specific features and key information necessary for developing the Kenyan marine cadastre. To achieve this, the focus of the second research question is based on the first research question, which seeks to understand the current state of Kenya's marine and coastal administration strategies in Kenya. As a result of the questions asked during the fieldwork process, a process schema shown in Figure 15 was created. As can be understood from this figure, participatory planning among institutions for marine spatial planning in Kenya is not commonly observed, and each institution tends to focus on its own area. However, a project led by the Ministry of Mining, Blue Economy, and Maritime Affairs is currently working on designing a common platform that incorporates the work and data of all institutions involved in marine spatial planning, using the United Nations Educational, Scientific and Cultural Organization's (UNESCO) "Marine Spatial Planning: A Step-by-Step Approach toward Ecosystem-based Management" guidelines. Another significant initiative for the management of marine and coastal areas in Kenya is the Go Blue project[12], funded by the United Nations, which aims to achieve Integrated Coastal Zone Management. Within this project, there is an effort to gather all data related to coastal areas on a single platform. Both the platforms developed for marine spatial planning and Integrated Coastal Zone Management projects are still in the construction phase.

To gain a deeper understanding of marine and coastal management in Kenya, a diagram presented in Figure 16 was created based on literature, acts, and policies. This diagram effectively links the activities prioritized in Kenya's marine and coastal areas with the institutions authorized to manage these activities and the acts to support them. This approach not only summarizes extensive information into a coherent schema, making it more comprehensible, but also facilitates access to marine-specific features and key information necessary for the development of the LADM profile for marine cadastre. Additionally, during the creation of this diagram, it was observed that the names and scopes of ministries in Kenya have undergone multiple changes in recent years, and the institutions under these ministries have changed their affiliations. This phenomenon

[12] http://jkpnodes.rcmrd.org/#/

can be attributed to the diversification of marine and coastal activities in Kenya and the consequent formulation of new acts and policies in response to changes in current focus areas.

Subsequently, the acts and policies used for the management of these areas were thoroughly examined. A list of marine-specific features and key information necessary for the development of the LADM profile in Kenya was created. The key information was later used to create the code lists in the LADM profile. Tables 11, 12, and 13 below reference the sources from which each key information, i.e., the values assigned to some of the code lists created in the LADM profile, were obtained. Since the administrative source type list code list was determined during the fieldwork process, and the code lists for external classes were extracted from articles related to Marine Spatial Planning (MSP) in Kenya, a separate table was not created for these.

5.2. Discussion for the Justification of the Selection of the LADM

In objective 1, the focus is on justifying the selection of the LADM as a suitable data model for integrating marine and land cadastre in Kenya. For this purpose, in section 4.2, the data models that could be chosen for developing the marine cadastre data model have been compared. The most significant reason for choosing LADM in this comparison is the existence of the LADM profile previously developed for the land cadastre in Kenya. This makes the integration work easier if the LADM data model is chosen for developing the data model for the marine cadastre.

Numerous academic studies have also been published regarding the suitability of LADM Edition 1 for marine cadastre. These studies have concluded that an LADM-based marine cadastre is feasible (Athanasiou et al., 2017; Griffith-Charles & Sutherland, 2014; Lemmen et al., 2019; Sutherland et al., 2016). Some academic studies have also focused on creating a marine cadastre data model specific to certain countries using LADM. These studies have been conducted in Malaysia, Croatia, Greece, Trinidad & Tobago, and Canada (Abdul-Rahman, 2017; Flego et al., 2018; Griffith-Charles et al., 2018; Sutherland et al., 2016; 2022; Zamzuri & Hassan, 2021b). This situation indicates that LADM is a suitable data model for marine cadastre.

Also, other studies have also been conducted on the use of LADM in land administration in Kenya. For instance, Lengoiboni et al. (2010) studied the spatial and temporal land use attributes of pastoral areas in Northern Kenya and modelled them within the LADM framework. Another study by Siriba & Nwenda (2013) focused on developing a Kenyan LADM profile. In another study, Kuria et al. (2016) developed an LADM profile specifically for Kenya's land administration and published this model under the name "Africanized LADM." Most recently, in 2023, Okembo et al. (2023) developed a national LADM profile specifically for land areas in Kenya. This has led to the decision that LADM is a suitable data model for a seamless data model in Kenya.

In this study, LADM Edition 2 Part 3 (Marine geo-regulations) is used. This part was specifically created for marine cadastre by basing it on IHO S-121 (Maritime Limits and Boundaries) of LADM Edition 1, which is already considered sufficient for marine cadastre in many studies. As of June 2024, there are no marine cadastre data model studies developed using LADM Edition 2 Part 3 in the literature.

Table 11. References for the Party Package Code Lists

Package	Codelist	Attributes	REFERENCES	ARTICLE / SECTION
Party	PartyTypeList	baUnit	ISO 19152-1 (LADM Edition 1)	
		Group	ISO 19152-1 (LADM Edition 1)	
		NaturalPerson	The Fisheries Management And Development Act	Article 3.1
		privateCompany	National Oceans And Fisheries Policy	Section 3.3.8
		stateAgency	National Land Policy	Article 190
		state	National Land Policy	Article 233
		InternationalOrganization	Marine Spatial Planning And The Blue Economy In Kenya	Kenya's National And International Inspirations Related To MSP
	GroupPartyList	other		
		community	The Fisheries Management And Development Act	Article 29.2
		community_Informal	From Interviews	
		Agreement	IHO S-121	
		Association	Integrated National Transport Policy	Article 21
		Condominium	IHO S-121	
	PartyRoleType	ResearchInstitution	Integrated National Transport Policy	Article 167
		FishingCompany	National Oceans And Fisheries Policy	Section 3.2
		AquacultureOperator	National Oceans And Fisheries Policy	Section 3.3.7
		MaritimeTransporter	Integrated National Transport Policy	Article 148
		TouristOperator	Integrated National Transport Policy	Article 148
		MiningCompany	Mining Act	Article 20
		RecreationalUser	The Fisheries Management And Development Act	Article 5
		SecurityGuard	Integrated National Transport Policy	Article 166

Table 12. References for the Administrative Unit Package Code Lists

PACKAGE	CODELIST	ATTRIBUTES	REFERANCE	ARTICLE / SECTION
Administrative Unit	RightTypeList	mineralRight	Mining and Minerals Policy	Section 2.1
		recreationRight	National Land Policy	Article 193
		EasementRight	UNCLOS	Article from 56 to 58
		HarvestRight	UNCLOS	Article 56
		PassageRight	UNCLOS	Articles from 17 to 26
		SovereigntyRight	UNCLOS	Articles 2 through 16
		researchRight	National Oceans and Fisheries Policy	Section 5.1
		trainingRight	Integrated National Transport Policy	Article 167
	RestrictionTypeList	activityRestriction	UNCLOS	Article 33
		JurisdicationRestriction	UNCLOS	Article 33
		PassageRestriction	Merchant Shipping Act	Article 14
		ResourceRestriction	The Fisheries Act	Section 4.4
		TimeBasedRestriction	The Fisheries Act	Article 50
		easementRestriction	UNCLOS	Article 33
	ResponsibilityTypeList	MaintenanceResponsibility	UNCLOS	Article 192
		ProtectionResponsibility	UNCLOS	Article 192
		restorationResponsibility	National Environment Policy	Section 4.8

Table 13. References for the Spatial Unit Package Code Lists

PACKAGE	CODELIST	ATTRIBUTES	REFERANCE	ARTICLE / SECTION
SPATIAL UNIT	ZoneTypeList	ArchipelagicWaters	UNCLOS	Article 49
		ContiguousZone	UNCLOS	Article 33
		ContinentaShelf	UNCLOS	Articles 76 to 85
		ExclusiveEconomicZone	UNCLOS	Part V
		HighSeas	UNCLOS	Articles 86 to 90:
		InternalWaters	UNCLOS	Article 8
		Roadsteads	UNCLOS	Article 12
		TerritorialSea	UNCLOS	Part II
		TheArea	UNCLOS	Part XI
	UtilityNetworkType	gas	The petroleum act	Article 2
		oil	The petroleum act	Article 2
		telecommunication	Maritime Areas Act	Article 7
	spatialSourceTypeList	fieldSketch	From Interviews	
		gnssSurvey	Marine Spatial Planning And The Blue Economy In Kenya	Status of institutions involved in MSP implementation
		hydrographicChart	Marine Spatial Planning And The Blue Economy In Kenya	Status of institutions involved in MSP implementation
		lidarSurvey	Marine Spatial Planning And The Blue Economy In Kenya	Status of institutions involved in MSP implementation
		ortoPhoto	Marine Spatial Planning And The Blue Economy In Kenya	Status of institutions involved in MSP implementation
		satelliteImagery	Marine Spatial Planning And The Blue Economy In Kenya	Status of institutions involved in MSP implementation
		sonarSurvey	Marine Spatial Planning And The Blue Economy In Kenya	Status of institutions involved in MSP implementation

5.3. Discussion for the Development of the Kenya Marine Cadastre LADM Profile

The third objective consists of three research questions. The first research question focuses on the development of an LADM profile for Kenya. In developing the LADM profile for the Kenyan marine cadastre, it is essential to include the marine-specific features and key information outlined in Table 6 key information represents the code lists that will be created in the LADM profile, as discussed in Section 5.1. The marine-specific features are integrated with the classes and attributes found in the LADM profile.

5.3.1. Discussion about the Party Package

Firstly, the discussion will focus on how group party registrations within marine-specific features are implemented using the LADM. For a group party to be created in LADM, a feature unit within marine areas must have rights held by multiple parties. This can occur in two distinct ways. The first scenario, as illustrated in Figure 29, involves two different mining companies holding mineral rights over a single feature unit. In this case, these two parties form a group party for that feature unit, and the rights within that feature unit are equally shared among the parties. The total share of rights allocated among the parties must sum to 1.

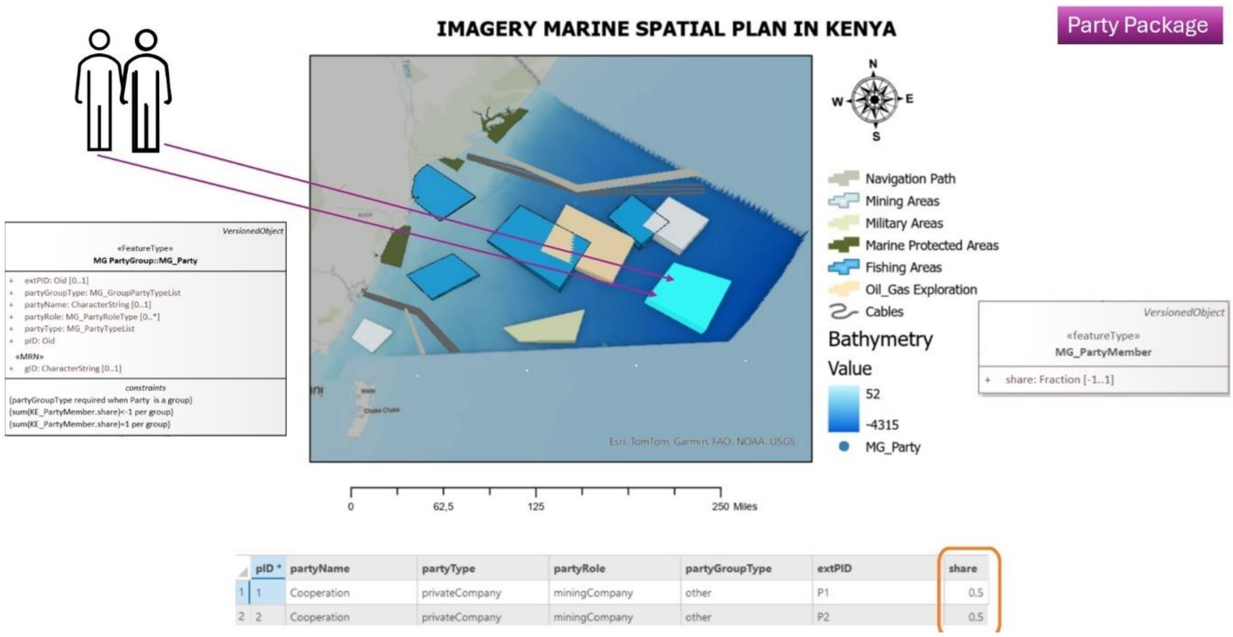
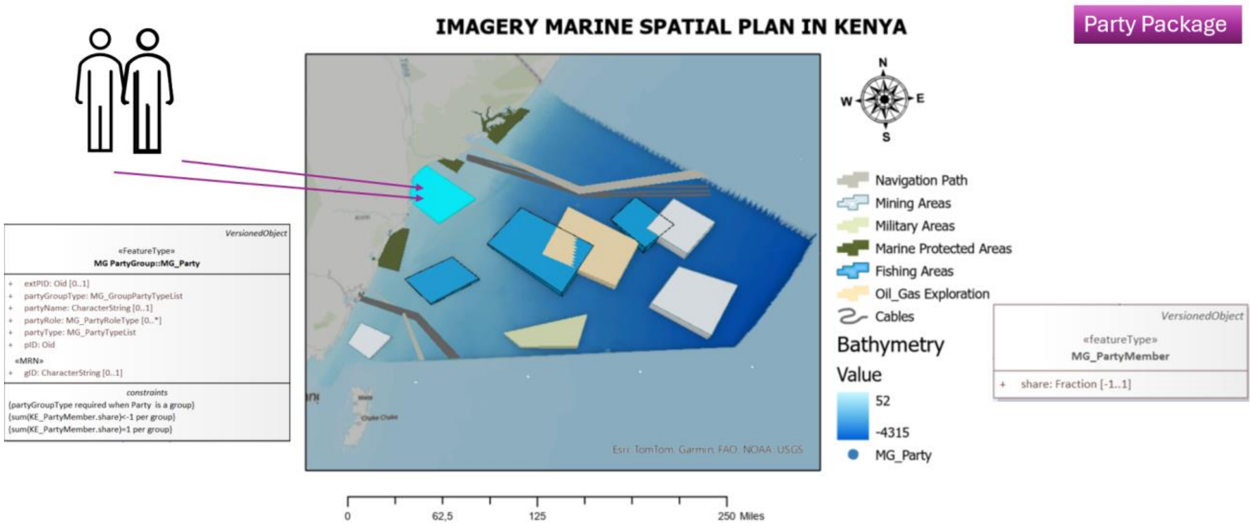


Figure 29. Visualization of the First Scenario for Creating a Group Party in LADM

Another scenario involves multiple parties claiming rights over a feature unit, with the rights being shared among the parties, allowing them to act as a single party holding the rights. An example of this, as shown in Figure 30, is where multiple fishing companies or natural persons hold harvest rights in a fishing area. In this case, the fishing area is not subdivided for each party; instead, each fishing company or natural person can exercise their harvest rights at any point within the designated fishing area. To represent this situation in LADM, the share attribute is used, where each party holding harvest rights in that area is assigned a share value of -1.



	pID *	partyName	partyType	partyRole	partyGroupType	extPID	share
1	1	Cooperation	privateCompany	fishingCompany	other	P1	-1
2	2	Cooperation	privateCompany	fishingCompany	other	P2	-1

Figure 30. Visualization of the Second Scenario for Creating a Group Party in LADM

The third research question of the third objective focuses on the validity of the developed LADM profile for Kenya's marine cadastre. During the interview process, four questions related to the party packages were asked. One of these questions addressed whether the scenarios presented for group party registration are applicable in Kenya. All experts responded affirmatively, indicating that the scenarios are indeed applicable. Another question inquired about the use of the share attribute in the developed LADM for Kenya's marine cadastre. Three experts confirmed its applicability, while two experts provided a somewhat positive response.

5.3.2. Discussion about the Administrative Unit Package

The second marine-specific feature listed in Table 6 is dynamic activities in marine areas. The term "dynamic activities" refers to the temporary inability to exercise a right during certain times of the year. This situation is recorded in the LADM profile using the RRR class within the Administrative Unit package. For example, consider a party that holds a 10-year license for fishing activities in a specific feature unit. As illustrated in Figure 31, this party is deprived of their harvest right every seventh month of the year due to the breeding season of the fish. This restriction applies every year for the duration of the license.

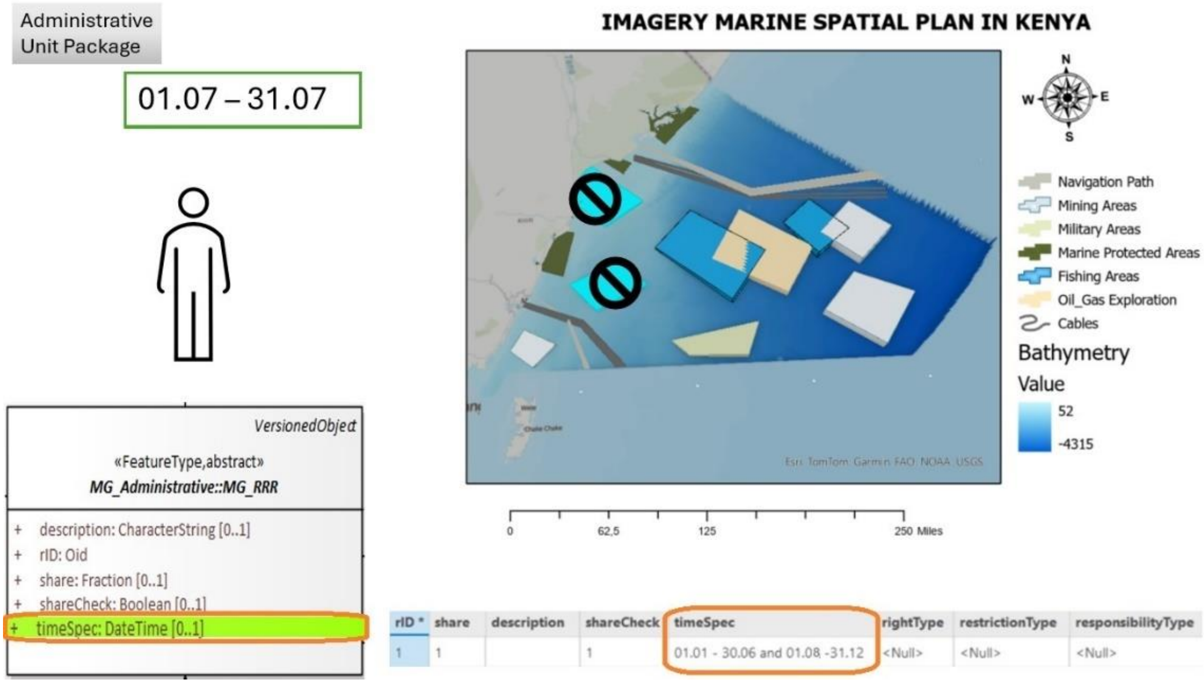


Figure 31. Visualization of the Recording Dynamic Activities in LADM

Another marine-specific feature included in the Administrative Unit package of the LADM profile is the recording of temporary restrictions. This is managed using time-based restrictions, a type of restriction. An example of this would be the state announcing that oil and gas exploration activities will be conducted in a portion of the marine area for a specific period. As shown in Figure 32, this area may overlap with an existing fishing area. Parties holding harvest rights in the fishing areas cannot exercise their rights in the overlapping zone during the period when oil and gas extraction activities are being carried out.

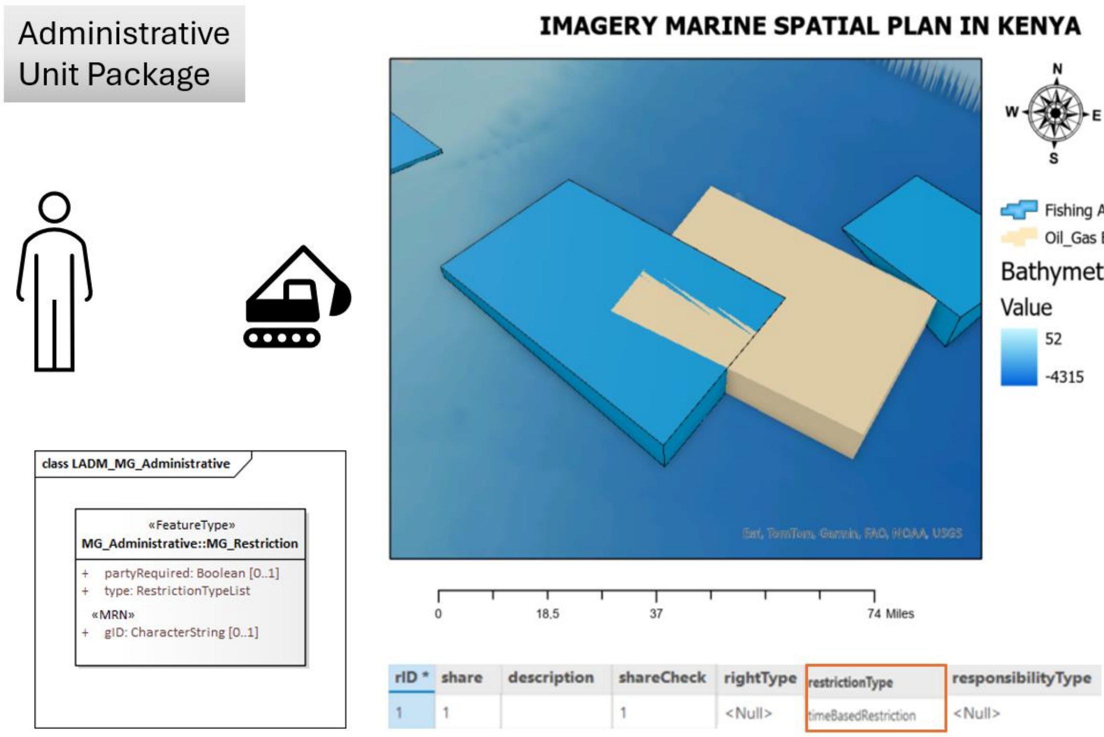


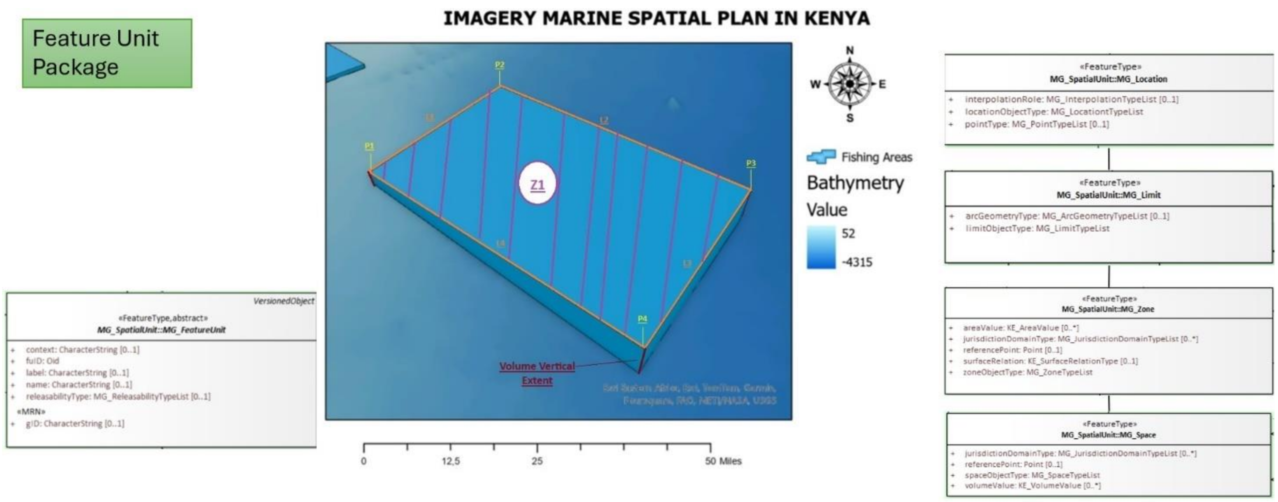
Figure 32. Visualization of the Recording Temporary Restriction in LADM

The third research question of the third objective examines the suitability of the developed LADM profile for Kenya's marine cadastre. During the interview process, four questions related to the Administrative Unit package were posed. One question addressed the methods of recording marine-specific features, such as dynamic activities and temporary restrictions, in the LADM. All experts responded positively to this question. Additionally, another question focused on whether a right associated with an activity in Kenya could come with associated responsibilities or restrictions within the Administrative Unit package. All experts confirmed that this situation is possible. This response also validates the co-dependence relationship inherent in the RRR class.

5.3.3. Discussion about the Feature Unit Package

Another marine-specific feature pertains to the recording of three-dimensional (3D) spatial data. In the LADM, the recording of spatial data is managed through the feature unit package, as shown in Figure 33. This package includes four subclasses that are connected to the feature unit package via a generalization relationship. These subclasses are MG_Location, which stores vertex information; MG_Limit, which stores edge information; MG_Zone, which stores 2D feature unit information; and MG_Space, which stores 3D spatial data.

To record 3D spatial data in the LADM, the MG_Volume_Attributes class, which is linked to the MG_Space class via an aggregation relationship, is utilized. This class includes the attributes volumeVerticalPosition and volumeVerticalExtent. The volumeVerticalPosition attribute records the vertex information used to create the feature unit, which is also stored in the MG_Location class. The volumeVerticalExtent attribute records the distance from these vertices to the seabed surface in meters. By maintaining the distance data for each vertex from the seabed surface, the LADM can comprehensively record 3D spatial data.



fuID *	Name	label	releasabilityType	context	Geometry	jurisdicationDomainT...	zoneObjectType	volumeVerticalPosition	volumeVerticalExtent
1				<Null>	<Null>	waterColumn	continentalShelf	P1	20
2	<Null>	<Null>	<Null>	<Null>	<Null>	waterColumn	continentalShelf	P2	24
3	<Null>	<Null>	<Null>	<Null>	<Null>	waterColumn	continentalShelf	P3	23
4	<Null>	<Null>	<Null>	<Null>	<Null>	waterColumn	continentalShelf	P4	25

Figure 33. Visualization of the Recording 3D Spatial Data in LADM

Another marine-specific feature involves recording which United Nations Convention on the Law of the Sea (UNCLOS) zone marine activities are located in. This is managed using the ZoneObjectType attribute in the MG_Zone class, as depicted in Figure 33. This attribute utilizes a code list containing all marine zones defined by UNCLOS. By selecting the appropriate zone type, one can determine the specific UNCLOS zone in which a feature unit is situated.

The final marine-specific feature concerns the management of rights, restrictions, and responsibilities within a 3D environment. In the LADM, this is addressed through the jurisdictionDomainType attribute within the MG_Space class of the feature unit package. This attribute records which of the following zones a given feature unit occupies: airspace, land surface, seabed surface, subsoil, water column, or water surface. For example, as illustrated in Figure 34, navigation paths and cables may appear as overlapping on a 2D map. However, a 3D map reveals that they do not actually overlap, with one situated in the water surface zone and the other in the seabed surface zone. In the LADM, the jurisdictionDomainType attribute allows for the recording of spatial data within specific zones, thereby clarifying that, despite their proximity, these features do not overlap spatially.

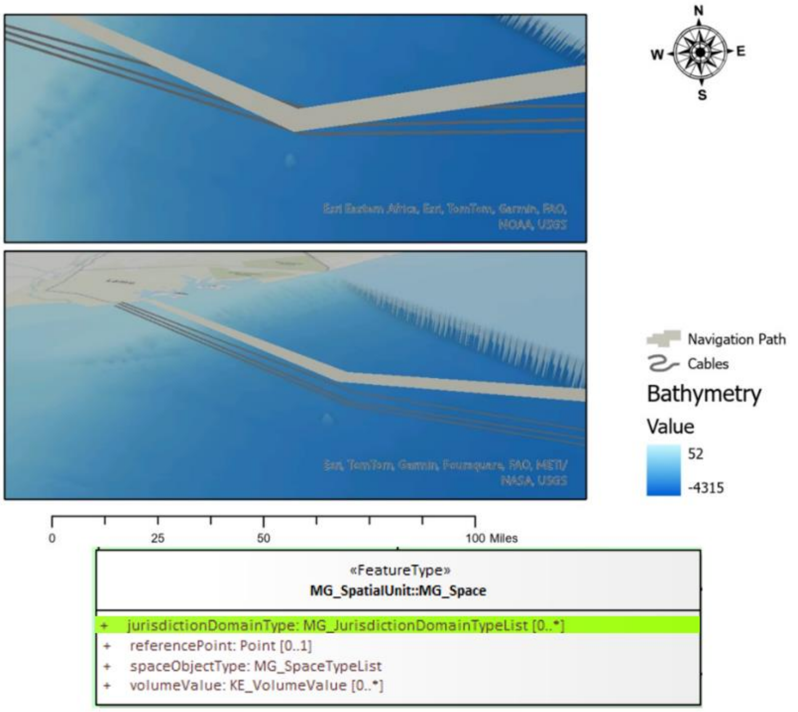


Figure 34. Visualization of the Recording 3D Rights and Restriction Management in LADM

The third research question of the third objective examines the suitability of the developed LADM profile for Kenya's marine cadastre. During the interview process, two questions related to the feature unit packages were posed. One question addressed the validity of the method for recording 3D spatial data in the LADM profile within the Kenyan context. In response, three experts affirmed that the method is applicable, while two experts responded with a somewhat positive validation. This indicates that further feedback from additional experts may be needed and potential modifications to the feature unit packages could be considered to enhance the 3D representation capabilities of the LADM profile.

This section demonstrated how the marine-specific features identified for Kenya were integrated into the LADM. Feedback obtained through interviews validated the extent to which the developed LADM profiles represented Kenya's marine administration. With the achievement of this first research question, attention subsequently shifted to the next goal: developing a seamless data model for the integration of land and marine cadastres in Kenya.

5.4. Discussion for the Integrated LADM Profile for Marine and Land Cadastre in Kenya

The second research question of the third objective of the thesis was to develop an LADM profile for a seamless data model applicable to both marine and land cadastre in Kenya. To achieve this, realization relationships were utilized to integrate the LADM profile developed for the Kenyan marine cadastre with the LADM profile for the Kenyan land cadastre, as developed by Okembo et al. (2023). The resulting integrated data model is a critical component for projects requiring an integrated coastal zone management approach, as it enhances interdisciplinary communication.

By consolidating data within the LADM structures for both marine and land administration, the model facilitates improved access to relevant data and promotes planning that aligns with both marine and land management objectives in coastal areas. Utilizing the integrated LADM profiles represents a significant step in enhancing institutional integration. Institutions involved in land or marine administration can access cadastre data for both domains, and due to the seamless data model, they can easily understand and apply data from one domain to the other, thanks to the consistent data structures.

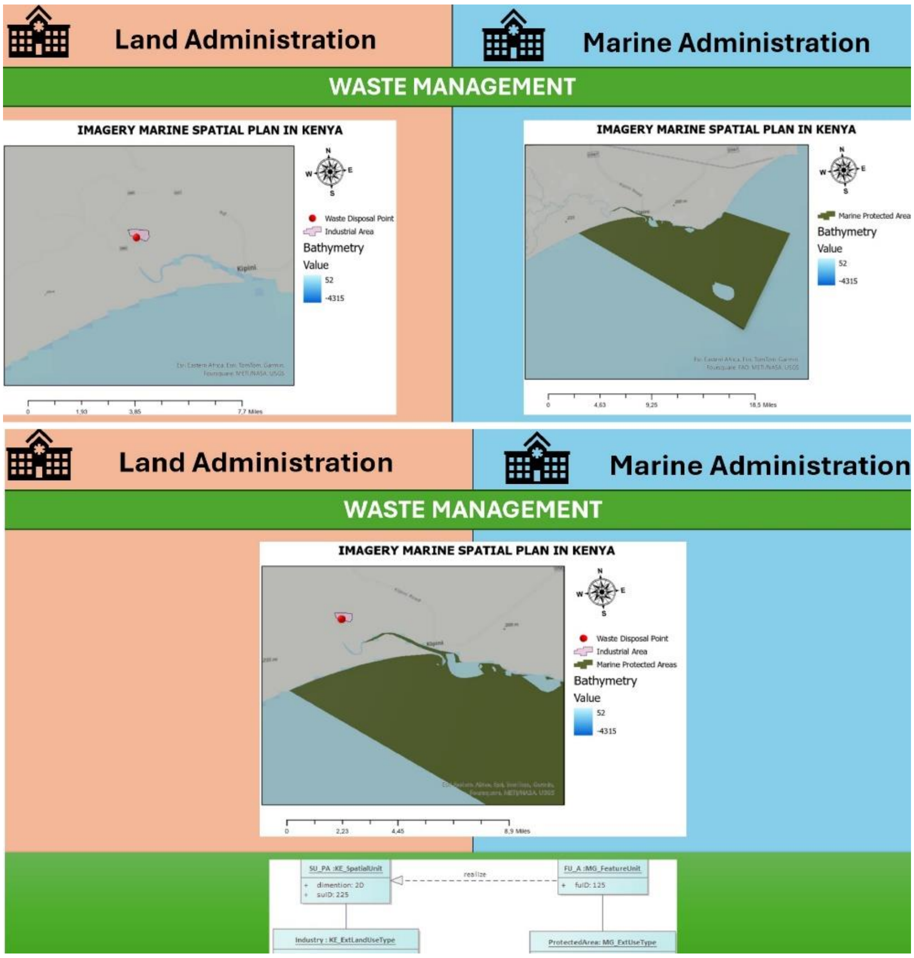


Figure 35. Imaginary Scenario for Waste Management in KENYA

To illustrate, one of the challenges faced by Kenya is managing waste in coastal areas in a way that does not harm the ecosystem. This issue requires integration between institutions, as depicted in Figure 35, where planning for both land and marine areas must be managed in an integrated manner. If planning for industrial zones and waste disposal points in land areas does not take into account marine area planning, there is a risk that waste could be transported to Marine Protected Areas (MPA) via rivers, potentially causing ecological damage to these regions. Therefore, it is crucial that planning utilizes a common platform that integrates data from both marine and land administration, enabling participatory planning among institutions. In this scenario, the integrated LADM profiles allow for the location of industrial areas in land zones and protected areas in marine zones to be accessed, thereby facilitating the analysis of whether waste disposal impacts MPA.

Another application of the developed integrated LADM profiles is in the effective management of rights and restrictions for parties operating in coastal zones, contributing to sustainable coastal management. As illustrated in Figure 36, the imaginary scenario for the Kenyan coast displays areas where tourism activities occur, regions inhabited by coastal communities, and MPA. These three components are interrelated and require integration.

Coastal communities depend on activities such as fishing and harvesting sea grass and coral reefs, which are integral to their daily lives. Excessive harvesting of sea grass and coral reefs can significantly harm coastal ecosystems. Conversely, tourism companies conduct cruising activities in MPA and organize snorkeling and diving activities under marine safari tours in regions with rich marine ecosystems.

With the integrated LADM profiles, it is possible to manage these activities by recording the specific areas where coastal communities are permitted to fish and harvest sea grass and coral reefs, as well as areas where these activities are restricted. Similarly, the profiles can document the zones designated for tourism activities. This comprehensive management approach makes complex coastal area situations more understandable and manageable.

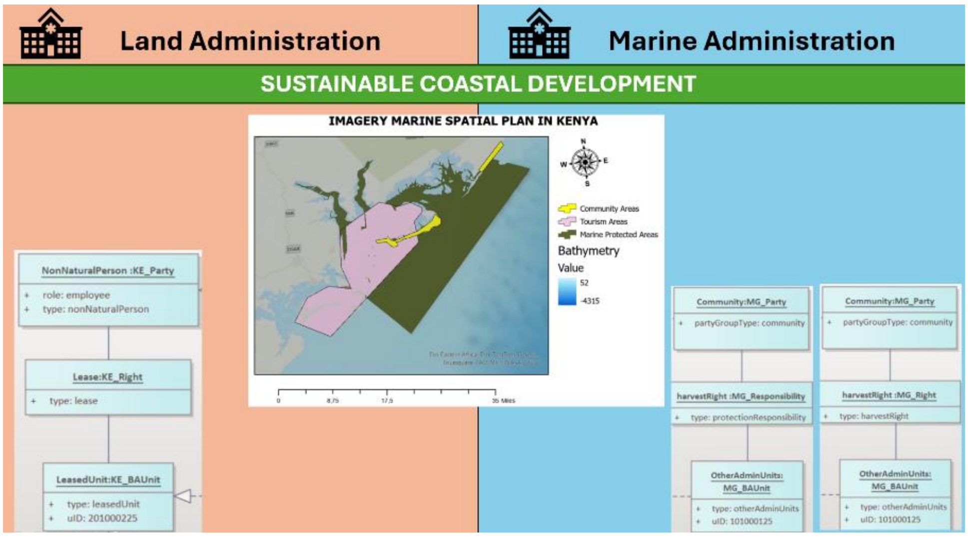


Figure 36. Imaginary Scenario for Sustainable Coastal Development in KENYA

Another scenario where the integrated LADM profiles can be utilized, as shown in Figure 37, involves determining the location of a newly constructed port. The location of ports is influenced by specific requirements in both marine and land areas. For marine areas, this might involve ensuring that the navigation path is located a certain distance from fishing areas and marine protected zones. For land areas, the requirements might include situating the port south of Mombasa while ensuring proximity to main roads. To address these requirements, it is necessary to evaluate data from both marine and land areas in conjunction and to facilitate collaboration between the ministries responsible for marine and land management. The integrated LADM profiles simplify this interdisciplinary approach, making it easier to meet the spatial and regulatory conditions necessary for optimal port location planning.

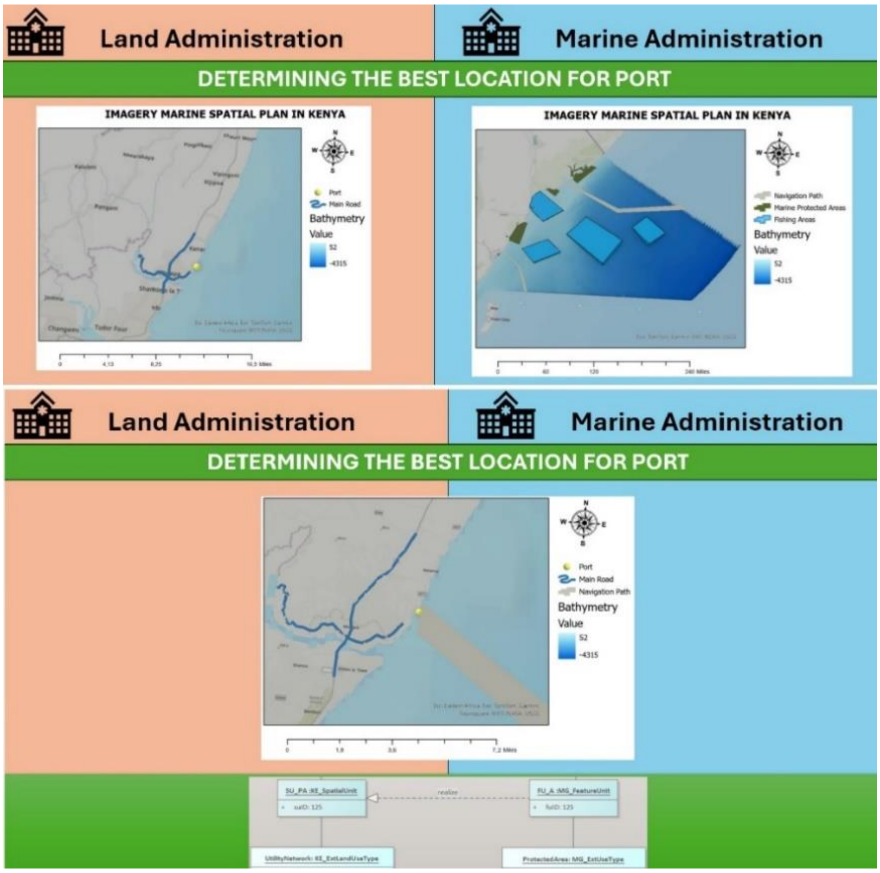


Figure 37. Imaginary Scenario for the Determining Port Location

The third research question of the third objective focused on validating the extent to which the integrated LADM profile contributes to the integration of marine and land administration in Kenya. To address this, interviews were conducted with experts. During the interview process, scenarios developed for the application of the integrated LADM profiles in Kenya were presented to the experts to gather feedback on whether the profiles could support the integration of land and marine cadastre.

Three main questions were posed during the interviews. The first question asked whether the developed scenarios accurately reflected the Kenyan context. The second question inquired whether the integrated LADM profiles could enhance marine and land management in Kenya. The final question addressed the importance of having integrated data models for marine and land management in Kenya. All five experts interviewed responded positively, affirming that the integrated LADM profiles would contribute to enhancing land and marine management and underscoring the need for a seamless data model for effective coastal area management in Kenya.

5.5. Comparison with Existing Literature and Practical Implications

The primary aim of this thesis is to develop a seamless data model for marine and land cadastre systems in Kenya using the LADM. By creating a seamless data model, the thesis seeks to improve the planning of inter-agency projects in Kenya and enhance the management of coastal areas. The literature highlights numerous studies on the use of LADM as a data model for marine cadastre and the necessity of land-sea integration.

In this thesis, the development of LADM profiles for marine cadastre has been explored, following previous academic work. One notable study identified the criteria required for LADM profiles for marine cadastre and validated whether LADM meets these criteria, concluding that LADM is applicable for marine cadastre (Sutherland et al., 2016). Several academic studies have aimed at creating a national marine cadastre data model using LADM Edition 1, with research conducted in Malaysia, Croatia, Greece, Trinidad & Tobago, and Canada.

The key difference between these studies and the marine cadastre LADM profiles developed in this thesis is that while the previous studies utilized LADM Edition 1, this thesis employs LADM Edition 2 Part 3 for marine geo-regulations. Although there are no significant differences in the main structures between LADM Edition 1 and LADM Edition 2 Part 3, notable differences exist, especially in the spatial unit packages. LADM Edition 2 Part 3 supports the recording of 3D spatial data and includes marine zones defined by UNCLOS, whereas LADM Edition 1 does not support 3D spatial data recording. Additionally, in the administrative unit packages, LADM Edition 2 Part 3 incorporates governance classes and information related to proclamations, laws, or treaties. As LADM Edition 2 was newly published, there were no academic studies found during the writing of this thesis that used LADM Edition 2 Part 3 for developing a national data model.

Globally, numerous academic studies have addressed the integration of land and marine systems, which aligns with the third objective of this thesis. One notable study highlights the growing need for the integration of marine and terrestrial planning systems and delves into the origins of the fundamental differences between marine and terrestrial planning. The study concludes that a full merger of marine and terrestrial planning into a unified system is unattainable (Kerr et al., 2014). Another paper discusses the impressive speed of changes in coastal areas, which pose governance challenges and often lead to inadequately addressed new challenges. It emphasizes the important role of land-sea integration in resolving these issues (Schlüter et al., 2020). Several other studies have also highlighted the lack of integration in coastal zone management and the legal and planning systems between land and sea (Smith et al., 2011; Yue et al., 2023). However, these studies primarily focus on legislative and institutional perspectives on land-sea integration and do not address seamless data models or Spatial Data Infrastructure.

Research on the integration of marine and land cadastre has also been conducted in New Zealand and Australia. Hoogsteden & Robertson (1998) discuss the importance of incorporating maritime environments within the National Spatial Data Infrastructure (NSDI) in their study on building a seamless cadastre for New Zealand. In Australia, the ARC Marine Cadastre project has focused on developing offshore spatial data infrastructure to delineate, manage, and administer legally definable offshore boundaries and associated rights, restrictions, and responsibilities (Binns et al., 2014). This project aims to integrate the terrestrial and marine environments by utilizing the Australian Spatial Data Infrastructure.

These studies emphasize the legislative and institutional aspects of land-sea integration and underscore the crucial role of spatial data infrastructure in achieving seamless integration. However, they mainly address the need for an integrated data model without providing detailed guidance on its development. This thesis, in contrast, focuses on creating a seamless data model for marine and land cadastre, highlighting the importance of such a model as discussed in the literature. To facilitate this integration, LADM has been chosen as the preferred framework. Consequently, the feasibility of using integrated LADM profiles for achieving land-sea integration and improving coastal zone management in Kenya was evaluated through expert interviews. The findings suggest that the concept of integrated LADM profiles is a promising approach for enhancing integration.

The concept of integrated LADM profiles also represents a significant contribution to recent efforts in MSP and integrated coastal zone management (ICZM) in Kenya. During the fieldwork, interviews revealed that separate platforms are currently being developed for both ICZM and MSP initiatives. Specifically, interviews concerning MSP in Kenya indicated that, in addition to the existing platform, efforts are underway to develop a data model for MSP. The LADM profiles approach developed for the Kenyan marine cadastre demonstrates practical applicability in real-world contexts. Furthermore, in ICZM efforts, the use of integrated LADM profiles as a practical tool can enhance land-sea integration, thereby contributing positively to coastal management practices.

5.6. Summary of Chapter 5

In transitioning from the discussion to the conclusion and recommendations, it is essential to consolidate the insights gained from the research and highlight their broader implications for Kenya's marine and land cadastre systems. The discussion emphasized the critical need for a tailored LADM profile that addresses Kenya's unique marine and coastal management requirements. It also underscored the challenges encountered, such as limited documentation and the difficulty of bridging expertise gaps between marine and land administration professionals. The subsequent sections of this thesis will encapsulate these findings and their implications, examining how the development of a Kenya-specific marine cadastre LADM profile and its integration with the land cadastre LADM profile contributes to a more cohesive and efficient data management system. The conclusion will summarize the research outcomes, while the recommendations will outline strategic actions to address the identified limitations, enhance integration efforts, and support the Government of Kenya in achieving effective Marine Spatial Planning and Integrated Coastal Zone Management. By addressing these areas, the thesis aims to provide actionable insights and practical solutions for improving Kenya's cadastre systems.

6. CONCLUSION AND RECOMMENDATIONS

In this thesis, the objective is to enhance the integration of marine and land cadastre systems in Kenya through the application of the Land Administration Domain Model (LADM). Initially, the study examines the management practices of marine and coastal areas in Kenya, the implementation of spatial planning, and the relevant existing acts and legislation. This examination aims to gather the necessary information for developing a Kenya-specific LADM. Subsequently, an LADM profile for Kenya's marine cadastre was developed and validated through expert interviews. In the final stage, the developed marine cadastre LADM profile was integrated with the land cadastre LADM profile, created by Okembo et al. (2023), using the realization relationship. This integration resulted in a seamless data model for Kenya's marine and land cadastre systems. The following sections summarize the key findings, implications, limitations, and recommendations derived from the research.

The first key finding of this study is the development of a marine cadastre LADM profile for Kenya. This model was developed using marine-specific features and key information obtained from analyses of Kenya's legislation on marine and coastal areas, as well as a literature review. LADM Edition 2 Part 3 was selected as the data model. During the interviews conducted in Kenya, it was noted that the Ministry of Mining, Blue Economy, and Maritime Affairs is involved in Marine Spatial Planning initiatives and is developing a platform to collect all marine data. This platform includes efforts to develop a data model for the studies to be compiled. The marine cadastre LADM profile approach developed in this thesis can be considered a methodological response to this need in Kenya.

Furthermore, to enhance the integration of marine and land cadastre in Kenya, an integrated LADM profile was developed. This integrated LADM profile yielded a seamless data model for both marine and land cadastre, thereby aiming to improve their integration in Kenya. Additionally, the Go Blue project, aimed at Integrated Coastal Zone Management (ICZM), is being implemented in Kenya. This project is funded by the European Union (EU) and receives technical support from the United Nations Environment Programme (UNEP), involving numerous government agencies in Kenya. During the interviews, it was mentioned that a platform is being created under this project for improved coastal zone planning, where the necessary spatial data for coastal zone management will be maintained. The integrated LADM profile developed in this thesis can enhance data management, institutional collaboration, and coastal zone management, thus contributing to more effective ICZM in Kenya.

6.1. Limitations

During the course of this thesis, several limitations were encountered. A notable limitation was the lack of availability of the International Organization for Standardization (ISO) documentation for LADM Edition 2 Part 3. To mitigate this issue, the study utilized the IHO S-121 (Maritime Limits and Boundaries) documentation alongside the LADM Edition 2 Unified Modeling Language (UML) diagrams and descriptions available on the ISO-TC211 (Geographic information/Geomatics) GitHub page to understand the model. Another limitation occurred during the interview process. Efforts were made to interview experts responsible for both land and marine area management. However, challenges arose because marine area experts had limited familiarity with LADM, while land area experts lacked detailed knowledge of marine management. This disparity led to difficulties during the pre-interview thesis presentation, which addressed different challenges for both groups. A further limitation was the time constraint associated with interviews.

Due to the busy schedules of the experts and the need to thoroughly explain the thesis work, particularly given the different areas of expertise (marine or land administration), the limited interview time required careful management and optimal adjustment of interview questions to ensure comprehensive coverage of the topics. Also, the area of specialties of the experts may not be sufficient to represent all related stakeholders in Kenya. Additionally, access to data used for marine and coastal areas in Kenya was restricted, which posed another limitation. While the integrated LADM profiles were designed to address Kenya's specific needs, their applicability to other contexts or countries may necessitate further adaptation.

6.2. Recommendations

In terms of future research recommendations, a focus on the implementation area, which is also a limitation of this thesis, could be valuable. Conducting longitudinal studies would assist in evaluating the effectiveness of the integrated model over time and identifying any technical and operational deficiencies or areas requiring improvement in the integrated LADM profiles during the implementation process. Additionally, exploring alternative integration methods beyond the realization approach for integrating land and marine cadastre data models could be beneficial. Comparing these integrated data models by listing their respective advantages and disadvantages could provide further insights.

Furthermore, several recommendations are proposed for the Government of Kenya regarding the establishment of marine cadastre and enhanced land-sea integration. First, while Kenya prioritizes Marine Spatial Planning (MSP) and ICZM, there is a lack of dedicated work on marine cadastre. It is essential for Kenya to support MSP and ICZM efforts with marine cadastre initiatives to establish a more robust system. Specifically, parcelization of terrestrial areas for ICZM would facilitate the management of coastal areas.

Moreover, consolidating separately conducted projects for MSP and ICZM into a single unified project and gathering data on marine and coastal areas in one platform would expedite ICZM efforts. Publishing Geographic Information System (GIS) visualizations of the data on this platform and providing users with the ability to easily interpret and utilize integrated cadastral data would enhance decision-making throughout the project. Additionally, incorporating time-varying elements into the data on this platform could be useful for the management and governance of leasehold and license rights, such as aquaculture leases or fishing licenses.

LIST OF REFERENCES

Abdul-Rahman, A. (2017). *Advances in 3D Geoinformation*. http://www.springer.com/series/7418

Abramic, A., Norton, D., Sarretta, A., Menegon, S., Katsika, M., Gekas, V., Rybka, K., & Fernández-Palacios, Y. (2023). *Maritime Spatial Planning Data Framework (MSPdF)*. https://doi.org/10.2926/440667

Alattas, A. F., Perencanaan, B., Nasional, P., & Kalogianni, E. (2021). *The Foundation of Edition II of the Land Administration Domain Model*. https://www.researchgate.net/publication/353481187

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). https://doi.org/10.3390/ijgi6070194

Ayyam, V., Palanivell, S., & Chandrakasan, S. (2019). *Coastal Ecosystems of the Tropics-Adaptive Management*.

Bar-Maor, A. (2022). *Mapping ArcGIS Parcel Fabric to LADM - Commonalities, Gaps and Implementation*. https://doi.org/10.4233/uuid:5af28bb8-ab49-4ec5-bf9e-e1c3639215a8

Barry, M., & Molen, P. Van Der. (2003). *Ocean governance and the marine cadastre: The Netherlands North Sea*. https://www.researchgate.net/publication/228952029

Beaupré, J.-F., Lévesque, S., Ahola, R., Durand, S., O'Brien, D., Pritchard, J., & Alcock, M. (2022). Development of S-121 for Maritime Limits and Boundaries. *The International Hydrographic Review*, *28*, 94–107. https://doi.org/10.58440/ihr-28-a07

Bertolino, A., Angelis, G. De, Sandro, A. Di, & Sabetta, A. (2011). Is my model right? Let me ask the expert. *Journal of Systems and Software*, *84*(7), 1089–1099. https://doi.org/10.1016/j.jss.2011.01.054

Binns, A., Rajabifard, A., Collier, P. A., & Williamson, I. (2014). *Developing the Concept of a Marine Cadastre: An Australian Case Study*. https://www.researchgate.net/publication/251786258

Body, C., Lemmen, C., Kara, A., & Oosterom, P. Van. (2022). *Progress Report on the Revision of the Land Administration Domain Model (LADM) Management*.

Calado, H., & Gil, A. (2010). *Geographic Technologies Applied to Marine Spatial Planning and Integrated Coastal Zone Management*.

Coast Development Authority. (2012). *COAST DEVELOPMENT AUTHORITY ACT*. www.kenyalaw.org

Cockburn, S., Nichols, S., & Monahan, D. (2003). *UNCLOS' POTENTIAL INFLUENCE ON A MARINE CADASTRE: DEPTH, BREADTH, AND SOVEREIGN RIGHTS AUTHORS*. http://www.sli.unimelb.edu.au/maritime/publications/PCGIAP-Cadastral%20WG-Marine%20Cadastre-

Contarinis, S., Pallikaris, A., & Nakos, B. (2020). The value of marine spatial open data infrastructures-potentials of IHO S-100 standard to become the universal marine data model. *Journal of Marine Science and Engineering*, *8*(8). https://doi.org/10.3390/JMSE8080564

Daria, R., Vladimir, Z., Mikhail, S., Boris, A., & George, G. (2012). Concept of State Cadastre of the marine coastal zone of the Russian Federation. *Ocean: Past, Present and Future - 2012 IEEE/OES Baltic International Symposium, BALTIC 2012*. https://doi.org/10.1109/BALTIC.2012.6249170

Dawidowicz, A., & Źróbek, R. (2014). *Multipurpose Water-Marine cadastre in Poland-Development directions*. www.grida.no/baltic/

Erbas, Y. S., Nisanci, R., Ozcelik, A. E., Yomralioglu, T., & Selcuk, Y. (2014). *The Requirements of Marine Cadastre in Turkey*.

European Union. (2014). *Marine Strategy Framework Directive*.

Flego, V., Roić, M., & Benasić, I. (2018). *Is LADM ready for the Maritime Domain?-Case study Croatia*.

Fowler, C., & Treml, E. (2001). *Building a marine cadastral information system for the United States - a case study*. www.elsevier.com/locate/compenvurbsys

Griffith-charles, C., & Sutherland, M. (2014). *Governance in 3D, LADM Compliant Marine Cadastres* (Vol. 3).

Griffith-charles, C., Sutherland, M., & Lalloo, S. (2018). *Extensions to the LADM Trinidad and Tobago toward a Juridical, Fiscal and Marine Cadastre*.

Hernandi, A., Abdulharis, R., Hendriatiningsih, S., & Saptari, A. Y. (2014). *Exploring of Possibility of Developing Multipurpose Marine Cadastre INDONESIA Exploring the Possibility of Developing Multipurpose Marine Cadastre in Indonesia*.

Hoogsteden, C., & Robertson, B. (1998). *On land off shore strategic issues in building a seamless cadastre for New Zealand*.

International Federation of Surveyors. (2003). *CUNB-FIG Meeting on Marine Cadastre Issues*.

International Hydrographic Organization. (2015). *S-100 - Universal Hydrographic Data Model - Edition 2.0.0*. www.iho.int

International Hydrographic Organization. (2016). *IHO S121 Feature Model for Maritime Limits and Boundaries*.

International Hydrographic Organization. (2017). *The S-121 Maritime Limits and Boundaries Standard*.

International Hydrographic Organization. (2019a). *Maritime Limits and Boundaries Product Specification*.

International Hydrographic Organization. (2019b). *Maritime Limits and Boundaries Product Specification - Annex A: Data Classification and Encoding Guide*.

Irene, M., Yadav, P., Chaubey, A., Singh, S. S., & Professor, A. (2022). *PROTECTION OF MARINE HEALTH TO BOOST BLUE ECONOMY-AN IMMINENT MEASURE FOR EQUITABLE EXISTENCE OF LIFE IN OCEAN AND ON LAND*. https://doi.org/10.48047/NQ.2022.20.22.NQ10395

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

Kaminskis, J., Neimane, L., & Adel Shokry Fahim, M. (2022). *Characteristics and Dynamics of the Latvian, Lithuanian and Egyptian Marine Cadastre*.

Kara, A., Lemmen, C., Oosterom, P. van, Kalogianni, E., Alattas, A., & Indrajit, A. (2024). Design of the new structure and capabilities of LADM edition II including 3D aspects. *Land Use Policy*, *137*. https://doi.org/10.1016/j.landusepol.2023.107003

Kerr, S., Johnson, K., & Side, J. (2014). Planning at the edge: Integrating across the land sea divide. *Marine Policy*, *47*, 118–125. https://doi.org/10.1016/j.marpol.2014.01.023

Kibiwot, R. (2008). *Towards The Formulation Of Kenya's Integrated Ocean Management Policy Including Institutional Framework*.

Kidd, S., & Ellis, G. (2012). From the Land to Sea and Back Again? Using Terrestrial Planning to Understand the Process of Marine Spatial Planning. *Journal of Environmental Policy and Planning*, *14*(1), 49–66. https://doi.org/10.1080/1523908X.2012.662382

Kuria, D., Ngigi, M., Gikwa, C., Mundia, C., & Macharia, M. (2016). A Web-Based Pilot Implementation of the Africanized Land Administration Domain Model for Kenya—A Case Study of Nyeri County. *Journal of Geographic Information System*, *08*(02), 171–183. https://doi.org/10.4236/jgis.2016.82016

Land Information New Zealand. (1999). *Principles for a Seabed Cadastre*.

Lee, H. (2009). *Building a Marine Cadastre for South Korea*.

Lemmen, C. (2012). *A Domain Model for Land Administration*. www.ncg.knaw.nl

Lemmen, C., & Oosterom, P. Van. (2011). *ISO 19152-THE LAND ADMINISTRATION DOMAIN MODEL*.

Lemmen, C., Oosterom, P. Van, Kalogianni, E., & Shnaidnman, A. (2019). *The scope of LADM revision is shaping-up*. https://www.researchgate.net/publication/335867359

Lengoiboni, M., Bregt, A., & Molen, P. van der. (2010). Pastoralism within land administration in Kenya-The missing link. *Land Use Policy*, *27*(2), 579–588. https://doi.org/10.1016/j.landusepol.2009.07.013

Longhorn, R. (2016). *MARINE SPATIAL PLANNING & MARINE CADASTRE: CHALLENGES AND ISSUES*.

Míguez, B. M., Novellino, A., Vinci, M., Claus, S., Calewaert, J. B., Vallius, H., Schmitt, T., Pititto, A., Giorgetti, A., Askew, N., Iona, S., Schaap, D., Pinardi, N., Harpham, Q., Kater, B., Populus, J., She, J., Palazov, A. V., McMeel, O., … Hernandez, F. (2019). The European Marine Observation and Data Network (EMODnet): Visions and roles of the gateway to marine data in Europe. *Frontiers in Marine Science*, *6*(JUL). https://doi.org/10.3389/fmars.2019.00313

Ministry For Environment And Mineral Resources. (2010). *Integrated Coastal Zone Management Action Plan For Kenya*.

Mwanguni, S. M., Mwandotto, J., & Ong'anda, H. (2023). *Integrated Coastal Zone Management in Kenya*. http://hdl.handle.net/1834/7116

National Council for Law. (2010). *THE CONSTITUTION OF KENYA*. www.kenyalaw.org

National Environment Management Authority. (2007). *Integrated Coastal Zone Management Policy*.

Nichols, S., Monahan, D., & Sutherland, M. (2000). *Good Governance of Canada's Offshore and a Zone Towards an Understanding of the Marine Boundary Issues*.

Obura, D. (2017). *Reviving the western Indian Ocean economy : actions for a sustainable future*. WWF, World Wide Fund for Nature.

Okembo, C., Lemmen, C., Kuria, D., & Zevenbergen, J. (2023). Land administration domain model profile for Kenya. *Survey Review*. https://doi.org/10.1080/00396265.2023.2293360

Omg. (2009). *OMG ® Unified Modeling Language ® (OMG UML ®)*. https://www.omg.org/spec/UML/20161101/PrimitiveTypes.xmi

Philip, O. (2020). *Utility Of Spatial Planning As A Tool For Regulating Tourism Activities In Kenya's Land-Sea Interface For Sustainable Blue Economy*.

Philip, O., Odote, C., & Kibugi, R. (2020). INTEGRATING MARINE SPATIAL PLANNING IN GOVERNING KENYA'S LAND-SEA INTERFACE FOR A SUSTAINABLE BLUE ECONOMY. *Law, Environment and Development Journal*, *16*(2), 178–194. https://doi.org/10.25501/SOAS.00033484

Post, J., & Lundin, C. (1996). *Guidelines for integrated coastal zone management*.

Psomadaki, S., Dimopoulou, E., & Oosterom, P. van. (2016). Model driven architecture engineered land administration in conformance with international standards. *Open Geospatial Data, Software and Standards*, *1*(1). https://doi.org/10.1186/s40965-016-0002-3

Reddy, K. (2015). *Investigating The Feasibility Of Establishing A South African Marine Cadastre*.

Robertson, B., Benwell, G., & Hoogsteden, C. (1999). *The Marine Resource: Administration Infrastructure Requirements*. https://www.researchgate.net/publication/2579948

Ruwa, R. (2011). *Policy And Governance Assessment Of Coastal And Marine Resource Sectors In Kenya In The Framework Of Large Marine Ecosystems*.

Schlüter, A., Assche, K. Van, Hornidge, A. K., & Văidianu, N. (2020). Land-sea interactions and coastal development: An evolutionary governance perspective. *Marine Policy*, *112*. https://doi.org/10.1016/j.marpol.2019.103801

Seidl, M., Scholz, M., Huemer, C., & Kappel, G. (2015). *UML @ Classroom - An Introduction to Object-Oriented Modeling*. http://www.springer.com/series/7592

Sheppard, V. (2021). *Research Methods for the Social Sciences: An Introduction*.

Siriba, D., & Nwenda, J. (2013). *Towards Kenya's Profile of the Land Administration Domain Model (LADM).*

Smith, H., Maes, F., Stojanovic, T., & Ballinger, R. (2011). The integration of land and marine spatial planning. *Journal of Coastal Conservation*, *15*(2), 291–303. https://doi.org/10.1007/s11852-010-0098-z

Strain, L., Binns, A., Rajabifard, A., & Williamson, I. P. (2005). *SPATIALLY ADMINISTERING THE MARINE ENVIRONMENT.*

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

Sutherland, M., & Nichols, S. (2006). *Issues in the Governance of Marine Spaces.*

The Fletcher School. (2017). *Law of the Sea.* The Fletcher School of Law and Diplomacy, Tufts University. https://sites.tufts.edu/lawofthesea/

UK Hydrographic Office. (2019). *Consideration Of A Regional Marine Spatial Data Infrastructure (MSDI).* https://www.iho.int/srv1/index.php?option=com_content&view=article&id=483&It

Uku, J., Allela, A., Osore, M., & Wambiji, N. (2023). *MARINE SPATIAL PLANNING and the Blue economy in Kenya.* http://www.unesco.org/open-access/

UNESCO. (2009). *Marine spatial planning A Step-by-Step Approach.*

United Nation. (1985). *Nairobi Convention.*

United Nations. (1982). *United Nations Convention on the Law of the Sea.*

United Nations. (2023). *Strengthening cooperation for integrated coastal zone management for achieving sustainable development.* https://unesdoc.unesco.org/ark:/48223/pf0000381388.

Ying, S., Zhang, W., Wang, M., Guo, R., Jia, H., Zhang, C., Chen, X., & Li, C. (2022). *Regulations and Utilizations for 3D Marine Cadastre in China.*

Yue, W., Hou, B., Ye, G., & Wang, Z. (2023). China's land-sea coordination practice in territorial spatial planning. In *Ocean and Coastal Management* (Vol. 237). Elsevier Ltd. https://doi.org/10.1016/j.ocecoaman.2023.106545

Zamzuri, N. A. A. (2022). *The Development Of Malaysia's Three-Dimensional Marine Cadastre Data Model Based On Land Administration Domain Model.*

Zamzuri, N. A. A., & Hassan, M. I. (2021). 3D Marine Cadastre within Land Administration. *IOP Conference Series: Earth and Environmental Science*, *767*(1). https://doi.org/10.1088/1755-1315/767/1/012039

Zamzuri, N. A. A., Hassan, M. I., & Rahman, A. A. (2021). *Developing 3D Marine Cadastre Data Model within Malaysian LADM Country Profile – Preliminary Result.*

Zamzuri, N. A. A., Hassan, M. I., & Rahman, A. 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. https://doi.org/10.5194/isprs-archives-XLVI-4-W3-2021-337-2022

ANNEXES

Annex 1: Questions for Semi-structured Interview

Questions- marine and coastal management in Kenya

1. Is the coastal area included in the terrestrial cadastre system?
2. Do you have a title system for marine areas?
3. What is the current state of Marine Cadastre development in Kenya?
4. Have coastal and marine areas been parceled, or are there plans to do so?
5. What is the current state of Integrated Coastal Zone Management in Kenya?
6. What is the current state of Marine Spatial Planning (MSP) in Kenya?
7. What activities are focused on in marine and coastal areas?
8. Which institutions are involved in MSP, and what are their responsibilities?
9. What roles do the coastal states and National Land Commission play in Marine Spatial Planning and Integrated Coastal Zone Management?
10. Who is responsible for surveying the Kenyan coasts and marine areas?
11. Does Kenya share its Exclusive Economic Zone (EEZ) and territorial sea with Tanzania and Somalia? If so, do you have treaties with these countries, and are there any constraints or fixed borders in these shared zones?
12. Do you have a platform for sharing data related to marine and coastal areas?
13. Is the Kenya National Oceanographic Data Centre (KeNODC) still active?
14. Have the areas designated for activities been planned and delineated?
15. Are you currently using any data model for land administration?
16. Are you using any data model for marine administration?
17. What methods do you use to conduct surveys in marine areas, and is all the data digital?
18. How do you record 3D data for marine areas?
19. What do you use for the monumentation of boundaries?
20. Can individuals hold rights in marine areas?
21. Can private companies lease areas in marine regions?
22. Does any international organization have rights in Kenya's EEZ?
23. Do any other countries have rights in Kenya's EEZ?
24. Do you record use types in marine administration?
25. Do you record cover types in marine administration?
26. Do you have a mortgage system for marine areas?
27. What types of rights do communities have in coastal or marine areas?
28. When determining rights for marine areas, are they specified by zones such as sea surface, water body, and seabed?
29. Do you keep historical data?
30. For example, if you grant fishing licenses to multiple companies in an area, do they fish randomly in the granted area, or is the area divided among them?
31. Is there a licensing system in Kenya for activities in marine areas?

Questions- Feedback for the first draft of LADM Profile

Source and VersionedObject Class

1. Do we need the Source and VersionedObject classes for the situation in Kenya?
2. Is the `beginRealWorldLifespanVersion` attribute necessary for marine management in Kenya?
3. Should we add the `collection` attribute to describe the feature membership to a dataset or collection, such as indicating that a set of data is part of a particular nation's collection and was deposited by that nation?
4. Should the `sourceOnlineResource` attributes in the Source class be kept or removed?
5. Does the `administrativeSourceTypeList` code list match the situation in Kenya?
6. Does the LA_`AvailabilityStatusType` code list match the situation in Kenya?
7. Do you have any suggestions for this package?

Party Package

1. Is the Party class suitable for the Kenyan context?
2. Is the `partyGroupType` attribute appropriate for Kenya?
3. Is the concept of constraints within the party class appropriate for the situation in Kenya?
4. Are the code lists for `MG_PartyTypeList`, `MG_GroupPartyTypeList`, and `MG_PartyRoleType` correct for Kenya?
5. Do you have any suggestions for this package?

Administrative Unit Package

1. Is the Governance class suitable for Kenya?
2. Is the BAUnit class suitable for Kenya?
3. Is the `timeSpec` attribute meaningful to keep for Kenya?
4. Is the Condependance relationship relevant to Kenya's marine management system?
5. Do the code lists for rights, restrictions, and responsibilities reflect the legal framework in Kenya?
6. Do you have any suggestions for this package?

Spatial Unit Package

1. Does the method for recording 3D spatial data match the way 3D spatial data is recorded in Kenya?
2. Does the SpatialSourceType list represent the source types for marine areas in Kenya?
3. What is the featureToFeatureRelation relationship for Feature Units?
4. Is the MG_LegalSpaceUtilityNetwork class relevant and MG_`UtilityNetworkType` represent the situation in Kenya.
5. Do you have any suggestions for this package?

External Class

1. Is it necessary to have extension classes to record marine cover type and marine use type for marine areas?
2. Do the `ExtUseType` and `ExtCoverType` codelist represent the situation in Kenya?
3. Do you have any suggestions for this package?

Annex 2: Questions for Validation

QUESTIONS REGARDING STRUCTURE OF STANDARDIZATION

Questions regarding structure of ***party packages***

	Yes	Somewhat	No	NE	DK
Is it necessary to record the types of parties who hold rights to the marine environment?	○	○	○	○	○
Is it necessary to record the roles of parties who hold rights to the marine environment?	○	○	○	○	○
Is it possible for more than one party to have rights in a single planned marine area?	○	○	○	○	○
Does the presented method of recording group party shares accurately represent the situation in Kenya?	○	○	○	○	○

Which one of these components is a kind of **party type?** (You can choose more than one)

- ☐ baUnit
- ☐ group
- ☐ natural person
- ☐ private company
- ☐ non natural person
- ☐ state agency
- ☐ international organization
- ☐ state

Which one of these components is a kind of **group party type?** (You can choose more than one)

- ☐ community
- ☐ Informal community
- ☐ family Polygamy
- ☐ Aggrement
- ☐ Association
- ☐ Condominium

Which one of these components is a kind of **party role type?** (You can choose more than one)

- [ ] Aquaculture Operator
- [ ] Fishing Company
- [ ] Maritime Transporter
- [ ] bank
- [ ] Mining Company
- [ ] notary
- [ ] Recreational User
- [ ] Research Institute
- [ ] Security Guard
- [ ] Tourist Operator

Questions regarding structure of ***administrative unit packages***

	Yes	Somewhat	No	NE	DK
Is it possible for a single party to hold rights in multiple planned marine areas?	○	○	○	○	○
Is it necessary to keep documents such as proclamations, laws, or treaties related to marine rights, restrictions and responsibilities?	○	○	○	○	○
Can a type of right occur in time intervals within a year, where you cannot benefit from this right during certain months?	○	○	○	○	○
Is it possible that when you have a right for an activity in the marine sector, it comes with associated responsibilities or restrictions?	○	○	○	○	○

Which one of these components is a kind of **right type?** (You can choose more than one)

- [ ] easement Right
- [ ] harvest Right
- [ ] training Right
- [ ] mineral Right
- [ ] passage Right
- [ ] usurufct
- [ ] recreation Right
- [ ] researchRight
- [ ] sovereignty Right

Which one of these components is a kind of **restriction type?** (You can choose more than one)

- [ ] activity Restriction
- [ ] easement Restriction
- [ ] servitude
- [ ] jurisdication Restriction
- [ ] mortgage
- [ ] passage Restriction
- [ ] resourceRestriction
- [ ] timeBased Restriction

Which one of these components is a kind of **responsibility type?** (You can choose more than one)

- [ ] maintenance Responsibility
- [ ] protectionResponsibility
- [ ] restoration Responsibility

Questions regarding structure of ***feature unit packages***

	Yes	Somewhat	No	NE	DK
Does the method for recording 3D spatial data align with current practices in Kenya?	○	○	○	○	○
Is it necessary to record information about utilities in Kenya's marine administration?	○	○	○	○	○

Which one of these components is a kind of **utility type?** (You can choose more than one)

- [ ] electricity
- [ ] gas
- [ ] oil
- [ ] sewerage
- [ ] telecommunication

Which one of these components is a kind of **spatial source type?** (You can choose more than one)

- [ ] field sketch
- [ ] gnss Survey
- [ ] hydrographic Chart
- [ ] lidar Survey
- [ ] ortophoto
- [ ] satellite Imagery
- [ ] Sonar Survey

	Yes	Somewhat	No	NE	DK
Is it necessary to identify the nation or organization responsible for creating data related to marine areas?	○	○	○	○	○

Which one of these components is a kind of **use type?** (You can choose more than one)

- [ ] Anchorage
- [ ] Energy Instrument
- [ ] Fishing
- [ ] Forest
- [ ] Military
- [ ] Mining
- [ ] Navigation
- [ ] Protected Area
- [ ] Recreational
- [ ] Research

Which one of these components is a kind of **cover type?** (You can choose more than one)

- ☐ Coastal Forest
- ☐ Coral Reef
- ☐ Mangrove Forest
- ☐ Sandy Beach
- ☐ Sea Grass Bed
- ☐ Wetland

QUESTIONS REGARDING APPLICABILITY OF THE INTEGRATED MODEL

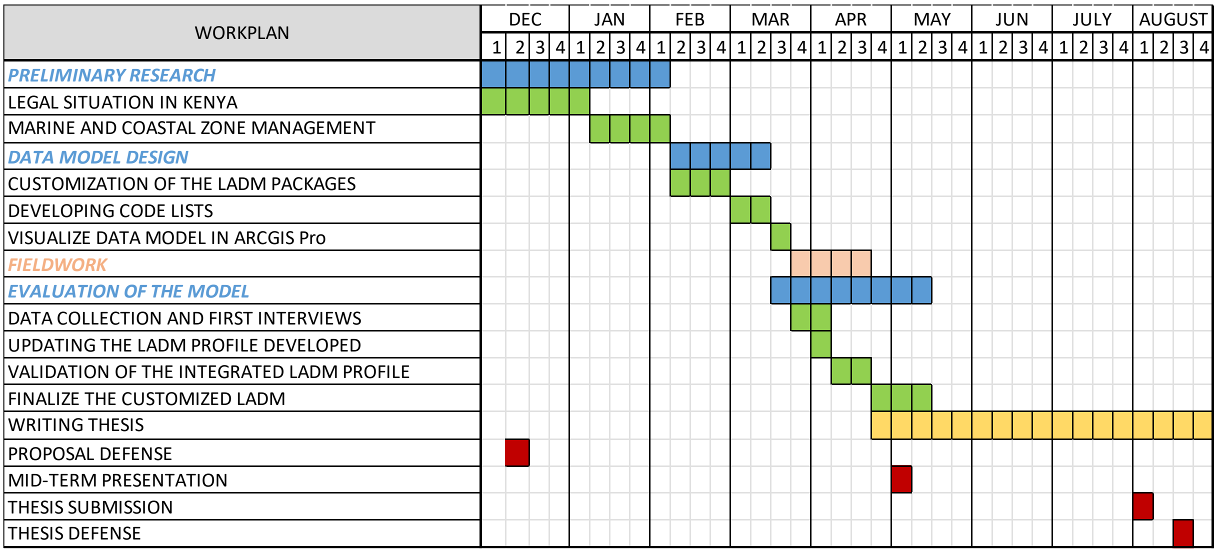
Question about the integration of LADM profiles

	Yes	Somewhat	No	NE	DK
Do you think these scenarios represent the situation in Kenya?	○	○	○	○	○
Do you think this integrated LADM profile will enhance the integration of marine and land management in Kenya?	○	○	○	○	○

How important do you think it is to have integrated data models for marine and land management in Kenya?

Your answer

Annex 3: Workplan



Annex 4: Data Management Plan

SUB-TOPIC	NAME OF DATA FILE	SOURCE (PRIMARIY OR SECONDARY DATA)	IF SECONDARY, WHO IS THE OWNER	RESTRICTIONS AND LICENSE	DATA FORM	DATA FORMAT	YEAR OF DATA	CONTAINS PERSONAL DATA (Y/N)	LINKS
EEZ of the Kenya	ExclusiveEconomicZone	Secondary	Flanders Marine Institute	Open data policy	Vector	.shp	2023	N	https://www.marineregions.org/gazetteer.php?p=details&id=8349
Marine Protected Areas	MarineProtectedAreas	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Navigation Path	NavigationPath	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Mining Areas	MiningAreas	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Military Areas	MilitaryAreas	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Fishing Areas	FishingAreas	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Oil and Gas Exploration	OilandGasExploration	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Cables and Pipelines	CablesandPipelines	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Tourism Areas	TourismAreas	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Industrial Areas	IndustrialAreas	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Community Areas	CommunityAreas	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Main Roads	MainRoads	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Port	Port	Primary		Open data policy	Vector	.shp	2024	N	Created by Author
Waste Disposal Point	WasteDisposalPoint	Primary		Open data policy	Vector	.shp	2024	N	Created by Author

Annex 5: Research Matrix

Objectives	Research Questions	Methods	Respondent	Data Sources	Expected Outcome
1 To understand the current state of Kenya's marine and coastal administration strategies, including relevant laws, policies, and spatial planning initiatives for developing a data model for marine cadastre in Kenya.	**RQ1:** What are the marine and coastal administration strategies, including relevant laws, policies, and spatial planning initiatives in Kenya?	Document Analysis		- Documents for the projects regarding Marine Spatial Planning and Integrated Coastal Zone Management in Kenya	- Identification of Responsible Ministries - Understanding Data Collection and Sharing between Government agencies - Comprehensive Scenario Analysis for Marine Cadastre in Kenya
	RQ2: What are the marine-specific features and key information that are essential for developing the data model for marine cadastre in Kenya?			Acts and Policies in Kenya about - Land-Sea Integration - Parks and Wildlife Conservation - Fisheries and Mariculture - Mining and Energy - Tourism and Recreational Activities - Ports and Maritime Transport - Coastal Agriculture and Forestry - Defense - Cables and Telecommunication	- Documentation of Rights, Restrictions, and Responsibilities - Identification of Responsible Parties - Identification of necessary Classes, attributes and associations between classes
2 To justify the selection of the LADM as a suitable data model for integrating marine and land cadastre in Kenya.	**RQ3:** Why is the LADM considered a suitable data model for integrating marine and land cadastre in Kenya, based on its accessibility, inclusion of marine-specific features, and ability to integrate with existing land administration models?	Comparison between data models		- LADM Edition 2 Part 3 - IHO S121 - National Data Models - Maritime Spatial Planning Data Framework (MSPdF)	- Among the available data models, LADM was selected due to its suitability for integrating marine and land cadastre, compared to alternative data models.

3 To develop a marine cadastre LADM profile for Kenya, integrate this profile with the existing LADM profile for the land cadastre and validate both the marine cadastre and the integrated LADM profiles.	**RQ4:** What specific modifications, inclusions, or exclusions are necessary to tailor LADM Edition 2 Part 3 for the Kenyan marine cadastre context based on identified marine-specific features and key information?	LADM Profile Design for Marine Cadastre		- Laws, Policies and the documents regarding MSP and ICZM Projects in Kenya - LADM Edition 2 Part 3 Documents - IHO S-121 Documents	- Development of LADM Profile for Kenya marine cadastre - Clear Representation of Legal Framework
	RQ5: How does the integration of LADM profiles for marine and land cadastre enhance data interoperability and facilitate seamless administration in Kenya?	LADM Profile Integration	- Clifford Okembo (Academician developing LADM profiles for land administration in Kenya)	- LADM Edition 2 Part 3 Documents - Developed Kenya Marine Cadastre LADM Profile - LADM Profile for Land Administration in Kenya developed by Clifford Okembo	- Seamless LADM data profile for marine and land cadastre in Kenya - Improved Spatial Planning in Kenya - Improved Integrated Coastal Zone Management in Kenya
	RQ6: To what extent does the developed LADM profile represent marine administration in Kenya, and how does the integrated LADM profile contribute to the integration of marine and land administration, according to expert-based interviews?	Semi Structured Interviews and Validation Method Used in Antonia Bertolino's study "Is my model right? Let me ask the expert"	- Domain Experts	- Feedback from the experts	- Refinement of Kenya Marine Cadastre LADM Profile - Validity of Kenya Marine Cadastre LADM Profile - Validity of Kenya Integrated LADM Profile