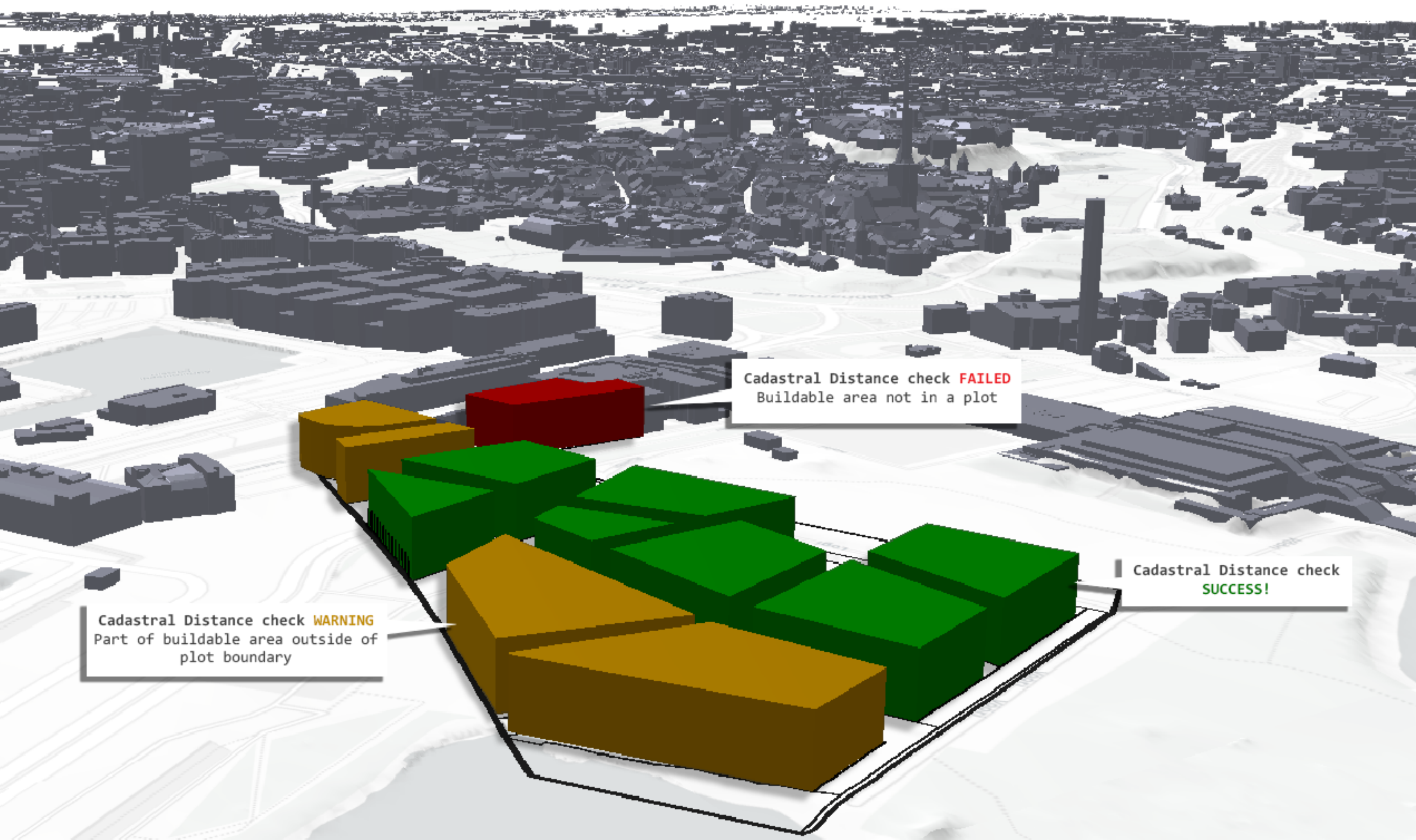
MSc thesis in Geomatics

Spatial Plan Registration and Compliance Checks in Estonia, based on LADM Part 5: Spatial Plan Information

Simay Batum

2024



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Simay Batum : Spatial Plan Registration and Compliance Checks in Estonia, based on LADM Part 5: Spatial Plan Information (2024)

Code access

The thesis repository, which includes database scripts, pilot IFC files used in the prototype, the FME script, and additional machine learning tools, can be accessed at the following link: https://github.com/simaybtm/LADM-4-Estonia

The work in this thesis was conducted in collaboration with Future Insight Group.

https://www.futureinsight.nl/

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Abstract

Traditional planning processes are often manual, time-consuming, and prone to errors. While much of the recent research has focused on automating the permitting phase, this study addresses an earlier step: automating compliance checks between spatial plans and against local regulations in the early planning stages. To ensure that spatial plans align with general regulatory frameworks prior to the permitting stage, this research introduces a standardized approach by integrating Industry Foundation Classes (IFC) with the Land Administration Domain Model (LADM) Part 5 Spatial Plan Information (ISO Draft International Standard: 19152-5). This integration enhances data management, facilitates seamless information exchange, and ensures adherence to international standards. By automating early-stage plan compliance checks—such as verifying building height limits or distances between structures—the research aims to streamline the process, ensuring that only compliant plans proceed to the permitting phase, where the design itself is assessed for approval.

To achieve this, the integration of IFC with LADM Part 5 is explored to standardize model-based checking between spatial plans during the early planning stage, using Estonia as a case study. As one of the most advanced digital societies, Estonia is continually improving its digital services, making it an ideal setting for this research. The primary goal is to enhance efficiency, interoperability, and standardization in these checks by incorporating LADM Part 5 into the framework, ensuring that various levels of spatial plans adhere to both higher-level regulations and local requirements before progressing to the permitting stage. This includes assessments and validation between different plan levels (e.g., Master Plan vs Detailed Plan) and within the same level (e.g., Detailed Plan vs Detailed Plan).

The methodology involves several key steps. First, a country profile for Estonia using LADM Part 5 is developed and tailored to the specific needs of the Estonian spatial planning system, detailing how the country acquires, stores, and manages its plan data. Subsequently, a new database is created based on this country profile, establishing a framework for data storage. Then, pilot Detailed Plan datasets, encoded in IFC format, are imported into the new LADM database using custom scripts, enabling checks to be executed through standardized data structures. Findings indicate that integrating LADM with Industry Foundation Classes improves data representation and interoperability while creating a consistent framework for plan assessments, thereby contributing to more efficient and reliable planning systems. Additionally, some simpler checks can be performed directly within the new database using straightforward queries.

Keywords: Spatial Plans, Compliance Checking, LADM, IFC, BIM

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Acronyms

This chapter provides a list of abbreviations and key terms used throughout the report, along with figures and tables. Terms marked with an asterisk (*) are specific to Estonia.

Frequently Used Acronyms

AEC	Architectural Engineering and Construction
BIM	Building Information Modelling
CAD	Computer Aided Design
CityGML	City Geography Markup Language
FME	Feature Manipulation Engine
GIS	Geographic Information Systems
IFC	Industry Foundation Classes
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO	International Organization for Standardization
LADM	ISO 19152 Land Administration Domain Model
LAS	Land Administration Systems
NIBS	The National Institute of Building Sciences (USA)
OGC	Open Geospatial Consortium
SDI	Spatial Data Infrastructures
SEA	Strategic Environmental Assessment
UML	Unified Modeling Language
WFS	Web Feature Service
WMS	Web Map Service

Key Project Terms and Explanations

ACCORD	An EU-funded project focused on automating building permitting and compliance checks.
BCRL	*Building Code Rule Language*, used to define and automate the checking of building regulations.
DSR	*Design Science Research*, a methodology focused on creating and evaluating artifacts to solve problems.
EHR*	*The Estonian Building Registry*, a national database used for managing building information.
IdS	*Information Delivery Specification*, which outlines the specific data required for information exchange.
LADM Part 5 / Part 5	A specific part of the LADM that deals with the management of spatial plan information (19152-5).

NDSP*	*National Designated Spatial Plans* in Estonia, representing large-scale national planning efforts.
NSP*	*National Spatial Plan*s in Estonia, which guide overall land use and development at the national level.
PLANIS*	Estonia’s system for managing planning procedures and tracking spatial plan submissions.
PLANK*	*Üleriigiline planeeringute andmekogu*, Estonia’s centralized national spatial plan database.
PoC	*Proof of Concept*, an initial test or demonstration to show that a concept or approach is feasible.
RPIS*	Estonia’s Spatial Planning Information System, integrated with other national government databases.
STDM	*Social Tenure Domain Model,* an UN-HABITAT model that records informal and customary land tenures, offering an alternative for countries without formal land administration systems.
TCG	*Tallinn City Government*, responsible for managing urban planning and development in Tallinn, Estonia.

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1. Introduction

1.1. Background and Motivation

In the ever-changing realm of urban development, Land Administration Systems (LAS) play a pivotal role in land management and governance. They provide the infrastructure necessary for implementing a country's land-related policies and strategies (Williamson et al., 2008). LAS manage vast amounts of supporting data, typically stored in centralized database systems, including Land Registry, Cadastral systems, Land Information Systems, Land Tenure Systems, and Land Use Planning Systems. As these systems evolve, the increasing complexity of land management demands more sophisticated tools. Specifically in spatial planning disciplines, the reliable and efficient management of space has become more critical than ever for sustainable development (Dželalija & Roić, 2021). To enhance management, transparency, and the efficiency of spatial processes, the move towards digitalization is accelerating (Rodima-Taylor, 2021). This shift has led architects, urban planners, and regulatory bodies to increasingly adopt 3D modeling for collaboration and accessing spatial data through digital platforms.

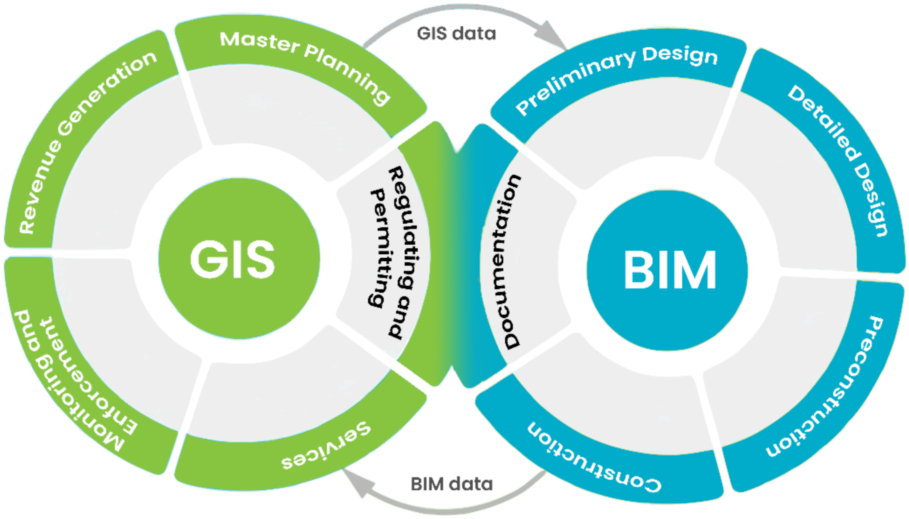

Figure 1. Integration of GIS and BIM. Figure adapted from John Victor.

The rise of digital technologies in the Architectural Engineering and Construction (AEC) sector, driven by advancements in hardware and software, has revealed new possibilities for improving workflows and data management (Noardo et al., 2022; Sabri & Witte, 2023). One of the most transformative developments has been the integration of Geographic Information Systems (GIS) and Building Information Modelling (BIM), which enables collaborative workflows from individual buildings to city-scale planning. These integrated workflows, shown in Figure 1, provide valuable data for LAS and emphasize efficient collaboration across disciplines, promoting data reusability (Kalogianni et al., 2020a).

Among the processes influenced by these integrated workflows are "*regulation and permitting*." Increasingly, there is a growing focus on digitizing these processes to enhance efficiency and accuracy (*ACCORD*, 2024; CHEK: Digital Building Permit Process Map, 2023; *European Network for Digital Building Permits*, n.d.; Noardo et al., 2022; Ullah et al., 2022). Traditional permitting processes typically involve manually reviewing submitted plans for conformity with building regulations—a time-consuming and error-prone approach (Beach et al., 2020). By utilizing BIM models for automated processes, instead of humans manually going through plans, computer algorithms can automate compliance checks, streamlining the process and improving accuracy. Figure 2, illustrates the comparison between simplified traditional permitting and the emerging BIM-based permitting processes.

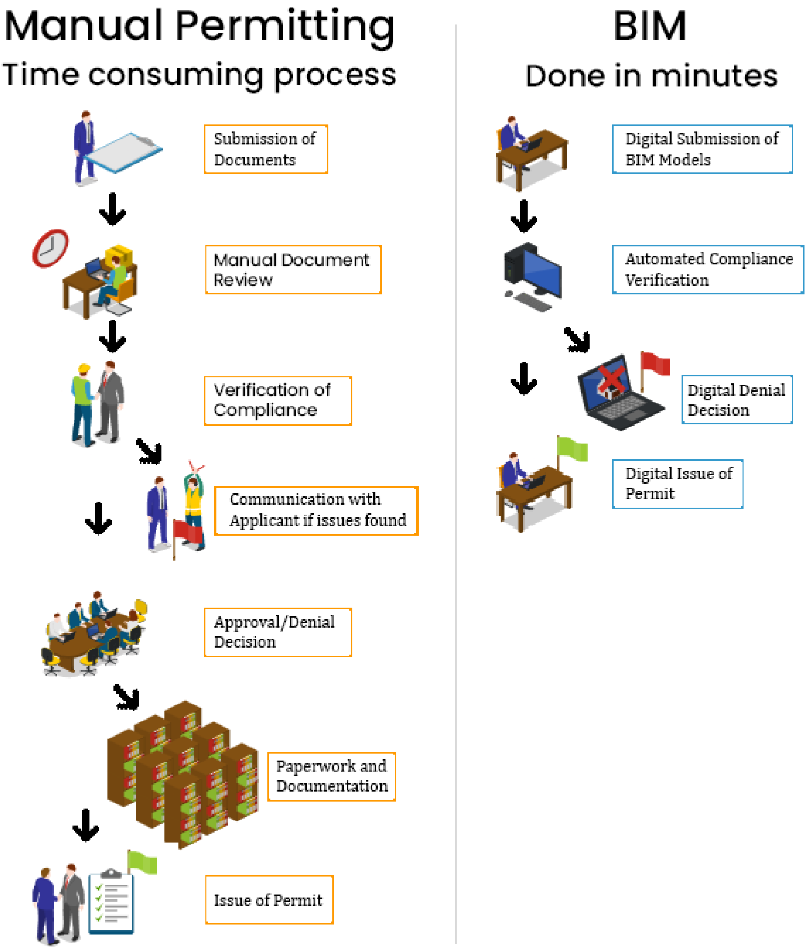

Figure 2. Traditional permitting compared to BIM based permitting.

While most research has focused on the actual BIM-based permitting phase (*ACCORD*, 2024; CHEK: Digital Building Permit Process Map, 2023; Kallinen, 2023), there appears to be limited attention given to the earlier steps, such as compliance checking between spatial plans, that play an vital role before permitting happens. This represents a critical gap in both research and practice, as addressing these checks earlier in the planning process could prevent potential issues that arise during the permitting stage and the sustainability of the implemented design. As noted by Padeiro (2016), a conformance-based approach is essential for evaluating how well land-use planning aligns with predefined planning intentions, ensuring consistency across different levels of spatial plans prior to development. These checks help identify potential key discrepancies early in the planning process, preventing conflicts later in the permitting process. Additionally, research also emphasizes how inconsistencies between local and higher-level planning frameworks can lead to disconnected and inefficient spatial outcomes, highlighting the critical need for vertical coherence between different planning scales (Acheampong & Ibrahim, 2016). For instance, if a Detailed Plan proposes a 12-story building in an area where the Master Plan restricts construction to maximum 3 stories, there is little point in checking for adherence to more detailed building regulations like fire safety measures (usually included in the permitting process). Addressing such discrepancies early on avoids unnecessary permitting checks and streamlines the process by minimizing delays caused by non-compliance issues discovered later.

1.2. Research Problem

In the past, and still in many places today, 2D drawings and paper-based documentation were used for the design, construction, and management of infrastructure and buildings. Drafts that required a lot of work were replaced with more effective documentation methods when Computer Aided Design (CAD) became available (Ondogan & Erdogan, 2006). While CAD was initially not limited to producing 2D models, it brought with it the ability to produce 3D models as well, offering a more flexible and dynamic method of design and documentation. This development cleared the path for additional breakthroughs in digital representation in the AEC sector. One of those breakthroughs was BIM. Because of efficiency, life-cycled data usage, collaborative opportunities and many more, the demand for BIM models at the completion of a building increased. Just like the widespread switch from 2D CAD to 3D solid models in the 1990s, this caused the AEC industry to rapidly favor BIM.

BIM is a process used to create a 3D representation of an asset with both physical and functional information. According to NIBS of USA (the National Institute of Building Sciences) it is also "*...a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle, defined as existing from earliest conception to demolition.*" (Kubba, 2012). While CAD creates 2D or 3D drawings that do not distinguish between their elements, BIM can incorporate 4D (time), 5D (costs) and 6D (asset management) too. Unlike CAD, BIM utilizes an object-oriented information model, providing a classifiable differentiation of individual elements such as "walls," "doors," and "windows" as distinct objects with their unique features and attributes.

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[1] (https://www.oneltd.com/project/birmingham-dental-hospital-school-dentistry-bim/)

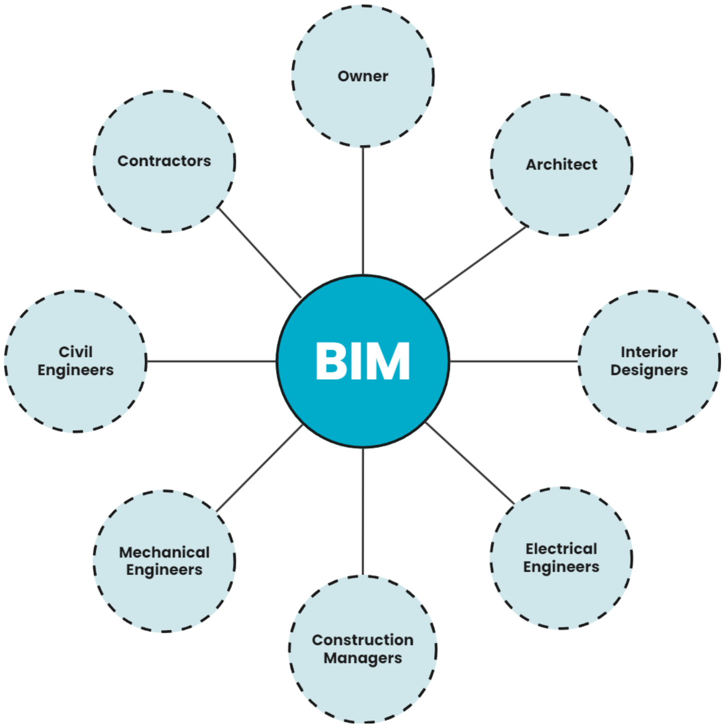


Figure 3. Relationship of BIM to the various stakeholders and project team members.
Figure adapted from M. Shaban & Ashraf Elhendawi (2018).

Information in a BIM model can be shared through a mutually accessible online space referred to as a CDE (Common Data Environment)(Ozkan & Seyis, 2021), and the data collected is referred to as an 'information model'. Figure 3 and Figure 4 show the collaborative nature of a BIM process. This makes it possible for various users to manage information effectively at every stage of a project's life cycle, automating tasks like manufacturing, construction planning, programming, conceptual and detailed design, analysis, documentation, and renovation or demolition. BIM can be stored in various file formats due to the different native software used in the industry, such as ".RVT" for Autodesk's Revit, ".PLN" for ArchiCAD, and more. However, interoperability is achieved through common non-proprietary formats such as the Industry Foundation Classes (IFC) of buildingSMART or Construction Operations Building Information Exchange (COBie), facilitating exchange among different platforms.

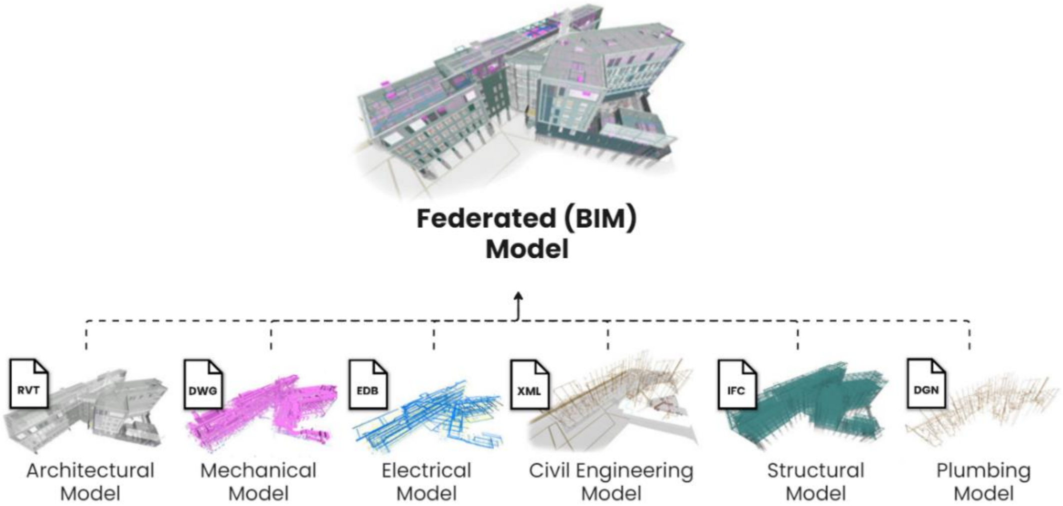


Figure 4. Integration of various discipline models into a federated BIM model.
Figure adapted from ONE Creative environments Ltd.

Although BIM is mostly known for representing detailed building designs, it is also being utilized for use in plan data, as illustrated in Figure 5. Plan data refers to spatial information related to land use and urban planning, including zoning, land registry, and detailed planning data. This data is often still on paper or in CAD formats without a data model however, with the digitalization and collaborative workflows increasing, there has been on-going researches to utilize IFC for planning data (Kardinal Jusuf et al., 2017; Lars Harrie et al., 2021; OGC, 2016). This trend towards digitalization and the growing demand for standardized spatial data models underlines the relevance of frameworks like the Land Administration Domain Model (LADM), which offers a structured approach for managing various types of LAS information, including spatial plan data.

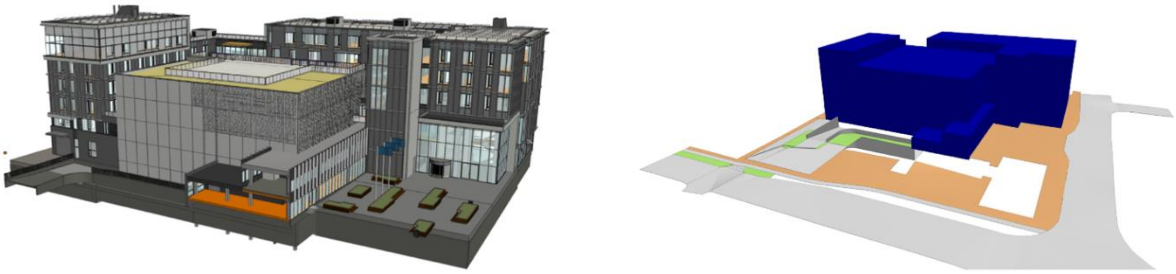


Figure 5. Example of a BIM model of building design (left) and a BIM model of a Detailed Plan (right). Figure by Future Insight Group (2023).

LADM, an ISO standard (ISO19152:2012), serves as an infrastructure for efficient LAS by promoting a common ontology for shared data exchange (Van Oosterom & Lemmen, 2015). LADM Part 5: Spatial Plan Information (DIS 19152-5, 2024) extends the LADM framework to support the integration of spatial plans by standardizing how spatial planning information, such as land use regulations and zoning, is represented and managed within land administration systems. It facilitates the organization and management of plan units, supports planning hierarchies, and allows for consistent representation of spatial regulations and restrictions across different planning scales (Kara et al., 2022).

The need for standardization and consistency in spatial planning is fundamental for improving the efficiency and reliability of planning systems. Integrating frameworks like LADM Part 5 with IFC plan data can improve data representation, enhance interoperability, and create a consistent approach for conducting plan assessments. Beyond ensuring that spatial plans adhere to higher-level regulations, such as verifying that a Detailed Plan aligns with the guidelines in a Master Plan (sometimes referred also as a Comprehensive Plan), it is equally important to standardize local regulations within the same plan level. For example, ensuring that Detailed Plans meet regulations for minimum building distances from roadways is just as essential as cross-level compliance. LADM Part 5 can address these challenges by providing a clear and standardized framework for documenting planning regulations, storing plan data along with related additional information, and help optimize the checking process for both hierarchical and local requirements. This integrated approach facilitates the seamless validation of spatial plans across multiple levels and ensures internal consistency within the same plan, streamlining the overall planning and later permitting processes.

1.3. Scope of the Study

This research investigates the integration of LADM Part 5 into the workflow for compliance checking between spatial plans. Although BIM-based permit checks have gained attention in recent years, the focus of this study lies in the earlier stages of the planning process, specifically ensuring that spatial plans—such as Detailed Plans—align with higher-level plans, like Master Plans, and other compliance requirements before reaching the permitting phase. Figure 6 illustrates simplified versions of both the manual and the new automated permitting process. The focus of the study lies specifically in "*Step 3*" of the "*New Process*", show in a red box. Thus, the permitting phase (*Step 4*) is beyond the scope of this research, with the study concentrating on improving the interoperability and efficiency of compliance checks during the earlier stages.

Figure 6. Scope of the study.

Plan compliance checks are necessary steps that must be conducted before any permitting process begins, as they ensure that each plan aligns with broader regulatory frameworks. If a plan does not conform to higher-level plans or local regulations, there is no need to proceed with the later building permit checks, as the project would not be viable under existing standards. This highlights the relationship between early-stage plan compliance checks and the BIM-based permitting process: by ensuring conformity between various levels of spatial plans and local regulations, the later permitting process can be streamlined and efficient, reducing the need for repetitive reviews and ensuring that only compliant projects move forward for further assessment.

This study is done in collaboration with Future Insight Group's project with Ministry of Climate (*Kliimaministeerium*) of Estonia that involves the construction of such prototype model. The Estonia project, "*Detailed analysis of the use of the information model of the plan and creation of a prototype solution*," will be used as a case study to develop and assess the LADM Part 5 implementation. More details about the case study can be found in Chapter 3.

The integration of LADM Part 5 will primarily use IFC encoding, with a theoretical comparison to CityGML. The focus is on how these encoding standards can improve the interoperability of spatial plans by facilitating seamless validation between different plan levels and/or other compliance requirements. Although IFC will be the primary focus due to data availability in the case study, the theoretical comparison with CityGML will offer insights into its applicability for similar compliance-checking tasks in the planning process. Overall, this theoretical comparison will highlight how CityGML might perform in similar contexts.

A key scope consideration involves the dataset used in the study. The technical implementation, specifically the development of a script to upload plan data into the new LADM database, focuses on Detailed Plans due to the research's emphasis on the IFC format (which is more suitable for the level of detail required in such plans). Master Plan data, available as WMS and WFS services in the case study, was not included in the implementation phase, as these formats are less relevant for the research's primary focus on BIM-based 3D spatial data. Nonetheless, both the LADM country profile and database were designed to accommodate both Master and Detailed Plans, ensuring that the necessary structures for compliance checks between planning levels are in place.

Furthermore, to explore the compatibility of Estonia's existing 2D-based system with the proposed LADM framework, this research also includes a theoretical investigation of 2D data formats currently in use, as described in section 5.4. This investigation evaluates the limitations of 2D CAD drawings and CSV metadata by examining an example from Estonia's PLANK system (described in section 0). The findings highlight the constraints of the current 2D data environment and underscore the importance of transitioning toward more integrated 3D models like IFC. While the implementation concentrated on Detailed Plans, the study lays a solid foundation for future developments, such as the integration of Master Plan data through additional scripts for formats like WFS and WMS. This focus provides a practical starting point, supporting the broader goals of achieving spatial plan interoperability and enhancing compliance checks across planning levels.

1.4. Research questions

This section addresses the main research question of the thesis. Following, the sub-questions derived from the main one will be discussed. The main research question is:

"How can BIM/IFC be leveraged for the registration of spatial plans and compliance checking in Estonia, utilizing LADM Part 5 Spatial Plan Information (ISO19152-5)?"

The study is structured around the following guiding sub-questions:

1. How can LADM Part 5 be effectively utilized with IFC data models through extensions or other schema mechanisms?
2. What theoretical advantages and challenges would arise from using CityGML data models with LADM Part 5?
3. To what extent can the inclusion of LADM Part 5 contribute to the efficiency of automated compliance checking processes using IFC, impacting accuracy and speed, and what potential differences could exist if CityGML were used?
4. What is the current state of compliance checks between spatial plans in Estonia using IFC models, and how does the proposed solution compare to the existing checking processes in Estonia?
5. How effectively can LADM Part 5 (ISO/DIS 19152-5) represent Estonian spatial plan information and support its utilization for compliance checks?

1.5. Methodology

The methodology used in this study consists of two main steps:

1. Integration of LADM Part 5 into plan data encoded in IFC
2. Assessment of compliance checks with and without LADM in the process

The Estonia case study is used as a reference point throughout the development process of the thesis, utilizing the concurrently developed "*Detailed analysis of the use of the* *information model of the plan and creation of a prototype solution*" project (Future Insight Group, 2024) as a robust testing mechanism. The research was conducted using Design Science Research (DSR) approach (Hevner & Chatterjee, 2010). DSR provides a structured framework that emphasizes the creation of practical artifacts to address real-world problems, making it particularly useful for management and information systems research (Alattas, 2022). The DSR approach differs from traditional research paradigms by prioritizing innovative approaches for development and evaluation.

DSR comprises three interrelated cycles: the *Relevance Cycle*, *Design Cycle*, and the *Rigor Cycle*.

1. **The Relevance Cycle** is fundamental in DSR, establishing the framework for the entire process. It begins with an in-depth understanding of the application domain, comprising organizational systems and technical systems working toward a common goal.
2. **The Rigor Cycle** draws from a comprehensive knowledge base that includes existing theories, methods, and the state of the art in the application domain. It ensures that the research is built on top of the existing knowledge and that the work produced is innovative.
3. **The Design Cycle** is where the actual construction, evaluation, and refinement of the artifact take place, guided by feedback from each iteration (Hevner & Chatterjee, 2010).

Inspired by Alattas' attempt (Alattas, 2022) for implementing DSR, a three-staged approach was developed to answer the research questions guiding the thesis. Figure 7 illustrates this process and the connections between steps.

Stage 1: Preliminary Level

This stage begins with a comprehensive review of the existing literature to understand the current state of research on LADM, IFC, and CityGML, and their application in spatial planning. Feedback from the application domain is used to define the problem: the need for better interoperability and compliance checking between spatial plans in Estonia. Existing research on BIM-based compliance checks and LADM integration is examined to prepare for the next stage. The knowledge gained from LADM will also be used to contextualize the development of a country profile for Estonia.

Stage 2: Conceptual Level

In this stage, the focus is on the initial development of a conceptual model to address the identified problem. This involves defining and developing an integrated model for LADM and BIM automation, utilizing the outputs and knowledge from Stage 1. The process includes mapping codelists for semantic interoperability and investigating how spatial plan data can be accurately mapped to LADM (within the context of the Estonia project). It also includes developing an LADM country profile for Estonia, ensuring it fully reflects the information required by specific Estonian data models, checks, and spatial plans. By integrating new codelists into this profile, the study aims to provide a comprehensive understanding of how localized spatial data and compliance checks interact with BIM and LADM standards.

Stage 3: Design Level

The design stage involves transforming the conceptual model into a technical model, focusing on implementation and optimization. Additionally, the transformation involves the development of an FME script for uploading plan data, as well as a PostgreSQL database for the country profile, which contributes to the overall automation process. The technical model, also considered as an implementation model, is thoroughly evaluated, and assessed to identify any limitations or weaknesses. In order to ensure that the final product is dependable and efficient, a feedback loop is set up to continuously examine and enhance the model based on assessment results.

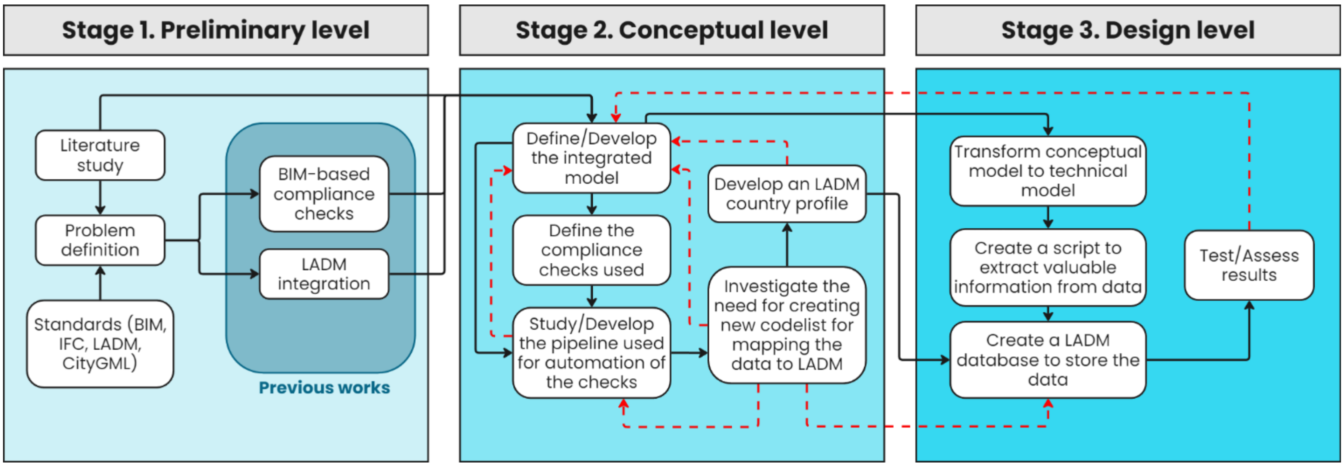


Figure 7. Research methodology.

1.6. Thesis Overview

This thesis is structured to address the research problem of leveraging BIM/IFC for spatial plan registration and compliance checks in Estonia using LADM Part 5. Chapter **1. Introduction** sets the stage by providing the research background, motivation, and objectives, along with the main research question and guiding sub-questions. Following this, Chapter **2. Theoretical Framework** investigates the foundational concepts and standards, discussing spatial plans, Building Information Modeling (BIM), and the Land Administration Domain Model (LADM). This chapter also explores related domain models and compares encoding standards such as IFC and CityGML within the context of spatial planning.

Chapter **3. Case Study: Estonia** provides an in-depth examination of the Estonian spatial planning framework, detailing how the prototype BIM-based compliance check system is integrated into this structure. It includes an analysis of current practices, data requirements, and the specific checks to be implemented within the Estonian project. Subsequently, Chapter **4. Country Profile of Estonia** describes the development of the Estonia-specific LADM profile, tailored to meet the needs of Estonian land administration and spatial planning systems. This chapter also outlines how the profile combines with the national spatial plan database (PLANK) and other relevant data sources.

In Chapter **5. Implementation**, the technical aspects of the research are discussed, including the setup of the LADM database, the importation of IFC data, and the possible integration with the automated compliance checks pipeline. Additionally, the existing 2D data was investigated theoretically to assess its compatibility with the proposed framework and its potential for integration into automated workflows. Chapter **6. Assessment and Evaluation** evaluates the performance of this integrated approach, assessing its compliance with relevant standards, and comparing its efficiency and effectiveness. Finally, the Chapter **7. Conclusion and Future Directions** provides a summary of the research findings by revisiting the research questions and offering conclusions based on the study's results. It also suggests recommendations for future work, addressing limitations and identifying areas for further exploration and improvement.

2. Theoretical Framework

2.1. Spatial Plans

Spatial plans play a crucial role in guiding land use and development across various governance levels, including local, regional, and national authorities. While spatial planning systems differ across countries, they often follow a similar hierarchical structure, with each level addressing specific policy goals. As shown in Figure 8 (a conceptual illustration not reflecting any particular country's procedures), this hierarchy ensures that national objectives are implemented locally while considering regional needs. According to the Organization for Economic Co-operation and Development (OECD, 2017), responsibility for land-use and spatial planning is typically divided among national, regional, and local governments, with each level responsible for enacting and implementing plans that align with broader policy frameworks.

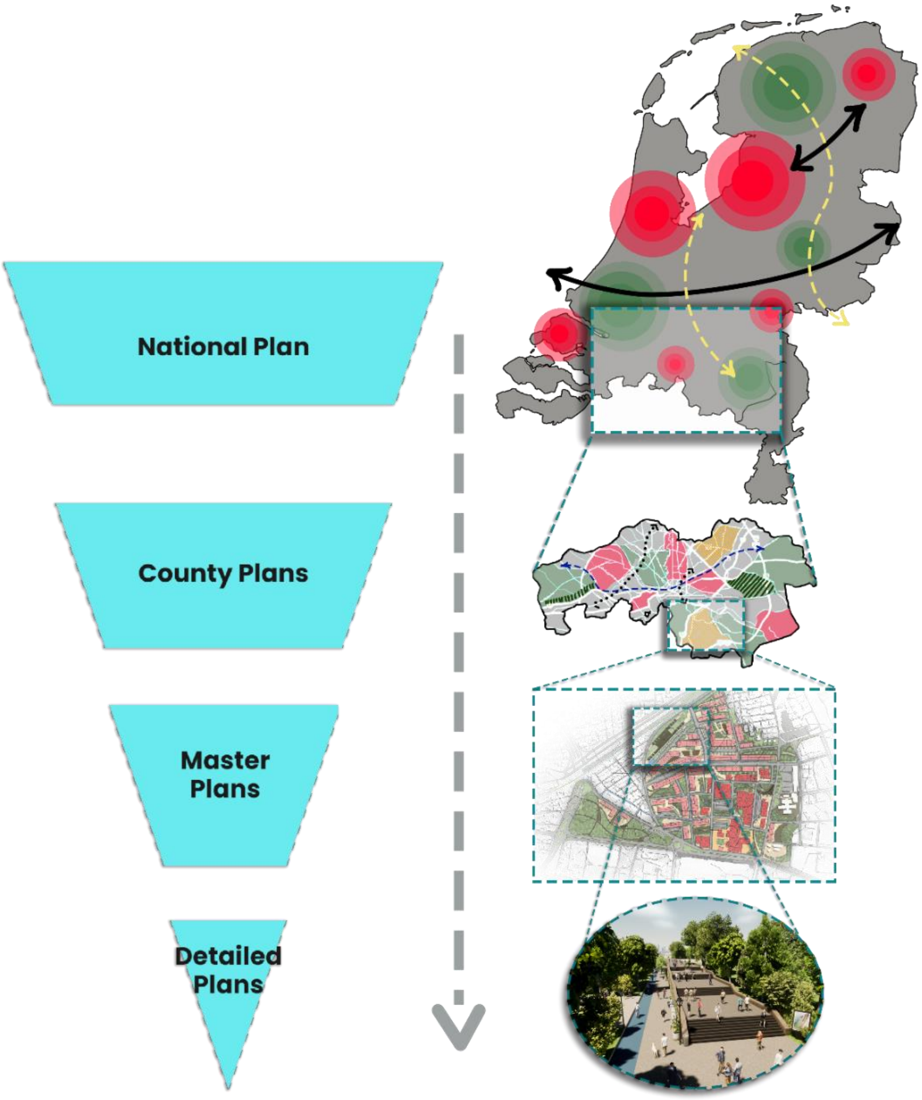


Figure 8. Hierarchy of different spatial plans.

At the **national level**, spatial plans provide a framework for coordinating development across the entire country. They set key policies and objectives for land use, transportation infrastructure, environmental protection, and economic development. These plans aim to ensure balanced regional development, reduce disparities between urban and rural areas, and support national growth objectives. Figure 9 shows an example of a national plan from the Netherlands from the Summary of National Policy Strategy for Infrastructure and Spatial Planning of Netherlands.

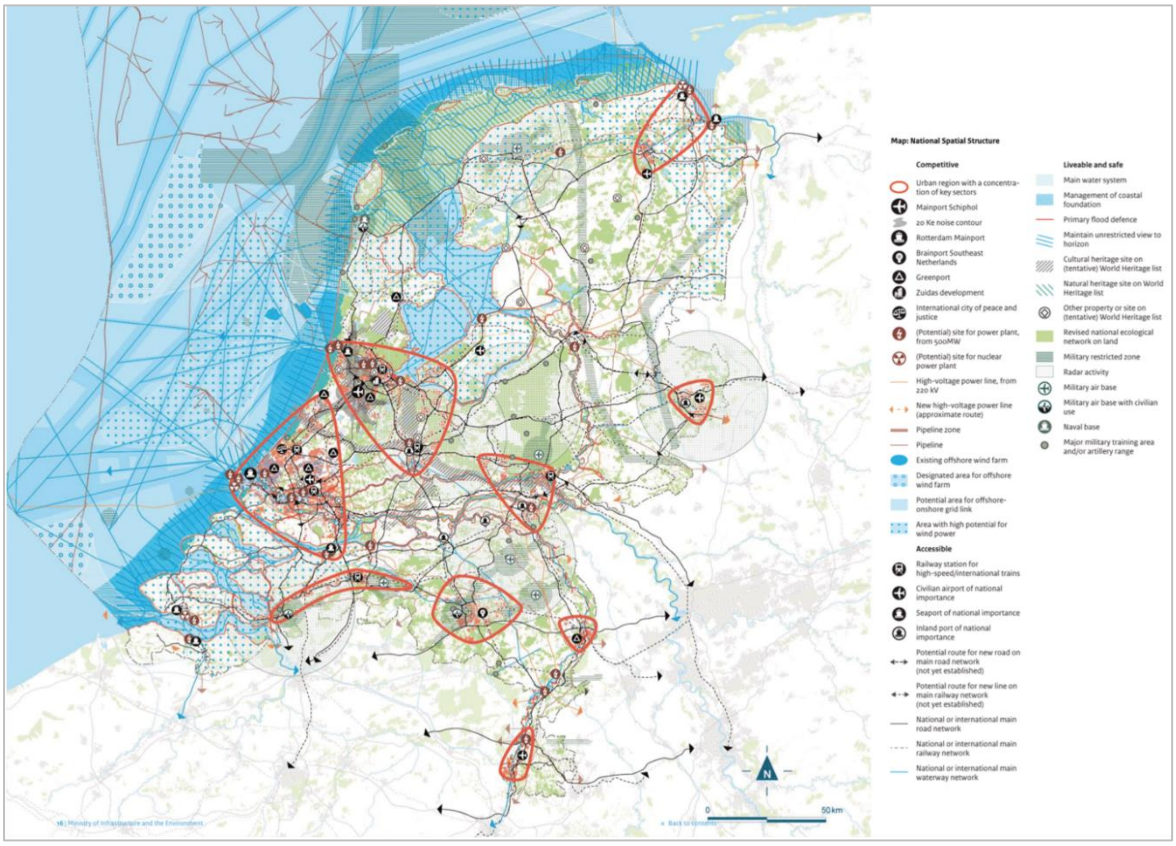


Figure 9. Netherlands' National Spatial Structure Plan (Reference: Ministry of Infrastructure and Environment).

County or Regional Plans bridge the gap between national directives and local needs. These plans cover smaller geographic areas and provide more detailed guidance on land use. They include information on regional infrastructure, housing, commercial development, and environmental conservation. County Plans are crucial for coordinating land use across municipalities, ensuring that local development aligns with broader regional objectives.

Master Plans are often developed for cities or large municipalities, focusing on urban development and zoning. These plans detail the allocation of land for residential, commercial, industrial, and recreational purposes (i.e., land use). They also address transportation networks, public services, and utilities. Master Plans help planners and architects manage urban growth and prevent urban sprawl. They typically are developed within the development visions of a country, covering 10-20 years of envisioned spatial development for a specific region.

Detailed Plans offer the highest level of detail and are used to guide development at the neighborhood or parcel level. These plans include precise information on building regulations, land subdivision, and public space design. Often referred to as the "construction/implementation level" plans, they include information on a granular scale that ensures individual projects comply with broader planning objectives and zoning laws. They provide clear guidelines for developers and are often used to assess building permit applications.

Each level of spatial plan is interconnected, ensuring a coherent approach to land use and development. National Plans set the strategic direction, County Plans translate these strategies into regional actions, Master Plans provide detailed urban development guidelines, and Detailed Plans ensure compliance and implementation at the local level.

Building permits play a crucial role in ensuring that construction and renovation projects comply with local, regional, and national plans, as well as other relevant regulations. While not directly part of the spatial planning process, building permits serve as legal authorizations granted by local governments, ensuring that proposed developments adhere to building codes, zoning laws, and local standards. They represent the last step in bringing a design or plan to life. The process typically involves submitting detailed architectural and engineering plans, which are reviewed by planning officials to verify compliance with these regulations. Once approved, the building permit allows construction to proceed as planned.

Plan compliance checks, on the other hand, are crucial to ensure that Detailed Plans adhere to higher-level Master Plans and other relevant regulations. Without these checks, there is a risk of inconsistencies between different planning levels, leading to failures in plan implementation. To give an example, according to a study evaluating China's National General Land Use Plan, difficulties in coordination with higher-scale regulations, policy discrepancies, redundant governance, and weak monitoring of plan implementation were key factors contributing to the failure of spatial plans (Zhong et al., 2014). These highlight the necessity of ensuring alignment between various planning levels to avoid misalignment, which can result in inefficient development outcomes or non-compliance with strategic goals. By focusing on compliance between plans at various levels, such checks help maintain consistency and facilitate sustainable growth.

In summary, spatial plans at different scales serve distinct yet interconnected roles in guiding land use and further spatial development. Ensuring that plans at all levels—national, regional, and local—are following each other is essential for maintaining a coherent and efficient planning system. Without such alignment, discrepancies between plans can hinder sustainable development and lead to project delays.

Moreoevr, in preparation for the subsequent chapters, Appendix B investigates *"Relevant BIM-based initiatives for permit checking"* to further explore the integration of compliance checks within the planning framework. While the primary focus of this research is on compliance checks between spatial plans before the permitting phase, examining BIM-based permit checks serves a valuable purpose. This analysis is important not only because BIM-based checks are more extensively researched but also because they offer insightful methodologies for automated compliance verification. Although both processes involve performing compliance checks against models, the key differences lie in the types of models used and the motivations behind these checks. By reviewing these established BIM-based initiatives, this study aims to draw valuable lessons that can inform and enhance the implementation phase of the research.

2.2. Related Domain Models

In land administration domain, LADM stands as the foremost standardized information model, offering a comprehensive framework for recording and managing land-related data. However, it is essential to recognize that LADM is not alone; similar standardized information models exist, tailored to address specific aspects of land administration.

INSPIRE cadastral parcels

One such model is the *INSPIRE cadastral parcels*, which, like LADM, aims to provide a structured approach to capturing and representing land-related information.

> INSPIRE (Infrastructure for Spatial Information in the European Community) is an initiative of the European Union aimed at facilitating the exchange and sharing of spatial data across member states. Established under the Infrastructure for Spatial Information in the European Community Directive (2007/2/EC), INSPIRE lays down the legal framework for enhancing spatial data infrastructure within Europe, fostering collaboration, and facilitating the interoperability of spatial data across member states.

While LADM focuses on a holistic understanding of land administration, including ownership, rights, and responsibilities (RRR), INSPIRE cadastral parcels primarily concentrate on geometrical aspects, omitting detailed information on ownership and other rights (FIG Publication - *Best Practices 3D Cadastres*, 2018). Despite these differences, both models share the common goal of enhancing land administration practices and supporting sustainable development initiatives.

INSPIRE planned land use

Another key important initiative is the INSPIRE Planned Land Use theme, which relates to spatial plans defined by planning authorities and depicts the potential future use of land. The Planned Land Use application schema of INSPIRE is primarily based on two elements: **ZoningElement**, which reflects the zoning defined by planners, and **SupplementaryRegulation**, which overlays additional regulations on the zoning (ISO, 2024b). It's important to note here that, although it has not been published yet, the ISO draft DIS 19152-5's Annex E (ISO, 2024b) states that the INSPIRE Planned Land Use theme can be represented within the LADM Part 5 framework without inconsistencies.

Social Tenure Domain Model (STDM)

Another recognized example of similar standardized information models to LADM is the Social Tenure Domain Model (STDM). It is well-established that LAS serves as the infrastructure for implementing land policies and management strategies to support sustainable development. However, it is crucial to note that LAS are not universally available, with only approximately 25-30 countries worldwide possessing such infrastructure (Lemmen, 2010). Existing LAS also face limitations in incorporating informal and customary tenures. STDM, introduced by UN-HABITAT, aims to address this gap by enabling the recording of various tenure types, including informal and customary tenures. This provides a more inclusive and flexible approach to land administration, recognizing the lack of LAS infrastructure and providing an alternate solution.

STDM can be seen both as an implementation and a specialized extension of LADM, specifically for developing countries that have very little or no cadastral coverage in urban or rural areas (Lemmen, 2010; Zevenbergen et al., 2015). It emphasizes the importance of understanding and formalizing social tenure relationships, recognizing that land rights extend beyond formal ownership to include tenancies, customary rights, and other informal arrangements.

Lastly, while LADM serves as a foundation in standardized land administration models, it is crucial to acknowledge the existence of similar models adapted to address specific land administration challenges. These models complement LADM by offering specialized solutions for capturing and managing land-related information, thereby contributing to the advancement of LAS practices.

2.3. Land Administration Domain Model (LADM)

LADM, officially recognized as ISO 19152:2012, is a globally acknowledged ISO standard that provides a comprehensive framework for land administration. Land administration (LA), as defined by both the United Nations Economic Commission for Europe (UNECE) and the International Federation of Surveyors (FIG), involves the "*systematic processes of recording and disseminating information about land ownership, value, use, and the relationship between people and land, encompassing legal, economic, social, and environmental dimensions*" (Simon Hull et al., 2024; UNECE, 1996). Building on these definitions, LADM is a knowledge domain standard describing the semantics of the LA domain (Kara et al., 2023).

The original idea for such a standard was introduced at the 2002 FIG congress in Washington D.C. (Van Oosterom et al., 2013). The development of LADM was driven by the recognition that land administration practices varied widely across different countries and regions, often leading to inefficiencies and inconsistencies in how land-related data was recorded and managed. From 2002 to 2008, several milestones marked the incremental development of LADM. Various versions of the model were presented at international workshops and conferences, allowing experts to refine the model based on feedback (Van Oosterom et al., 2013). The FIG played an important role in advancing the model towards standardization, submitting it to the ISO Technical Committee for Geographic Information (ISO/TC211) in 2008 (Lemmen et al., 2009). This collaborative effort involved contributions from numerous organizations and institutions, ensuring the model addressed a wide range of land administration challenges.

The initial proposal to ISO (2008) outlined the objectives and scope of the proposed standard, setting the stage for the following development phases. Throughout this period, detailed discussions and workshops were held in various international locations, where experts inspected the draft model, providing critical input to enhance its accuracy and applicability. Comprehensive feedback and final adjustments were made, ensuring the model's robustness and comprehensiveness. In June 2011, LADM was officially adopted as ISO 19152:2012 (GIM, 2012). This extensive and collaborative process, supported by contributions from numerous organizations and institutions, ensured that LADM addressed a wide range of land administration complexities and facilitated its implementation across various jurisdictions.

The acceptance of LADM as an ISO standard marked a significant milestone. This enabled LADM's adaptation to different legal and administrative contexts and supported the integration of land administration into broader Spatial Data Infrastructures (SDI) (Van Oosterom et al., 2009).

Overview and Components of LADM

This section will outline the components of both LADM Edition I and LADM Edition II to provide a comprehensive understanding of the model's evolution. It will cover the core packages of LADM Edition I and the new additions and refinements introduced in LADM Edition II, with a focus on their applications and implications.

LADM Edition I

The original LADM (ISO 19152:2012) comprises three core packages that address different aspects of land administration (Lemmen et al., 2015):

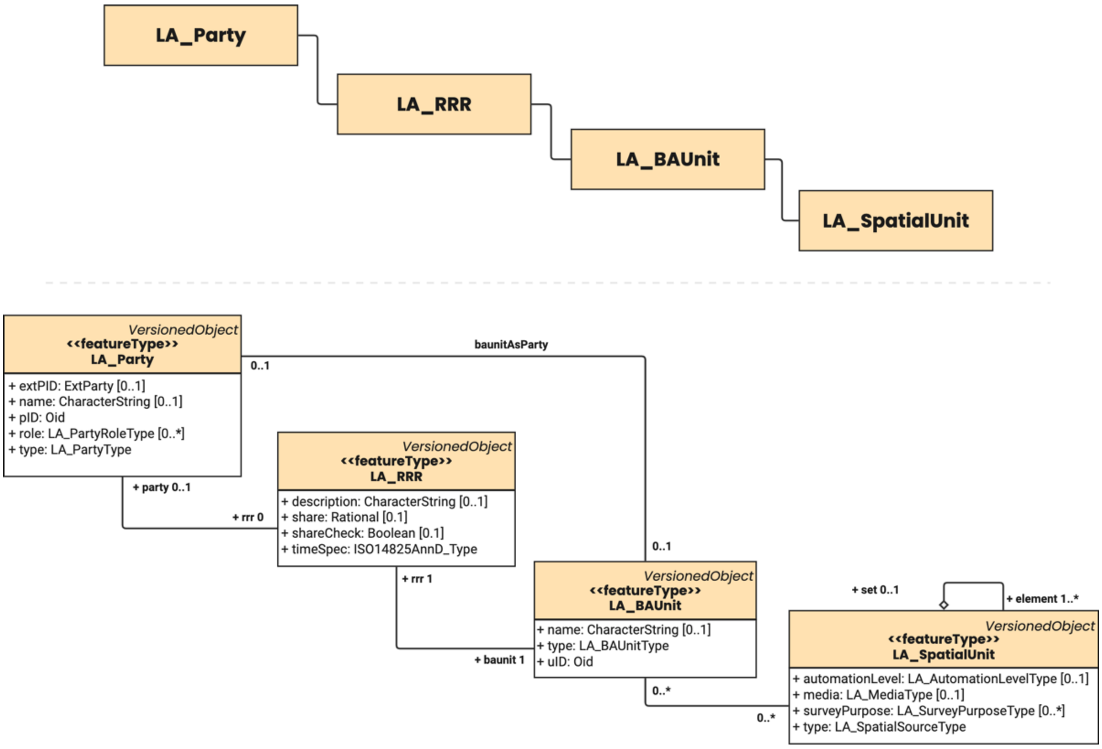


Figure 10. LADM core classes (ISO 19152:2012).

1. **Party Package:** This package deals with the people and organizations involved in land administration, known as parties. It includes classes to represent individuals, groups, and organizations that hold rights or responsibilities related to land parcels. The main class, *LA_Party*, is further specialized in *LA_GroupParty* to accommodate group entities. This package supports the management of information regarding who holds what right over which piece of land.

2. **Administrative Package:** This package covers rights, restrictions, and responsibilities (RRR) related to spatial units. The core classes include LA_RRR, which is abstract and further specialized into *LA_Right*, *LA_Restriction*, and *LA_Responsibility*. Additionally, it includes the *LA_BAUnit* class (Basic Administrative Unit), representing the smallest administrative entity with homogeneous RRRs. This package ensures that all legal and administrative

information about land rights is systematically recorded and managed.

3. **Spatial Unit Package:** This package defines spatial units such as parcels, buildings, and utility networks. It includes classes like *LA_SpatialUnit*, *LA_SpatialUnitGroup*, and *LA_Level*. The spatial unit package also comprises sub-packages for surveying (*LA_SpatialSource*) and spatial representations (LA_Point, *LA_BoundaryFaceString*, *LA_BoundaryFace*). This package facilitates the accurate and detailed representation of physical land features and their legal boundaries.

These three core packages were derived from earlier conceptual models and initiatives, such as Henssen's 1995 model and FIG's "*Cadastre 2014*" (Henssen, 1995; Kaufmann & Steudler, 2014). Later, however, it was realized that a "Basic Administrative Unit" (*LA_BAUnit*) was needed to bridge the gap between *LA_RRR* and *LA_SpatialUnit*, allowing for the representation of complex property units that may consist of multiple parcels. This resulted in four core classes as shown in Figure 10, enabling LADM to represent various types of people-land relationships (Lemmen et al., 2010). In the end, LADM extended traditional cadastral concepts to include all spatial units with social, legal, or economic relevance, making it a more versatile model for land administration.

LADM Edition II

Currently, LADM Edition I is widely used and covers a variety of applications (Kalogianni et al., 2021) however, the main focus of the model is mainly on land tenure and spatial units. The scope of the standard excluded a variation of important aspects in LAS such as land value, land use, and maritime spaces. To address these gaps and ensure standards like LADM remain up to date and functional, ISO requires regular reviews. In 2017, experts determined that revising LADM Edition I was necessary to enhance tenure security tools and improve LA coverage (Kara et al., 2024). To revise LADM Edition I, several FIG LADM Workshops were held to discuss improvements and extensions. Therefore, the ISO revision process started in 2018, focusing on integrating valuation information, supporting 3D land administration, refining survey models, enriching codelist values and improving interoperability with other standards.

In LADM Edition I, the model was structured around the four core packages: *Party, Administrative, BAUnit* and *Spatial Unit*, all within a single standard (ISO 19152:2012). This meant that all components and functionalities of the model were included in one comprehensive document. However, LADM Edition II introduces a multi-part structure (Lemmen et al., 2021), where the standard is divided into separate parts, each addressing specific aspects of land administration in more detail. As a result, six standards that are backward compatible with Edition I have been developed as a multi-part series, each of which is a stand-alone standard (Kara et al., 2024). This approach allowed for more focused and specialized standards within the broader framework of LADM, enabling more updates and enhancements to specific parts without having to change the standard as a whole.

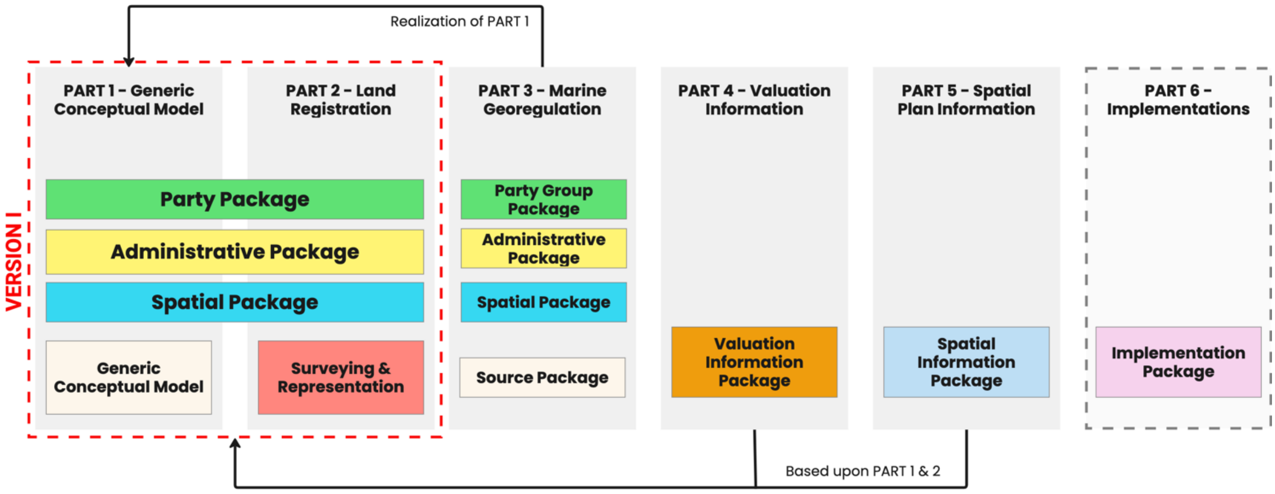


Figure 11. Packages of LADM Edition II. Figure adapted from Kara et al. (2024).

The multi-part structure for LADM Edition II is as follows, also shown on Figure 11:

Part 1 - Generic Conceptual Model
Part 2 - Land Registration
Part 3 - Marine Georegulation
Part 4 - Valuation Information
Part 5 - Spatial Plan Information
Part 6 - Implementations

Overall, LADM Edition II enhances the model's coverage in the LAS domain, bringing it closer to implementation with technical models and processes. Specifically, Part 6 will include methodologies for developing country profiles, frameworks for land administration workflows, management of enriched code list values, and support for various data encodings (Kara et al., 2024). Since LADM is a conceptual model, implementation with these real-life processes and models requires the development of an application schema, such as a country profile.

LADM Part 5: Spatial Plan Information

This section will be a detailed overview of LADM Part 5: Spatial Information, which is the LADM Part that is focused on this thesis.

One of the primary goals of LADM is to document the RRRs of individuals or entities with interests in land or space. Before the development of LADM Part 5, the model lacked to cover an important source of RRRs: spatial plans (Indrajit et al., 2020). To increase knowledge and support city-level decision-making, a country must guarantee that spatial plans are compatible with data from land tenure, value, and development activities (Indrajit et al., 2021). This integration addresses the previously overlooked connection between land administration and spatial planning. LADM Part 5 is designed to effectively link land tenure with spatial information, involving various spatial themes such as land cover, land use, utilities, regulatory zones, and natural risk zones (Van Oosterom et al., 2019). By including these elements, LADM Part 5 ensures a comprehensive and integrated approach to land management. As a standard, LADM Part 5 (ISO/DIS 19152-5) is currently under development and has entered the enquiry phase, where it is being reviewed and voted on by ISO member countries (June 2024).

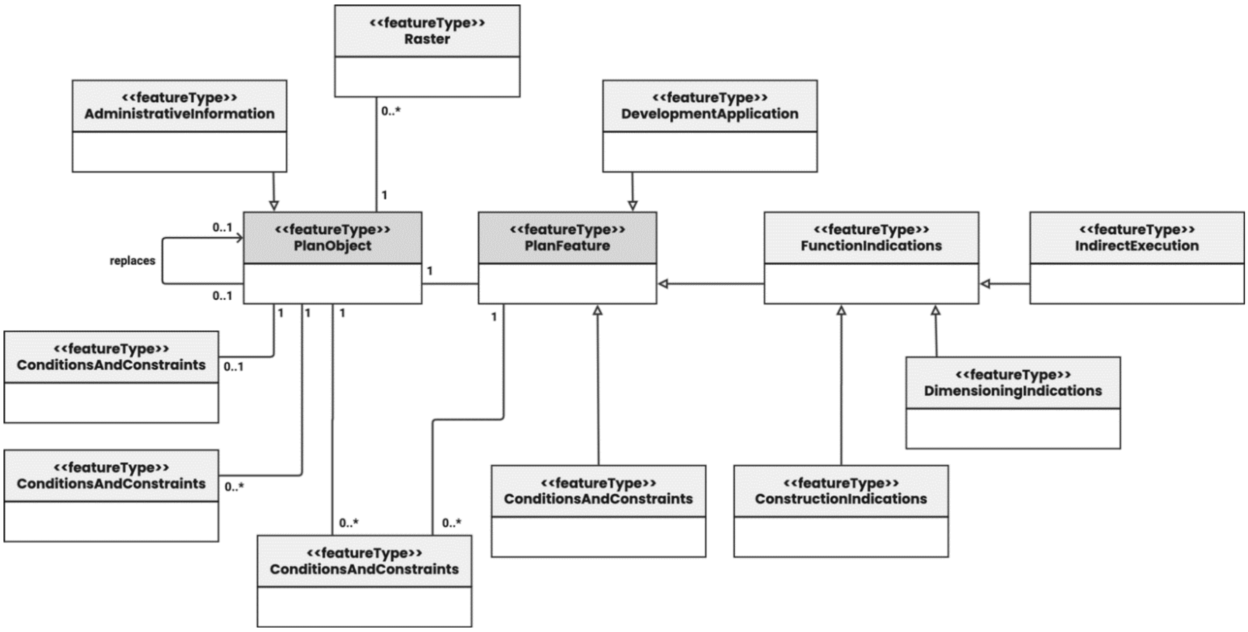


Figure 12. Simplified view of the Plan4all Land Use data model. Adapted from Bergheim et al. (2011).

The development of LADM Part 5 has been significantly influenced by the Plan4All project, which was initiated by the European Union in 2009 to achieve interoperability of spatial planning information (Murgante et al., 2011). The project helped to standardize spatial data by creating a data model (shown onFigure 12) according to the INSPIRE Directives (2007). Plan4All's model differentiates between existing and planned land use, introducing two main classes: *PlanObject* and *PlanFeature*. *PlanObject* provides geometric, textual, and administrative/process information for spatial planning, while *PlanFeature* details land use indications such as status, regulation types, and criteria (Bergheim et al., 2011; Indrajit et al., 2020; Murgante et al., 2011). This project's insights have contributed to shaping the data model and required classes in LADM Part 5, ensuring compatibility with INSPIRE directives at the same time.

The classes of the Spatial Plan Information package are represented with “SP” prefix, indicating Spatial Planning. The package includes five main classes: *SP_PlanBlock, SP_PlanUnit, SP_PlanGroup, SP_PlanUnitGroup*, and *SP_Permit* (Figure 13).

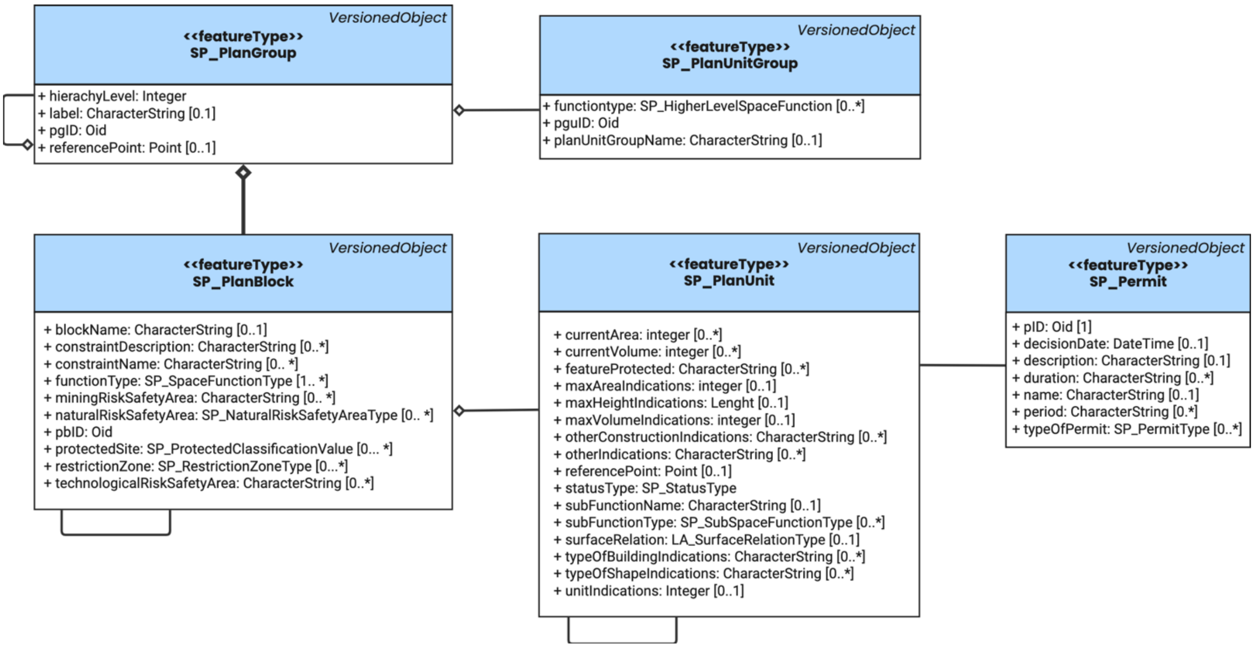


Figure 13. Spatial Plan Information Package's classes

SP_PlanUnit represents the specific zones within a spatial plan, detailing their characteristics and intended uses. These units can be two-dimensional, three-dimensional, or even four-dimensional spaces, each designated for specific functions such as office, education, or commercial purposes (Kara et al., 2024). Each *SP_PlanUnit* is assigned a specific set of RRRs based on the spatial planning policies and regulations, which define how the land can be used and what limitations and obligations apply. These units might share boundaries with other zones or stand alone. At its core, *SP_PlanUnit* represents the smallest instance that is registered, such as a specific 3D building model in a Detailed Plan. This granularity ensures precise documentation and efficient management of the RRRs.

SP_PlanBlock represents the general land use recommendations or requirements for a specific area, defined by spatial planning policies. It sets the rules and expectations for how land should be used, such as what types of buildings are allowed, what activities can take place, and any restrictions or obligations. Essentially, *SP_PlanBlock* sets the framework within which *SP_PlanUnit* operates, ensuring that land use within a larger area aligns with overall planning objectives.

SP_PlanGroup organizes spatial plans into hierarchical levels, such as regional, national, state, municipal, and local levels.

SP_PlanUnitGroup aggregates multiple *SP_PlanGroup,'* as shown in Figure 13. This class helps in organizing and managing groups of spatial units that share similar functions or purposes.

SP_Permit stores information about permits issued by authorities to parties for specific actions within a designated plan unit. A permit serves as official authorization, confirming a party's right to carry out an activity that aligns with the designated function of the relevant plan unit (Kara et al., 2024).

Together, these classes provide a comprehensive and structured approach to managing spatial planning information within the LADM framework.

LADM Country Profiles

In the development of LADM Edition I, eight country profiles were established, representing Portugal, Queensland (Australia), Indonesia, Japan, Hungary, The Netherlands, the Russian Federation, and the Republic of Korea (Kalogianni et al., 2021). A country profile in this context is a modified version of the LADM that aligns with a particular country's specific land administration needs and systems (International Organization for Standardization (ISO), 2012). These profiles outline the application of the LADM as a standard to represent LAS specific to each country's context. They help in understanding how the tailored LADM profiles can meet local requirements and support the modernization and integration of LAS with other domains.

Country profiles can either describe the current state of LAS and align them with LADM concepts, or they can articulate a vision for future developments and needs in the domain (Kalogianni et al., 2021). In this context, LADM should be regarded as a framework for organizing spatial and non-spatial data related to 3D cadastral features, offering guidelines and principles rather than prescribing a rigid implementation method (Lemmen et al., 2015).

Creating these profiles, as described by Kalogianni et al. (2019), typically starts with an in-depth analysis of the current state of land administration, including relevant legislation, existing data models, and the overall vision or objectives for the country profile. This is then followed by the alignment of key concepts from existing models with LADM classes. This alignment can be quite complex due to the intricate nature of land administration systems (LAS) and because of the conceptual nature of LADM. Furthermore, the process is not always straightforward, as multiple classes or concepts from the current cadastral model may align with a single LADM class, or vice versa. In certain instances, there may be no existing class that directly corresponds to LADM concepts, necessitating the creation of new classes and codelists tailored to the country’s specific needs.

Previous research and examples of country profiles also indicate that these profiles can either adopt a comprehensive approach, representing multiple aspects of LAS (e.g., The Netherlands and Polland), or focus on a specific application or domain (e.g., natural resources in China or the utility cadaster in Serbia) (Kalogianni et al., 2021). For the scope of this thesis, the developed country profile using the case study will focus only on representing the existing spatial information infrastructure and data in Estonia (detailed later in Chapter 3).

One of the country profiles that provide significant insights into the practical application of the LADM standard is for Indonesia by Indrajit et al. (2020). This profile emphasizes the integration of spatial planning information with LAS, particularly focusing on the implementation of LADM Part 5 and the representation of RRRs in a 3D context. This approach was essential for addressing Indonesia’s dynamic land use and urban planning needs. Before implementing the LADM country profile, Indonesia's land information was often siloed within different government agencies, hindering efficient data sharing and coordination. The process involved a thorough analysis of Indonesia’s existing land administration practices, relevant legislation, and current data models (Indrajit, 2021). The iterative prototyping and refinement process, which incorporated stakeholder feedback, ensured the model’s accuracy and relevance. This iterative approach allowed the creation of a profile that accurately reflects the current legal and spatial realities of Indonesia while facilitating better data interoperability and accessibility. The Indonesian profile highlights the adaptability of LADM to meet local requirements while supporting the modernization and integration of LAS, showing the necessity of a standardized approach to managing land information for effective data sharing.

Another notable example of a country profile that offers important insights is the Malaysian LADM country profile developed by Zulkifli et al. (2014). This profile integrates both 2D and 3D cadastral registration systems, incorporating existing spatial and administrative systems with new developments inspired by the LADM standard. It contains various spatial units, including customary areas, reserved lands, lots, buildings, strata parcels, and utilities. The profile also introduces innovative aspects like full version management, historical information inclusion, and explicit linkage of all land administration data to source documents. The development of the new Malaysian profile aimed to improve information interoperability and support the National Spatial Data Infrastructure (SDI), facilitating seamless information exchange among governmental bodies.

Additionally, more profiles developed between 2012 and 2020, with the ongoing revision of LADM Edition II (Kalogianni et al., 2021) and are detailed in Appendix A Table 11.

2.4. IFC

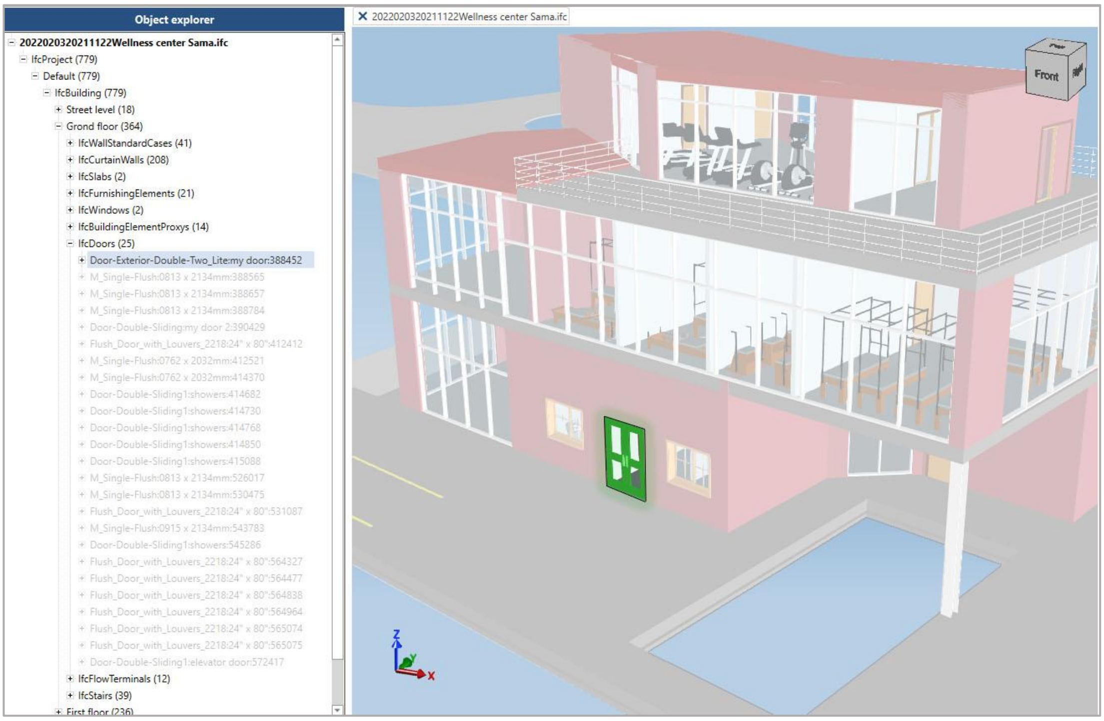
In the digital AEC domain, most popular software programs save their data in proprietary formats, known as native formats. For instance, projects saved in Autodesk's Revit produce a "*.rvt*" file, while those saved in Graphisoft's ArchiCAD generate a "*.pln*" file. However, this creates challenges when multiple stakeholders use different tools in collaborative projects; and leads to some important aspects to consider in collaborative environments: *How do industries coordinate and exchange models effectively across various native formats? How do they determine which file format serves as the primary information carrier?* And most importantly, *how do models from various software programs interact with one another?* The open IFC (Industry Foundation Classes) file format is the solution to all these challenges.

IFC is an open standard developed by buildingSMART International to facilitate interoperability in the AEC industry. As a vendor-neutral and platform-independent data model, IFC is designed to provide a universal language for exchanging BIM data across various software applications (*Industry Foundation Classes (IFC)*, 2024). The IFC standard, officially known as ISO 16739-1:2018 (International Organization for Standardization (ISO), 2024a), is essential to facilitating smooth communication and cooperation between parties at every stage of a building's lifecycle, from planning and development to maintenance and operation.

IFC is both a file format and a data model standard. The IFC schema refers to the set of rules and definitions that describe the structure of IFC data. It's a detailed design schema that describes what entities (e.g., walls, doors, spaces) can be included in an IFC file and how these entities come together. By specifying the syntax and semantics of the building information data, it guarantees consistency and interoperability. The schema is essential for ensuring that software applications that support the IFC standard can read and interpret IFC files consistently.

The IFC data can be encoded in various file formats for storage and exchange. The most common format is the STEP Physical File (*.ifc*), which contains building information modeled according to the IFC schema. There are also XML-based representations such as *.ifcXML*, which is a more human-readable format. Additionally, formats like *.ttl* (Terse RDF Triple Language), *.rdf* (Resource Description Framework), and *.json* (JavaScript Object Notation) offer other ways to encode and represent IFC data, each with its advantages. The choice of the file format depends on factors such as readability, software support, and practical considerations for handling larger datasets.

In the IFC schema, data is organized in a structured manner to ensure that all elements and their attributes are clearly defined and organized. For example, the **IfcDoor** entity within the IFC schema represents doors in a building model. Each IfcDoor entity can have attributes such as dimensions, materials, spatial position, and type (e.g., hinged, sliding). These attributes ensure that the door is thoroughly represented and can be interpreted accurately by different software applications. Figure 14 shows an example IFC model and where an IfcDoor is stored in the model. Additionally, property sets (**Pset**) provide collections of related properties assigned to IFC entities, such as **Pset_DoorCommon** for IfcDoor, which includes properties like fire rating, acoustic rating, external status among many others.



Object explorer

- **2022020320211122Wellness center Sama.ifc**
  - IfcProject (779)
    - Default (779)
      - IfcBuilding (779)
        - Street level (18)
        - Grond floor (364)
          - IfcWallStandardCases (41)
          - IfcCurtainWalls (208)
          - IfcSlabs (2)
          - IfcFurnishingElements (21)
          - IfcWindows (2)
          - IfcBuildingElementProxys (14)
          - IfcDoors (25)
            - Door-Exterior-Double-Two_Lite:my door:388452
            - M_Single-Flush:0813 x 2134mm:388565
            - M_Single-Flush:0813 x 2134mm:388657
            - M_Single-Flush:0813 x 2134mm:388784
            - Door-Double-Sliding:my door 2:390429
            - Flush_Door_with_Louvers_2218:24" x 80":412412
            - M_Single-Flush:0762 x 2032mm:412521
            - M_Single-Flush:0762 x 2032mm:414370
            - Door-Double-Sliding1:showers:414682
            - Door-Double-Sliding1:showers:414730
            - Door-Double-Sliding1:showers:414768
            - Door-Double-Sliding1:showers:414850
            - Door-Double-Sliding1:showers:415088
            - M_Single-Flush:0813 x 2134mm:526017
            - M_Single-Flush:0813 x 2134mm:530475
            - Flush_Door_with_Louvers_2218:24" x 80":531087
            - M_Single-Flush:0915 x 2134mm:543783
            - Door-Double-Sliding1:showers:545286
            - Flush_Door_with_Louvers_2218:24" x 80":564327
            - Flush_Door_with_Louvers_2218:24" x 80":564477
            - Flush_Door_with_Louvers_2218:24" x 80":564838
            - Flush_Door_with_Louvers_2218:24" x 80":564964
            - Flush_Door_with_Louvers_2218:24" x 80":565074
            - Flush_Door_with_Louvers_2218:24" x 80":565075
            - Door-Double-Sliding1:elevator door:572417
          - IfcFlowTerminals (12)
          - IfcStairs (39)
        - First floor (236)

Figure 14. An example IFC model visualized in Open IFC Viewer.

An IFC model is organized in a hierarchical manner, where elements are interconnected in a tree-like structure instead of existing as isolated entities. This hierarchy can be seen in Figure 15. This means that elements like IfcDoor are connected to other building elements, such as walls and floors, and these relationships are defined within the schema. This organized structure allows for comprehensive representation and seamless information exchange among different platforms.

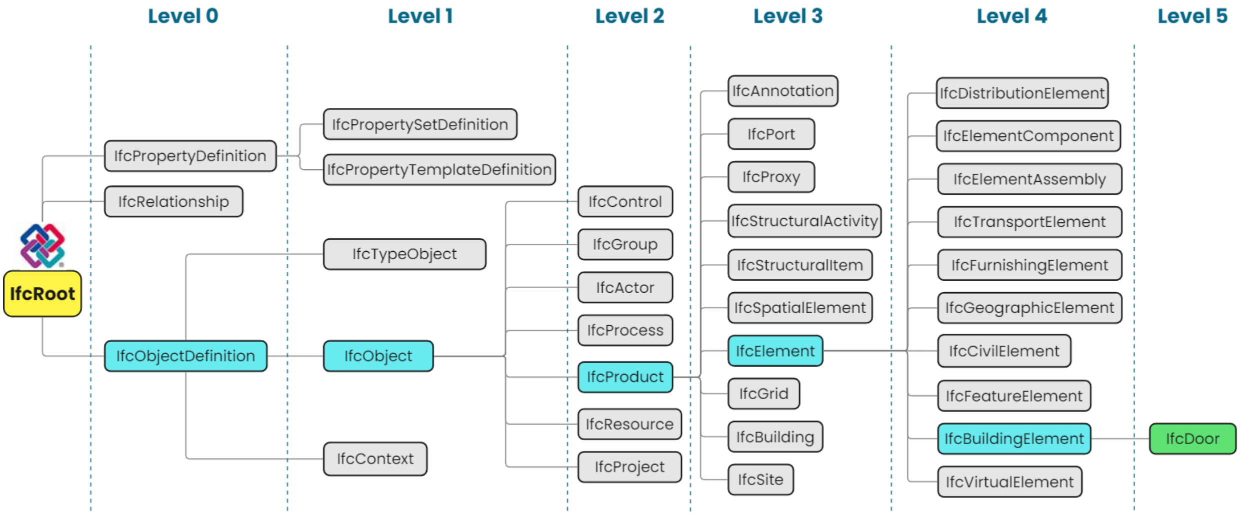


Figure 15. IFC schema levels.

2.5. CityGML

Before CityGML (2012), most 3D city models were restricted to graphical or geometrical representations (such as VRML, CAD), ignoring topological and semantic factors. Because of this, the main application for these models was visualization as they were not appropriate for analytical work, thematic queries, or spatial information mining (OGC, 2012). To meet the information needs of the different application fields, a more general modeling approach had to be adopted.

CityGML is based on Geography Markup Language (GML), which is an XML-based standard for encoding geographic information. GML contains a set of primitive object types such as *Feature*, *Geometry*, *Coordinate Reference System*, and *Unit of Measure*, among others. These primitive objects allow users to define their own object types for specific applications, creating “domain-specific application schemas.” By allowing this, object types in these customized schemas reference the primitives defined in the GML standard. CityGML, therefore, is an application schema based on GML, acting as a specialized data model derived from the more general GML standard. Other examples of public GML application schemas include IndoorGML (2014), which is an OGC standard for indoor spatial information, and SensorML (OGC, 2007), a schema for describing instruments and processing chains.

CityGML is an open data model and XML-based format specifically designed for the storage and exchange of 3D city models. Developed by the Open Geospatial Consortium (Open Geospatial Consortium (OGC), 2012), it was designed to represent the geometric, topological, and semantic properties of urban objects. As an application schema of the Geography Markup Language (GML version 3.1.1), it extends the standard to cover city and regional modeling.

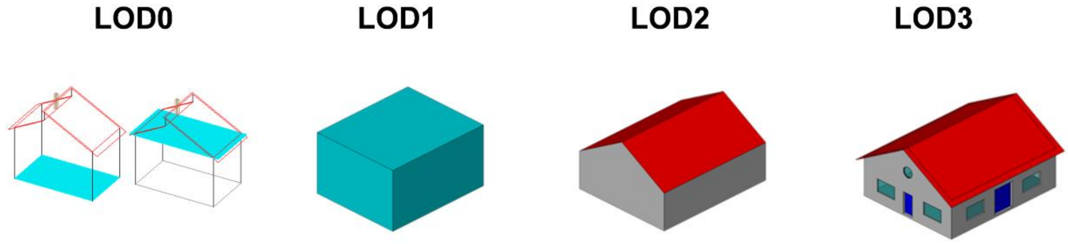


Figure 16. Representation of a building in the Levels of Detail ‘0’. Figure by OGC CityGML v3 (2021).

Additionally, CityGML supports different levels of detail (LoD). These levels range from simple models (LoD0) that provide a broad overview of the topography and layout of cities to highly detailed models (LoD4) that include the interiors of buildings. As illustrated in Figure 16, each successive level of detail refines and adds more information to the models of the previous levels. This multi-scale representation allows users to use the LoD of their choice for their specific needs, enabling analysis at various scales.

Ultimately, the versatility of LoDs makes CityGML more adaptable for a variety of applications compared to other 3D city model standards.

Similarly, CityGML is both a data model and a file format. The most common encoding of the data model is XML, with the rules encoded in an XSD file (XML Schema Definition). The contents are written in an XML document that adheres to the rules of the XSD file, a process known as validation. However, other encodings exist, such as CityJSON and SQL.

The CityGML data model comprises a core module and thematic extension modules. The core module includes the basic concepts and components of the CityGML data model, while the thematic extension modules cover specific thematic fields of the 3D city model. All thematic extension modules depend on the CityGML core module, ensuring a common foundation for understanding different aspects of a city. Because all modules refer to the core module, they share a common language and set of rules.

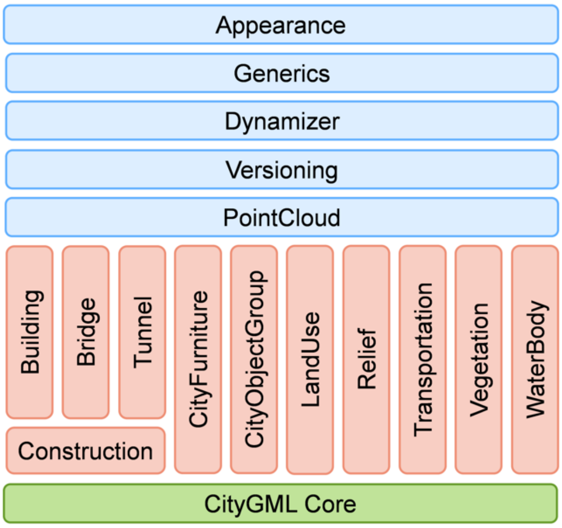


Figure 17. CityGML 3.0 module overview. The vertical boxes show the different thematic modules. Horizontal modules specify concepts that are applicable to all thematic modules. Figure by OGC CityGML 3.0 (2021).

The thematic extension modules logically separate thematic components and introduce 11 modules in CityGML v3 (red modules in Figure 17): Bridge, Building, CityFurniture, CityObjectGroup, Construction, LandUse, Relief, Transportation, Tunnel, Vegetation, WaterBody.

Every CityGML model must include the CityGML core module. However, a CityGML model doesn't necessarily have to include all the features or components inside the core module. The CityGML conceptual model is thematically decomposed into a Core module and different kinds of extension modules, as shown in Figure 17. The Core module, depicted in green, comprises the basic concepts and components of the CityGML core module and must be implemented by any conformant system. Each red-colored module covers a specific thematic field of 3D city models. The five blue-colored extension modules add specific modeling aspects that can be used in conjunction with all thematic modules, such as the Appearance module, which contains concepts to represent the appearances (like textures and colors) of city objects, and the PointCloud module, which provides concepts to represent the geometry of city objects by 3D point clouds. If a specific application requires information beyond the scope of the CityGML data model, this data can be incorporated within the existing modules using CityGML' s Application Domain Extension (ADE) mechanism.

2.6. Comparison of Encodings

When comparing different encodings within the scope of LAS and spatial planning, it is important to assess their theoretical capabilities and practical applications too. It is critical to note here that IFC models are predominantly used for design models rather than spatial plan information models (as previously mentioned and illustrated in Figure 5). As a result, there is no clear standardization for using IFC models as encodings for spatial plan data. This makes it challenging to assess IFC's applicability in theory. However, for the purposes of this theoretical comparison, the most suitable IFC classes will be mapped to the most relevant LADM Part 5 classes to explore potential alignment.

This assessment is critical for this research, specifically regarding spatial plan representation, data integration, the development of LADM country profiles, and the application of the profile in the permitting process. As previously mentioned in the scope of the research, the practical implementation methods and insights will focus only on IFC due to data availability from the case study that is presented in Chapter 3. However, the theoretical comparison focuses on IFC and CityGML data, with an emphasis on how they manage spatial information that is required for compliance between different spatial plan levels, interoperability, representation, and mapping efficiency to LADM.

CityGML

CityGML, as explained in Section 2.5, is suitable for representing urban features due to its detailed semantic structure and representation capabilities at different scales. The flexibility of CityGML's LODs makes the encoding adaptable for various urban planning tasks, from broad urbanistic overviews to detailed building characteristics. This adaptability is important for representing spatial plan information, where different scales of representation are needed to fully reflect various levels of information, as explained previously in Section 2.1.

CityGML includes several thematic modules (seen in Figure 17) that can be mapped to LADM Part 5 classes. These modules provide a structured framework for representing various aspects of urban environments, and their alignment with LADM classes ensures that detailed spatial plan information can be integrated seamlessly into the LADM framework.

The **Building module** in CityGML (Open Geospatial Consortium (OGC), 2012) captures comprehensive information about buildings, integrating geometric, semantic, and topological aspects. The attributes of the Building module’s *AbstractBuilding* class align closely with those of LADM Part 5's *SP_PlanUnit* class, covering similar attributes for representing building-level information. The UML class comparison can be seen in Figure 18. However, it should be noted that this module is primarily useful for building-level information, such as building height, floor area, and usage type. Higher-scale maps like county or national plans’ smallest unit of information tend to be zoned regions rather than buildings. The Building module's detailed attributes may not be as relevant for these cases since these scales provide unit-scaled information such as buildings rather than more zoning information.

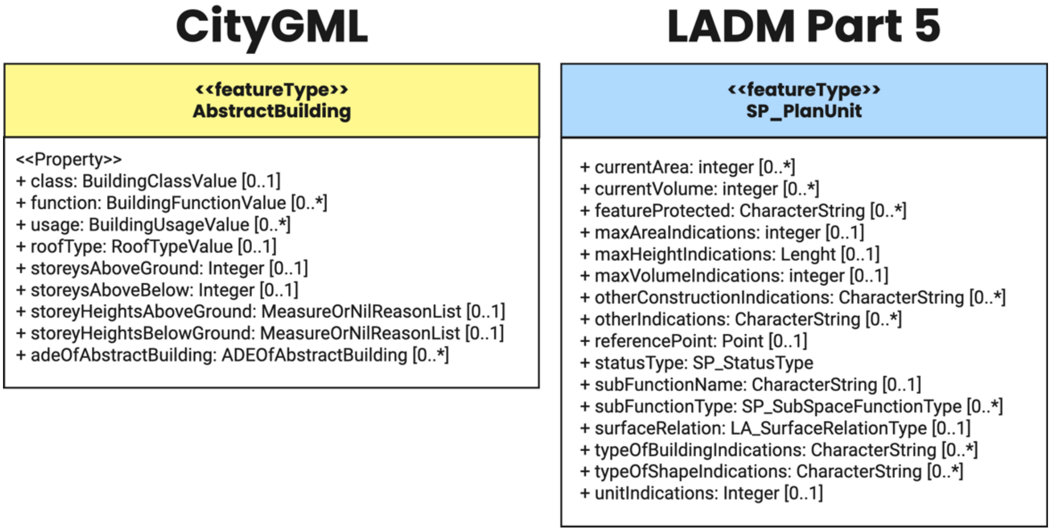


Figure 18. CityGML's AbstractBuilding class versus LADM Part 5's SP_PlanUnit class

The **LandUse module** in CityGML (Open Geospatial Consortium (OGC), 2012) represents zoning and land use regulations, essential for spatial planning at various scales. The *LandUse* class in the module can be aligned with LADM’s *SP_PlanBlock* class (seen in Figure 19) allowing land use information to be integrated with the spatial plan classes. While *SP_PlanBlock* doesn’t directly include attributes for representing land use information, the *SP_SpaceFunctionType* codelist can be adapted to capture land use details effectively. This allows for a flexible representation of land use types and functions within the LADM framework, ensuring that zoning regulations and land use information are accurately integrated into spatial plans. This module is especially useful for representing higher-scale maps, such as county or national plans, where zoning and land use information are more relevant than detailed building-level information.

The **Transportation module** covers road networks, railways, and other transportation infrastructure. LADM Part 5 does not have a related class or an attribute that can help. represent this information. Similarly, the **Vegetation module** which includes spatial information about trees, forests, and other vegetation cannot be directly mapped to an existing LADM Part 5 class or an attribute. In these situations, the developed LADM Part 5 profile for a specific country can be extended by adding new classes and attributes to represent the missing information.

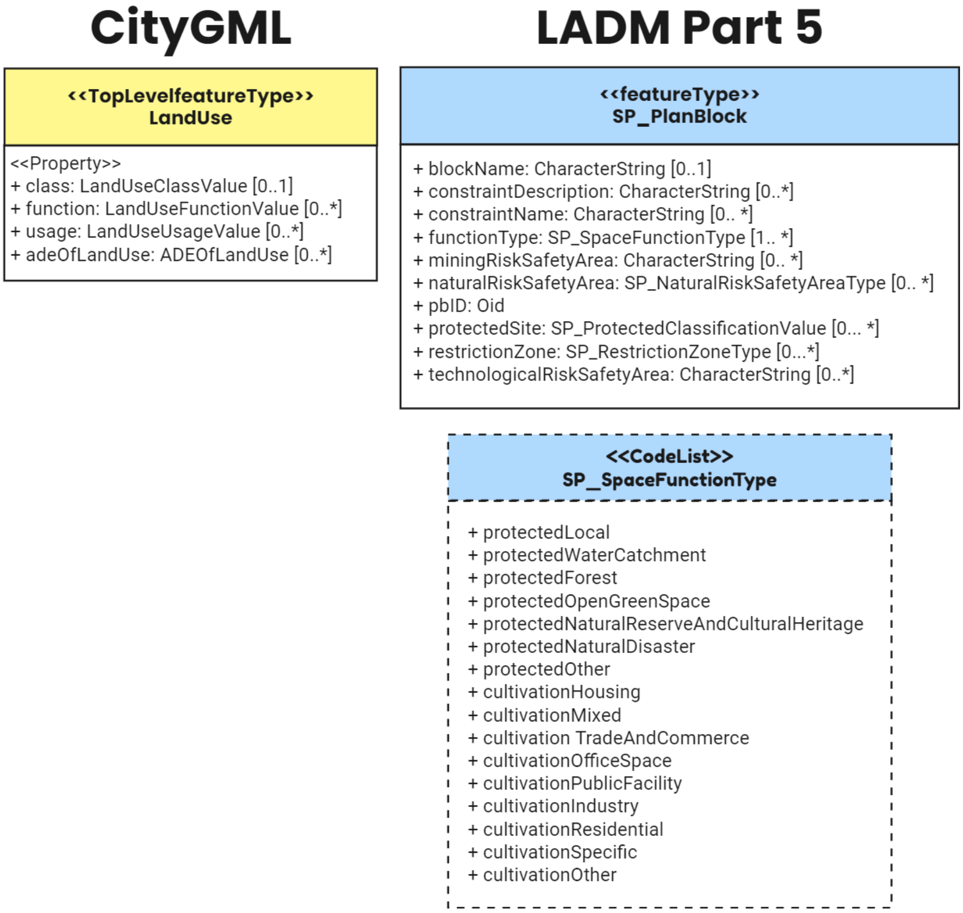


Figure 19. CityGML's LandUse class versus LADM Part 5's SP_PlanBlock class

Overall, while CityGML provides a strong framework for representing urban features and detailed building information, its applicability differs depending on the scale of the spatial plan. For larger-scale plans, such as county or national plans, modules like *LandUse* are more relevant. For detailed plans focusing on individual buildings, the *Building* module is more applicable. Representing vegetation and transportation elements can be done by using additional codelist and classes to fully represent the spatial data. In the end, the integration of CityGML data into LADM requires careful mapping of relevant classes and may require extending LADM Part 5 with new classes and attributes to capture all necessary spatial information.

IFC

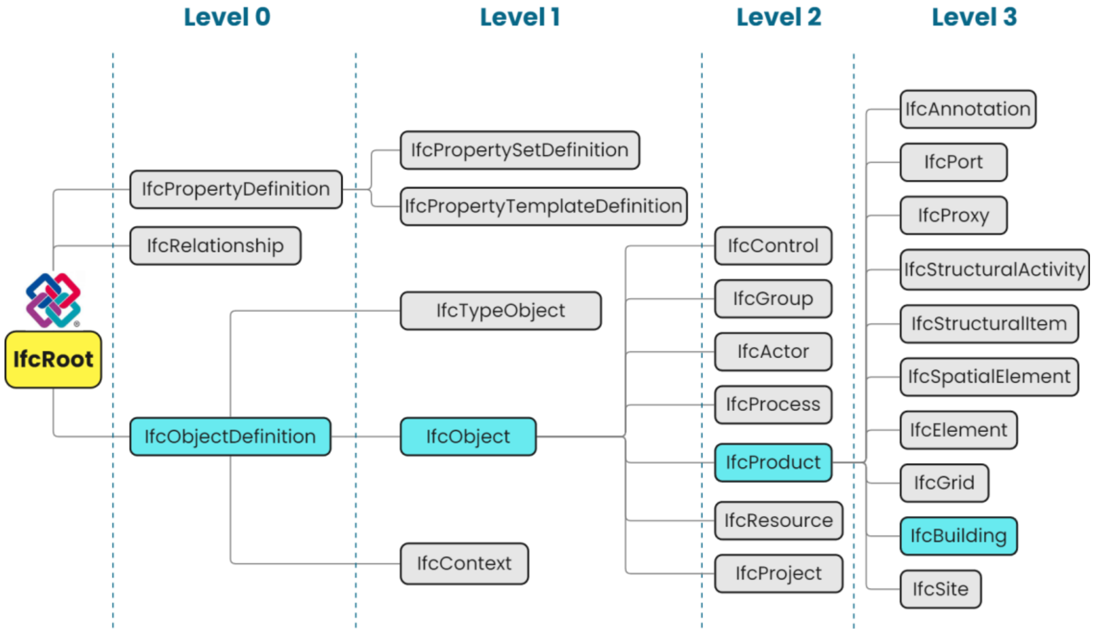


Figure 20. IFC Schema levels; IfcBuilding

IFC, as outlined in Section 0, serves as a vendor-neutral and platform-independent data model, providing a universal language for exchanging BIM data. The **IfcBuilding** class in IFC (seen in Figure 20) can be compared to LADM Part 5's **SP_PlanUnit** class. *IfcBuilding* includes attributes such as building geometry, location, and functional characteristics, which closely represents some of *SP_PlanUnit*'s attributes like *currentArea*, *currentVolume*, and various indication attributes for height, volume, and shape. Both classes provide detailed information about individual building level within a spatial plan data, but *IfcBuilding* offers more specific construction-related attributes.

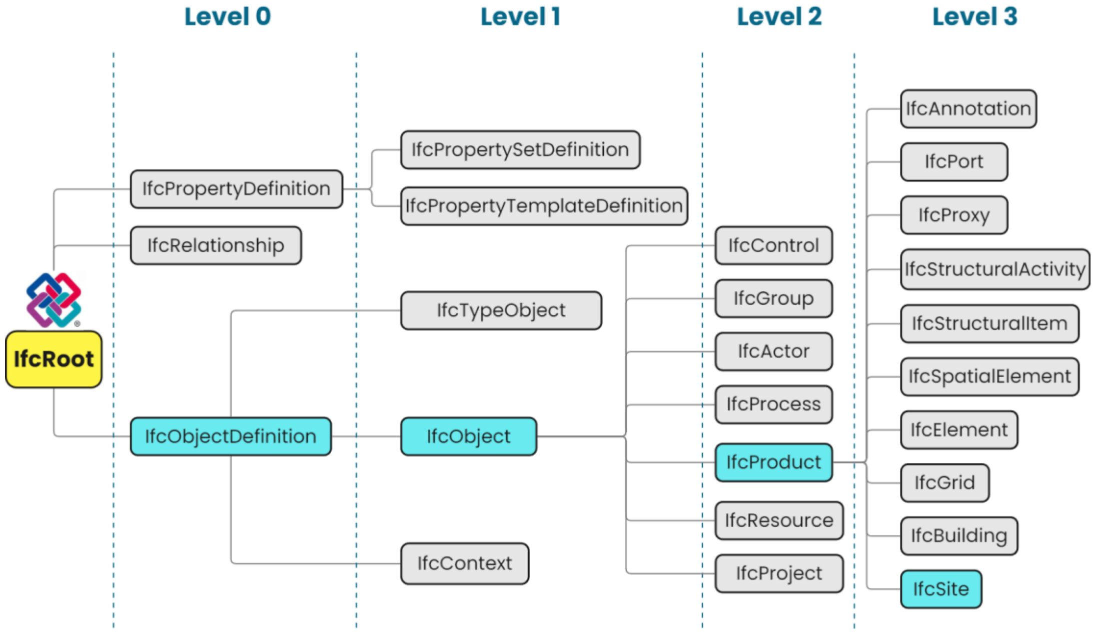


Figure 21. IFC Schema levels; IfcSite

If specified, a building is associated to a site (buildingSmart, 2020). The **IfcSite** class in IFC (seen in Figure 21) represents the context of a building project, including the geographic location, terrain, and site conditions. This class can be aligned with LADM's **SP_PlanBlock** class, which includes information about larger spatial blocks within a planning framework. *IfcSite* includes attributes such as site area, site volume, and site geometry, which correspond to some of *SP_PlanBlock*'s attributes such as *blockName*, *functionType*, and various risk and safety area indications.

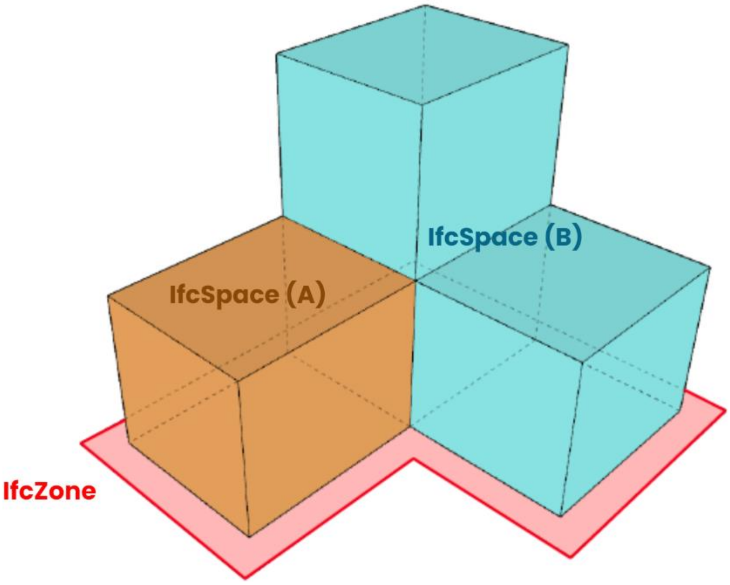


Figure 22. IfcZone consisting of multiple IfcSpace.

The **IfcZone** class in IFC represents a group of spaces that share a common function or attribute, such as fire zones or thermal zones. This can be mapped with the LADM's **SP_PlanUnitGroup** class, which groups multiple spatial units based on common characteristics or functions. This enables the management of spatial units by grouping them into functional categories. For example, as seen in Figure 22, IfcZone can define a collection of spaces (i.e., **IfcSpace**) within a building, like living rooms, kitchens, bedrooms, into zones such as "habitable areas". These zones can be represented with *SP_PlanUnitGroup*'s attributes like *functionType* and *planUnitGroupName*, allowing consistent classification and management of spaces.

Overall, IFC also provides an efficient structure that can be closely mapped to LADM Part 5's spatial planning classes. The encoding's ability to store detailed architectural, engineering, and construction data makes it suitable for building-level spatial plans. However, it should be noted that for broader spatial planning at the county or national level at bigger scales, its detailed focus may be insufficient. This can require complementary usage with other models, such as CityGML, to ensure comprehensive coverage of all spatial plan scales mentioned in Section 2.1.

In assessing the theoretical capabilities of both CityGML and IFC within the scope of spatial plans and LADM Part 5 mapping, it is evident that each encoding offers unique strengths suited to different aspects of spatial representation. CityGML excels in providing a multi-scale urban model that captures detailed semantic and geometric information at various levels of detail. This makes it ideal for broad urban planning tasks and regional zoning. The Building, Transportation, and LandUse thematic modules align well with LADM classes, although some areas may require extending the LADM model to fully capture the data. However, CityGML is not typically used for representing AEC products like BIM, which may limit its effectiveness for Detailed Plan representation.

On the other hand, IFC is strong in representing detailed building information, making it suitable for building-level spatial planning such as Detailed Plans. While IFC has primarily been used as a design model, its structured schema allows for the possibility of using IFC as a plan information model in spatial planning. However, there is no established standardization for representing spatial plans using IFC, which poses challenges when assessing its broader applicability. Its ability to map to LADM's spatial units enables detailed spatial plans to be represented, though IFC's focus on AEC data may limit its use for larger-scale plans like regional or national plans without complementary models.

It should also be noted that this theoretical assessment might not match closely with practical usage or data, as real-world challenges like data availability and software compatibility often differ from theoretical predictions. Additionally, organizations and countries might implement the encoding differently, which leads to variations in how the data is stored and represented by the encoding itself. Therefore, while the theoretical mapping provides a solid foundation for assessing the encodings, practical validation is required to examine the extent of the mapping efficiency of the encodings to LADM Part 5.

3. Case Study: Estonia

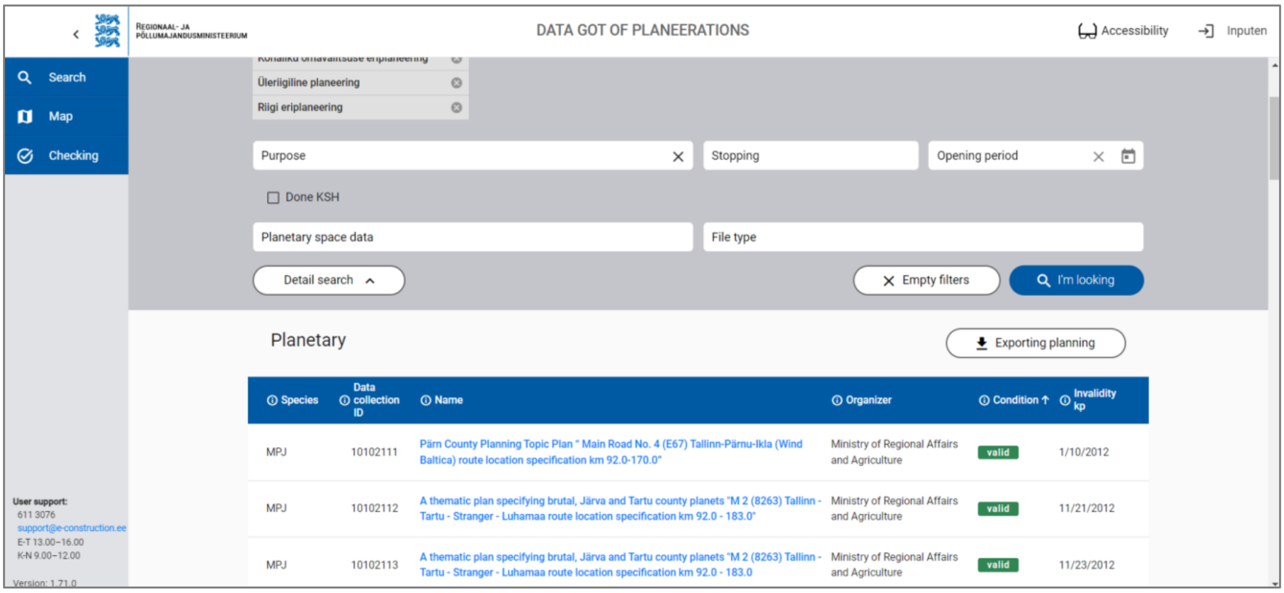
The thesis is conducted in collaboration with Future Insight Group and the case study examined in this context is based on a project of the company in collaboration with the Ministry of Climate (*Kliimaministeerium*) of Estonia. The selection of Estonia as a case study was motivated by several factors.

> First, LADM Part 5 is still a draft standard (DIS 19152-5, 2024), and the development of country profiles for this part remains limited. While some countries are working on profiles, there aren't currently fully established or widely used examples in real-world spatial plan applications. This made Estonia an ideal setting for exploring how LADM Part 5 can be applied, particularly in compliance checks between spatial plans, an area where practical implementation is still underdeveloped.
>
> Second, the study aimed to assess the LADM standard within a real-world, implementation-level scenario, and the collaboration with Future Insight in Estonia provided the necessary context. This was particularly valuable as there are few examples of Part 5 being applied beyond conceptual discussions, providing a unique opportunity to test the standard in practice and with real data.
>
> Additionally, the availability of real-world 3D data was not a determining factor in selecting the case study because the project included pilot 3D data, which was specifically tailored and developed for the collaboration of Future Insight Group with the Ministry of Climate. While the data was not from a real-life, fully developed 3D system, it was sufficient for demonstrating the applicability of LADM Part 5 and its assessment in the compliance checking process.
>
> Finally, choosing Estonia provided the chance to work with a country developing its digital infrastructure, which includes spatial planning processes. Estonia is known for its progressive approach to digital government services, making it an ideal environment to explore advanced applications such as automated compliance checks.

This project, "*Detailed analysis of the use of the information model of the plan and creation of a prototype solution*", builds on Future Insight's initial work in 2018 on automated BIM-based permit checks, which laid the foundation for the advancements discussed in this project. The earlier initiative is detailed in Appendix B: "*Relevant BIM-based Initiatives for Permit Checking: BIM-Based Permit Check – Estonia*."

3.1. PLANK

The digitization of the planning process in Estonia took a significant step forward with the introduction of PLANK (2022), the Estonian database of established spatial plans. PLANK, shown in Figure 23, has been mandatory for all 79 municipalities in the country to use since November 2022[2]. This ensures that all valid plans are readily accessible in digital form in a central database. The main goal is to reduce the burden on municipalities, ensure all plans are up-to-date, and facilitate a collaborative usage of the planning data with other information systems.



Species	Data collection ID	Name	Organizer	Condition ↑	Invalidity kp
MPJ	10102111	Pärn County Planning Topic Plan " Main Road No. 4 (E67) Tallinn-Pärnu-Ikla (Wind Baltica) route location specification km 92.0-170.0"	Ministry of Regional Affairs and Agriculture	valid	1/10/2012
MPJ	10102112	A thematic plan specifying brutal, Järva and Tartu county planets "M 2 (8263) Tallinn - Tartu - Stranger - Luhamaa route location specification km 92.0 - 183.0"	Ministry of Regional Affairs and Agriculture	valid	11/21/2012
MPJ	10102113	A thematic plan specifying brutal, Järva and Tartu county planets "M 2 (8263) Tallinn - Tartu - Stranger - Luhamaa route location specification km 92.0 - 183.0	Ministry of Regional Affairs and Agriculture	valid	11/23/2012

User support:
611 3076
support@e-construction.ee
E-T 13.00–16.00
K-N 9.00–12.00
Version: 1.71.0

Figure 23. Main page of PLANK, translated to English.

PLANK includes its own automatic validation checking on plans, allowing only validated plans to be shared and shown in the database[3]. When a plan file is submitted, a check is performed to ensure compliance with rules and business requirements established in the system. Table 1, provides an overview of the categorization of checks, including the ranges of check codes, translated into English. In addition to the general checks happening about the metadata of the file submitted (i.e., 100-105 and 400-417), there are some data specific checks as well. For example, specific layers must be used when a particular topic is addressed in a spatial plan. If a topic is used but the defined layer name is not, PLANK notifies the user of the unrecognized layer name and ignores it ("Code 206: *There is a layer with an unknown name in the DWG file*"). If PLANK recognizes the layer, it checks for attribute data, which are specific information or properties associated with that layer. The overall checking system is fully automated, requiring no manual intervention.

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[2] https://planeerimine.ee/digi/plank/

[3] https://planeerimine.ee/digi/plank/plank-juhendid/automaatsed-kontrollid/

Table 1. Main categorization of the automatic checks performed by PLANK.

Code Range	Check Category	General Description
100-105	Metadata Integrity	Ensures metadata completeness, accuracy, and adherence to required formats and values.
200-209	Spatial Data Integrity	Verifies the validity, correctness, and compliance of spatial shapes with specified geometric standards and their proper inclusion within planning areas.
210-224	Plan Compliance & Uniqueness	Checks for overlaps with existing plans, adherence to municipal territories, uniqueness of plan identifiers, and compliance with broader planning frameworks.
300-314	Object and Layer Validation	Validates object properties, layer naming, and attribute data types against predefined standards to ensure data structure correctness.
400-417	Document and Data File Checks	Confirms the presence and correctness of mandatory documents (e.g., explanatory memorandums, drawings), spatial data files, and ensures only required files are submitted.

(This table shows the main focuses of the automatic checks conducted by the PLANK.)

The introduction of PLANK in 2022 has established a foundation for an integrated e-construction platform and standardization throughout the planning process in Estonia. However, while PLANK includes validation checks, these are limited to 2D. Still, there is a need for a check mechanism capable of handling both 2D and 3D data and automatically checking for compliance with regulations. Additionally, plans are only registered in PLANK after the planning procedure, whereas having Detailed Plan data available throughout the planning process would be more beneficial for early-stage decision-making (Future Insight Group, 2023).

Building on the foundation of Estonia's initial BIM-based permit checking system, the current project shifts focus from building permits to investigating the compliance of plan requirements in the early planning stage. This approach addresses the need for early-stage validation in the planning process and ensures that larger area designs/plans adhere to the regulations (Future Insight Group, 2024).

3.2. Interview and Desk Research Findings

The first stage of the project involved comprehensive desk research and interviews with various stakeholders to understand the current planning processes, challenges, and opportunities for improvement.

Table 2. Overview of the organizations that took part in the interviews. Table by Future Insight Group.

	Organization	**Function (Role)**
1	Lääne-Harju Municipality	Architect & planner
2	Hades Geodeesia & Estonian Digital Construction Cluster	CEO & Board member
3	Estonian Architects Union & PLUSS	Head of project management & PLUSS
4	Hendrikson & Ko & Estonian Association of Spatial Planners	Head of comprehensive and regional planning department
5	Skepast & Puhkim	Planning department manager & project manager
6	City of Tallinn	Head of planning department & architect & Head of planning board
7	Port of Tallinn & Estonian Digital Construction Cluster	Head of development department & board member
8	City of Tartu	Spatial planner
9	Ministry of Climate	Head of client service help desk
10	K-Projekt	Leading Expert
11	Ministry of Regional Affairs and Agriculture	Digital Division of Spatial Planning

A total of 11 interviews were conducted with representatives from both public and private organizations (seen in Table 2). The interviewees held various roles within the planning process in Estonia. They were first asked about their view on the current planning process, their role in it, and the bottlenecks they identified (results illustrated in Figure 24). The full list of questions can be found in Appendix C, "*Interview Questions*." PlanBIM, which serves as a model for automated compliance checking of Detailed Plans using 3D representations and open standards like IFC and CityGML, was then introduced as an example. Following this, they were asked about their view on the future (based on the 2018 PlanBIM example) and what possibilities and obstacles they see (Future Insight Group, 2023).

The insights gained from these interviews highlighted several key points (Future Insight Group, 2024).

- The need for improved planning process standardization, collaboration, and version control is recognized.
- The benefits of creating Detailed Plans in 3D are acknowledged.
- Some basic standardization efforts already exist but need further extension to meet the goals for automated checking of Detailed Plans in 3D.

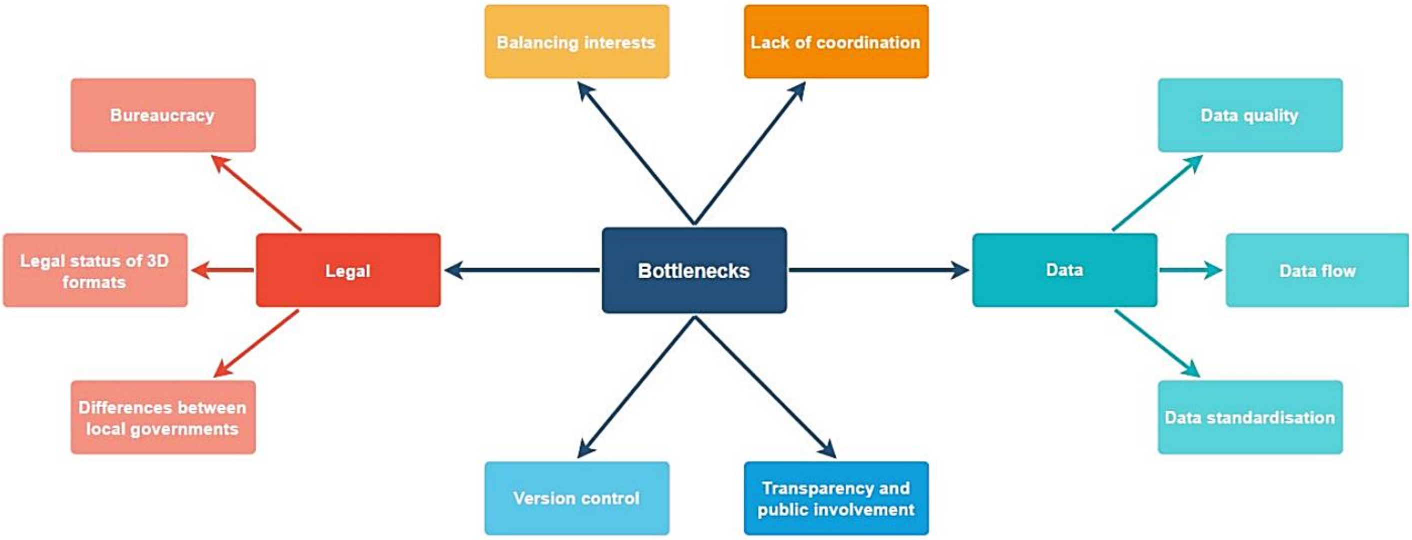

Figure 24. Recognized bottlenecks from the interviews. Figure by Future Insight Group.

Additionally, the desk research aimed to evaluate the data formats currently used in the Estonian planning process and their suitability for a Plan Information Model[4].

The findings showed (Future Insight Group, 2023):

- The current planning data in Estonia is primarily in 2D CAD or GIS formats and is not based on a Plan Information Model.
- Standardization in 3D planning datasets is absent and this hinders interoperability and further integration.
- Not all plans are digitized, with many only available as PDFs or paper documents, complicating their use for automated checks.
- Planning data must be standardized and follow a consistent format (i.e., naming of properties, entities, and attributes).
- Open standards like IFC and CityGML are recommended to improve interoperability. While IFC is currently used in prototype models, other formats like CityGML also need further investigation.
- Supporting 3D data is essential for achieving the project's objectives.

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[4] A 3D collection of planning data linked to corresponding elements, such as building area data to building elements and landscaping data to landscape features (e.g., trees, shrubs, surfaces). [Majandus ja Kommunikatsiooniministeeriumi Ehitisregistri talitus, "*Detailed Analysis Of Using The Planning Information Model And Creation Of A Prototype Solution*," Appendix 1. 2023].

3.3. Value Case and Solution Design

Based on the insights from the interviews and desk research, several key bottlenecks were identified in the current Estonian planning process. These included a lack of standardization, reliance on manual checks, and time-consuming approval processes (Future Insight Group, 2024). It was also essential for the solution design to be integrated with, or capable of integration with, Estonia's central e-construction platform. While currently PLANK establishes the foundation for this integrated platform concept, its checks are limited to 2D validation, lacking a 3D component.

Interviews and desk research also revealed the various formats used in the spatial planning process in Estonia, such as CAD, PDF, CSV and GIS, with only some data complying with data regulations. Meanwhile, the increasing popularity of BIM applications highlighted IFC as one of the most commonly used formats. Based on this, the project focused on developing a standardized IFC protocol for spatial plans Estonia, aiming to establish requirements for Master Plans, Detailed Plans, and designs (Future Insight Group, 2024).

3.4. Prototype Compliance Check Model

The prototype solution was developed based on the results of the desk research and interviews. The main aim of the prototype was to address the identified challenges and improve the planning process in Estonia. The solution was designed to integrate seamlessly with the existing e-construction platforms, building on the foundation of PLANK and its validation checking system for submitted plans.

The development of the prototype solution involved setting up the basic technology, preparing the required data, and establishing the checks to be executed. Initially, a shortlist of ten possible checks was created, from which seven checks were developed (explained in section 3.5). The prototype was designed with scalability in mind, ensuring it could manage various IFC plan data and support potential future expansions and additional functionalities.

The technical infrastructure of the prototype was based on an online microservice architecture using international open standards, ensuring flexibility, scalability, and futureproofing. The infrastructure consisted of **Clearly.HUB**[5] for organizing and storing data, and **FME Flow** for orchestrating the checks. Clearly.HUB is Future Insight's digitally connected ecosystem that already supports Sensor, 2D, 3D and BIM data with additional functionalities (Future Insight Group, 2024). Moreover, the data required for

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[5] https://www.futureinsight.nl/clearly-hub?lang=en

the checks, including 3D Detailed Plans in IFC format, was collected, and made available in Clearly.HUB. Figure 25 illustrates how all of this comes together.

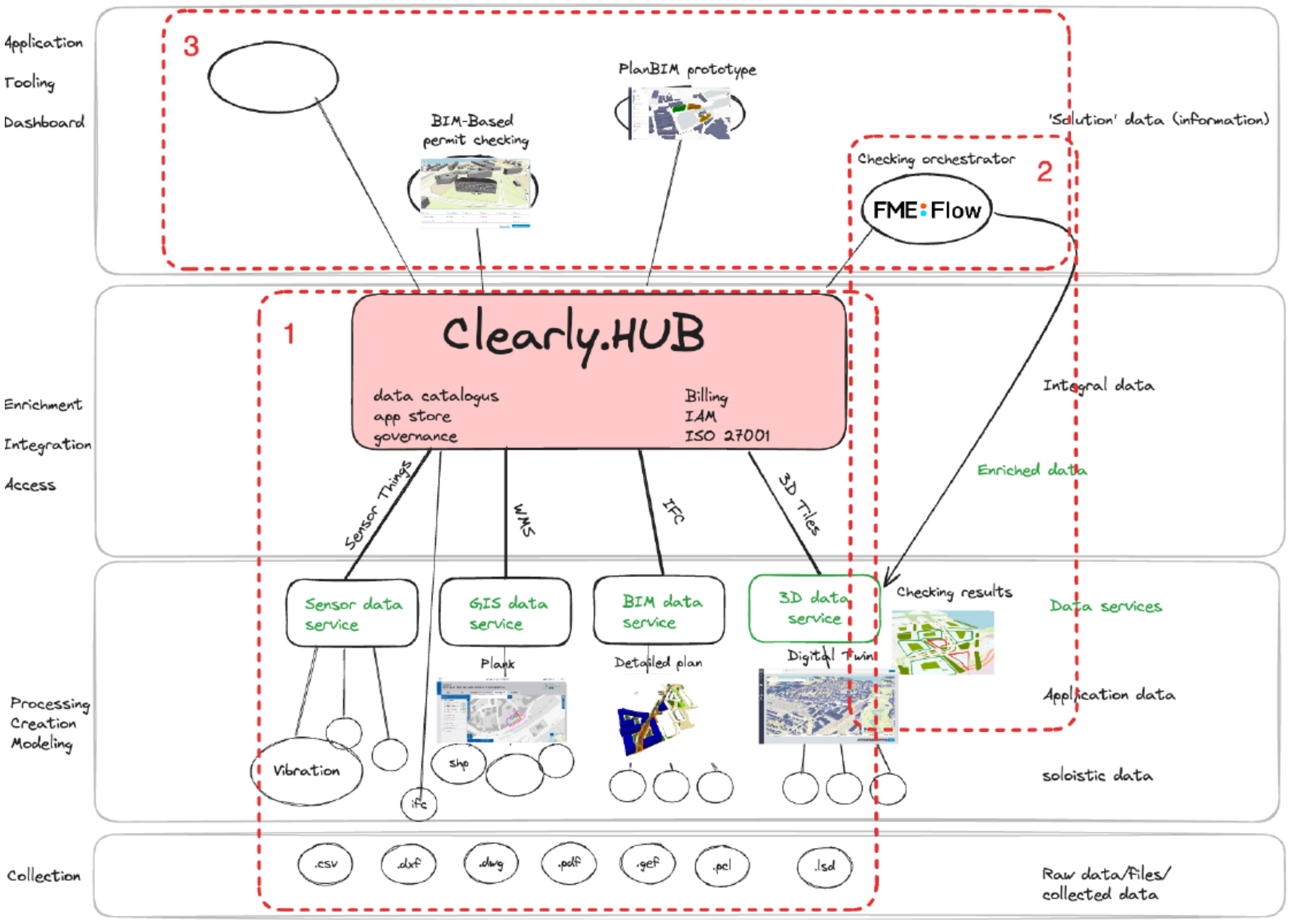


Figure 25. Overview of the technical infrastructure of the Clearly.HUB for this project. Figure by Future Insight Group.

To clarify the interaction between these components:

- **Clearly.HUB** acts as the central repository where all spatial planning data is uploaded and organized, including IFC files for Detailed Plans and WMS/WFS data for Master Plans. This serves as the main interface for storing the input data and the results of the compliance checks.
- **FME Flow** is the engine that executes the compliance checks. FME Flow reads the IFC and other datasets and runs the compliance checks (e.g., verifying building heights, distances between buildings, or zoning requirements) automatically. This eliminates the need for manual intervention once the checks are set up.

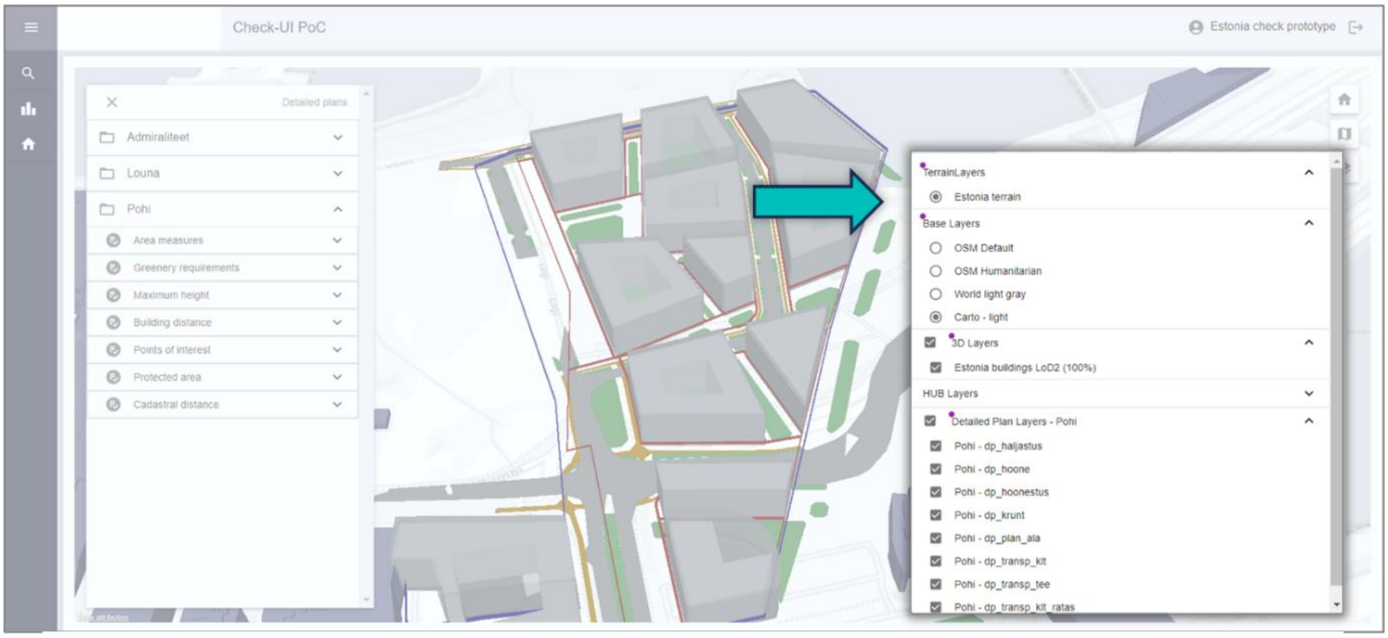
Together, these systems form the backbone of the automated compliance checking process. Clearly.HUB holds and organizes the data, and FME Flow performs the checks.

To ensure the prototype functions effectively, the process was broken down into three main steps (also outlined in Figure 25) (Future Insight Group, 2024):

First, the required source data was collected and organized, preferably also standardized and available for the pilot area. For this, data from the PLANK database was favored due to its standardized structure. If this was unavailable, open data such as the national 3D Digital Twin of Estonia[6] and datasets containing points of interest were used. All source data, including 3D Detailed Plans in IFC format, was organized in Clearly.HUB.

Second, the PlanBIM checks were developed and performed using the orchestrator, with the available data and provided Detailed Plan. The results were described and made available in a standardized structure in 3D Tiles format in Clearly.HUB. This helped establish accessibility for both the prototype and other web services, such as the BIM-based permit checking service.

Third, the standardized results were made available in a web service based on the open-source Cesium JS component, connected to Clearly.HUB. A standardized OAuth component was also integrated to this process to ensure secure authorization and access to Clearly.HUB. In the online prototype, all map layers in Clearly.HUB automatically appear as map layers, alongside configurations for the check results and reference map layers. Figure 26 illustrates the example layers seen in the online prototype.



TerrainLayers
● Estonia terrain

Base Layers
○ OSM Default
○ OSM Humanitarian
○ World light gray
● Carto - light

☑ 3D Layers
☑ Estonia buildings LoD2 (100%)

HUB Layers

☑ Detailed Plan Layers - Pohi
☑ Pohi - dp_haljastus
☑ Pohi - dp_hoone
☑ Pohi - dp_hoonestus
☑ Pohi - dp_krunt
☑ Pohi - dp_plan_ala
☑ Pohi - dp_transp_kit
☑ Pohi - dp_transp_tee
☑ Pohi - dp_transp_kit_ratas

Figure 26. Developed prototype's example layers.

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[6] https://3d.maaamet.ee/kaart/

3.5. Implemented Checks and Data Requirements

During the initial phase of the project, interviews with stakeholders identified 18 potential compliance checks, each evaluated based on four key criteria*: clarity, feasibility, value,* and *the advantage of using 3D data*. Some checks were suggested by multiple participants, the 18 unique checks were the combined version of the initial list. These checks were then discussed with the project's working group, and after careful analysis, 10 checks were shortlisted for further exploration and potential development.

In the second phase of the project, which focused on the creation of the prototype solution, these 10 shortlisted checks were analyzed again to determine the necessary data and infrastructure for their implementation. An agile approach was adopted, with a continuous cycle of setting up the technology, preparing the data, and implementing the checks. Throughout this process, schemes were developed to map out the necessary steps and the data required for each check.

Ultimately, 7 checks were selected for implementation in the final prototype, based on the *availability of data* and the *feasibility* of executing them within the scope of the project. Additional information on the selection criteria of the specific checks can be found in the project report of the company (Future Insight Group, 2024). Table 3 shows the finalized seven checks that were implemented, along with the specific plans needed to execute each check.

#	**Check name**	**Detailed Description**	**Plans Needed**
1	Check area measures	Calculates the area for each land use type, providing an overview of the building area.	DP-MP
2	Greenery demands (%)	Determines the percentage of greenery in the plan area to ensure it meets master plan requirements.	DP-MP
3	Maximum building height	Verifies that building heights comply with the maximum height regulations.	DP-MP
4	Building distance	Measures the distance between buildings in the digital twin to ensure compliance with fire safety regulations.	DP
5	Fire hydrants	Calculates the distance from buildable areas to fire hydrants, ensuring compliance with fire safety standards.	DP-MP
6	Protected area requirements	Checks for overlaps with protected areas like heritage sites or flood zones, issuing warnings or errors if detected.	DP-MP
7	Cadastral border distance	Measures the distance from buildable areas to cadastral borders to ensure compliance with minimum distance regulations.	DP

Table 3. Seven checks for implementation [Detailed Plans (DP), Master Plans (MP)].
Figure adapted from Future Insight Group.

These seven checks require Master Plan and Detailed Plan data to be executed. Table 3's "*Plans Needed*" column indicate which plan/plans are required for that specific check to be performed. As previously mentioned in section 0, the prototype was developed for IFC data of the BIM models of the Detailed Plans. It is good to note here that Estonian spatial plan layers have a requirement for standardized naming and structured relevant attributes of specific layers, regardless of the encoding. For both Master Plans and Detailed Plans, these requirements are available with English translations in Appendix D.

It is also worth noting that some checks, such as "4. *Building distance*" and "7. *Cadastral border distance*," refer specifically to Detailed Plans and do not rely on Master Plan data. These checks focus on localized regulatory compliance, including fire safety and minimum distance requirements, which are typically addressed at the detailed planning level. On the other hand, checks like "2. *Greenery demands*" and "1. *Check area measures*" require both Master and Detailed Plan data to ensure alignment with the planning goals. Therefore, the distinction between checks that involve broader planning data and those limited to detailed local regulations is also reflected in the "Plans Needed" column.

Additionally, while only one check -"3. *Maximum building height*"- directly leverages 3D data, the value of 3D tools extends beyond height verification. 3D data enhances visualization, public participation, and comparison between different planning levels, allowing stakeholders to better understand spatial relationships. Although simplified 3D models may suffice for certain checks, especially during the detailed planning phase, the strategic use of 3D improves overall clarity and reduces human errors during compliance checks. Moreover, 3D models provide a framework for automated processes, streamlining workflows and increasing efficiency, particularly for smaller municipalities with limited resources (Future Insight Group, 2023).

Detailed Plan Data Requirements

For the successful implementation of the prototype, specific data requirements must be met, particularly for the IFC models of the Detailed Plans and the Master Plans. The following data requirements are for the IFC model of the Detailed Plan (Future Insight Group, 2024):

- **File Format**: The detailed plan files must be in IFC format.
- **IFC Entities**: Objects in the IFC should be either *IfcBuildingElementProxy* or *IfcAnnotation*.
- **Property Sets**: Objects must contain a property set representing the discipline, with names limited to a specific list concurrent with regulations and PLANK (e.g., *dp_arhVoistlus, dp_avalik, dp_haljastus*, etc.).

- **Attributes**: The property sets should include attributes according to the mandated attribute list described in the regulations.
- **Plan Boundary**: The IFC should contain exactly one plan boundary, identified by the property set *dp_plan_ala* and modeled as a line in the IFC entity *IfcAnnotation*.
- **Plot Boundaries**: The IFC should contain one or more plot boundaries, identified by the property set *dp_krunt* and modeled as a line in the IFC entity *IfcAnnotation*.
- **Coverage**: Objects in the IFC must cover the entire planning area.
- **No Overlaps**: Objects in the IFC must not overlap with each other.
- **Georeferencing**: The IFC must have correct georeferencing and be modeled in EPSG:3301.

Master Plan Data Requirements

The Master Plan data for the prototype came from WMS and WFS services by the city of Tallinn and the Land Board of Estonia[7]. This data is not fully available in the PLANK database because not all Master Plans are included yet, and specific sections for detailed requirements like greenery percentages or building heights are missing. This makes the checks less scalable and require different data sources for similar requirements (Future Insight Group, 2024). The PLANK database, which stores spatial plans according to national regulations, offers benefits like centralized storage and uniformity. Additionally, it is accessible as a WFS service, if the requirements are structured in a standardized way this simplifies the data integration step for the automated checks.

For the Master Plan data used in the prototype, various requirements need to be met. Below are some (Future Insight Group, 2024):

- **Greenery Area**: The data should be available as polygons, containing an attribute that specifies the greenery requirement percentage as a numeric value between 0 and 100. This data should be accessible through an OGC WFS service.
- **Building Height**: The data should also be in polygon format, with attributes indicating the maximum building height in meters for both absolute and relative heights. These should also be accessible through an OGC WFS service.
- **Protected Areas**: The data should be available as polygons, lines, or points and provided through an OGC WFS service.
- **Cadaster Border Distance**: The maximum distance from the plot boundary to the building must be defined, along with the point or line from which this distance is measured.

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[7] https://geoportaal.maaamet.ee

More details about the overall project and functional elaboration for each check can be found at https://eehitus.ee/wp-content/uploads/2024/02/Final-work-report-PlanBIM-project-Estonia.pdf.

Furthermore, the lessons learned and recommendations from the company's project and the case study have been summarized in Appendix E: "*Reflections and Recommendations Based on the Case Study*". They are based on Future Insight's final project report. These suggestions focus on improving scalability, standardization, and overall effectiveness, highlighting key areas for future improvements.

3.6. Datasets

The data sources for the checks included both IFC models and various WMS and WFS services. There are three main IFC pilot projects representing the Detailed Plans (i.e., IFC as a plan information model) used in the development of the prototype. The IFCs used originate from the case study upon which this investigation is based. The detailed plan of the pilot project "*Tallinn Harbor area*" will be used as a test case. Despite IFC not yet being an official format for spatial planning in Estonia, these IFC models were developed specifically to explore the potential for automated checks, reflecting real, integrated data showcased in PLANK. Figure 27 show the three pilot Estonian IFC data used in the development of the prototype.

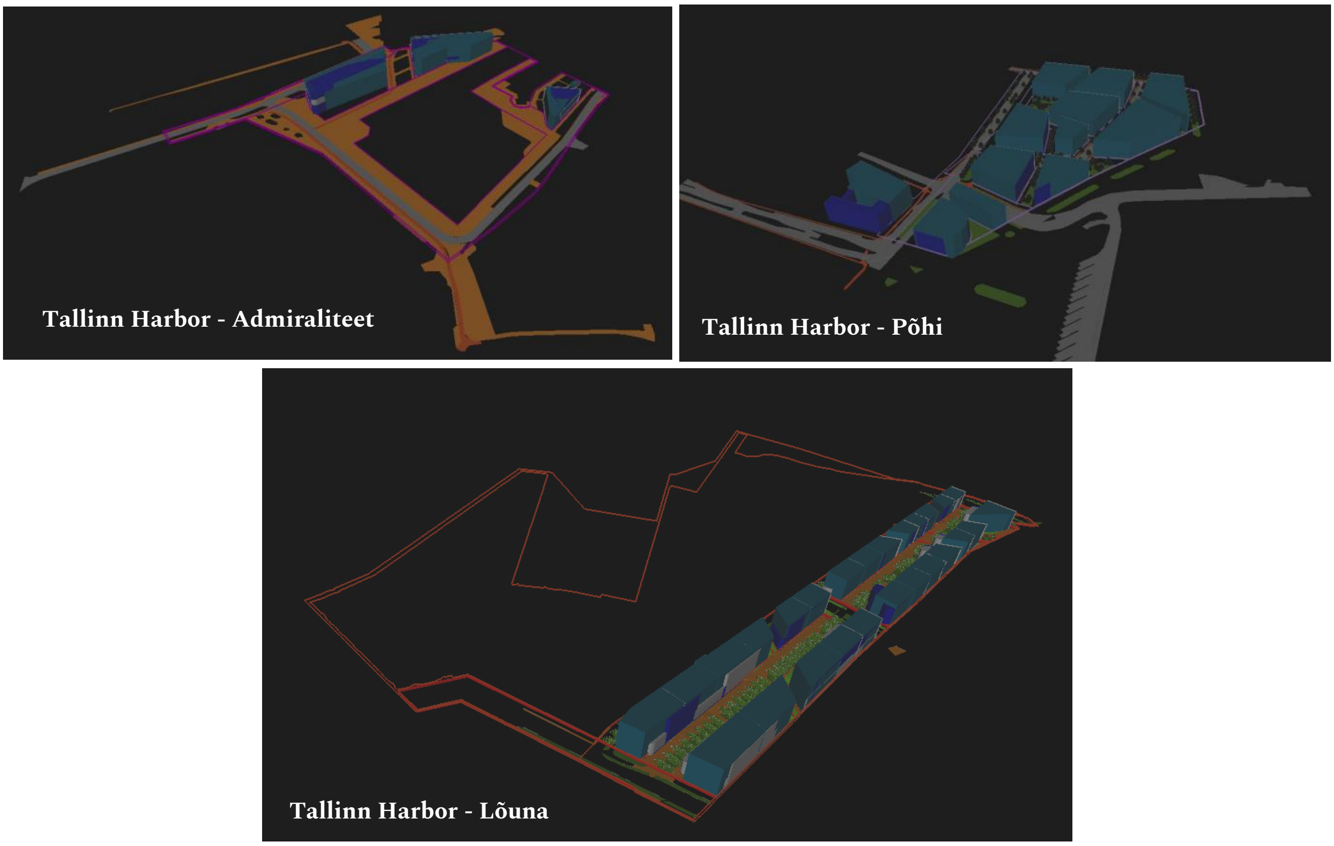
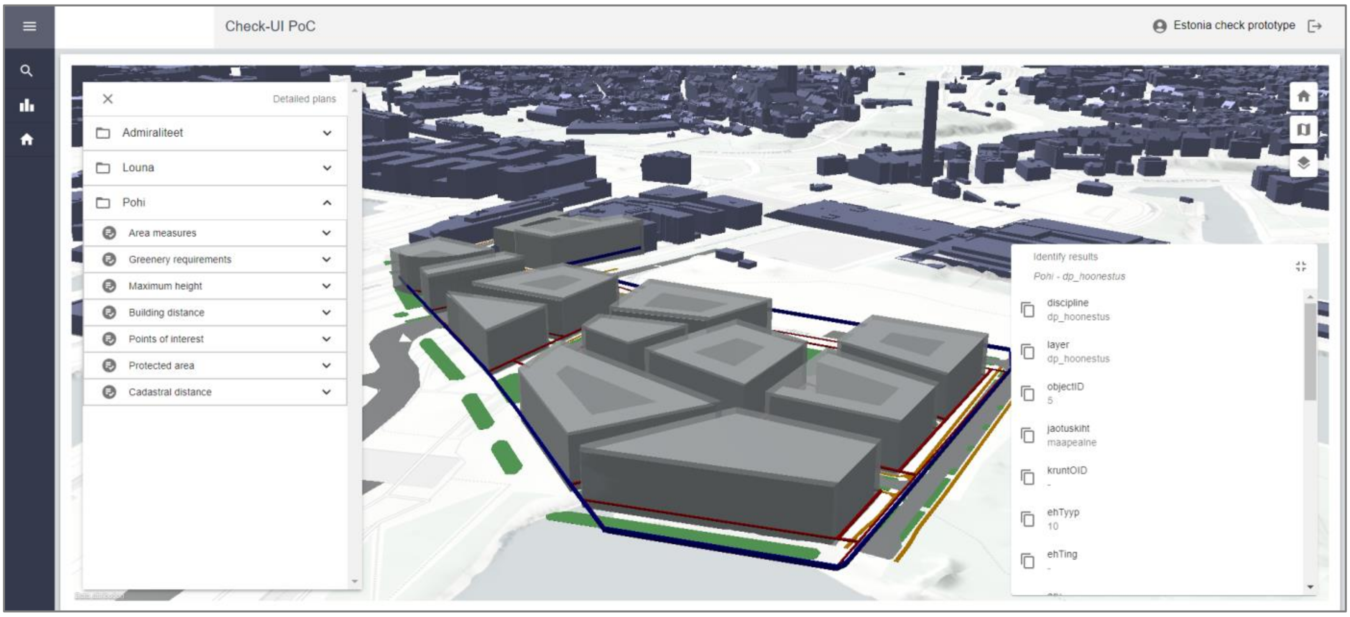


Figure 27. Estonian IFC datasets used in the development of the prototype solution.

The Master Plan data and existing object data (such as buildings and fire hydrants) were sourced from the city of Tallinn and the Land Board of Estonia. For example, the national 3D Digital Twin of Estonia (Figure 28), available in CityGML and 3D Tiles, was used. This dataset also includes detailed 3D representations essential for several checks.

Figure 28. 3D Digital Twin of Estonia. (https://3d.maaamet.ee/kaart)

The Master Plan data provided by the city of Tallinn was created specifically for and by the city. This data is not found in the PLANK database because not all of Tallinn's Master Plans are included there. Additionally, the PLANK data lacks specific fields for detailed requirements like greenery percentages or building height. Thus, for some of the check datasets available as WMS and WFS were used, but ideally, this data should come from the central PLANK database.



Pohi - dp_hoonestus

discipline
dp_hoonestus

layer
dp_hoonestus

objectID
5

jaotuskiht
maapealne

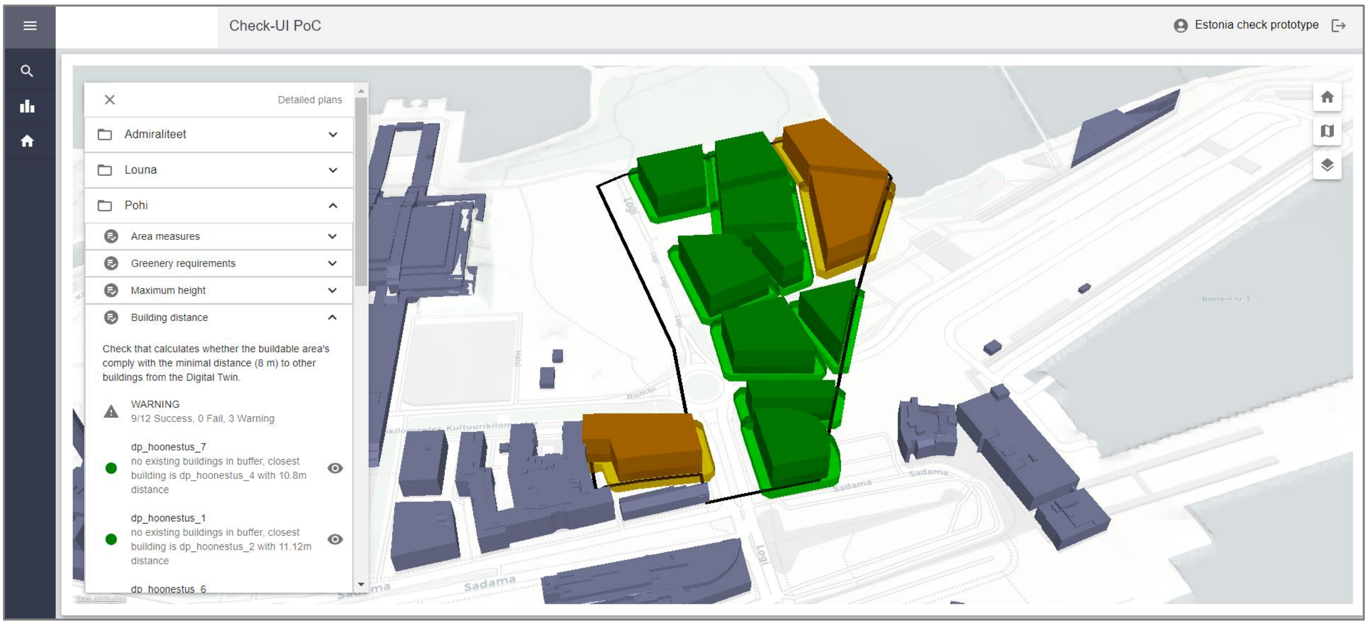
kruntOID
-

ehTyyp
10

ehTing
-

Figure 29. Clearly.HUB Estonia prototype visualization I.

These datasets were integrated into Clearly.HUB, for organizing and storing the data for the prototype. The checks utilized the Detailed Plan data (IFC) and the additional layers from these services to perform and visualize the automated checks. The visualization of the prototype is available online at https://estonia-poc.clearly.app/ with all these source datasets and the check results. A general login to get access is available using estonia@futureinsight.nl as user and the password can be requested from info@futureinsight.nl (Future Insight Group, 2024). Some examples of the capabilities of the prototype can be seen in Figure 29, Figure 31, Figure 30.



Check that calculates whether the buildable area's comply with the minimal distance (8 m) to other buildings from the Digital Twin.

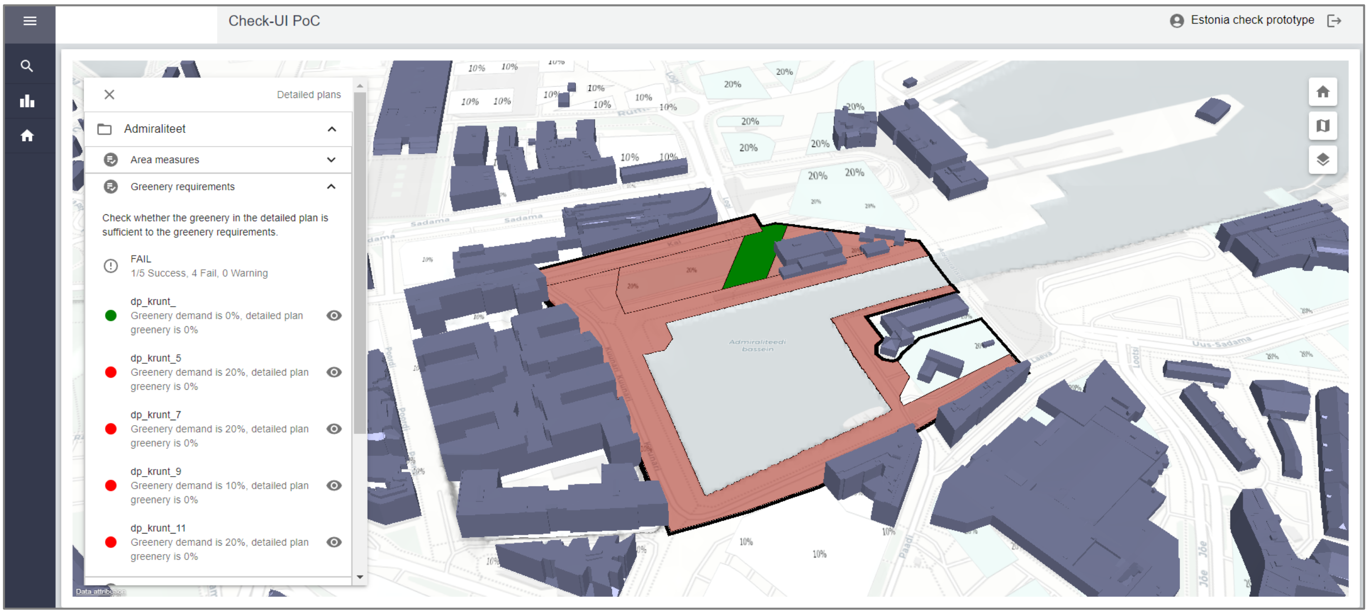
WARNING
9/12 Success, 0 Fail, 3 Warning

dp_hoonestus_7
no existing buildings in buffer, closest building is dp_hoonestus_4 with 10.8m distance

dp_hoonestus_1
no existing buildings in buffer, closest building is dp_hoonestus_2 with 11.12m distance

dp_hoonestus_6

Figure 31. Clearly.HUB Estonia prototype visualization II.



Check whether the greenery in the detailed plan is sufficient to the greenery requirements.

FAIL
1/5 Success, 4 Fail, 0 Warning

dp_krunt_
Greenery demand is 0%, detailed plan greenery is 0%

dp_krunt_5
Greenery demand is 20%, detailed plan greenery is 0%

dp_krunt_7
Greenery demand is 20%, detailed plan greenery is 0%

dp_krunt_9
Greenery demand is 10%, detailed plan greenery is 0%

dp_krunt_11
Greenery demand is 20%, detailed plan greenery is 0%

Figure 30. Clearly.HUB Estonia prototype visualization III.

4. Country Profile of Estonia

Creating a country profile is an essential step in understanding and implementing LADM within a specific national context. This guarantees that LADM, which provides a standardized methodology for recording LAS data, is tailored to the unique legislative, administrative, and technical requirements of a specific country. Particularly, by developing a country profile, the specific needs of Estonia's LAS can be addressed, allowing spatial plans and compliance checks to be effectively integrated into the broader national infrastructure.

The general layout of LADM classes and attributes might not always completely meet the needs of a country planning to utilize LADM. Therefore, creating a country-specific LADM profile is necessary to accommodate to those unique requirements. This process involves an agile attitude: creating or omitting classes and attributes and implementing new relationships if necessary to represent the specific needs of the country. There are two main approaches when developing an LADM country profile: a holistic view where all aspects of cadastral information are mapped, or a targeted approach where only specific parts of cadastral information are mapped according to the country's needs (Kalogianni et al., 2019). Due to the scope of this research involving spatial data and compliance checks, LADM’s Part 5: Spatial Plan Information package was considered relevant and will form the basis of the new Estonia country profile.

4.1. Estonia's Land Administration and Spatial Planning

This section will provide an analysis of Estonia’s land administration and planning system. It will also provide details about how the current system functions, its legislative and administrative structure, and the integration of spatial plans.

Estonia’s land administration and spatial planning system is governed by the Planning Act (*Planeerimisseadus – Riigi Teataja*), adopted on January 28, 2015, and came into force on July 1, 2015[8]. This Act redefined the principles, procedures, and responsibilities related to spatial planning, establishing a legal basis for all planning activities. It focuses on creating preconditions for sustainable development, encompassing environmental, economic, cultural, and social aspects. Additionally, spatial planning, initially organized under the Ministry of Finance, was transferred to the Ministry of Regional Affairs as of July 2023. The Planning Act establishes the legal basis for all planning activities. Furthermore, it defines new principles, procedures, and responsibilities for spatial planning across different levels of government.

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

The Planning Act outlines several key components essential to the spatial planning process. It emphasizes democratic, long-term, and balanced spatial development. The Act also ensures land use is environmentally sound, economically viable, culturally respectful, and socially equitable. The spatial scope of the Planning Act is extensive, covering land, water areas, airspace, and sub-surface ground, with certain exclusions such as areas related to national defense or emergencies. In addition, it makes it mandatory to include an explanatory letter and technical drawings in spatial plans to detail the analysis of the planning area. The Act also requires the creation of a state database ("PLANK," see 0) to store and publicize spatial plans, establishing both transparency and public accessibility. Furthermore, it provides clear definitions for some planning related terms to maintain consistency in the interpretation and application of the law across different contexts.

The Estonian spatial planning system is structured into a hierarchical framework that involves various levels of spatial plans (for more information about hierarchical structures of spatial plans, see 2.1) , each with distinct roles and responsibilities. This hierarchy establishes a comprehensive and consistent approach to spatial development. At the top of this hierarchy are national spatial plans, which provide key guidelines and strategies for the country's development. National Plans set guidelines to help regional and local plans develop in a coordinated way. This hierarchical structure ensures that all plans support national priorities. Figure 32 displays this hierarchy in Estonian context.

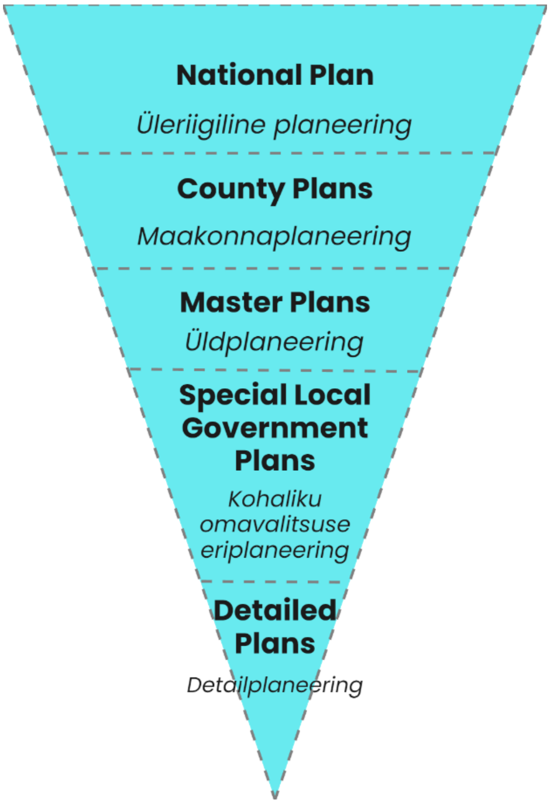

Figure 32. Spatial plan hierarchy of Estonia.

In general, Estonia's spatial planning system consists of national and local plans. National Plans include the National Spatial Plan (NSP) and National Designated Spatial Plans (NDSPs). The NSP, currently "*Estonia 2030+*"[9], outlines country-wide development principles and is managed by the Ministry of Regional Affairs and Agriculture. The NDSPs address significant projects with national or international impacts, such as national defense and energy infrastructure. These plans are prepared with input from various ministries and stakeholders and require strategic environmental assessments.

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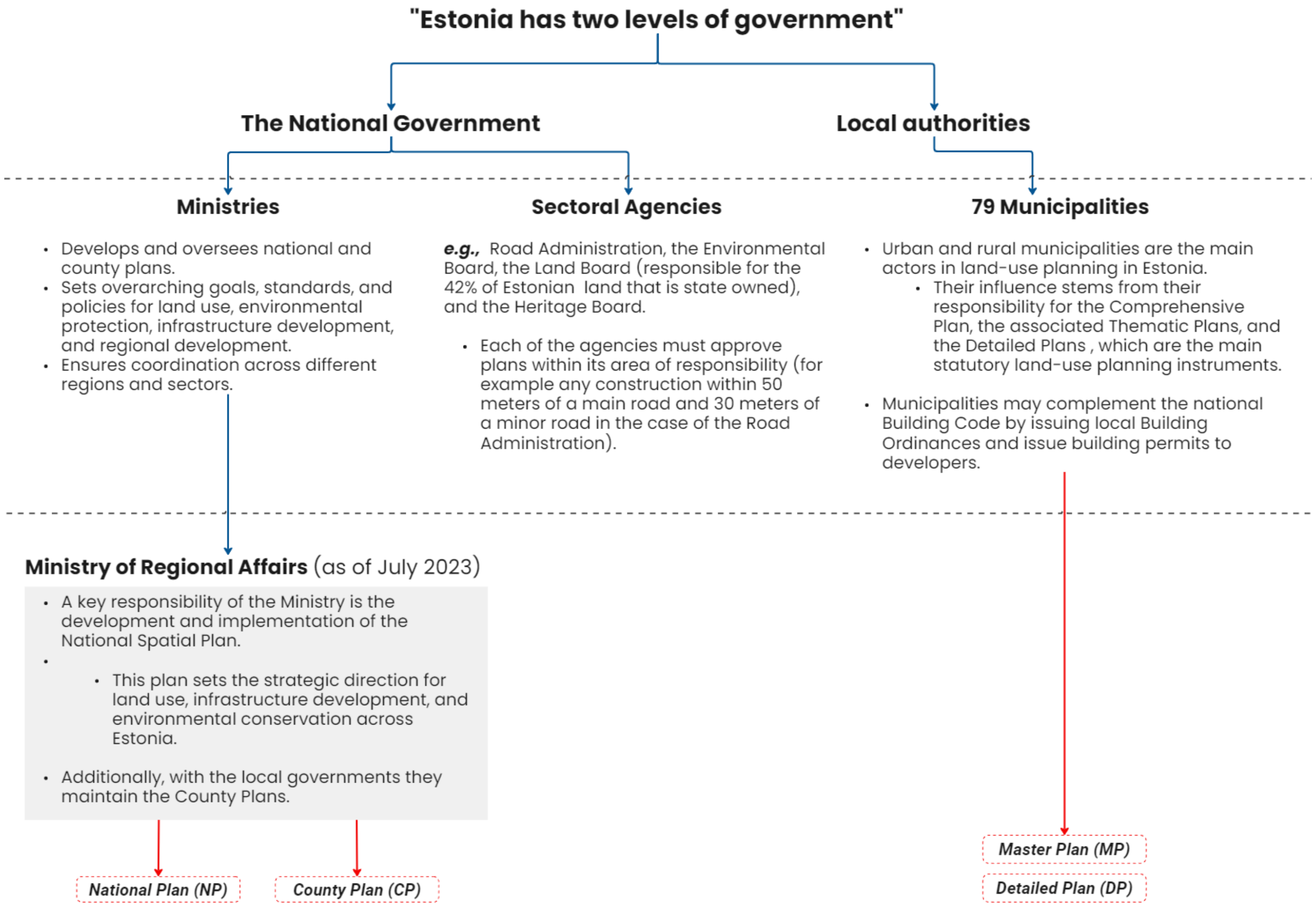
[9] https://eesti2030.files.wordpress.com/2014/02/estonia-2030.pdf

At the local level, spatial planning involves County-wide, Master Plans (also referred as Comprehensive Plans in Estonian context), and Detailed Plans. The Ministry of Regional Affairs and Agriculture manages County-wide Plans, while municipalities handle Master and Detailed Plans. All local plans are reviewed by the Ministry to ensure they align with national guidelines. Figure 33 illustrates the hierarchical structure of Estonia's spatial planning system, highlighting the roles and responsibilities of various administrative bodies in managing national and local plans.



"Estonia has two levels of government"

The National Government

Local authorities

Ministries

- Develops and oversees national and county plans.
- Sets overarching goals, standards, and policies for land use, environmental protection, infrastructure development, and regional development.
- Ensures coordination across different regions and sectors.

Sectoral Agencies

e.g., Road Administration, the Environmental Board, the Land Board (responsible for the 42% of Estonian land that is state owned), and the Heritage Board.

- Each of the agencies must approve plans within its area of responsibility (for example any construction within 50 meters of a main road and 30 meters of a minor road in the case of the Road Administration).

79 Municipalities

- Urban and rural municipalities are the main actors in land-use planning in Estonia.
  - Their influence stems from their responsibility for the Comprehensive Plan, the associated Thematic Plans, and the Detailed Plans , which are the main statutory land-use planning instruments.
- Municipalities may complement the national Building Code by issuing local Building Ordinances and issue building permits to developers.

Ministry of Regional Affairs (as of July 2023)

- A key responsibility of the Ministry is the development and implementation of the National Spatial Plan.
-
  - This plan sets the strategic direction for land use, infrastructure development, and environmental conservation across Estonia.
- Additionally, with the local governments they maintain the County Plans.

Figure 33. Administrative Responsibilities for Spatial Planning in Estonia: An Overview of National and Local Plan Management.

Additionally, Figure 34 shows the planning hierarchy in Estonia and general information about each level. The following sections will provide a brief overview of each level in this hierarchy, explaining the specific functions and responsibilities of the National Plan, County Plans, Special Local Government Plans, Master Plans and Detailed Plans.

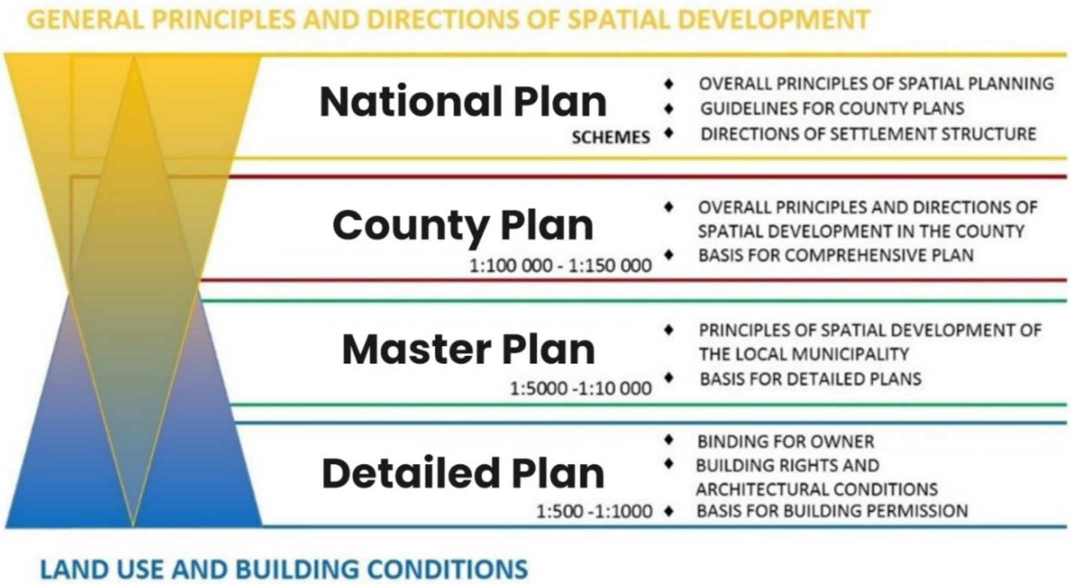


Figure 34. Spatial plan hierarchy and their details of Estonia.
Figure adapted from Ministry of Regional Affairs (Regionaal- ja Põllumajandusministeerium).

National Plan

The National Plan (NP) provides a broad, long-term vision for the spatial development of Estonia. As a strategic framework, it guides the country's overall development, setting general principles for settlement patterns, energy production, and transportation systems. The most recent National Plan, "*Estonia 2050*,"[10] was initiated on January 5, 2023, with the goal of defining Estonia's spatial structure and development principles up to 2050. It integrates regional characteristics and national objectives and is administered by the Ministry of Rural Affairs, with initiation and approval by the Government of the Republic. Previous plans include "*Estonia 2030+*" (effective from August 30, 2012) and "*Estonia 2010*" (approved by Government Order No. 770-k on September 19, 2000)[11]. An example of the National Plan's strategic vision can be seen in the analysis of railway services' potential within Estonia[12]. Figure 35 illustrates how 80% of Estonia's population lives near existing railway routes, highlighting the opportunity to enhance the utilization of railway services for improved mobility across the country.

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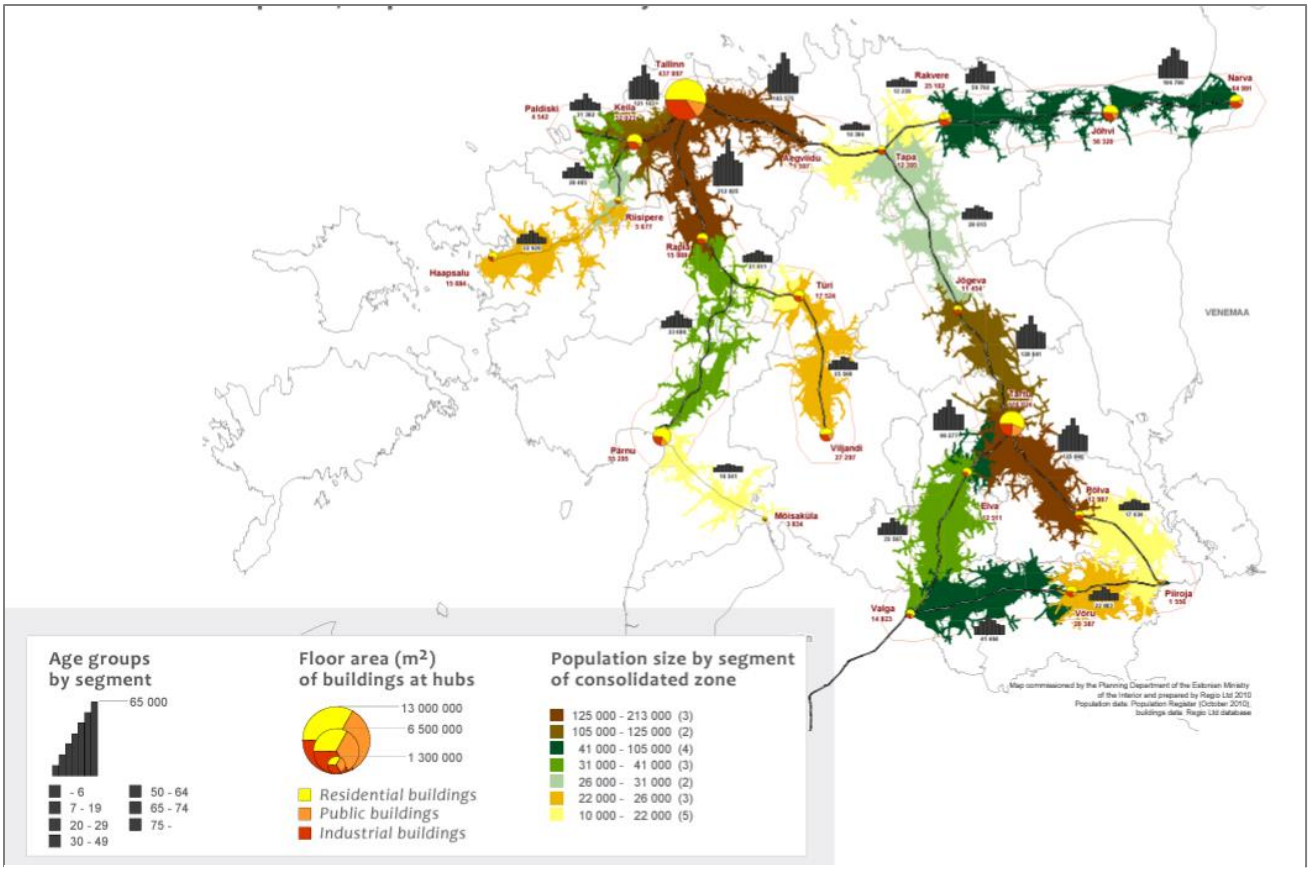
[10] https://riigiplaneering.ee/en/national-spatial-plan/national-spatial-plan-2050/national-spatial-plan-2050

[11] https://planeerimine.ee/ruumiline-planeerimine-2/riigi-strateegilised-planeeringud/

[12] https://eesti2030.wordpress.com/wp-content/uploads/2014/02/estonia-2030.pdf



Map commissioned by the Planning Department of the Estonian Ministry of the Interior and prepared by Regio Ltd 2010
Population data: Population Register (October 2010), buildings data: Regio Ltd database

Figure 35. Potential of railway services, from Estonia 2030+ (Ministry of Interior, 2012).

Special Local Government Plans

Special Local Government Plans (SLGP) address specific spatial needs at the municipal level, focusing on particular projects or areas of interest. Local governments develop these plans to meet unique local requirements not covered by general plans. SLGPs provide detailed guidance for specific projects, complementing broader County and National Plans.

Established by the planning law effective from July 1, 2015[13], these plans are necessary for projects that significantly impact transportation, pollution, visitor numbers, visual impact, noise, or resource requirements. SLGPs ensure significant projects are planned in suitable locations without hindering other activities. The process involves selecting the best location and creating a Detailed Plan in a single procedure, replacing the previous two-step process. If not implemented within five years, SLGPs expire, making them better suitable for near-term development rather than long-term strategic planning. Because SLGPs are created to address specific topics and lack the consistent format or, they will be omitted from the spatial hierarchy of Estonia required to create the country profile for this research. An example of such a plan is the proposed wind energy development in the Ülde area of Põhja-Sakala municipality[14], shown in Figure 36.

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[13] https://planeerimine.ee/aktid-ja-kohtulahendid/orme/

[14] https://www.pohja-sakala.ee/documents/17894261/24015245/P6hja-Sakala-valla_EP-LS-

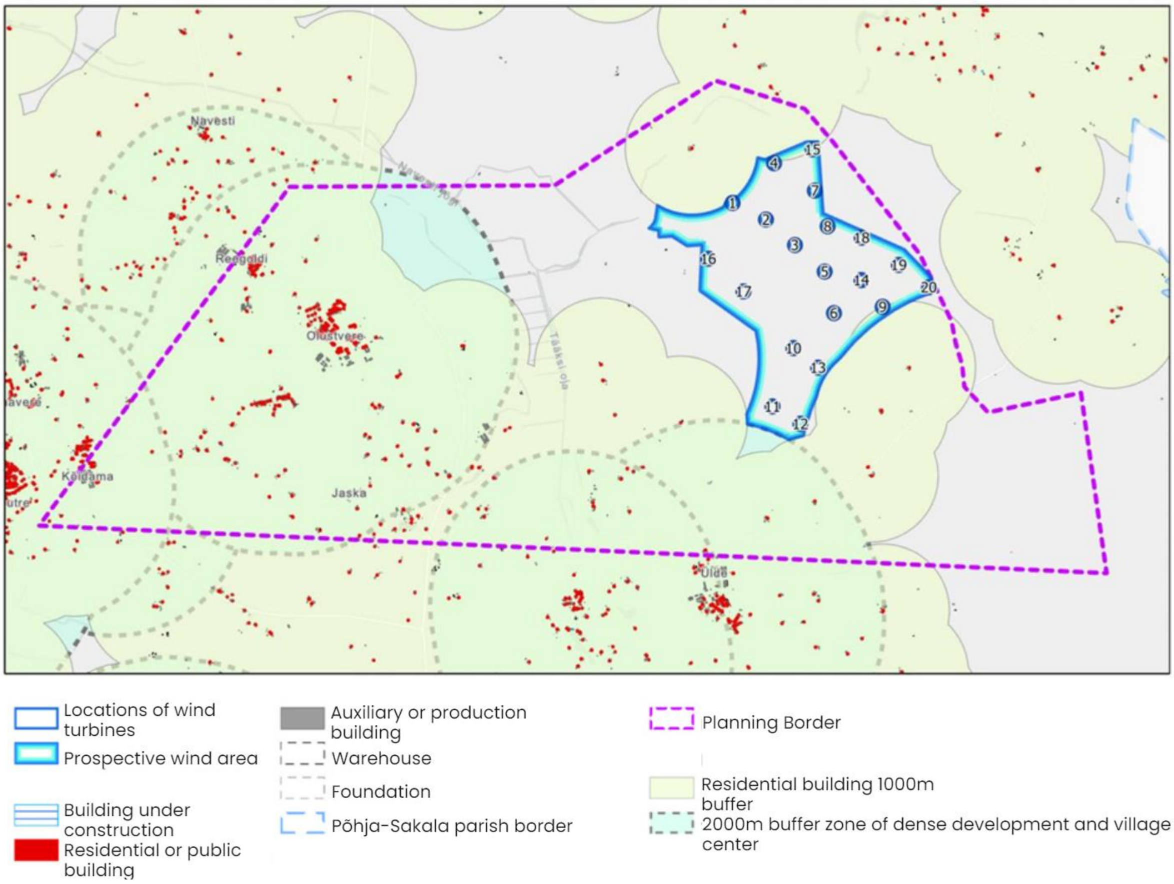

Figure 36. The proposed wind energy development plan for the Ülde area, Põhja-Sakala municipality, as of April 15, 2024. Figure by Skepast&Puhkim OÜ for Põhja-Sakala Vallavalitsus and Vestman Solar O.Ü. (Translated to English).

County Plan

The County Plan (CP) focuses on regional spatial development, balancing local and national needs, and provides guidelines for municipal planning. Developed to establish spatial development principles for each county, these plans integrate various sectoral interests and regional characteristics. They influence the preparation of municipal Master Plans, addressing settlement patterns, infrastructure, and regional development.

An example of a County Plan is the *Jõgeva County Plan*,[15] which outlines spatial development according to the vision and development trends agreed upon during the creation of the national plan "Estonia 2030+". This plan emphasizes environmental values and is detailed in Figure 37.

KSHP-ok.pdf/eff292fc-fcbb-42b8-84cd-90e95053964e

[15] https://planeeringud.ee/plank-web/#/planning/detail/10100015

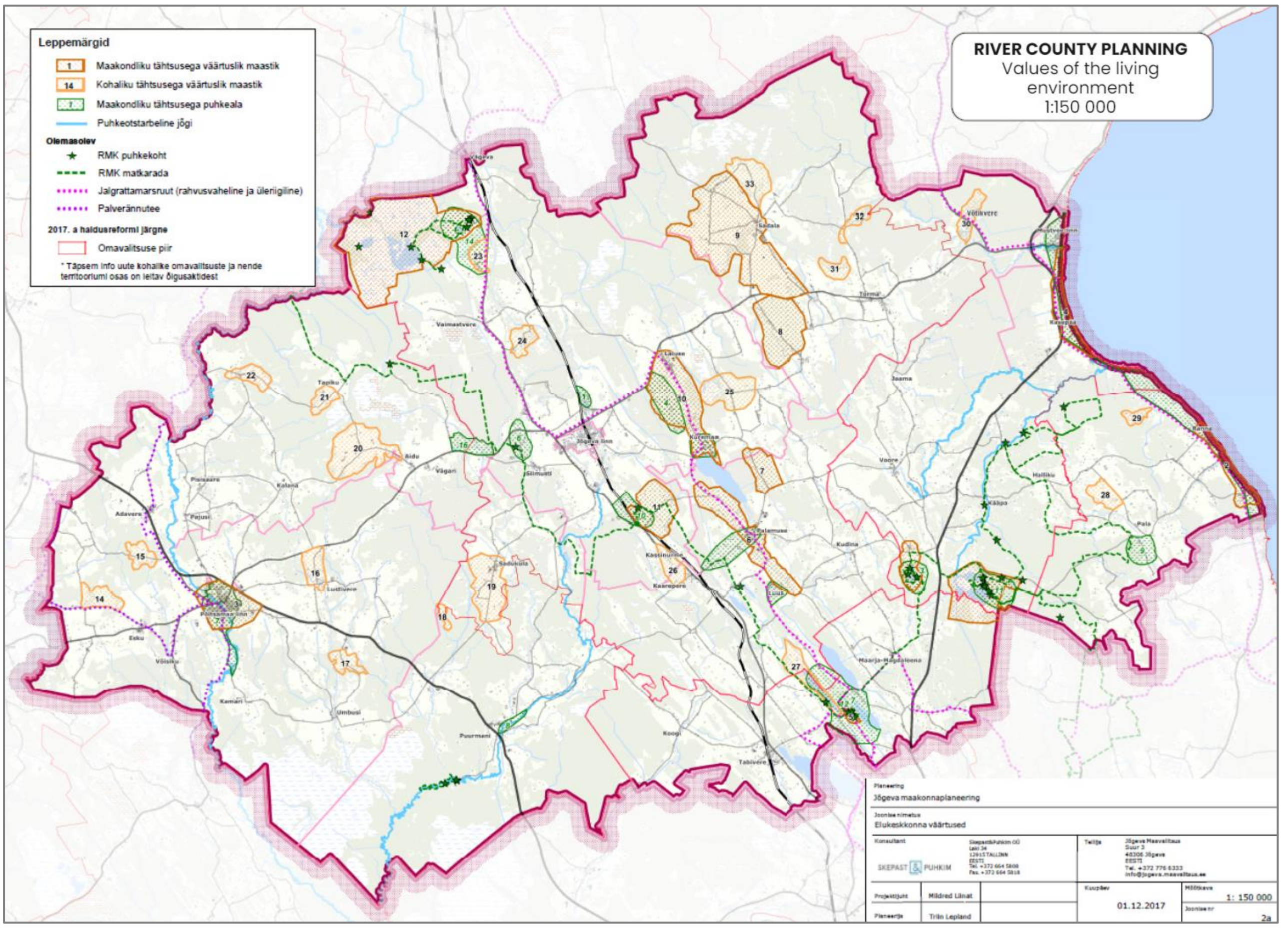

Figure 37. Jõgeva County Plan showing environmental values, from Jõgeva maakonnaplaneering (Jõgeva County Government). Figure by Skepast&Puhkim OÜ, 2017.

Master Plan

Master Plans are comprehensive plans that guide the development and use of land within specific areas. They provide a framework for land use, infrastructure, and community development. Municipalities are responsible for creating Master Plans, which align with County and National Plans and address local development needs. These plans set out general land use principles and development guidelines, providing a basis for more detailed planning activities[16].

An example of a Master Plan is the *Tapa Parish Master Plan*[17], which outlines spatial development principles for Tamsalu town and Uudeküla village. This plan is detailed in Figure 38.

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[16] https://planeerimine.ee/ruumiline-planeerimine-2/kov-planeeringud/

[17] https://planeeringud.ee/plank-web/#/planning/detail/20100048

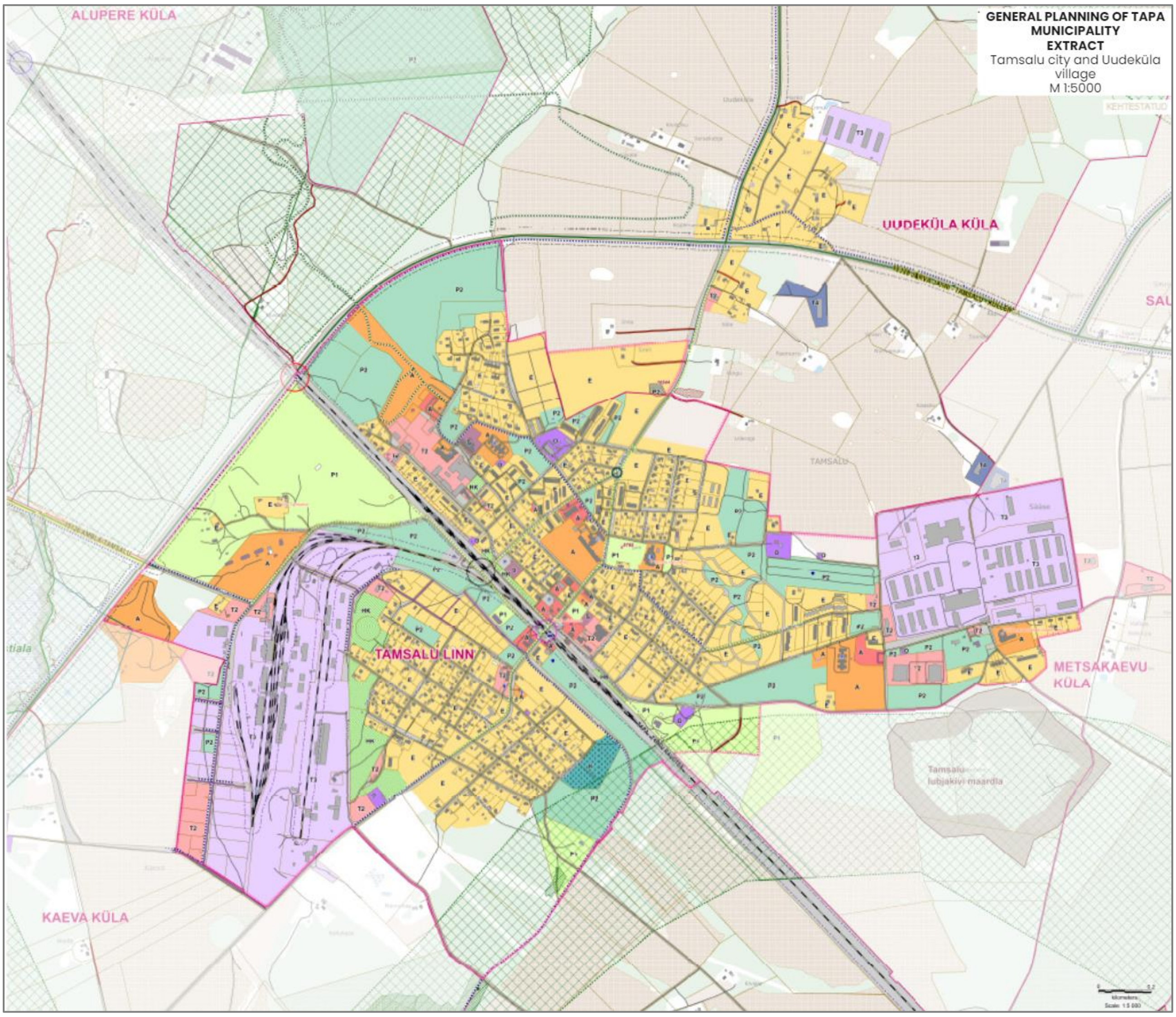

Figure 38. Tapa Parish Master Plan, showing Tamsalu town and Uudeküla village (scale 1:5000). Figure by Kerttu Kõll, Janne Tekku, and Piret Põllendik with Entec Eesti O.Ü.

Detailed Plan

Detailed Plans (DP) are the most specific level of planning, focusing on individual sites or projects. They provide precise instructions for land use, infrastructure, and construction. Prepared by local authorities or private developers, Detailed Plans ensure compliance with broader Master Plans and County Plans. These plans include detailed information on land use, building design, infrastructure, and other specifics necessary for implementation.

An example is the *Põllu tn 4 Area and Surroundings Detailed Plan*[18] (Figure 39), which specifies construction rights and land use changes for a commercial building.

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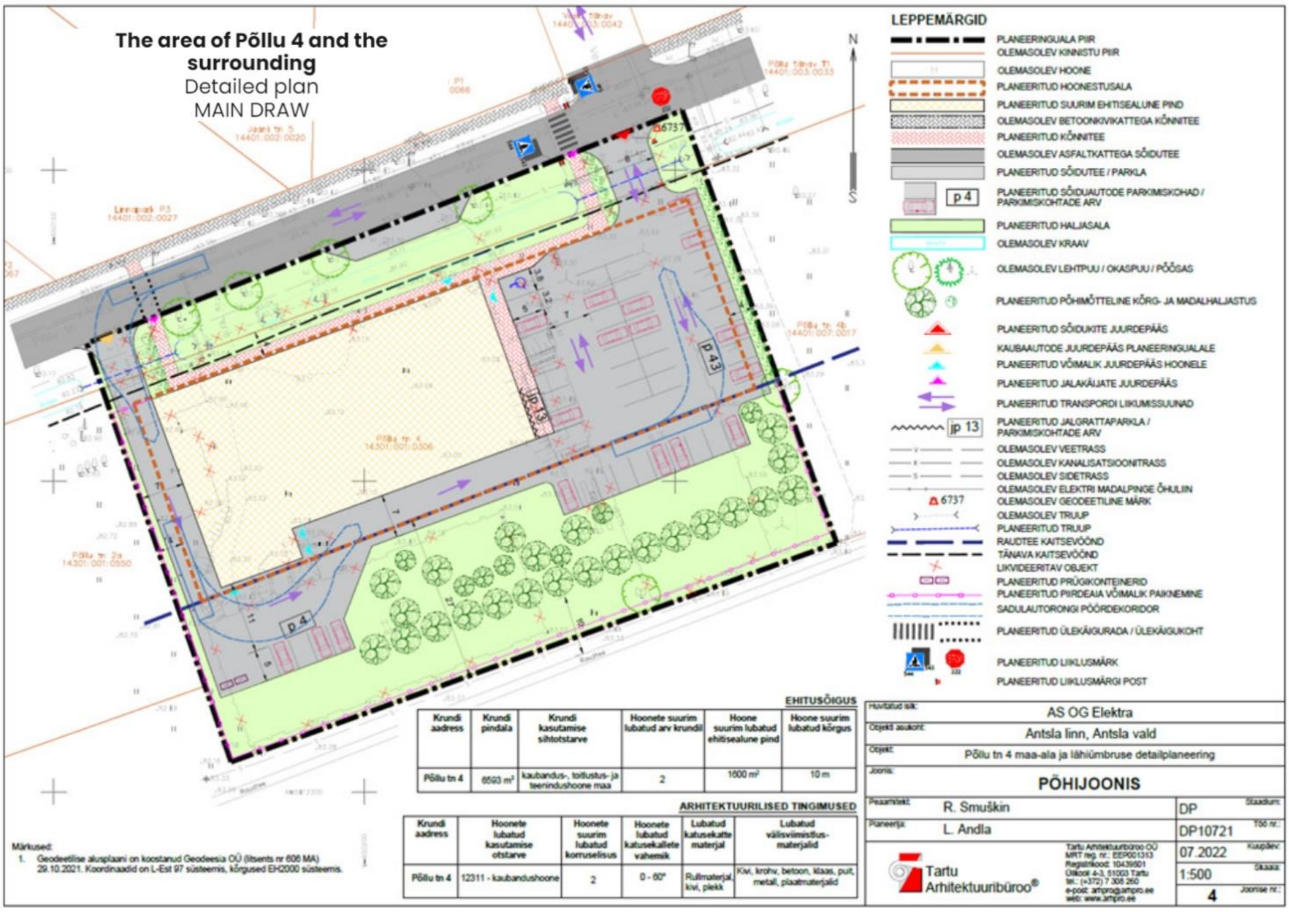
[18] https://planeeringud.ee/plank-web/#/planning/detail/30100010



EHITUSÕIGUS

Krundi aadress	Krundi pindala	Krundi kasutamise sihtotstarve	Hoonete suurim lubatud arv krundil	Hoone suurim lubatud ehitisealune pind	Hoone suurim lubatud kõrgus
Põllu tn 4	6593 m²	kaubandus-, toitlustus- ja teenindushoone maa	2	1600 m²	10 m

ARHITEKTUURILISED TINGIMUSED

Krundi aadress	Hoonete lubatud kasutamise otstarve	Hoonete suurim lubatud korruselisus	Hoonete lubatud katusekallete vahemik	Lubatud katusekatte materjal	Lubatud välisviimistlus-materjalid
Põllu tn 4	12311 - kaubandushoone	2	0 - 60°	Rullmaterjal, kivi, plekk	Kivi, krohv, betoon, klaas, puit, metall, plaatmaterjalid

Huvitatud isik:	AS OG Elektra
Objekti asukoht:	Antsla linn, Antsla vald
Objekt:	Põllu tn 4 maa-ala ja lähiümbruse detailplaneering
Joonis:	PÕHIJOONIS
Peaarhitekt:	R. Smuškin
Planeerija:	L. Andla
Staadium:	DP
Töö nr.:	DP10721
Kuupäev:	07.2022
Skaala:	1:500
Joonise nr.:	4

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web: www.arhpro.ee

Märkused:
1. Geodeetilise alusplaani on koostanud Geodeesia OÜ (litsents nr 606 MA) 29.10.2021. Koordinaadid on L-Est 97 süsteemis, kõrgused EH2000 süsteemis.

Figure 39. Põllu tn 4 Area and Surroundings Detailed Plan, showing land use and development specifics (scale 1:500)
Figure by Laura Andla.

Strategic Environmental Impact Assessment (SEA)

Each level of planning in Estonia is designed to address different aspects of spatial development, and it is crucial to assess the potential impacts of these plans on the environment. This is where *Strategic Environmental Assessment* (SEA)[19] becomes important. SEA is an important part of the planning process, ensuring that the potential environmental impacts of various plans are thoroughly evaluated and addressed. The purpose of SEA is to predict and mitigate the negative effects of planning activities on the environment before they are implemented.

In Estonia, the SEA process applies differently depending on the type of plan[20]. For National Plans, SEA is a mandatory procedure, focusing on strategic assessments of long-term and large-scale impacts on the environment. While County Plans are also important in regional development, typically do not require a separate SEA process.

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[19] https://environment.ec.europa.eu/law-and-governance/environmental-assessments/strategic-environmental-assessment_en

[20] https://planeerimine.ee/ruumiline-planeerimine-2/moju/

However, they should align with the environmental guidelines and principles established in the National Plan's SEA. Similarly, Special Local Government Plans may or may not undergo SEA, depending on the scale and nature of the specific project they address. Master Plans are detailed and more localized, thus often require a specific SEA to address the direct and indirect impacts of proposed developments. Detailed Plans, being the most specific, generally do not require an independent SEA but must comply with the SEA findings and recommendations from Master Plans.

Therefore, while not every level of planning is subject to SEA individually, the principles and findings from SEA at higher planning levels must inform and guide the lower levels.

4.2. Creation of the Estonia Profile

This section will explain the development of the Estonia-specific LADM profile. It will cover the process of customizing LADM classes and attributes to fit Estonia's needs, including any new classes or relationships introduced.

The development of the Estonia country profile began with a foundation based on the initial LADM Part 5 classes shown in Figure 13. This initial framework provided a standardized starting point, ensuring consistency with LADM’s main structure. The first step in creating the country profile required the representation of different plan types, such as National Plan, County Plan, Master Plan, and Detailed Plan.

During the initial mapping of the plan types to the existing classes, the following points from Kalogianni et al. (2019) were taken into consideration:

- **Inheritance from LADM core classes:** Classes specific to Estonia that were absent in representation in LADM Part 5 classes were created by including a prefix to indicate the country (e.g., "EST" for Estonia). These classes would be inherited from the related LADM Part 5 classes.
- **Addition of new attributes:** Additional attributes were incorporated to accommodate national requirements and needs.
- **Maintaining associations:** The original associations defined in LADM Part 5 were preserved.

The development of the Estonia-specific LADM profile went through numerous iterations, but for clarity, it can be generalized into three major versions. This simplification helps in better understanding the important updates and improvements made throughout the process. The first attempt of the country profile involved representing the different plan types as newly introduced Estonia (“EST”) classes, seen in Figure 40. For the attributes in the newly created classes, the tables in Appendix D, which detail the Estonian Plan data layer requirements, were primarily used. The layers and their corresponding representations were mapped to the new classes. Attribute naming was followed by the value naming used in the Estonian context, represented in brackets (e.g., +planType: CharacterString [*planLiik*]). Additionally, for the development of the profile, what the Estonian attribute represented was written below it in the UML diagram during the first phases. The general idea behind improving and optimizing the country profile involved first creating these classes separately to clearly distinguish and investigate if the existing LADM Part 5 classes created a common attribute or concept. If so, during later versions of the profile, the newly created attributes would be removed, and the existing LADM Part 5 attributes would be mapped to the related Estonian data, as previously suggested by Kalogianni et al. (2019).

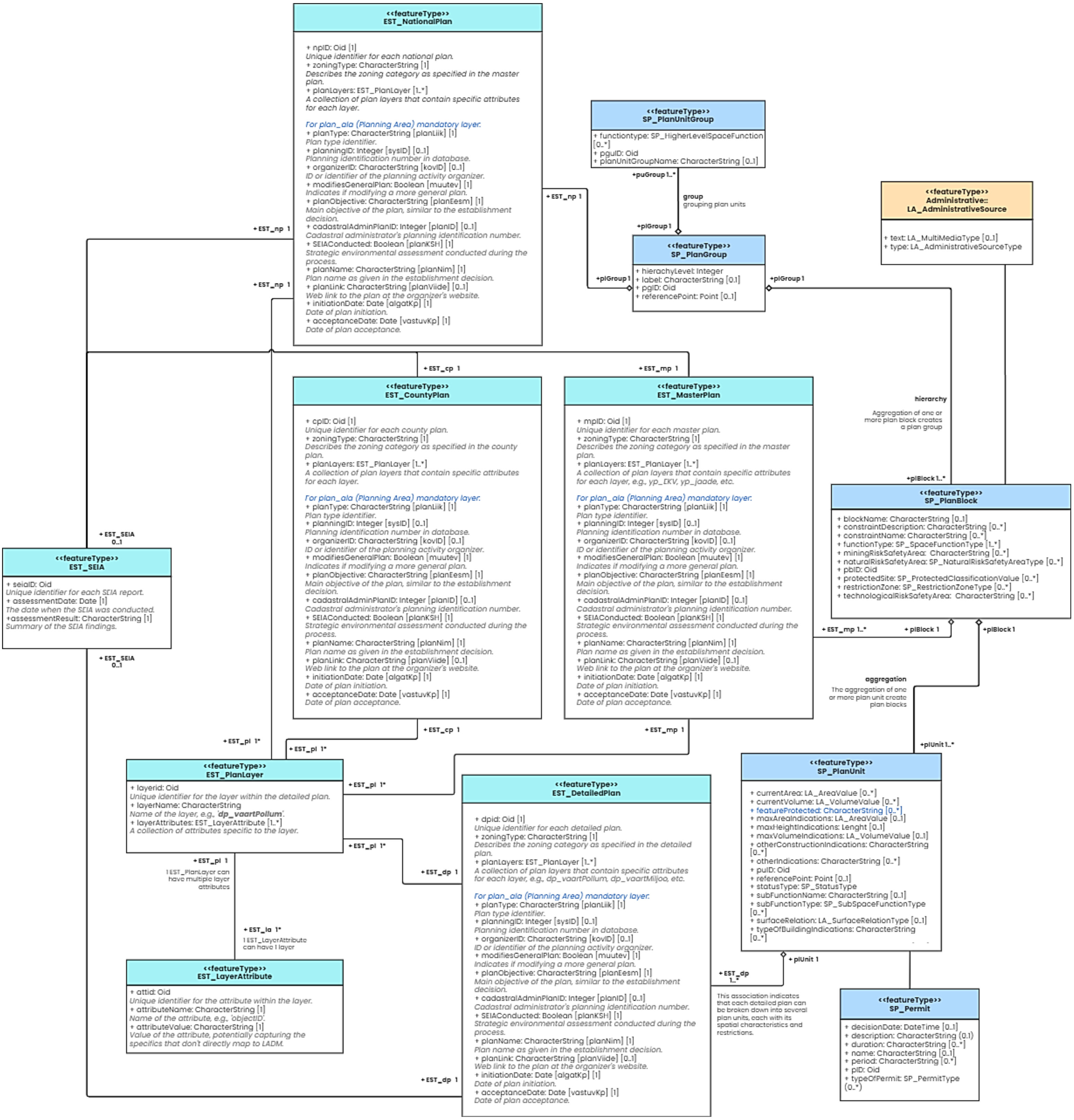

Figure 40. First version of the Estonian country profile.

It is important to note that in the UML representations of the country profile classes, seen in Figure 40 and subsequent versions, different colors were used for visualization purposes: cyan for the newly created Estonia-specific classes, blue for the original LADM Part 5 classes, and orange for the LADM Part 1: Generic Conceptual Model classes.

Following the initial development, the profile was updated and refined based on feedback from experts at Estonian Ministries. A significant update between version 1 and version 2 (shown in Figure 42) was the integration of the database model from the Estonian spatial plan database, PLANK. This model, which stores information on spatial data and additional metadata (e.g., the uploader of the plan, the software used, plan initiation dates, and last updated versions), had a considerable impact on the final country profile development.

The main improvements and updates between version 1 and version 2 include the following:

- To reduce the redundancy of attributes in the plan classes, common layer requirements for each plan type (e.g., according to Estonian regulations, every plan should have the '*planala*' layer, further mentioned in Appendix D) were created as separate classes (i.e., *EST_PlanArea, EST_Plot, EST_BuildingArea*). The plan classes would inherit attributes from these classes.

- The additional metadata provided by PLANK, such as uploader information, organization details, and temporal information on plan establishment, initiation, and last version, was integrated into LADM Part 1: Generic Conceptual Model classes that are related to Part 5 classes, such as *VersionedObject* and *LA_AdministrativeSource*. The temporal mapping can be seen in Figure 41 and their definitions in Estonian context in Table 4 respectively.

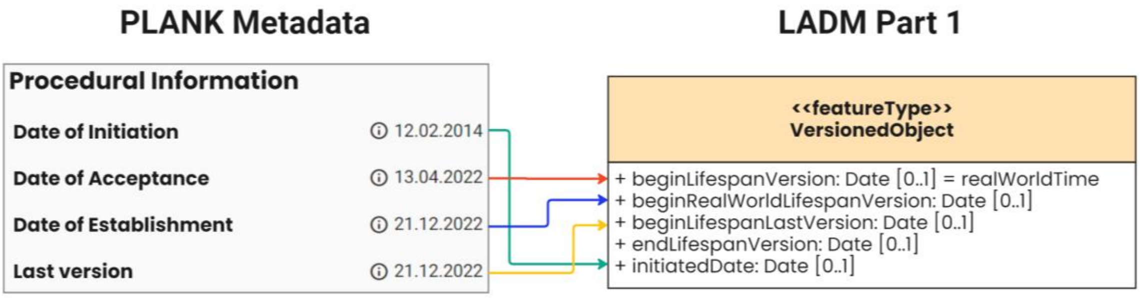

Figure 41. Mapping of the temporal PLANK metadata to *VersionedObject*.

Table 4. Temporal Estonian metadata mapping to *VersionedObject* and their meanings (cyan columns are added attributes).

Conceptual Date	LADM Attribute	Description
Date of Establishment	+beginLifespanVersion: DateTime [0..1]	When a plan starts being legally recognized and enforceable.
Date of Initiation	+initiatedDate: DateTime [0..1]	When the planning process officially begins.
Date of Last Version	+/beginLifespanLastVersion: DateTime [0..1] = realWorldTime	Tracks the creation of each new version of the document or plan.
Date of Acceptance	+beginRealWorldLifespanVersion: Date [0..1]	When the plan is formally approved by relevant authorities
Date of Finalization	+endLifespanVersion: Date [0..1]	When the plan is finalized, and construction has been completed.

- *LA_SpatialUnit* class from the Generic Conceptual Model package was also implemented to include spatial analysis attributes such as area and volume.

- New code list classes were created for attributes specific to Estonian data, such as plan type Estonian code values, Estonian land use type code lists, and construction types, to represent the plans comprehensively without information loss.

Overall, with the second version representing the information stored in PLANK, the model reflected a more accurate representation of the reality and nature of Estonian spatial data. The third version seen in Figure 47, being the finalized profile, added the aspect of real data representation and optimization for the overall model. So, the development process of the profile can be generalized as shown in Table 5:

Table 5. Major sources that affected each country profile version.

Version 1	Data layer requirements (Appendix D)
Version 2	Data layer requirements (Appendix D) + PLANK requirements and metadata
Version 3	Data layer requirements (Appendix D) + PLANK requirements and metadata + real data

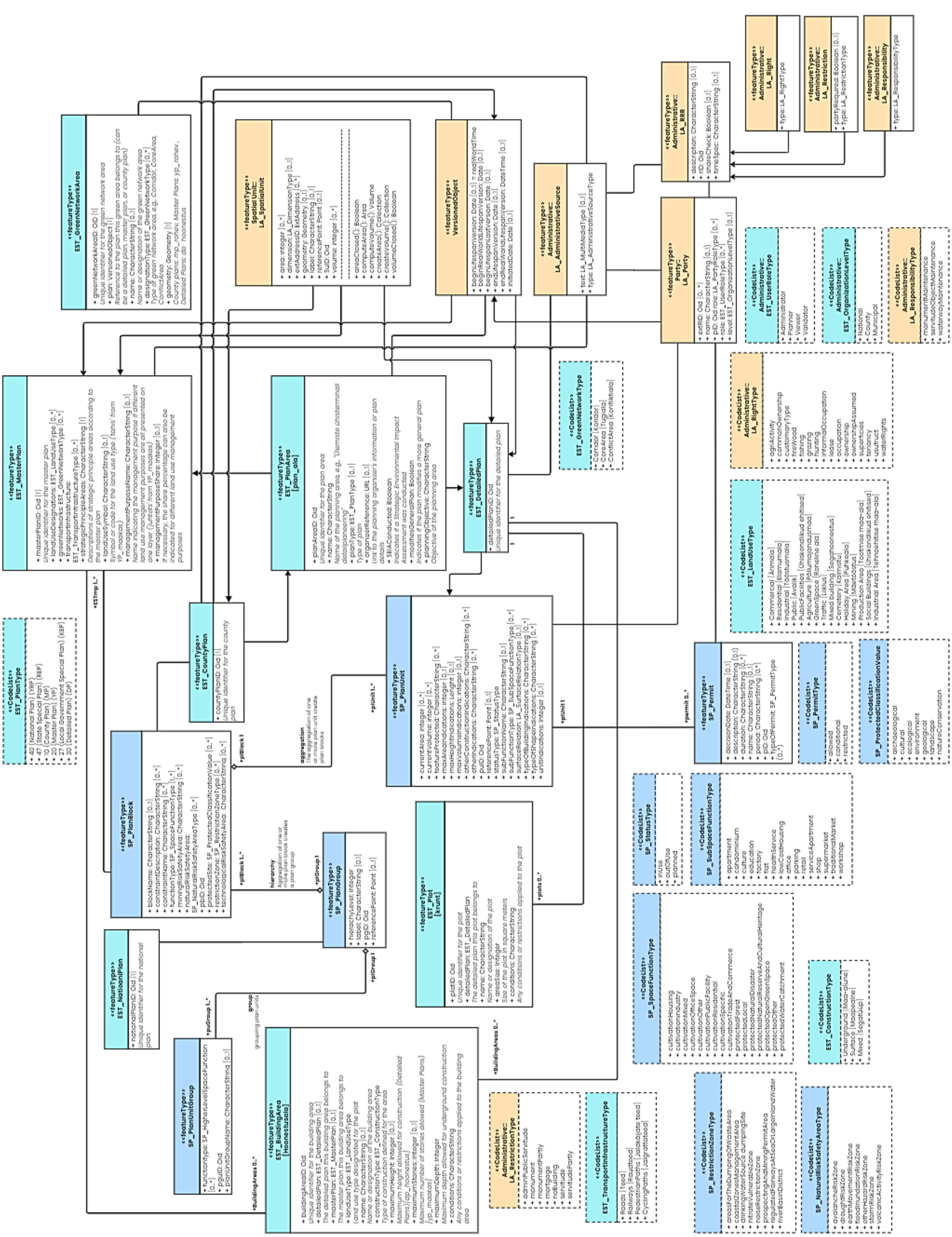

Figure 42. Second version of the Estonian country profile.

The development of the Estonia-specific LADM profile can be summarized into these three versions for better clarity. Version 1 was based on the initial data layer requirements outlined in Appendix D.

Version 2 integrated these data layer requirements with additional metadata from the PLANK database, including detailed information about spatial data and metadata such as uploader information, used software, and timestamps for plan initiation and updates. This significantly enhanced the model's accuracy and practicality in representing Estonian spatial data. The third and final version built upon these improvements by incorporating actual data representation and further optimizations, resulting in a comprehensive and realistic profile that accurately reflects the real-world use and management of Estonian spatial planning data.

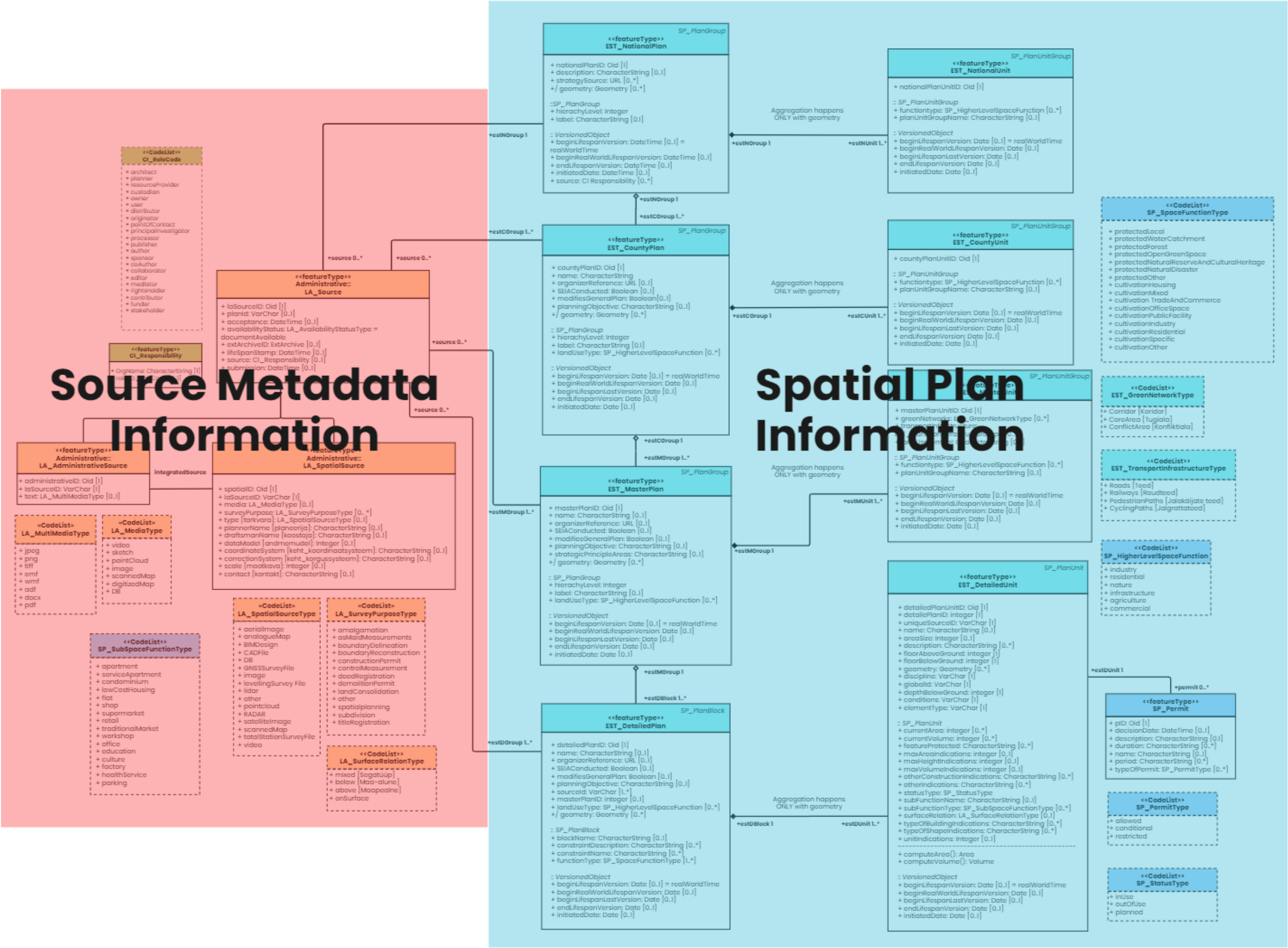

Figure 43. Final country profile divided into two categories by what the classes represent.

The final model structure can be better understood with Figure 43. The left part (seen in red) represents classes such as *LA_Source*, *LA_AdministrativeSource* and *LA_SpatialSource*. This part is more focused on representing and storing information about the source data and metadata of the uploaded plan. The right part of the model (seen in blue) represents the different plan classes, their units, and relationships with each other. The explanation of the final version will cover the “Spatial Plan Information” part and then “Source Metadata Information” respectively.

One of the most distinct differences between the final version and the previous version comes from the superclasses. Previously, plan classes were explicitly related to the LADM Part 5 classes. In the final version, Part 5 classes are superclasses of the plan classes (written in italics at the top right corner of the plan class). This means, for example, the *EST_DetailedPlan* class inherits all the attributes of the Part 5 class *SP_PlanBlock*. Overall, all the plan classes now inherit the related Part 5 classes' attributes and their specific plan attributes. Additionally, all the plan classes also inherit all the attributes of the *VersionedObject* class. This was done to establish that all plan data have thematic attributes such as establishment date/time or last version. In the final profile UML in Figure 47, all the attributes inherited by the plan classes are also shown to maintain legibility and illustrate what the plan classes are fully capable of representing.

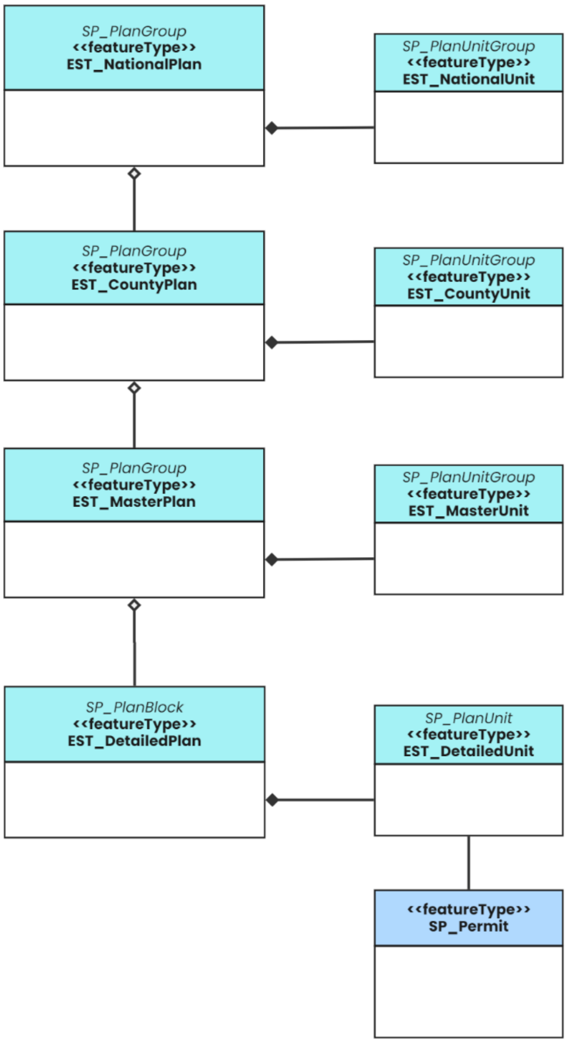

Figure 44. Simplified structure of the plan levels and their units.

Another significant difference in the final version from the previous versions comes from the relationships of plan classes among themselves. Previously, the plan classes were connected to generically created common classes such as *Plan Area*, *Building Area*, and *Green Network Area*. This, however, made the profile complex and harder to maintain. The next step of creating the database in PostgreSQL would complicate the structure even more. To have a systematic approach, these common classes were omitted, and the specific plan attributes were included in each plan class, as seen in Figure 47. Then, the structure among plan levels was organized systematically. The simplified version of this structure can be seen in Figure 44. For the vertical relationships, main plan classes—*EST_NationalPlan*, *EST_CountyPlan*, *EST_MasterPlan*, and *EST_DetailedPlan*—all have an “aggregation” relationship with each other in the UML model. This aggregation relationship represents the geometry aggregation rather than anything else, as mentioned in Figure 47. Initially, composition was thought to best represent the hierarchical nature of different plan levels and how they come together. An area represented in a Master Plan would surely consist of multiple Detailed Plans combining to form the totality of the Master Plan area. However, after discussions with experts, it was decided this relationship should be an aggregation and not a composition relationship. This was because composition implies a stricter relationship in UML where the “smaller” classes come together to form the “bigger” class. This might not always reflect the reality of spatial areas and their corresponding spatial plans. Thus, it was decided it would be better to keep this relationship as aggregation, which is more flexible than composition. It doesn't necessarily mean a Master Plan will overlap with multiple Detailed Plans; it shows that it can.

For the horizontal relationships, all plan classes were associated with a unit class on their own. Thus, *EST_DetailedPlan* has *EST_DetailedUnit*, *EST_MasterPlan* class has *EST_MasterUnit*, and so on. This was to represent the granularity in the plan classes. Unit classes represent a “unit” in the plan class, which can be, for example, a building or a park. By having these unit classes, more comprehensive information about specific elements in a plan can be stored in the model.

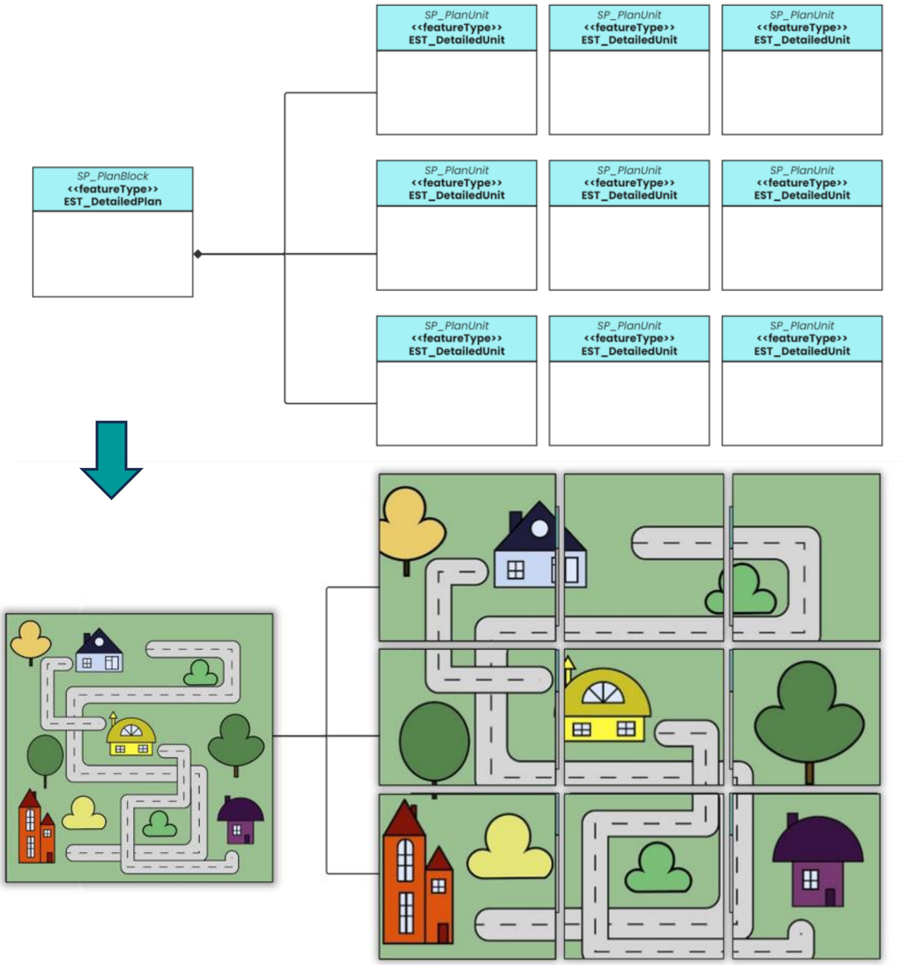

Figure 45. EST_DetailedPlan and its EST_DetailedUnit's.

Figure 45 demonstrates the structure of *EST_DetailedPlan* with multiple *EST_DetailedUnits* to provide an example. On the left, *EST_DetailedPlan* represents one Detailed Plan; thus, its attributes are more generalized and tailored to convey the main points of that Detailed Plan. Whereas each unit class on the right, connected to that Detailed Plan, represents a unit, a specific part of the plan. By dividing the units into different unit classes, details about that specific unit can be stored explicitly as well. This can be a building, its floor level restrictions, geometry, area, volume, and more. The overall idea can be summed up as follows: if someone wanted to find a specific building in a specific Detailed Plan in a database, they would look at the *EST_DetailedPlan* class first. After finding the plan that includes the building, they can query the plan's relevant *EST_DetailedUnits* classes (tables) and find every unit stored in detail. From there, they could access all the information stored regarding this building.

This hierarchical and detailed approach ensures that each unit within a plan can be individually addressed, providing a more granular and comprehensive dataset for planning and management.

Additionally, Part 5's *SP_Permit* class was connected to *EST_DetailedUnit* class (better seen in Figure 44) since it represents the most granular level of information in the model. The *SP_Permit* class from Part 5 can be utilized more effectively for building permits rather than plan compliance checks, which is beyond the scope of this research. However, for a comprehensive model that represents Estonian spatial data, it was also included in the final model.

Another significant update seen in the final version was the new structure and utilization of the *LA_Source, LA_AdministrativeSource* and *LA_SpatialSource* classes, seen in Figure 46. Just as like the same idea with plan classes and their corresponding unit classes, *LA_Source* represents the source in general. It provides general information about the source like submisson date/time, acceptance and more. Furthermore, it has direct relationships with the plan classes to ensure that the source of the plan data represented in the plan classes can be easily accesible in a database. On the other hand, *LA_AdministrativeSource* and *LA_SpatialSource* represent an "integrated source" that *LA_Source* inherits from. Just like the units, *LA_AdministrativeSource* and *LA_SpatialSource* allow more detailed, meticulous data to be stored accordingly; however, overall, this is represented comprehensively by *LA_Source*. Other than the new structure, additional attributes representing the metadata of the uploaded spatial plan in PLANK are added to these classes.

Finally, it should be noted that some of the attributes and optimizations seen in the final profile stem from technical experiences encountered while creating the PostgreSQL database and loading spatial data through FME to this database. These additional optimizations will be discussed further on Chapter 5: Implementation. Additionally, an interactive UML model was made available online[21] and can also be accessed through the research's GitHub repository.

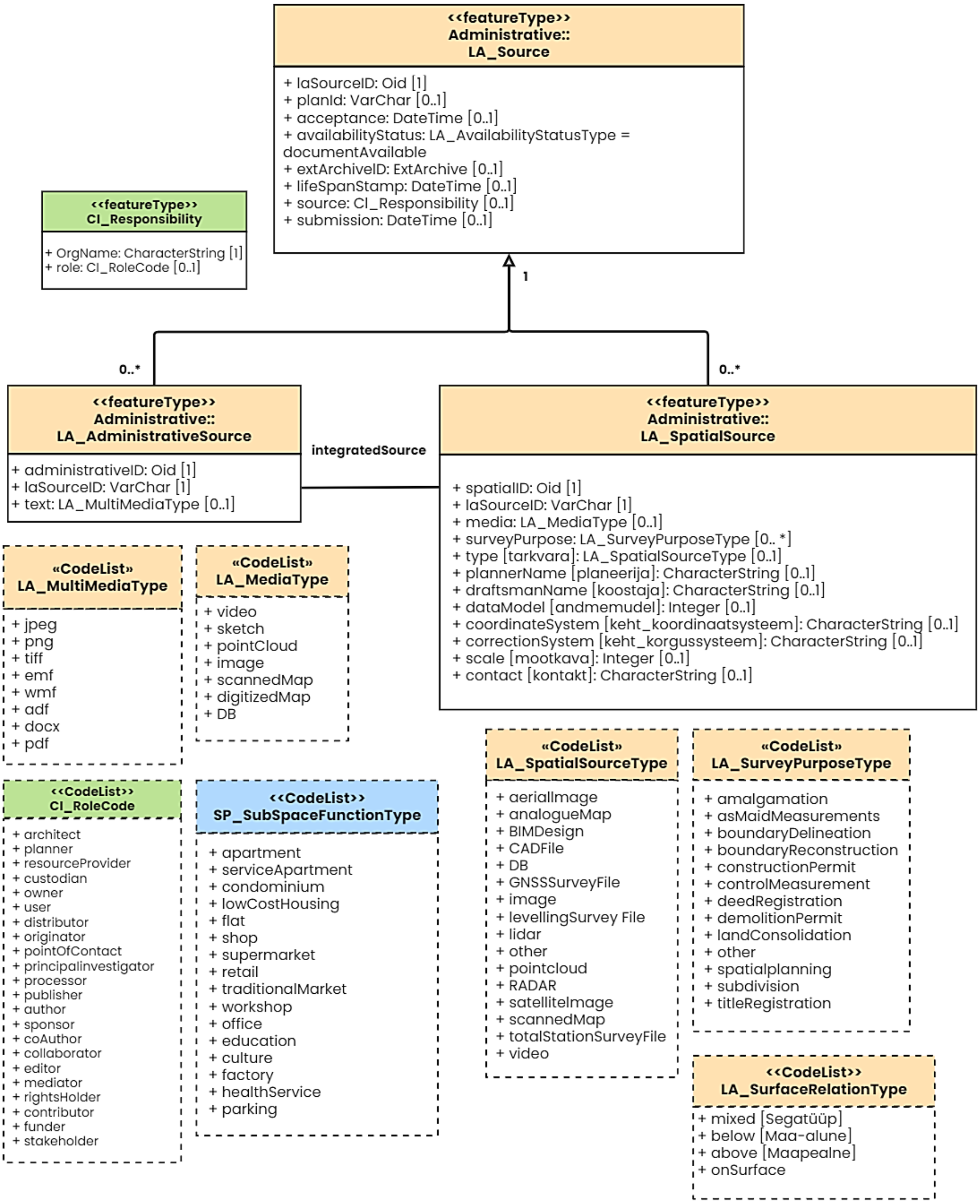

Figure 46. LA_Source, LA_AdministrativeSource and LA_SpatialSource in the model.

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[21] https://simaybtm.github.io/LADM-4-Estonia/Estonia_UML_Country_Profile.drawio.html

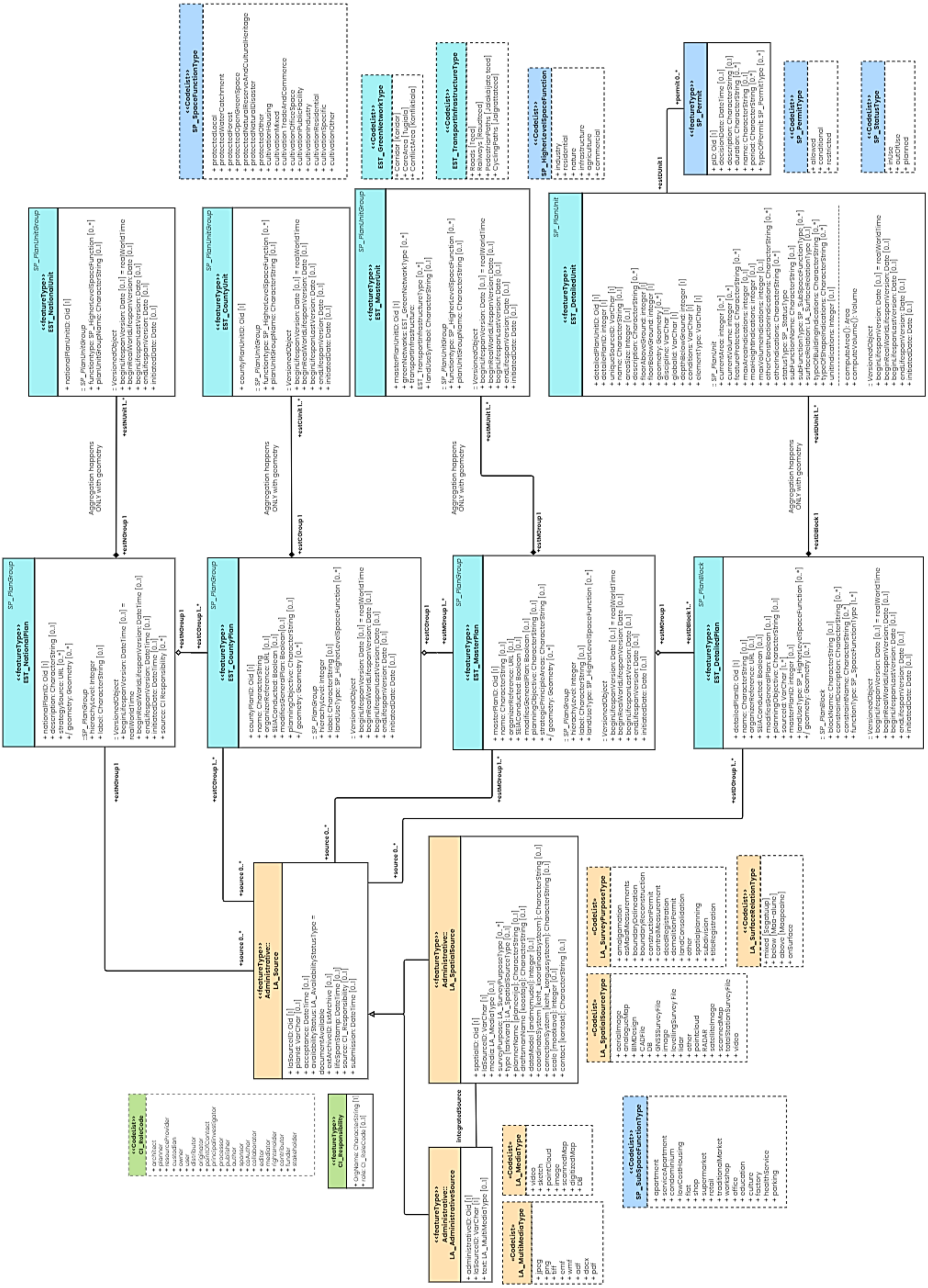


Figure 47. Third and final version of the Estonian country profile.

5. Implementation

This chapter details the practical steps taken to implement the Estonia-specific LADM profile, focusing on the creation of the LADM database and the importation of IFC data.

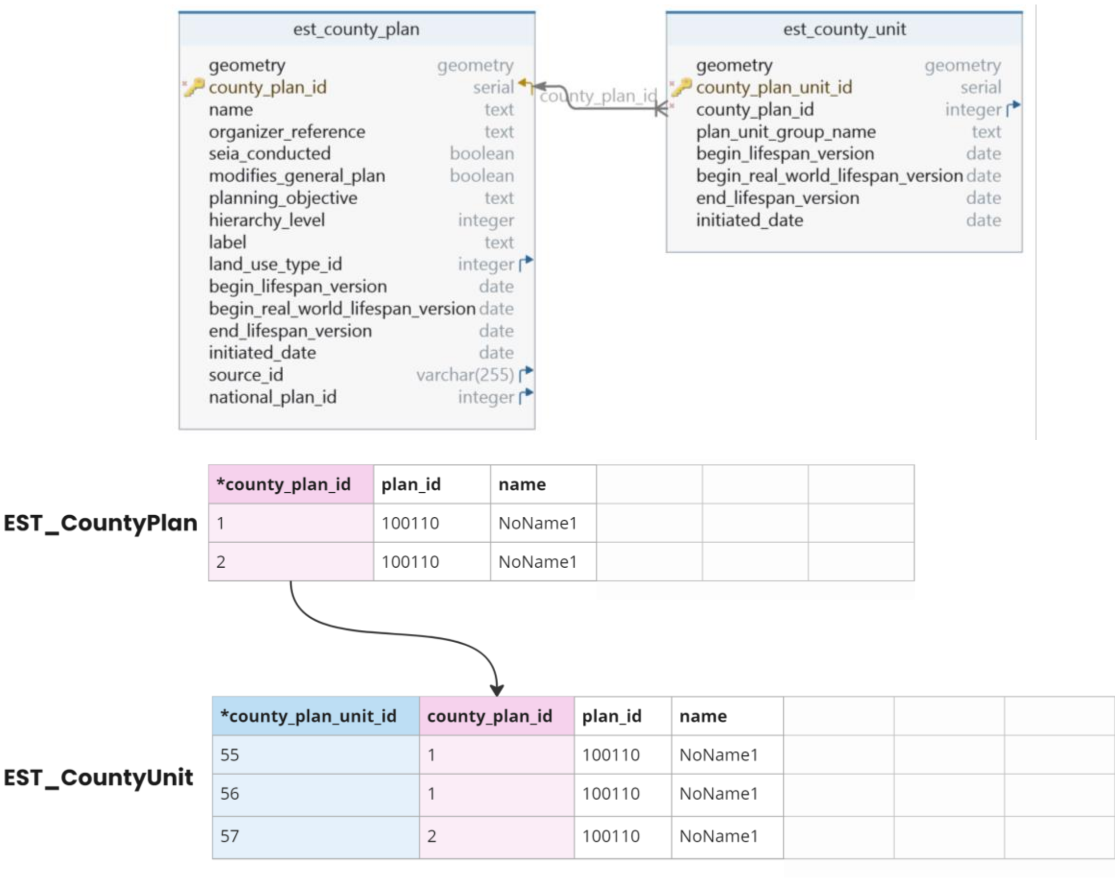
5.1. LADM Database Setup

The LADM database setup began with selecting PostgreSQL and PostGIS as supporting tools due to their robustness, support for spatial data types, and extensive GIS capabilities.

The first step in developing the database involved creating the feature classes of the country profile. These tables would serve as the primary repositories for all imported data. The key feature classes included: *EST_NationalPlan, EST_CountyPlan, EST_MasterPlan*, *EST_DetailedPlan, EST_NationalUnit, EST_CountyUnit, EST_MasterUnit, EST_DetailedUnit, SP_Permit, LA_Source, LA_AdministrativeSource* and *LA_SpatialSource.*

To establish relationships between the plan tables (i.e., *est_national_plan, est_county_plan, est_master_plan,* and *est_detailed_plan)* and their corresponding unit tables (i.e., *est_national_unit, est_county_unit, est_master_unit,* and *est_detailed_unit),* additional foreign key attributes were added to the unit tables. Figure 48 illustrates an example of this. In the figure, **county_plan_id** is the primary key of the *est_county_plan* table and a foreign key in the *est_county_unit* table. This configuration allows direct access and visibility of which unit (identified by **county_plan_unit_id**) belongs to which version of a specific plan.

It is important to note that different **county_plan_id** values in the *EST_CountyPlan* table do not necessarily indicate different plans. Instead, the "**plan_id**" attribute (e.g., "100110" in Figure 48) indicates the actual plan identity. What this attribute actually represents or how it is extracted will be explained in detail later. Essentially, different **county_plan_id** values represent different versions of the same plan, as indicated by the consistent **plan_id** value.



est_county_plan

geometry	geometry
county_plan_id	serial
name	text
organizer_reference	text
seia_conducted	boolean
modifies_general_plan	boolean
planning_objective	text
hierarchy_level	integer
label	text
land_use_type_id	integer
begin_lifespan_version	date
begin_real_world_lifespan_version	date
end_lifespan_version	date
initiated_date	date
source_id	varchar(255)
national_plan_id	integer

est_county_unit

geometry	geometry
county_plan_unit_id	serial
county_plan_id	integer
plan_unit_group_name	text
begin_lifespan_version	date
begin_real_world_lifespan_version	date
end_lifespan_version	date
initiated_date	date

EST_CountyPlan

*county_plan_id	plan_id	name			
1	100110	NoName1			
2	100110	NoName1			

EST_CountyUnit

*county_plan_unit_id	county_plan_id	plan_id	name			
55	1	100110	NoName1			
56	1	100110	NoName1			
57	2	100110	NoName1			

Figure 48. EST_CountyPlan and EST_CountyUnit relationship in the database.

Another design decision was the creation of intermediate tables to handle many-to-many relationships in the model. One important example is the relationship between plan classes and *la_source*. In theory and practice, a single plan representation in the database can be linked to multiple source datasets. For instance, a Detailed Plan might be a composition of CAD files and 2D PDF documents. Equally, a single source dataset can be associated with multiple plans. For example, a comprehensive topographical survey in *la_source* could be referenced by both a Master Plan and a Detailed Plan. Figure 49 illustrates this dual relationship between plans and sources. To represent these relationships accurately, intermediate tables between plan tables and *la_source* table such as *national_plan_la_source, county_plan_la_source, master_plan_la_source*, and *detailed_plan_la_source* have been created in the database.

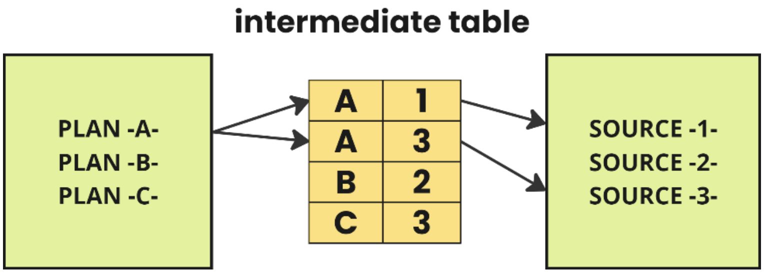


Figure 49. Many-to-many relationships represented by intermediate tables.

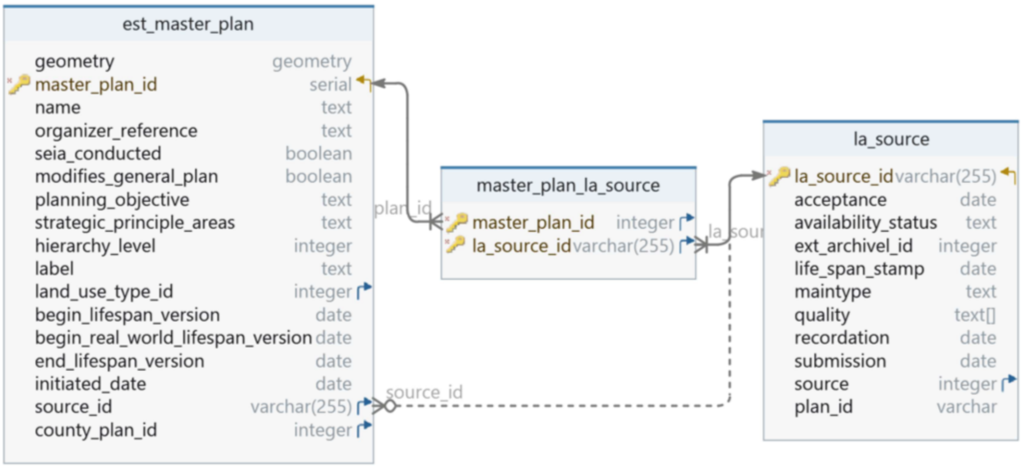
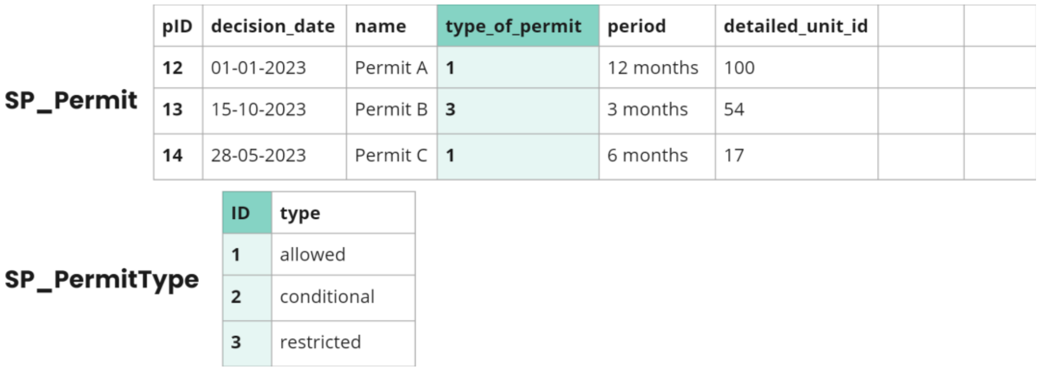


Figure 50. Example of primary and foreign key relationships in the master_plan_la_source table.

Figure 50 shows an example of how the primary and foreign keys work in this situation through the example of *master_plan_la_source* table. The *master_plan_la_source* table has two primary keys: **master_plan_id** and **la_source_id**. Each **master_plan_id** is a foreign key that references the *est_master_plan* table, and each **la_source_id** is a foreign key that references the *la_source* table. Together, these two keys uniquely identify each record in the table and allow a single Master Plan to be associated with multiple source datasets and vice versa.



SP_Permit

pID	decision_date	name	type_of_permit	period	detailed_unit_id		
12	01-01-2023	Permit A	1	12 months	100		
13	15-10-2023	Permit B	3	3 months	54		
14	28-05-2023	Permit C	1	6 months	17		

SP_PermitType

ID	type
1	allowed
2	conditional
3	restricted

Figure 51. Example of how codelist values are represented in the database.

Figure 52 shows the overall model structure in the database without the codelist tables. The codelist tables: *SP_HigherLevelSpaceFunction, CI_RoleCode, LA_MultimediaType, LA_MediaType, EST_TransportInfrastructureType, EST_GreenNetworkType, SP_SubSpaceFunctionType, SP_StatusType, SP_SpaceFunctionType, SP_PermitType, and LA_SurfaceRelationType*, are essential to maintaining the integrity of the country profile. These tables contain predefined codelist values that are either newly created for Estonia or derived from LADM standards. They are designed to be static, with records that should not be altered or supplemented with new entries unless modifications to the country profile necessitate it. For instance, Figure 51 illustrates how the SP_Permit table uses a codelist value from the *SP_PermitType* codelist table. In this example, a record in the *SP_Permit* table references a specific type of permit, as defined in the *SP_PermitType* codelist table. This ensures that only valid, predefined types of permits are used, maintaining consistency.

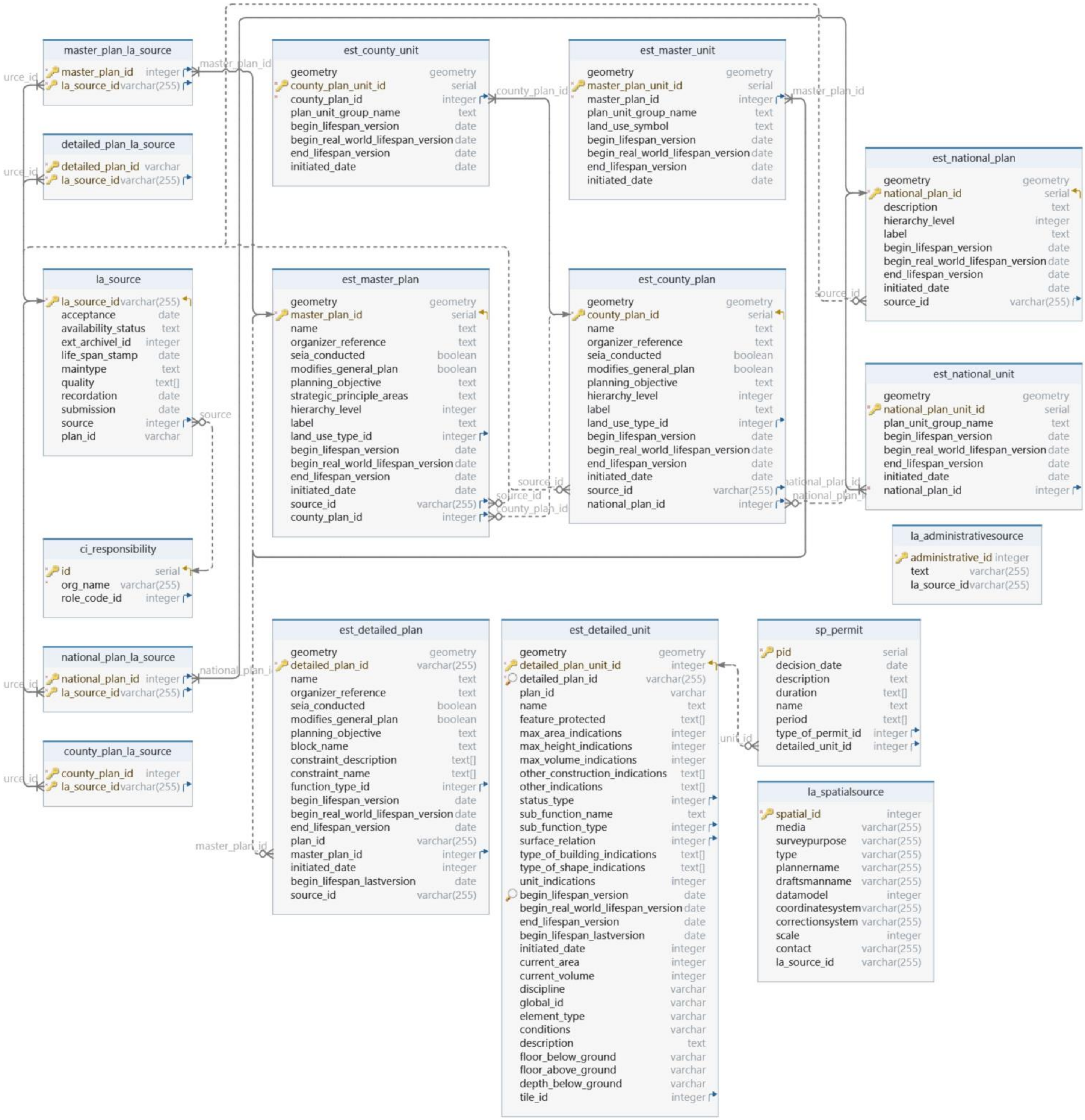
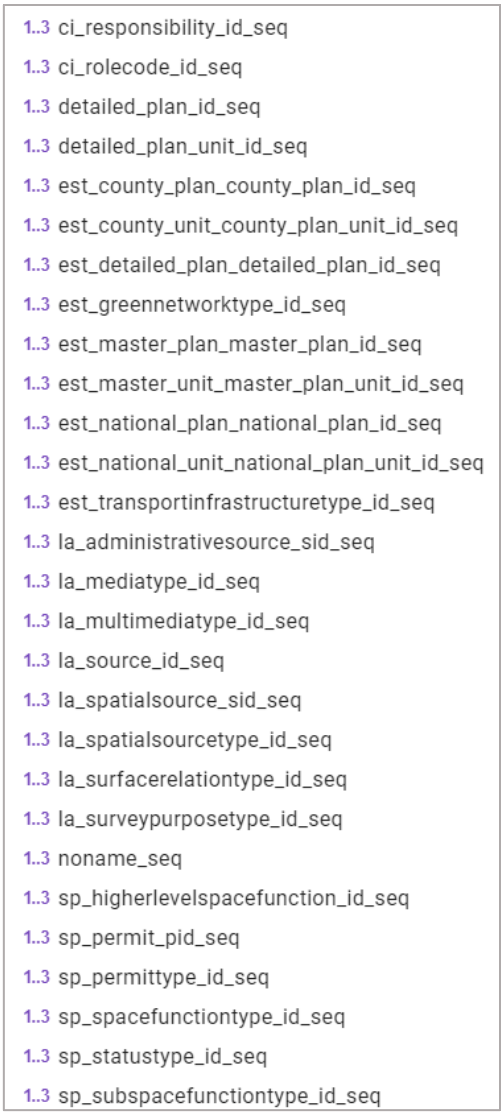


Figure 52. Model structure in the database without the codelist tables.

Furthermore, to optimize the database, some sequences, triggers, views, and functions were implemented.

Sequences are mainly used to generate unique identifiers for records in various tables, ensuring that each entry has a distinct and traceable ID. For instance, sequences *like ci_responsibility_id_seq, ci_rolecode_id_seq, detailed_plan_id_seq*, and many others (as listed in Figure 53) are created to automatically increment IDs, starting from 1, whenever a new record is inserted. This guarantees the uniqueness of each plan record's identifier.



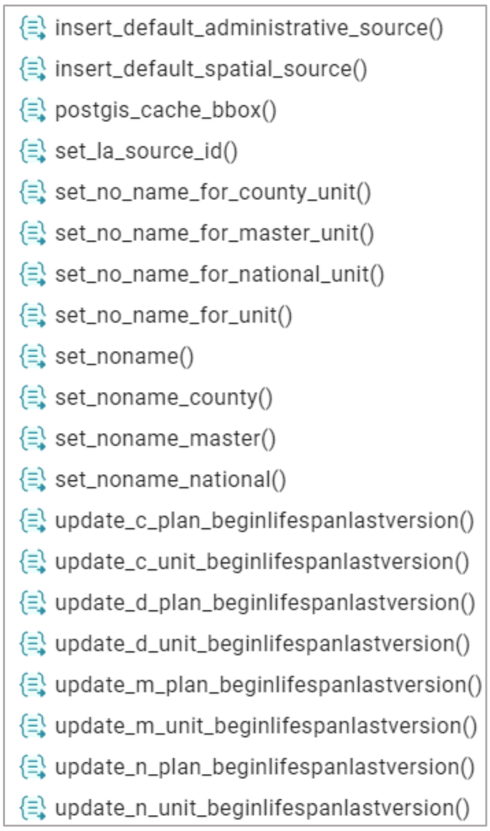
ci_responsibility_id_seq
ci_rolecode_id_seq
detailed_plan_id_seq
detailed_plan_unit_id_seq
est_county_plan_county_plan_id_seq
est_county_unit_county_plan_unit_id_seq
est_detailed_plan_detailed_plan_id_seq
est_greennetworktype_id_seq
est_master_plan_master_plan_id_seq
est_master_unit_master_plan_unit_id_seq
est_national_plan_national_plan_id_seq
est_national_unit_national_plan_unit_id_seq
est_transportinfrastructuretype_id_seq
la_administrativesource_sid_seq
la_mediatype_id_seq
la_multimediatype_id_seq
la_source_id_seq
la_spatialsource_sid_seq
la_spatialsourcetype_id_seq
la_surfacerelationtype_id_seq
la_surveypurposetype_id_seq
noname_seq
sp_higherlevelspacefunction_id_seq
sp_permit_pid_seq
sp_permittype_id_seq
sp_spacefunctiontype_id_seq
sp_statustype_id_seq
sp_subspacefunctiontype_id_seq

Figure 53. All of the sequences implemented in the database.

The *noname_seq* is an exception to the general sequence usage, specifically designed for handling data uploads that lack a "plan name" in the metadata of the IFCs. In cases where data uploaded to the database through FME does not include a plan name, the default dummy name 'NONAME' is set by the FME script. To address this, triggers are implemented within the database. These triggers catch insertion operations to specifically detailed plan tables. If the incoming data contains the 'NONAME' placeholder, the trigger function first queries the *est_detailed_plan* table to retrieve the most recent name associated with the same *plan_id*. This ensures consistency by using the same name if the same plan is uploaded multiple times. If no name is found for the *plan_id*, a new name is generated in the format 'NoName' followed by the next number in the sequence (e.g., NoName1, NoName2, NoName3…). This allowed for a more organized and consistent look in the database even if the plan names are absent in the data that is imported.

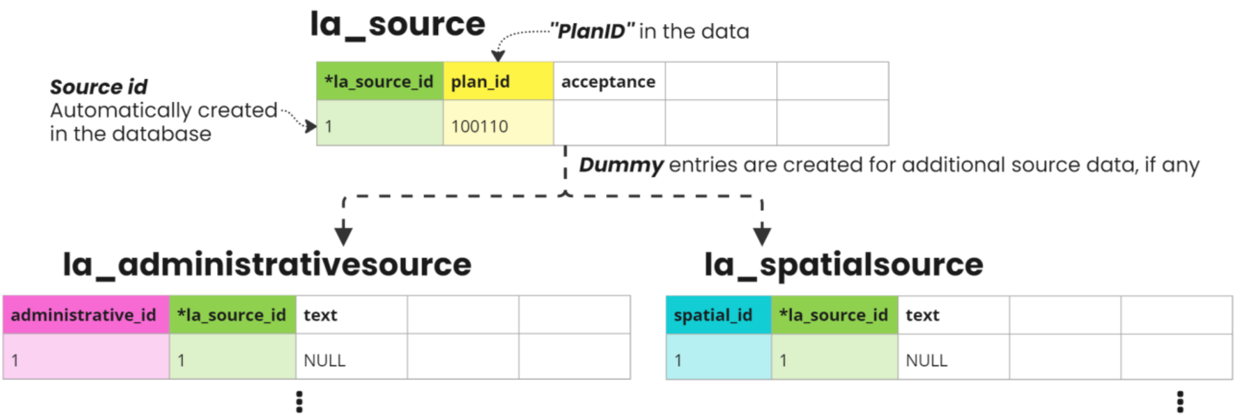
The database also contains several trigger functions to enhance efficiency and maintain data integrity, seen in Figure 54. For example, the *insert_default_administrative_source* and *insert_default_spatial_source* trigger functions run after a new entry is inserted into the *la_source* table through FME. These triggers call the *insert_default_administrative_source* and *insert_default_spatial_source* functions to insert corresponding "dummy" entries in the *la_administrativesource* and *la_spatialsource* tables. This establishes clear associations between the main source table (*la_source*) and the additional source tables (*la_administrativesource* and *la_spatialsource*), ensuring that the additional tables can be utilized if relevant data is imported as well. This mechanism can be seen in Figure 55.

The *set_la_source_id* function ensures that each new entry in the *la_source* table is assigned a unique identifier by generating the next value in the sequence. Since **la_source_id** in the *la_source* table is the primary key and has a NONULL data constraint in the database, the FME script cannot upload records without any value assigned to this attribute. As a solution, during the upload process via FME, a 'dummy' value of '999' is assigned to **la_source_id**. The *set_la_source_id* trigger recognizes this dummy value and automatically overwrites it with the next sequence value generated by the database, ensuring the uniqueness and integrity of the primary key.



- insert_default_administrative_source()
- insert_default_spatial_source()
- postgis_cache_bbox()
- set_la_source_id()
- set_no_name_for_county_unit()
- set_no_name_for_master_unit()
- set_no_name_for_national_unit()
- set_no_name_for_unit()
- set_noname()
- set_noname_county()
- set_noname_master()
- set_noname_national()
- update_c_plan_beginlifespanlastversion()
- update_c_unit_beginlifespanlastversion()
- update_d_plan_beginlifespanlastversion()
- update_d_unit_beginlifespanlastversion()
- update_m_plan_beginlifespanlastversion()
- update_m_unit_beginlifespanlastversion()
- update_n_plan_beginlifespanlastversion()
- update_n_unit_beginlifespanlastversion()

Figure 54. All of the trigger functions implemented in the database.



*la_source_id	plan_id	acceptance		
1	100110			

administrative_id	*la_source_id	text		
1	1	NULL		

spatial_id	*la_source_id	text		
1	1	NULL		

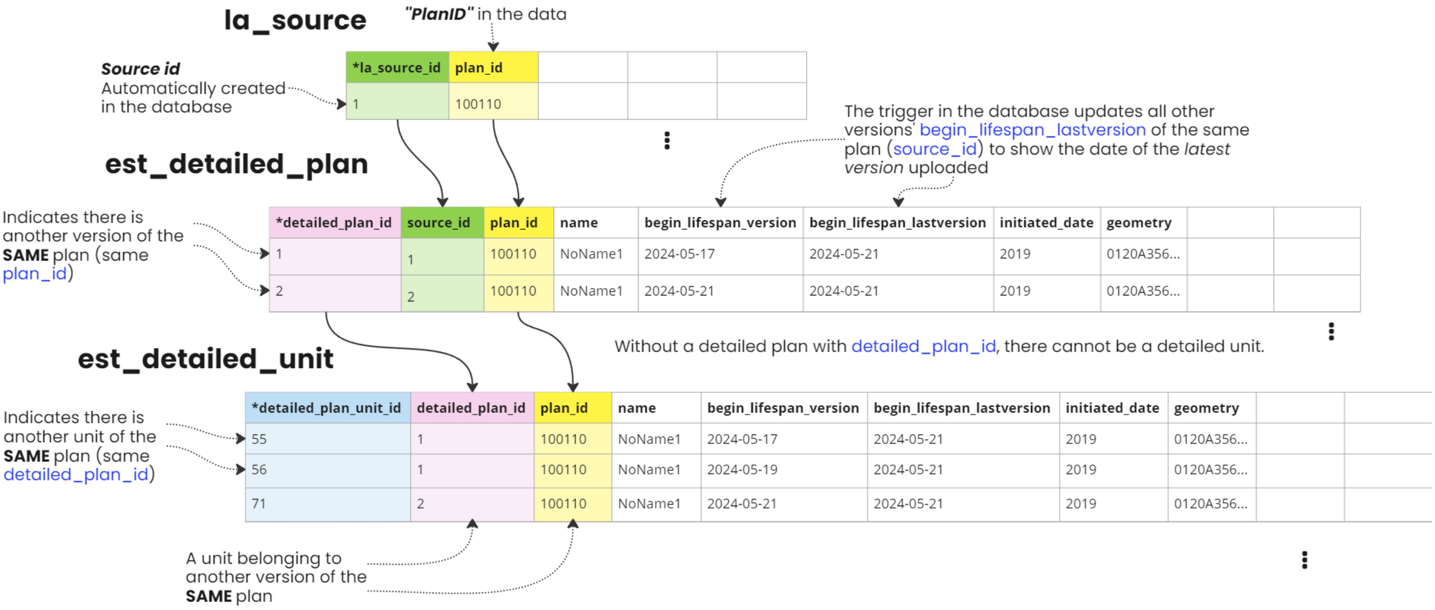
Figure 55. "Dummy" entries for la_administrativesource and la_spatialsource.

For versioning in the database, mechanisms in both the database and the FME script were utilized. The date of uploading (i.e., **begin_lifespan_version**) is added through the FME script to the data as an attribute before uploading to the database. The FME part of this will be explained in detail in Section 5.2. Because each spatial plan and unit uploaded can have different versions of the same plan, an attribute that shows the last version (i.e., **begin_lifespan_lastversion**) was added to the country profile during the development stages. The *VersionedObject* attribute **begin_lifespan_lastversion** is available in every plan table and their corresponding unit tables. The relevant letters “d,” “m,” “c” and “n” in the function naming indicate the first letters of the plan levels and which level the specific trigger function corresponds to them. For example, for Detailed

Plans, the *update_d_plan_beginlifespanlastversion* and *update_d_unit_beginlifespanlastversion* functions update the **begin_lifespan_lastversion** field in *the est_detailed_plan* and *est_detailed_unit* tables, respectively. These functions ensure that all records with the same **plan_id** reflect the most recent **begin_lifespan_version** date. Similar functions are implemented for the *est_master_plan, est_master_unit, est_county_plan, est_county_unit, est_national_plan,* and *est_national_unit* tables, ensuring consistency across different plan and unit types.

During the import process, both **begin_lifespan_version** and **begin_lifespan_lastversion** are set to the current date (the date of import = NOW). This shows that each new or updated record is initially marked as the latest version and, most importantly, something other than a NULL value for the database triggers to work. The trigger in the database updates all other versions' **begin_lifespan_lastversion** of the same plan (**source_id**) to show the date of the latest version uploaded.

Initially, the functions and triggers created to update the **begin_lifespan_lastversion** column caused infinite loops and max stack depth errors. The logic was too complex and led to recursive updates. The final solution involved refining the function logic. The function *update_d_unit_beginlifespanlastversion* updates the **begin_lifespan_lastversion** for all records with the same **source_id** only if the **begin_lifespan_version** of the new record is greater. This ensures that all records reflect the most recent version date. The trigger *trg_update_d_unit_lifespan* is triggered after an insert or update on the **est_detailed_unit** table, invoking the function to update the **begin_lifespan_lastversion** column. This approach avoids the infinite loop and stack depth issues previously encountered. The same logic applies to *est_detailed_plan* as well. Figure 56 illustrates an example scenario to demonstrate how the versioning works in the database.



"PlanID" in the data

Source id
Automatically created in the database

*la_source_id	plan_id			
1	100110			

The trigger in the database updates all other versions' begin_lifespan_lastversion of the same plan (source_id) to show the date of the *latest version* uploaded

Indicates there is another version of the **SAME** plan (same plan_id)

*detailed_plan_id	source_id	plan_id	name	begin_lifespan_version	begin_lifespan_lastversion	initiated_date	geometry		
1	1	100110	NoName1	2024-05-17	2024-05-21	2019	0120A356...		
2	2	100110	NoName1	2024-05-21	2024-05-21	2019	0120A356...		

Without a detailed plan with detailed_plan_id, there cannot be a detailed unit.

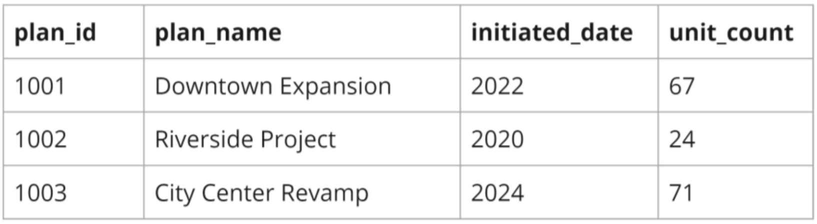
Indicates there is another unit of the **SAME** plan (same detailed_plan_id)

*detailed_plan_unit_id	detailed_plan_id	plan_id	name	begin_lifespan_version	begin_lifespan_lastversion	initiated_date	geometry		
55	1	100110	NoName1	2024-05-17	2024-05-21	2019	0120A356...		
56	1	100110	NoName1	2024-05-19	2024-05-21	2019	0120A356...		
71	2	100110	NoName1	2024-05-21	2024-05-21	2019	0120A356...		

A unit belonging to another version of the **SAME** plan

Figure 56. Example of how the versioning in the database works.

To further enhance the database's legibility, several views were implemented. For instance, the *est_detailed_plan_unit_count* view was created to aggregate detailed plans and their corresponding unit counts. This view provides a summarized count of units associated with each Detailed Plan, making it easier for users to get an overview of the data without needing to perform complex joins or queries themselves. Similar views were created for other plan levels, including Master Plans, County Plans, and National Plans. An example table of *est_detailed_plan_unit_count* is shown in Figure 57.



plan_id	plan_name	initiated_date	unit_count
1001	Downtown Expansion	2022	67
1002	Riverside Project	2020	24
1003	City Center Revamp	2024	71

Figure 57. Example est_detailed_plan_unit_count view table.

Most of the functions and triggers mentioned were created during the testing phase of the database by importing data through FME. This iterative process allowed for real-time optimization, ensuring both the FME scripts and the database were efficiently adjusted to handle the specific Estonian data requirements. The feedback loop between testing and development was crucial in achieving final database setup, including the plan tables' specifics. These steps and the details of the data import process will be mentioned in Section 5.2.

Additionally, a database dump script to deploy the database from scratch was included in the GitHub repository of the thesis[22]. The only requirement for the script to work is to create a schema in the database called "public" beforehand so the script can recognize it. Also, a script to reset the sequences and delete every record in the database, except for the codelist values in the codelist tables, is available on GitHub. This reset script was essential for maintaining the integrity of the database during testing and development phases.

5.2. Importing IFC data

This section outlines the steps and methodologies employed to facilitate the importation of IFC data to the database. It ensures that the information is accurately reflected and can be effectively used for permit checking and spatial planning purposes.

The import process begins with the preparation of IFC data, which involves ensuring that the data conforms to the required standards and formats. FME is used to manipulate and transform Estonian IFC data into a format compatible with the developed LADM

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

database. The basis for the FME script is derived from the case study project, utilizing the scripts created by the company for permit checks. These scripts automate the extraction, transformation, and loading (ETL) of data for the checks. Figure 58 illustrates the final FME script. The left part of the script, indicated by the blue square, covers general data extraction and initial validation methods for the IFC data. The right part of the script (in red), which executes after the blue section, handles necessary data transformations, additional data extraction mechanisms needed to represent the data comprehensively in the LADM profile, and finally, the data import into the new database.

Figure 58. Complete FME workflow.

The FME script plays an important role in transforming the IFC data into a format suitable for the LADM-based database. It begins by standardizing the data, ensuring it meets the specific requirements of the Estonian context. This includes verifying the completeness of metadata, ensuring spatial data integrity, and validating object properties and layer naming conventions, all according to the Estonian layer requirements mentioned in Appendix D. The FME script also handles the conversion of IFC data to match the schema of the LADM database, including mapping attributes and relationships to the appropriate tables and columns.

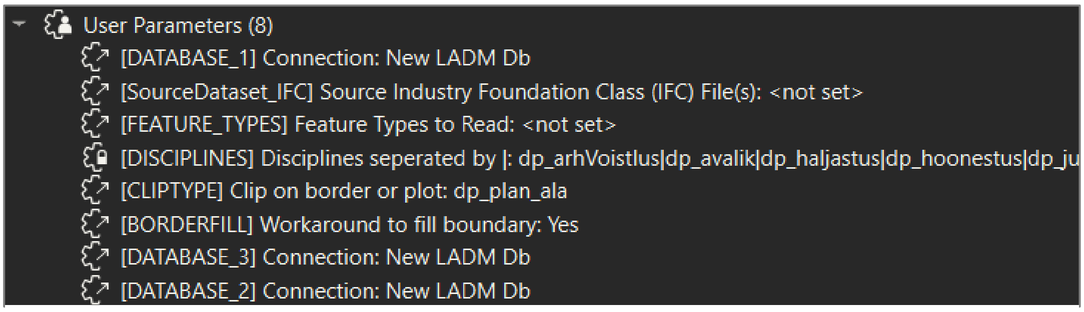

User Parameters (8)
[DATABASE_1] Connection: New LADM Db
[SourceDataset_IFC] Source Industry Foundation Class (IFC) File(s): <not set>
[FEATURE_TYPES] Feature Types to Read: <not set>
[DISCIPLINES] Disciplines seperated by |: dp_arhVoistlus|dp_avalik|dp_haljastus|dp_hoonestus|dp_ju
[CLIPTYPE] Clip on border or plot: dp_plan_ala
[BORDERFILL] Workaround to fill boundary: Yes
[DATABASE_3] Connection: New LADM Db
[DATABASE_2] Connection: New LADM Db

Figure 59. FME script's User Parameters.

One of the first steps in developing the FME workflow involved the creation of "User Parameters" to make the script as flexible as possible for various input data. Figure 59 shows all the defined User Parameters in the script. A few examples of the User Parameters are as follows:

- The three database parameters (i.e., **DATABASE_1**, **DATABASE_2**, **DATABASE_3**) indicate the three "writers" in the script that import the extracted and transformed data to three different tables in the database.

- The "**SourceDataset_IFC**" parameter allows the user to select the path to one or more IFC data files to be read by the program.
- "**DISCIPLINES**" indicates the objects in the IFC that contain a property set, whose name represents the discipline. The name of these property sets is limited to the following list for the case study (parallel with the regulations and PLANK): *dp_arhVoistlus*, *dp_avalik*, *dp_haljastus*, *dp_hoonestus*, *dp_juurdep*, *dp_KKTingimus*, *dp_KOVLoodus*, *dp_krunt*, *dp_krundiSihtotstarve*, *dp_maapar*, *dp_servituut*, *dp_sund*, *dp_tehno*, *dp_tingimus*, *dp_transp*, *dp_vaartloodus*, *dp_vaartMiljoo* and *dp_vaartPollum.*
- "**CLIPTYPE**" indicates the clipping factor type that clips the discipline layers to have an accurate plot area representation. According to the data, the clipping factor can be either plan border or the plot area.

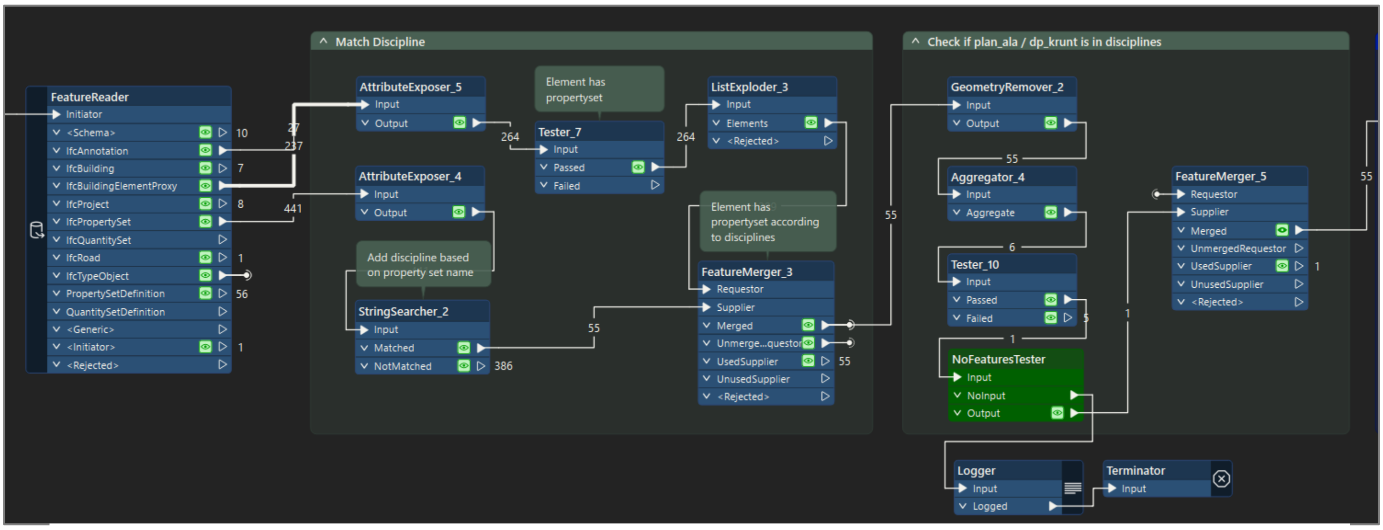


Figure 60. Snippet of the FME workflow I.

Figure 60 shows a snippet from the beginning of the FME workflow. After the FeatureReader reads the IFC files (multiple IFCs in one Estonian data), the data coming from IfcPropertySet and IfcAnnotation is compared against each other. The aim is to only keep the matched discipline records with a property set and exclude everything else. Next, it checks if the plan_ala or dp_krunt is in the kept disciplines. These layers represent the planning area and the plot area, respectively. According to Estonian layer requirements (Appendix D), it is mandatory that every plan data must have both layers. The **CLIPTYPE** user parameter allows the user to select which should be checked, with regards to the necessary compliance check requirements. In Figure 60, **Tester_10** contains this selection, and the workflow continues accordingly. If the preferred **CLIPTYPE** is missing in the data, the script stops. Another checking mechanism included here was to test if, after confirming the **CLIPTYPE** exists, the layer has any features/elements or is empty. This is done by the **NoFeatureTester** in Figure 60. The geometrical difference between *plan_ala* and *dp_krunt* can be seen in Figure 61.

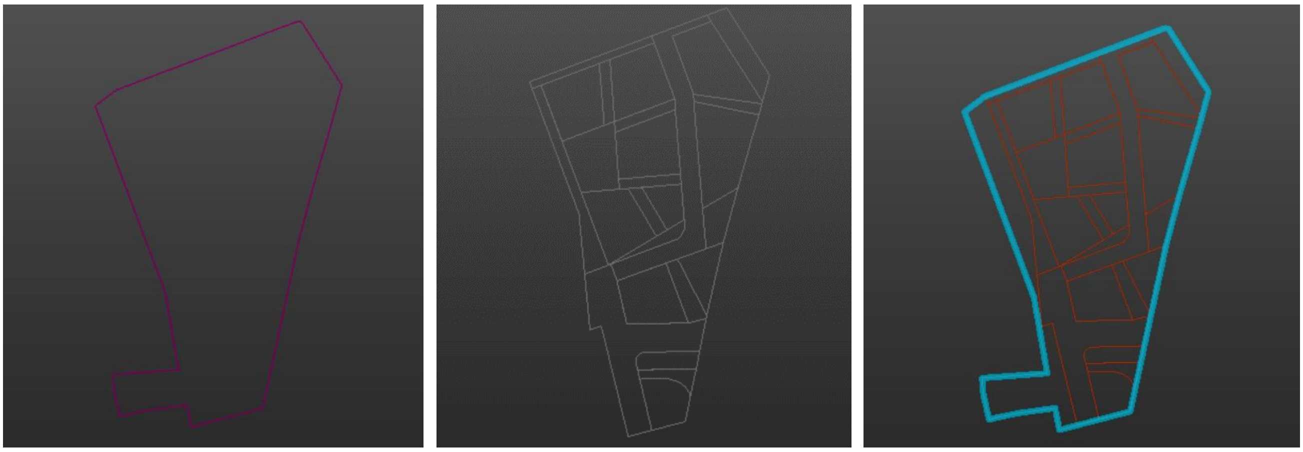
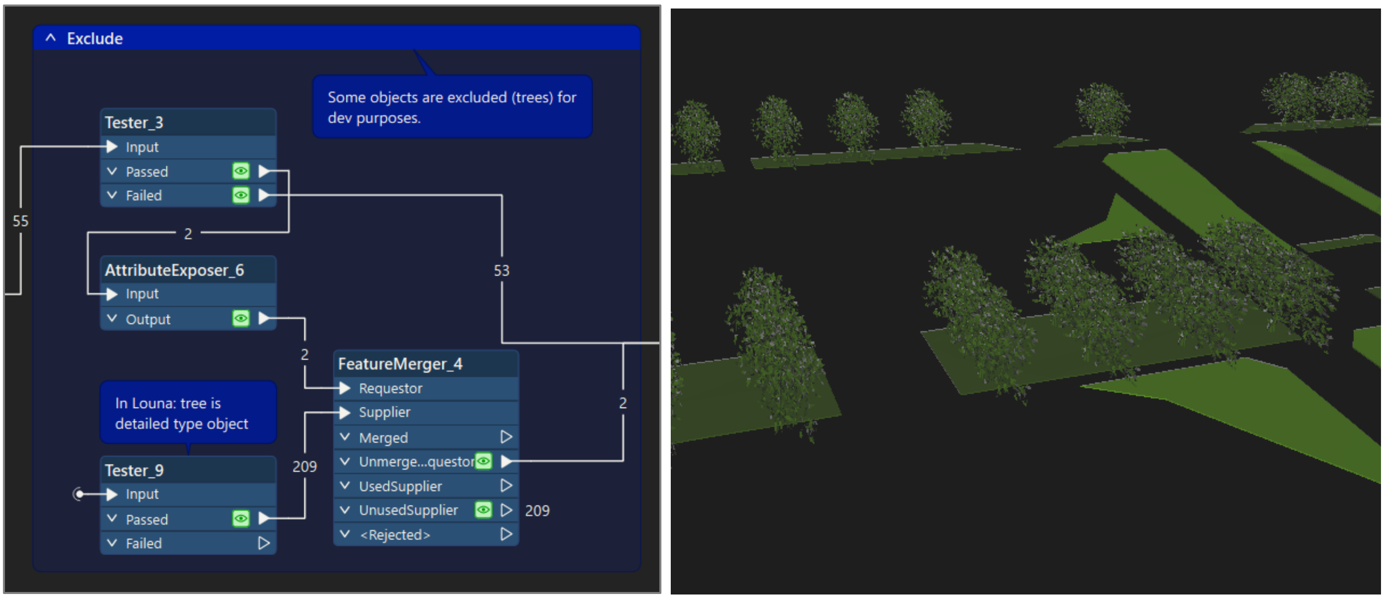


Figure 61. Difference between *plan_ala* (left) and *dp_krunt* (center). The merged area is on the right.

After the initial data validation, some objects are excluded from the records for development purposes, like trees, as seen in Figure 62. To avoid any relevant data loss, trees will be included again in the LADM section of the script before importing the data into the database.



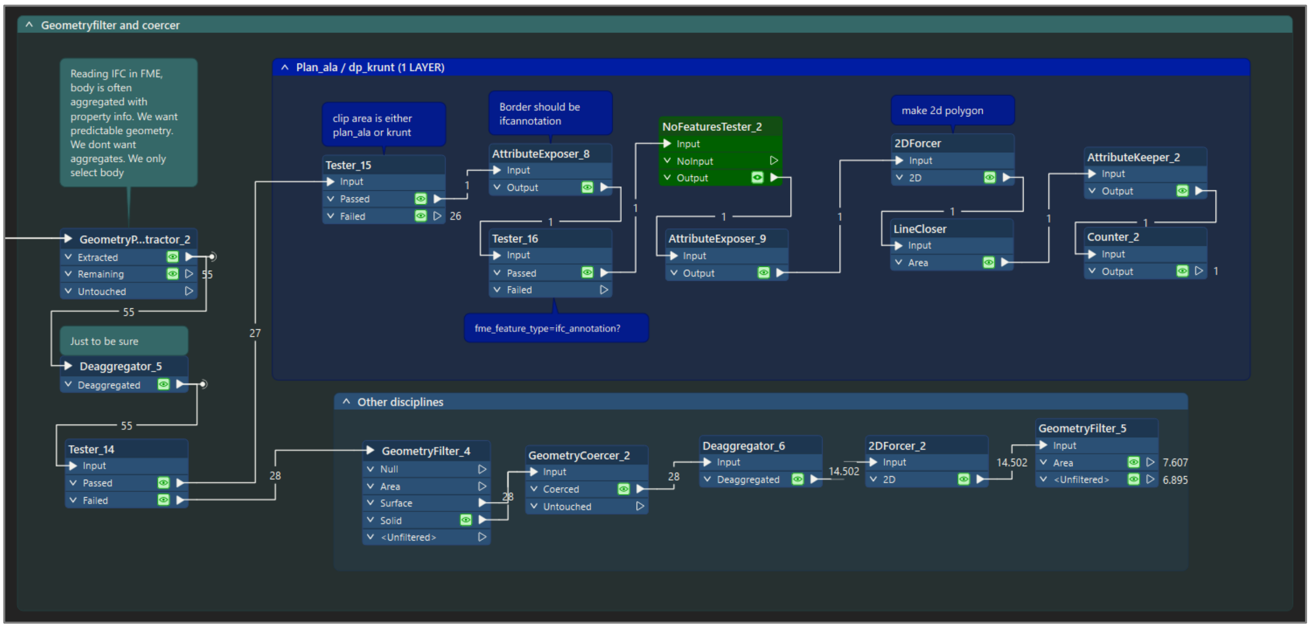
Some objects are excluded (trees) for dev purposes.

In Louna: tree is detailed type object

Figure 62. Snippet of the FME workflow II (left). Tree objects from Lõuna dataset (right).

Following the exclusion of some elements, the final data extraction and transformation before the LADM part focuses on geometries. This part, seen in Figure 63, utilizes the **Geometry_Part_Extractor** to handle the geometries within the IFC data.

When reading IFC files in FME, the "*Body*" geometry often includes aggregated property information. To ensure predictable and clean geometry data, it is important to avoid these aggregates and extract only the "*Body*" part of the geometry. The **Geometry_Part_Extractor** is used to select geometries with the name "*Body*." This ensures that the extracted geometries are consistent and free from unwanted aggregation.


Reading IFC in FME, body is often aggregated with property info. We want predictable geometry. We dont want aggregates. We only select body

clip area is either plan_ala or krunt

Border should be ifcannotation

make 2d polygon

Just to be sure

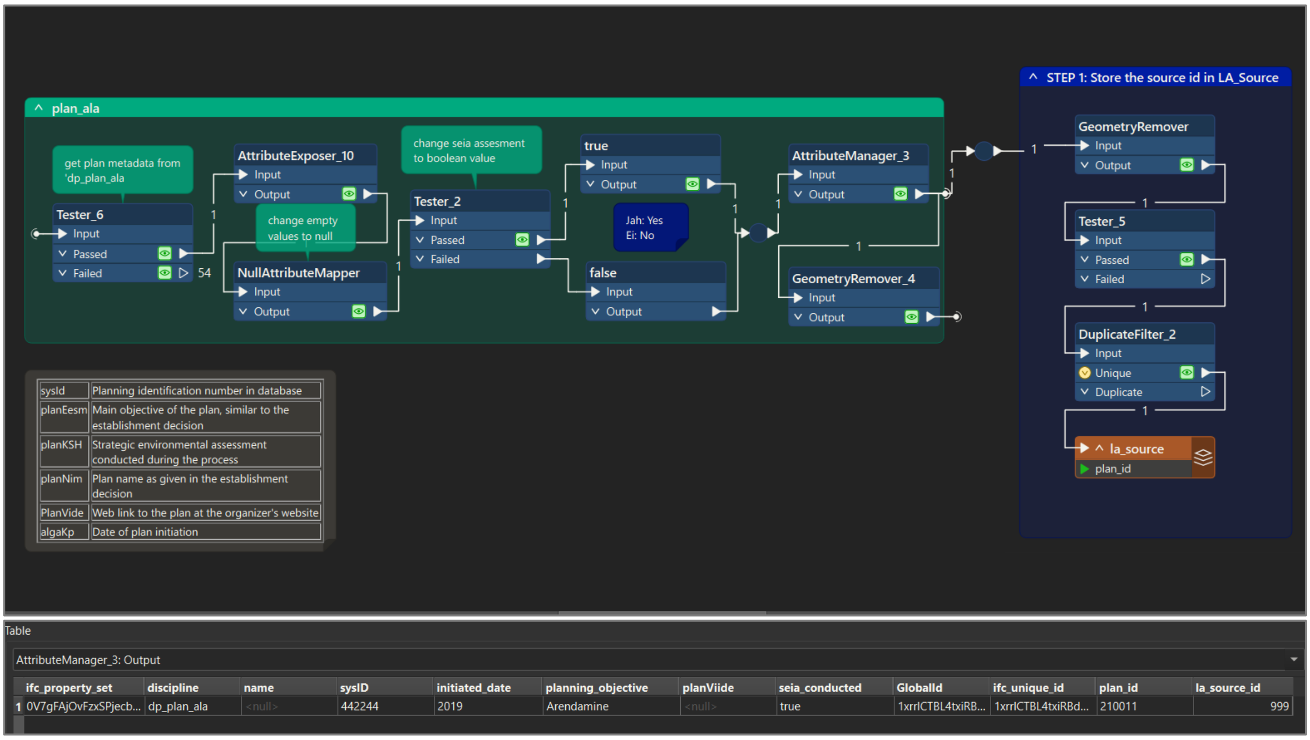
fme_feature_type=ifc_annotation?

Figure 63. Snippet of the FME workflow III.

After the **Geometry_Part_Extractor** part, the workflow focuses on specific layers, such as the planning area (i.e., plan_ala) and plot area (i.e., dp_krunt) layers, applying some checks and transformations, seen in Figure 63. These steps include validating layer presence, converting geometries to 2D representations, and ensuring that lines are closed to form valid polygons.

For other disciplines, similar validation and transformation processes are applied to ensure all geometries are correctly formatted and meet the required standards before continuing with the LADM part of the FME script. This guarantees that the spatial data is accurately represented, is consistent, and ready for the next steps.

The LADM part starts by exposing the metadata of the *plan_ala* layer, as seen in Figure 64. Necessary modifications are then made, such as removing unnecessary attributes that are not represented in the database or renaming some attributes to match the column names in the database. This is done with regards to the initial Estonian data mapping in the Country profile created, as seen in Figure 65. Another significant modification made is assigning “999” value to *la_source_id* attribute for previously mentioned reasons in Section 4.2. The *set_la_source_id* trigger in the database recognizes this value and automatically overwrites it with the next sequence value generated. This facilitates easier mapping with database tables/columns during the import process. It is important to note that for better representation in the database, attributes with "*missing*" values are converted to *null*. This ensures that even though there isn't a meaningful value representation, the database sees that it has a value (*null*) and doesn't produce errors during the import process.



sysId	Planning identification number in database
planEesm	Main objective of the plan, similar to the establishment decision
planKSH	Strategic environmental assessment conducted during the process
planNim	Plan name as given in the establishment decision
PlanVide	Web link to the plan at the organizer's website
algaKp	Date of plan initiation

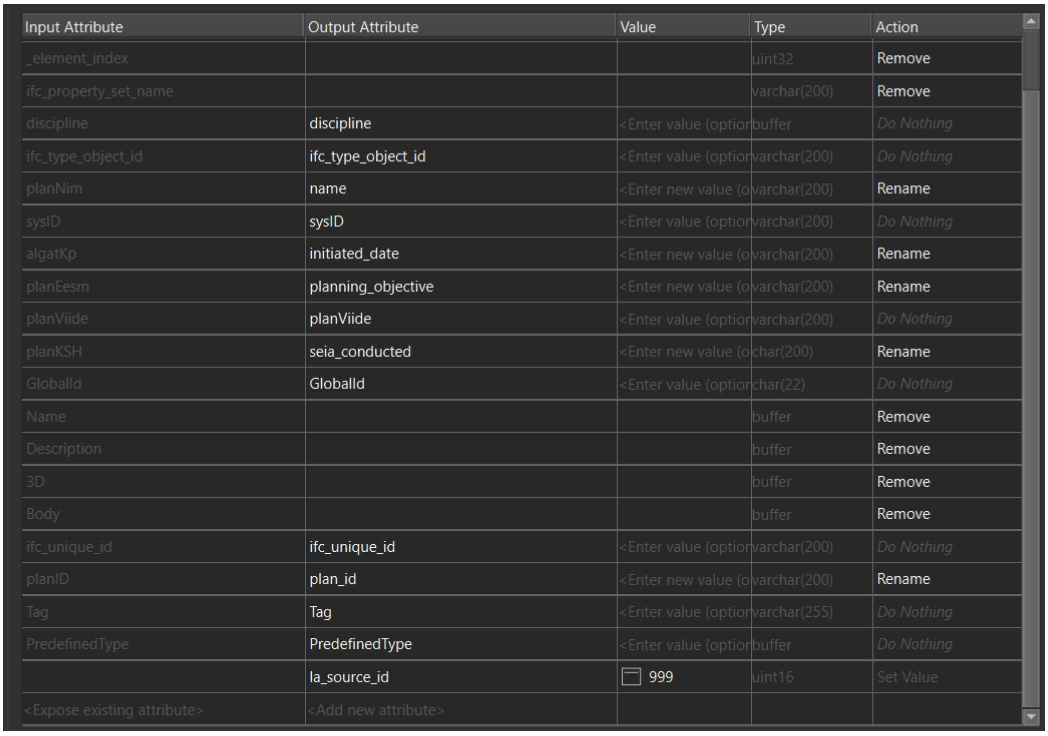
Table

AttributeManager_3: Output

	ifc_property_set	discipline	name	sysID	initiated_date	planning_objective	planViide	seia_conducted	GlobalId	ifc_unique_id	plan_id	la_source_id
1	0V7gFAjOvFzxSPjecb...	dp_plan_ala	<null>	442244	2019	Arendamine	<null>	true	1xrrICTBL4txiRB...	1xrrICTBL4txiRBd...	210011	999

Figure 64. Snippet of the FME workflow IV, LADM part.

The first table in the database to import information into is the *la_source* table. As previously explained in Section 4.2., the database has been developed with sophisticated constraints such that every plan uploaded must first have source data uploaded to the *la_source* table. This is crucial to maintain the integrity and traceability of the spatial data within the database.



Input Attribute	Output Attribute	Value	Type	Action
_element_index			uint32	Remove
ifc_property_set_name			varchar(200)	Remove
discipline	discipline	<Enter value (optior	buffer	Do Nothing
ifc_type_object_id	ifc_type_object_id	<Enter value (optior	varchar(200)	Do Nothing
planNim	name	<Enter new value (o	varchar(200)	Rename
sysID	sysID	<Enter value (optior	varchar(200)	Do Nothing
algatKp	initiated_date	<Enter new value (o	varchar(200)	Rename
planEesm	planning_objective	<Enter new value (o	varchar(200)	Rename
planViide	planViide	<Enter value (optior	varchar(200)	Do Nothing
planKSH	seia_conducted	<Enter new value (o	char(200)	Rename
GlobalId	GlobalId	<Enter value (optior	char(22)	Do Nothing
Name			buffer	Remove
Description			buffer	Remove
3D			buffer	Remove
Body			buffer	Remove
ifc_unique_id	ifc_unique_id	<Enter value (optior	varchar(200)	Do Nothing
planID	plan_id	<Enter new value (o	varchar(200)	Rename
Tag	Tag	<Enter value (optior	varchar(255)	Do Nothing
PredefinedType	PredefinedType	<Enter value (optior	buffer	Do Nothing
	la_source_id	☐ 999	uint16	Set Value
<Expose existing attribute>	<Add new attribute>			

Figure 65. Renaming and removing some attributes with regards to the Estonian LADM profile.

Since the *la_source* table primarily stores metadata about the source rather than the spatial information itself, the geometry is removed from this table. Figure 66 illustrates an example of pilot data, "*Põhi*," in the *la_source* table. Notice that there is one entry to represent one source data, which in this case refers to the combined IFC files representing the *Põhi* Detailed Plan. Another important column is the *plan_id*. It allows the data to be correctly uploaded to the Detailed Plan and Unit tables, as the database can now recognize the plan id and connect it to the source file.

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

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

Figure 66. Example entry to the la_source table using the pilot data, Põhi.

The order of the script's import to the database is crucial, even after the *la_source* table. Figure 64 shows an overview of the LADM part of the script. The correct order of import for a spatial plan to the database should be *la_source, est_detailed_plan*, and *est_detailed_unit* (for Detailed Plans). For example, for a county plan, the order would be *la_source*, *est_county_plan,* and *est_county_unit.* This approach aligns with the constraints mentioned previously in Section 4.2, which state that one or more plan units cannot exist without the plan existing first (Figure 45). Technically, there are also constraints in the database to prevent this from happening. Thus, the order in which the script executes also works meticulously to conform to these constraints.

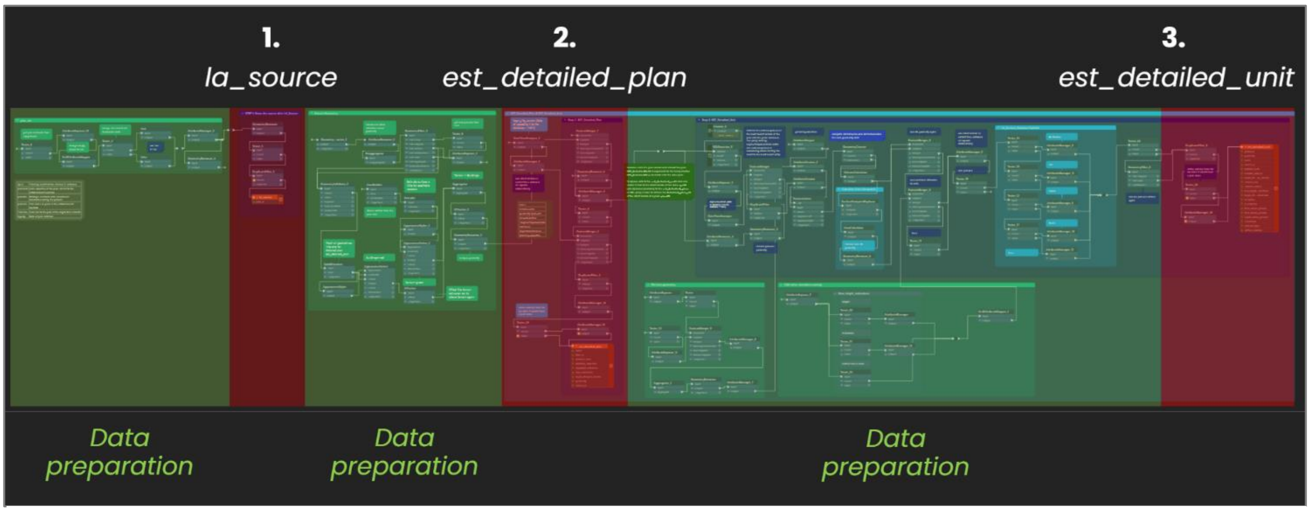
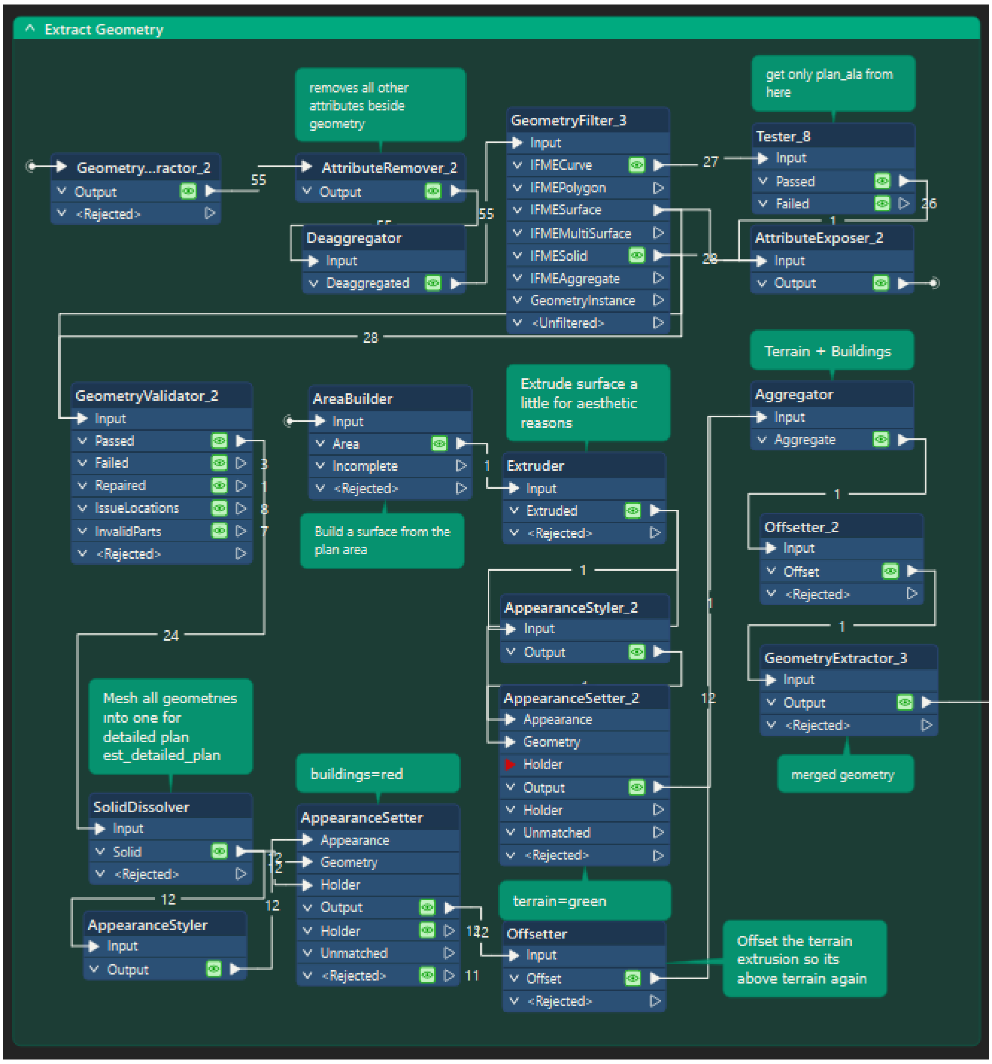


Figure 67. Overview of the LADM part in the FME script. Red areas represent the import to the database while green areas represent the data preparation and transformation sections.



removes all other attributes beside geometry

get only plan_ala from here

Terrain + Buildings

Extrude surface a little for aesthetic reasons

Build a surface from the plan area

Mesh all geometries into one for detailed plan est_detailed_plan

buildings=red

terrain=green

merged geometry

Offset the terrain extrusion so its above terrain again

Figure 68. Preparation and Merging of Geometries for est_detailed_plan table.

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

The IFC data, originally represented as 3D unit elements in terms of geometry, required necessary transformations to merge these units into one geometry. Figure 68 represents the preparation and merging of the geometries before the import into the *est_detailed_plan* table. To accurately represent the plan area (*plan_ala*, represented as a 2D line in the Estonian data), additional manipulations, such as creating a 3D platform of the plan area, were performed. It is noteworthy that while the plan_ala layer remained in 2D, all other layers were already in 2.5D or 3D in the input IFCs. These steps ensured that the final mesh visually reflected the entire plan area in 3D. Figure 69 shows an example of the final geometry product that is to be uploaded to the *est_detailed_plan* table.

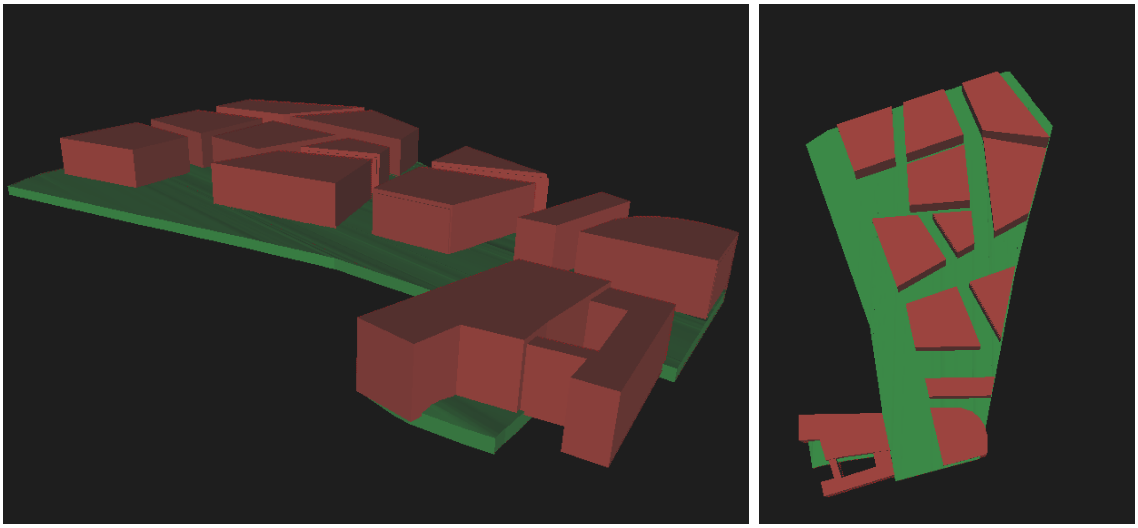
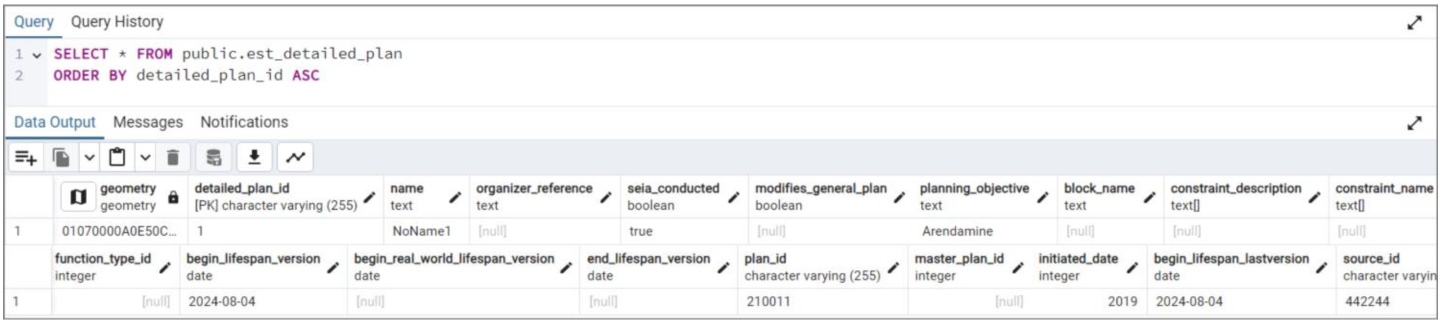


Figure 69. Final Geometry Product for est_detailed_plan table.

After the plan geometry is formed, the **DateTimeStamper** is used to set the date and time of the plan upload to the current time. This timestamp is added as an attribute, representing the *begin_lifespan_version* in the plan tables, indicating when the plan was uploaded. Additionally, the FME script creates the *begin_lifespan_last_version* attribute, which also reflects the current date and time by default. This attribute is recognized by the database through the triggers and functions mentioned in Section 4.2, will represent the latest version uploaded and exist in the plan table. Finally, after renaming attributes, cleaning unnecessary data, and merging with the geometry to represent a single record, the data is imported into the *est_detailed_plan* table in the database. Figure 70 shows an example representation in the database for the Põhi dataset. For better legibility, the continuation of the first row is pasted below, ensuring the complete information of the single entry is clearly visible and understandable. It should be noted that most of the null fields in the database come from the lack of the necessary data in the pilot dataset.



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

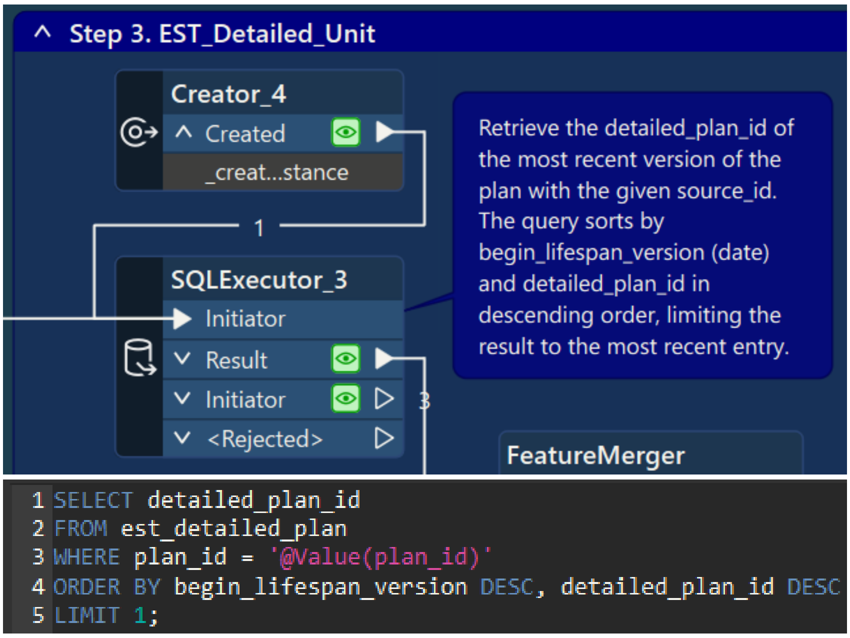
	geometry geometry	detailed_plan_id [PK] character varying (255)	name text	organizer_reference text	seia_conducted boolean	modifies_general_plan boolean	planning_objective text	block_name text	constraint_description text[]	constraint_name text[]
1	01070000A0E50C...	1	NoName1	[null]	true	[null]	Arendamine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

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

Figure 70. Example entry to the est_detailed_plan table using the pilot data, Põhi.

After importing the necessary information into *est_detailed_plan*, the script proceeds with the data preparation and transformations required for the *est_detailed_unit* table. These steps include adding additional geometries that were initially excluded, such as trees, incorporating other metadata like maximum height constraint information, and computing spatial analyses such as area and volume.

Before the data preparations and transformations, an SQL query is executed in FME (seen in Figure 71) to ensure that the later imported data is recognized as the units of the same plan. This query retrieves the most recently imported Detailed Plan's ID from the *est_detailed_plan* table. This allows the corresponding units to be connected to the specific plan imported into the *est_detailed_plan* table with a foreign key. This is why the FME script works as a whole, and the source, plan, and its units should be uploaded in one go and not separately. This constraint ensures data integrity in general but can be seen as a drawback that might be optimized in future developments to allow more flexibility.



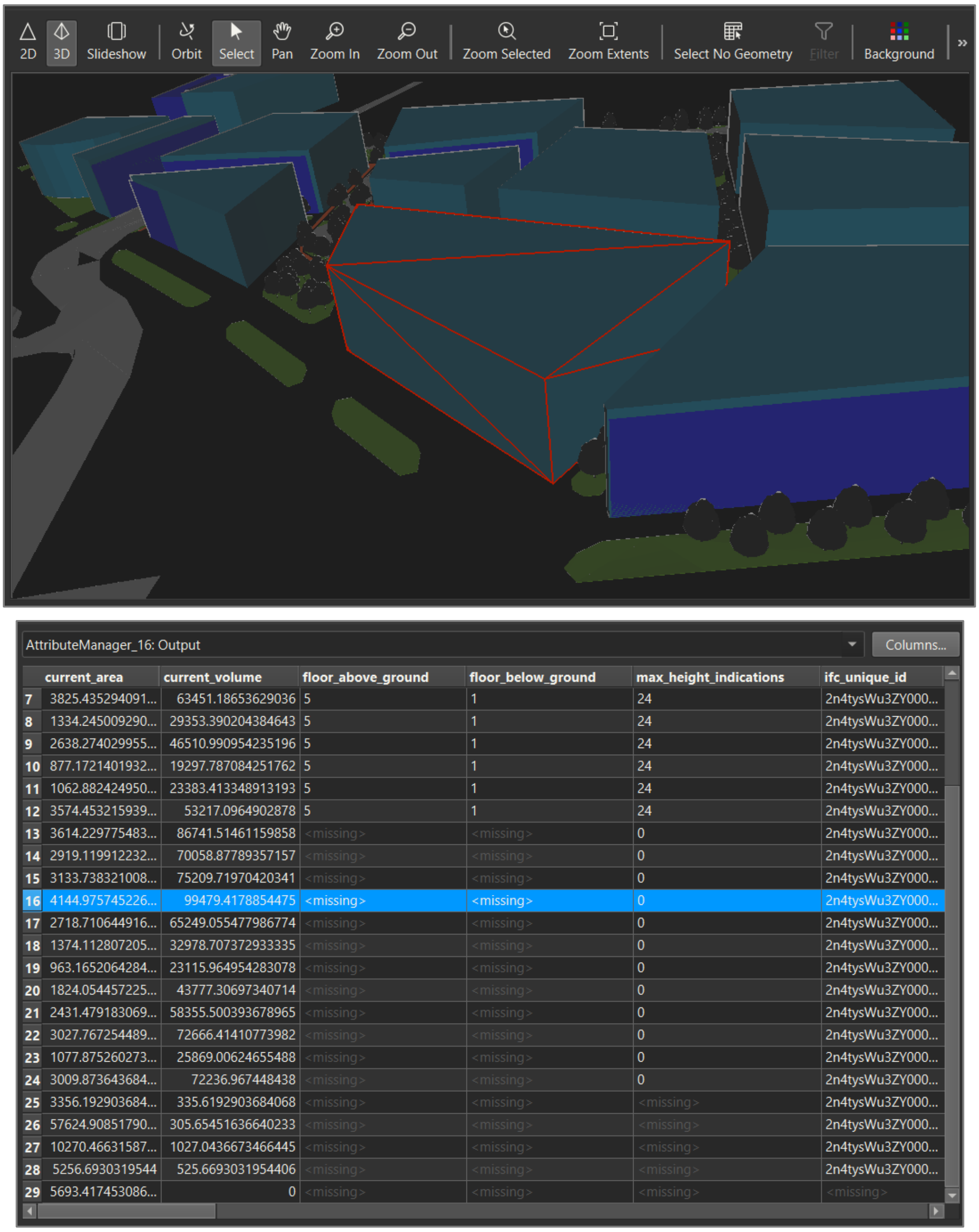
Retrieve the detailed_plan_id of the most recent version of the plan with the given source_id. The query sorts by begin_lifespan_version (date) and detailed_plan_id in descending order, limiting the result to the most recent entry.

```sql
SELECT detailed_plan_id
FROM est_detailed_plan
WHERE plan_id = '@Value(plan_id)'
ORDER BY begin_lifespan_version DESC, detailed_plan_id DESC
LIMIT 1;
```

Figure 71. SQL query executed in FME to get the ID of the previously imported plan.

Following these preparations, the script ensures that each unit's spatial and metadata are accurately represented and stored in the database. As previously mentioned, unit geometries should represent each IFC element in the dataset separately as presented.

Figure 72 shows an example of how different units are stored with their own metadata. The building geometry highlighted in red represents the sixteenth unit, which is highlighted in blue, in the table below.



AttributeManager_16: Output

	current_area	current_volume	floor_above_ground	floor_below_ground	max_height_indications	ifc_unique_id
7	3825.435294091...	63451.18653629036	5	1	24	2n4tysWu3ZY000...
8	1334.245009290...	29353.390204384643	5	1	24	2n4tysWu3ZY000...
9	2638.274029955...	46510.990954235196	5	1	24	2n4tysWu3ZY000...
10	877.1721401932...	19297.787084251762	5	1	24	2n4tysWu3ZY000...
11	1062.882424950...	23383.413348913193	5	1	24	2n4tysWu3ZY000...
12	3574.453215939...	53217.0964902878	5	1	24	2n4tysWu3ZY000...
13	3614.229775483...	86741.51461159858	<missing>	<missing>	0	2n4tysWu3ZY000...
14	2919.119912232...	70058.87789357157	<missing>	<missing>	0	2n4tysWu3ZY000...
15	3133.738321008...	75209.71970420341	<missing>	<missing>	0	2n4tysWu3ZY000...
16	4144.975745226...	99479.4178854475	<missing>	<missing>	0	2n4tysWu3ZY000...
17	2718.710644916...	65249.055477986774	<missing>	<missing>	0	2n4tysWu3ZY000...
18	1374.112807205...	32978.707372933335	<missing>	<missing>	0	2n4tysWu3ZY000...
19	963.1652064284...	23115.964954283078	<missing>	<missing>	0	2n4tysWu3ZY000...
20	1824.054457225...	43777.30697340714	<missing>	<missing>	0	2n4tysWu3ZY000...
21	2431.479183069...	58355.500393678965	<missing>	<missing>	0	2n4tysWu3ZY000...
22	3027.767254489...	72666.41410773982	<missing>	<missing>	0	2n4tysWu3ZY000...
23	1077.875260273...	25869.00624655488	<missing>	<missing>	0	2n4tysWu3ZY000...
24	3009.873643684...	72236.967448438	<missing>	<missing>	0	2n4tysWu3ZY000...
25	3356.192903684...	335.6192903684068	<missing>	<missing>	<missing>	2n4tysWu3ZY000...
26	57624.90851790...	305.65451636640233	<missing>	<missing>	<missing>	2n4tysWu3ZY000...
27	10270.46631587...	1027.0436673466445	<missing>	<missing>	<missing>	2n4tysWu3ZY000...
28	5256.6930319544	525.6693031954406	<missing>	<missing>	<missing>	2n4tysWu3ZY000...
29	5693.417453086...	0	<missing>	<missing>	<missing>	<missing>

Figure 72. Example unit geometries stored as individual records with specific metadata.

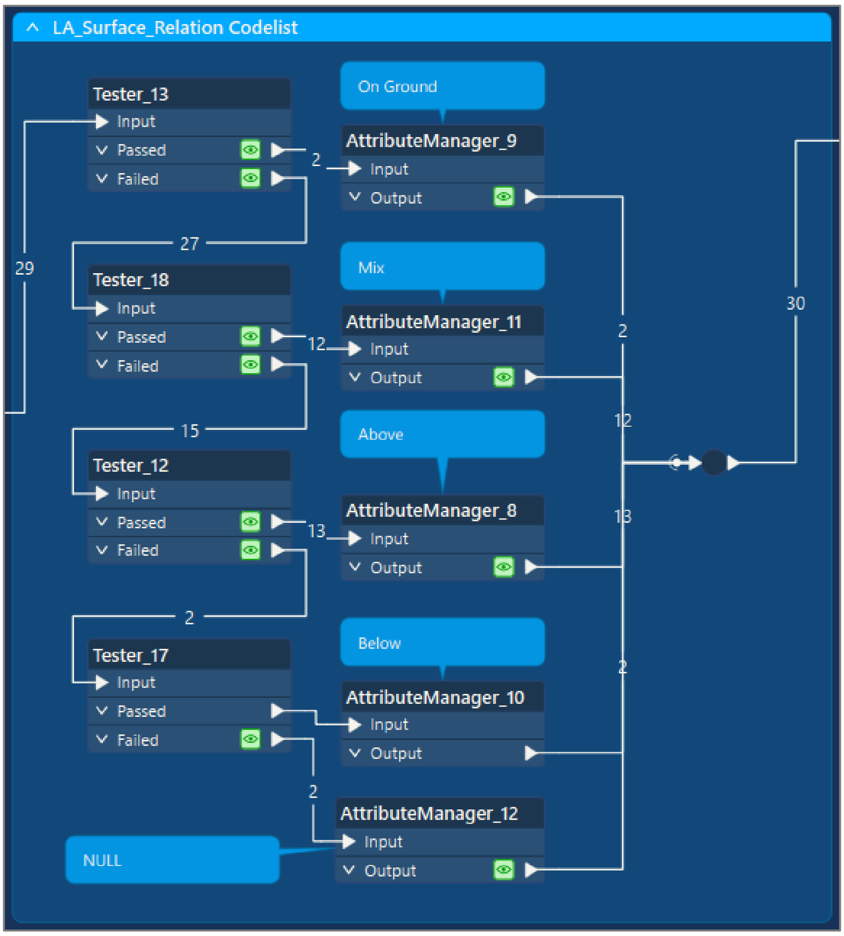
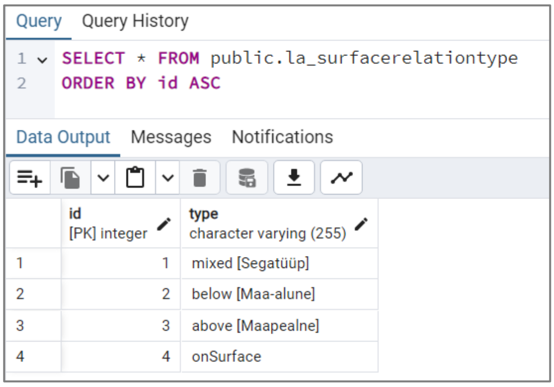


Figure 73. Example categorization mechanism for the input data with regards to the la_surface_relation codelist values.

Moreover, testing mechanisms were implemented to categorize codelist values. An example of this is shown in Figure 73, which illustrates a mechanism for categorizing the incoming data according to the *la_surface_relation* codelist table, as seen in Figure 74. This was tested with flexible methods such as allowing vegetation elements to be automatically recognized and labeled as "on surface" or comparing the depth below a building with the floor above and below the building, among other criteria. For instance, if an element is below ground, it is assigned a value of "2" according to Figure 74. This value is recognized by the codelist table as an ID and mapped as "below." This ensures that the incoming data is appropriately matched to the predefined codelist values set by the country profile and the database.



```
SELECT * FROM public.la_surfacerelationtype
ORDER BY id ASC
```

	id [PK] integer	type character varying (255)
1	1	mixed [Segatüüp]
2	2	below [Maa-alune]
3	3	above [Maapealne]
4	4	onSurface

Figure 74. la_surface_relation codelist values in the database.

Finally, after all the extraction, transformation, and manipulation of the data, the resulting unit records are imported into the *est_detailed_unit* table in the database. Figure 75 and Figure 76 show the imported geometries and an example of the unit table in the database for the pilot dataset, Põhi, respectively. Additionally, the FME script was also uploaded to the thesis GitHub repository[23] as "*detailed_plan_import.fmw*."

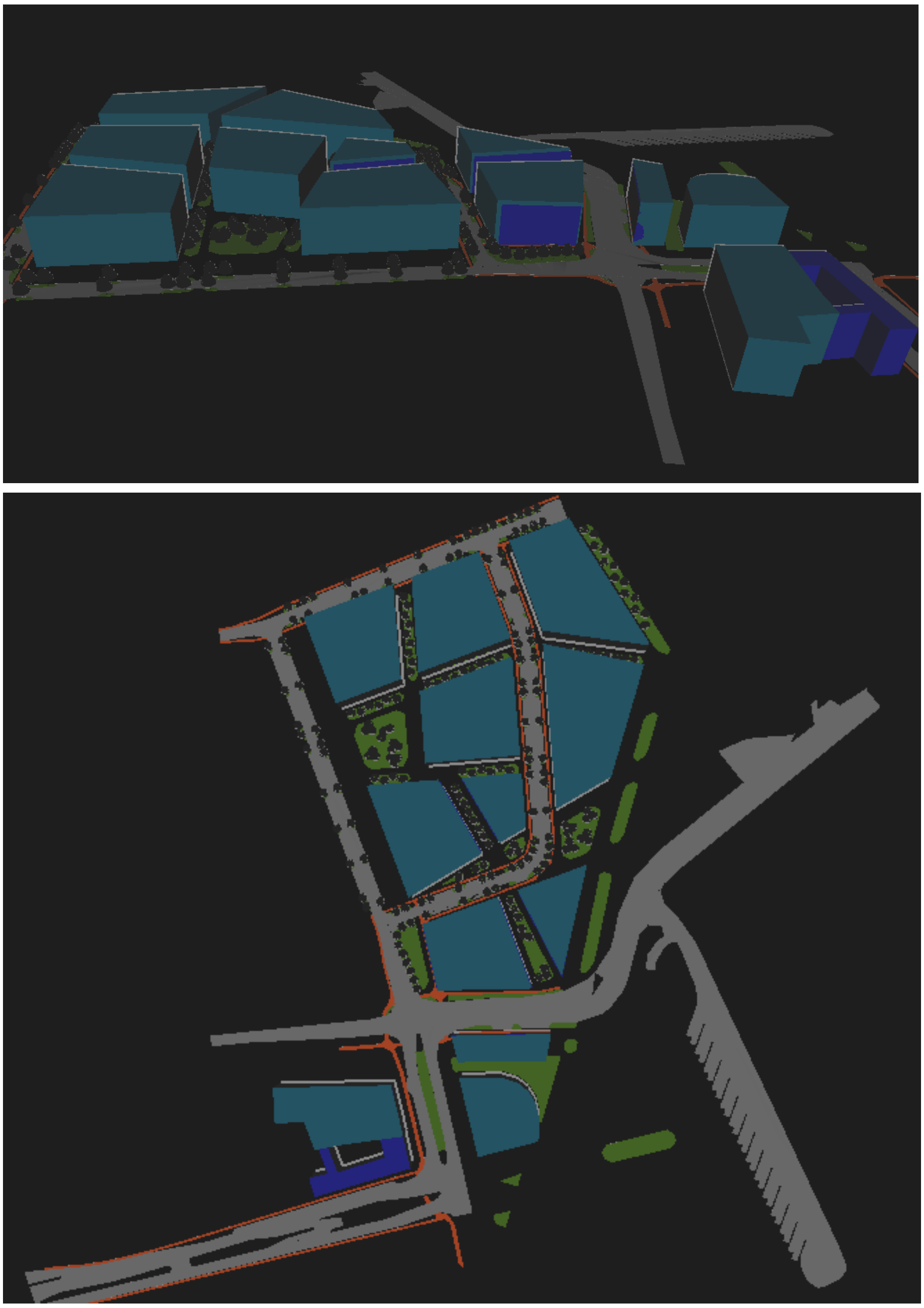
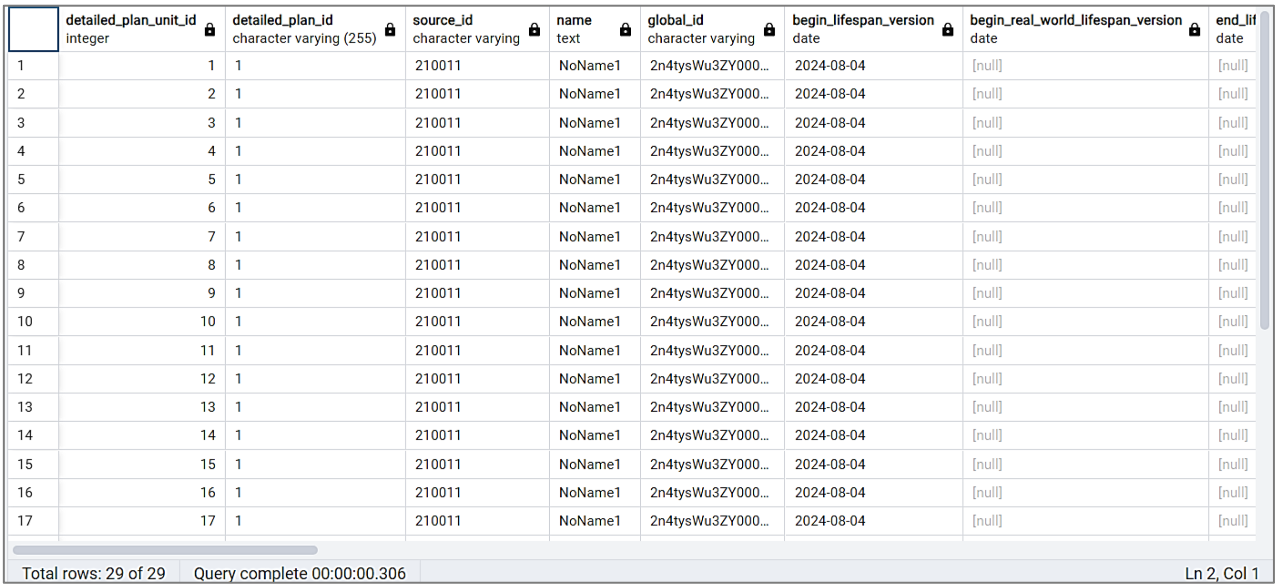


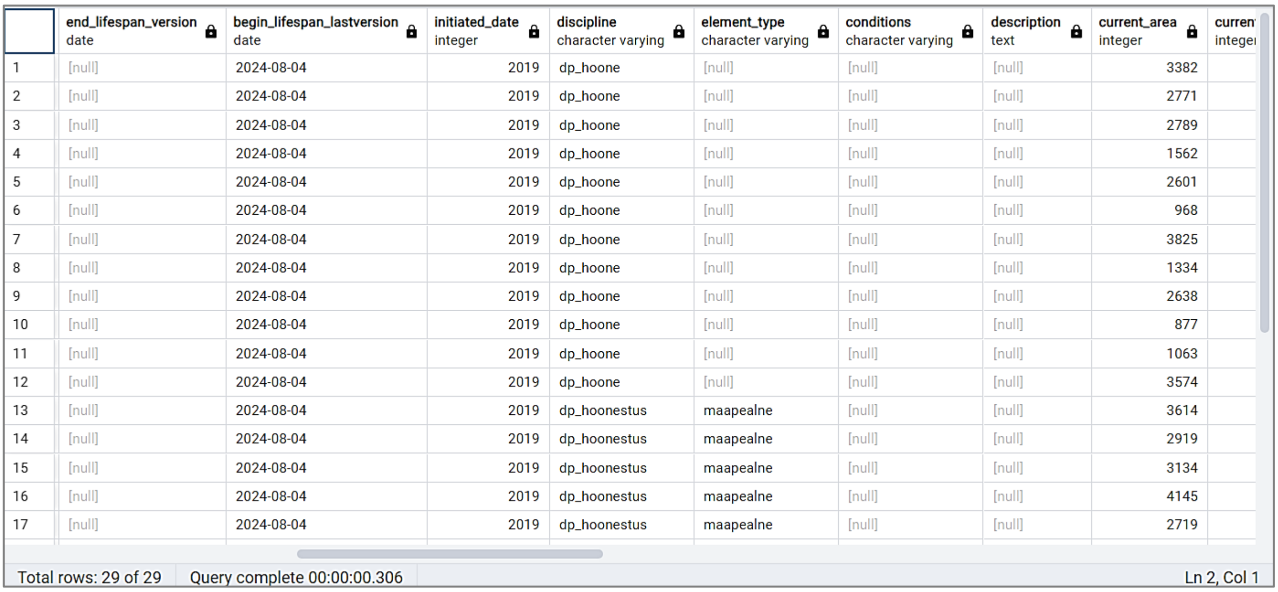
Figure 75. Final Geometry Product for est_detailed_unit table.

---

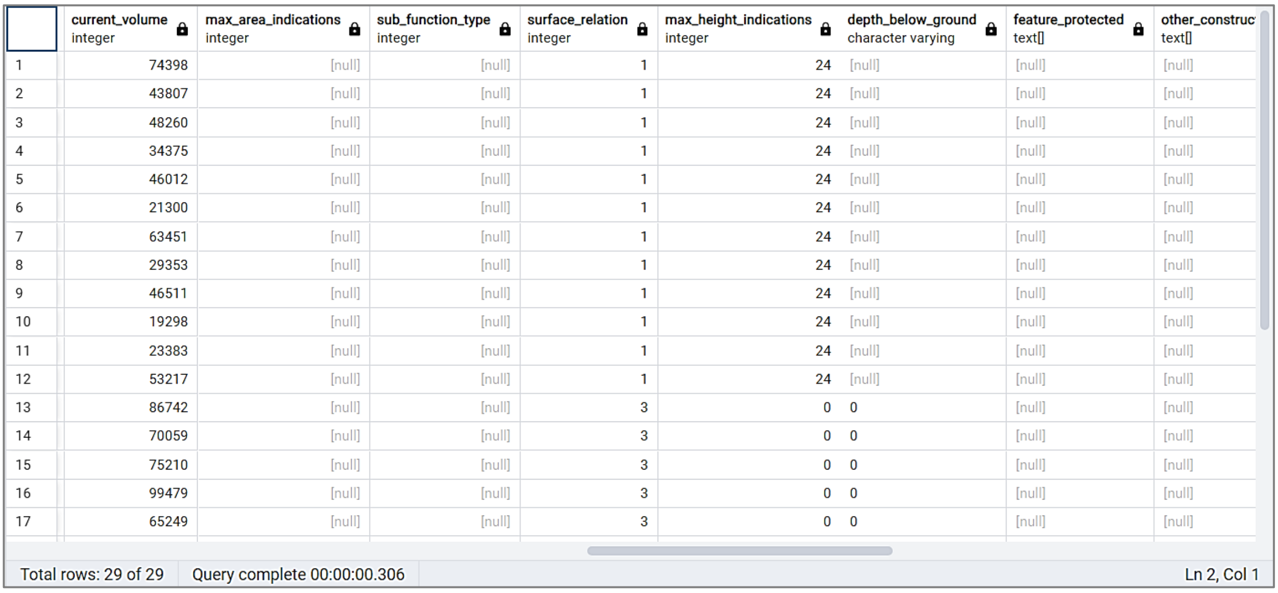
[23] https://github.com/simaybtm/LADM-4-Estonia



	detailed_plan_unit_id integer	detailed_plan_id character varying (255)	source_id character varying	name text	global_id character varying	begin_lifespan_version date	begin_real_world_lifespan_version date	end_lif date
1	1	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
2	2	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
3	3	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
4	4	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
5	5	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
6	6	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
7	7	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
8	8	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
9	9	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
10	10	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
11	11	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
12	12	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
13	13	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
14	14	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
15	15	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
16	16	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]
17	17	1	210011	NoName1	2n4tysWu3ZY000...	2024-08-04	[null]	[null]



	end_lifespan_version date	begin_lifespan_lastversion date	initiated_date integer	discipline character varying	element_type character varying	conditions character varying	description text	current_area integer	curren integer
1	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	3382	
2	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	2771	
3	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	2789	
4	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	1562	
5	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	2601	
6	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	968	
7	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	3825	
8	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	1334	
9	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	2638	
10	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	877	
11	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	1063	
12	[null]	2024-08-04	2019	dp_hoone	[null]	[null]	[null]	3574	
13	[null]	2024-08-04	2019	dp_hoonestus	maapealne	[null]	[null]	3614	
14	[null]	2024-08-04	2019	dp_hoonestus	maapealne	[null]	[null]	2919	
15	[null]	2024-08-04	2019	dp_hoonestus	maapealne	[null]	[null]	3134	
16	[null]	2024-08-04	2019	dp_hoonestus	maapealne	[null]	[null]	4145	
17	[null]	2024-08-04	2019	dp_hoonestus	maapealne	[null]	[null]	2719	



	current_volume integer	max_area_indications integer	sub_function_type integer	surface_relation integer	max_height_indications integer	depth_below_ground character varying	feature_protected text[]	other_construc text[]
1	74398	[null]	[null]	1	24	[null]	[null]	[null]
2	43807	[null]	[null]	1	24	[null]	[null]	[null]
3	48260	[null]	[null]	1	24	[null]	[null]	[null]
4	34375	[null]	[null]	1	24	[null]	[null]	[null]
5	46012	[null]	[null]	1	24	[null]	[null]	[null]
6	21300	[null]	[null]	1	24	[null]	[null]	[null]
7	63451	[null]	[null]	1	24	[null]	[null]	[null]
8	29353	[null]	[null]	1	24	[null]	[null]	[null]
9	46511	[null]	[null]	1	24	[null]	[null]	[null]
10	19298	[null]	[null]	1	24	[null]	[null]	[null]
11	23383	[null]	[null]	1	24	[null]	[null]	[null]
12	53217	[null]	[null]	1	24	[null]	[null]	[null]
13	86742	[null]	[null]	3	0	0	[null]	[null]
14	70059	[null]	[null]	3	0	0	[null]	[null]
15	75210	[null]	[null]	3	0	0	[null]	[null]
16	99479	[null]	[null]	3	0	0	[null]	[null]
17	65249	[null]	[null]	3	0	0	[null]	[null]

Figure 76. Snippets of the unit records in the est_detailed_unit table.

To test the imported results, another FME script was created to read the recently imported data from the database. Specifically, for the units in the *est_detailed_unit* table, the only requirement for this process is to input the *detailed_plan_id* into the reader so it only reads the plan units of the specific plan requested. Figure 77 shows an example of this. For versioning, this query can be made more specific to isolate the requested plan and the version available in the database.

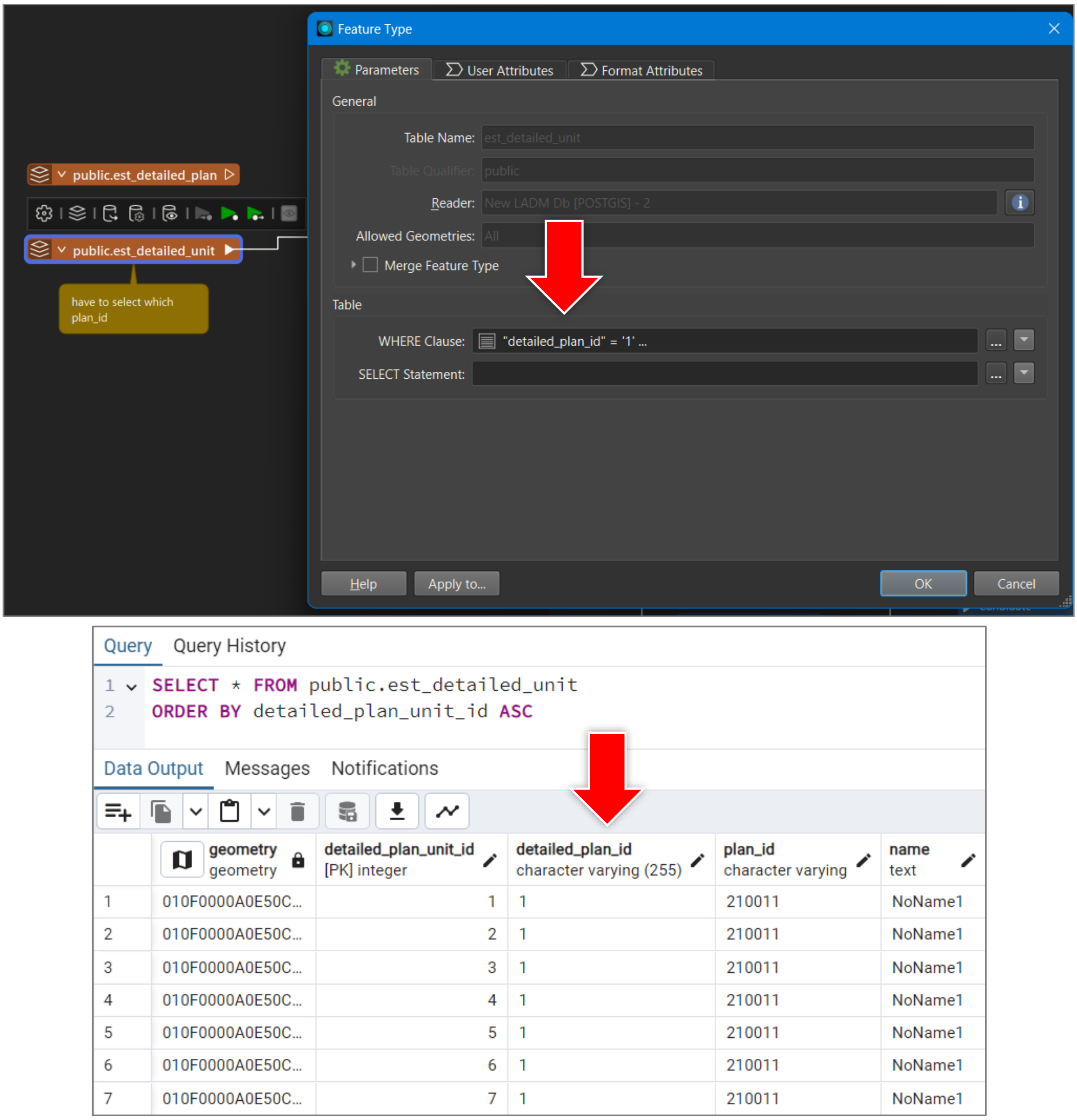


Table Name: est_detailed_unit

Table Qualifier: public

Reader: New LADM Db [POSTGIS] - 2

Allowed Geometries: All

☐ Merge Feature Type

WHERE Clause: "detailed_plan_id" = '1' ...

SELECT Statement:

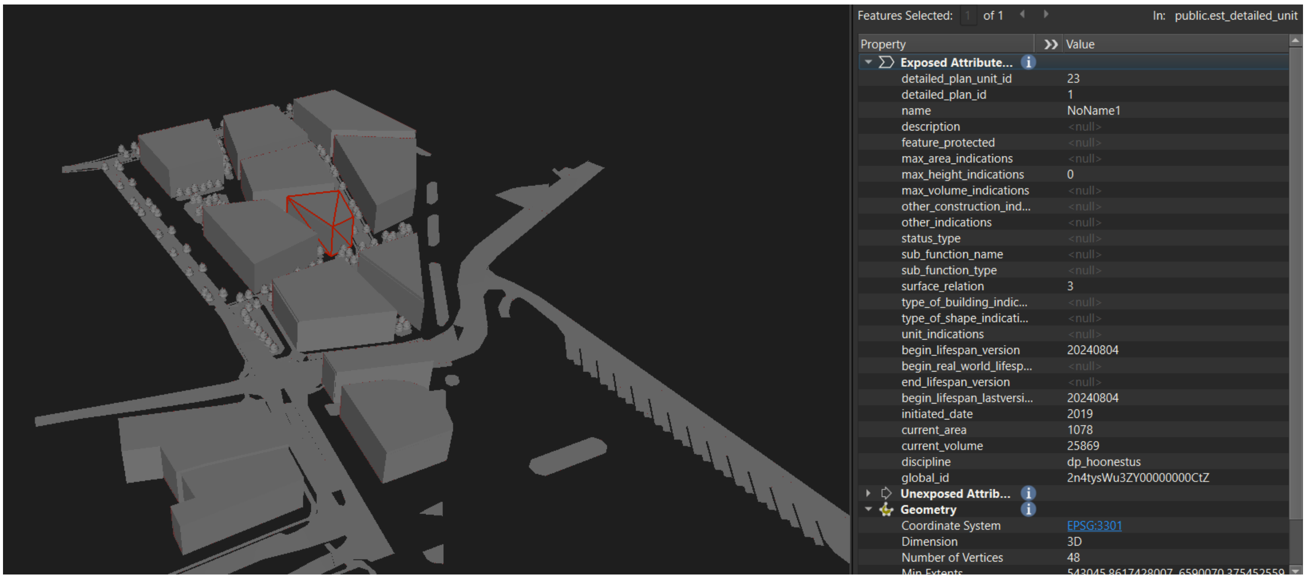
```
SELECT * FROM public.est_detailed_unit
ORDER BY detailed_plan_unit_id ASC
```

	geometry geometry	detailed_plan_unit_id [PK] integer	detailed_plan_id character varying (255)	plan_id character varying	name text
1	010F0000A0E50C...	1	1	210011	NoName1
2	010F0000A0E50C...	2	1	210011	NoName1
3	010F0000A0E50C...	3	1	210011	NoName1
4	010F0000A0E50C...	4	1	210011	NoName1
5	010F0000A0E50C...	5	1	210011	NoName1
6	010F0000A0E50C...	6	1	210011	NoName1
7	010F0000A0E50C...	7	1	210011	NoName1

Figure 77. Reading the unit data from the database.

Figure 78 shows the read geometries and metadata from the *est_detailed_unit* table with "*detailed_plan_id = 1*". Since there were no other versions of the same units, it was unnecessary to include the version information in the query as well. As seen from the figure, the geometries accurately reflect the original pilot dataset, and the metadata is stored correctly without any errors.

The only shortcoming encountered was PostGIS's inability to store geometry appearance/style, such as the color of the elements. This limitation stems from a technical constraint of PostGIS. While there wasn't a solution to overcome this limitation during the research, future optimization efforts could explore alternative options. For example, using a database that supports styling features like MongoDB with GeoJSON for rendering styled geometries could be considered. Additionally, although it would make the process more complex, developing custom scripts to store and apply styles separately from the geometry data could also be a potential solution.



Features Selected: 1 of 1 In: public.est_detailed_unit

Property	Value
Exposed Attribute...	
detailed_plan_unit_id	23
detailed_plan_id	1
name	NoName1
description	<null>
feature_protected	<null>
max_area_indications	<null>
max_height_indications	0
max_volume_indications	<null>
other_construction_ind...	<null>
other_indications	<null>
status_type	<null>
sub_function_name	<null>
sub_function_type	<null>
surface_relation	3
type_of_building_indic...	<null>
type_of_shape_indicati...	<null>
unit_indications	<null>
begin_lifespan_version	20240804
begin_real_world_lifesp...	<null>
end_lifespan_version	<null>
begin_lifespan_lastversi...	20240804
initiated_date	2019
current_area	1078
current_volume	25869
discipline	dp_hoonestus
global_id	2n4tysWu3ZY00000000CtZ
Unexposed Attrib...	
Geometry	
Coordinate System	EPSG:3301
Dimension	3D
Number of Vertices	48
Min Extents	543045.8617428007, 6590070.375452559

Figure 78. Read geometries and metadata from the database.

5.3. Checks within LADM Database

This section explores the application of compliance checks within the LADM framework, specifically focusing on scenarios where the LADM database can inherently execute and demonstrate the results of a compliance check using simple SQL queries. This assessment is relevant in cases where the information required for compliance checks is already available within the LADM database, without the need for external data or additional input. The goal of this exploration is to understand the potential and limitations of using the LADM database for executing compliance checks, particularly in identifying the scope of checks that can be automated and performed through simple SQL queries alone.

As an example, Table 3, Check 2: “*Greenery demands (%)*” represents a compliance check that can be executed directly within the LADM database using SQL queries. This specific check assesses whether the greenery area within a Detailed Plan meets the minimum percentage required by the Master Plan. The compliance check can be performed by querying the Detailed Plan data and comparing the greenery ratio against the required standard coming from the Master Plan data.

To perform this compliance check, the *EST_Detailed_Unit* class can be used, which contains data on various spatial units within the Detailed Plan, categorized by specific disciplines such as landscape areas (**discipline** = *dp_haljastus*). By querying this table, the total area designated as greenery (**currentArea** for *dp_haljastus*) can be compared with the overall plot area (**discipline** = *plan_ala*), which represents the total plot area of the plan. The calculated percentage of greenery is then compared with the requirements specified in the *EST_Master_Plan* class, where **strategicPrincipleAreas** can indicate constraints such as “*min 30% greenery for an area of 5000 square meters*.” Figure 79 illustrates the classes and attributes required to perform the check.

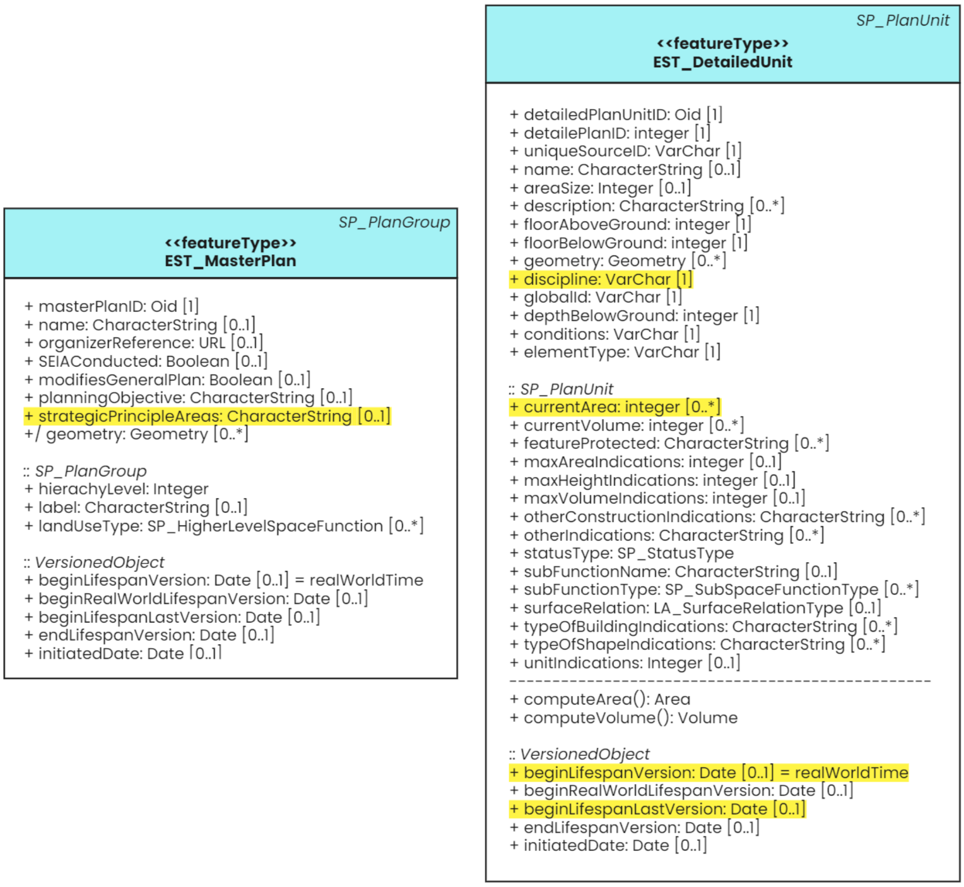
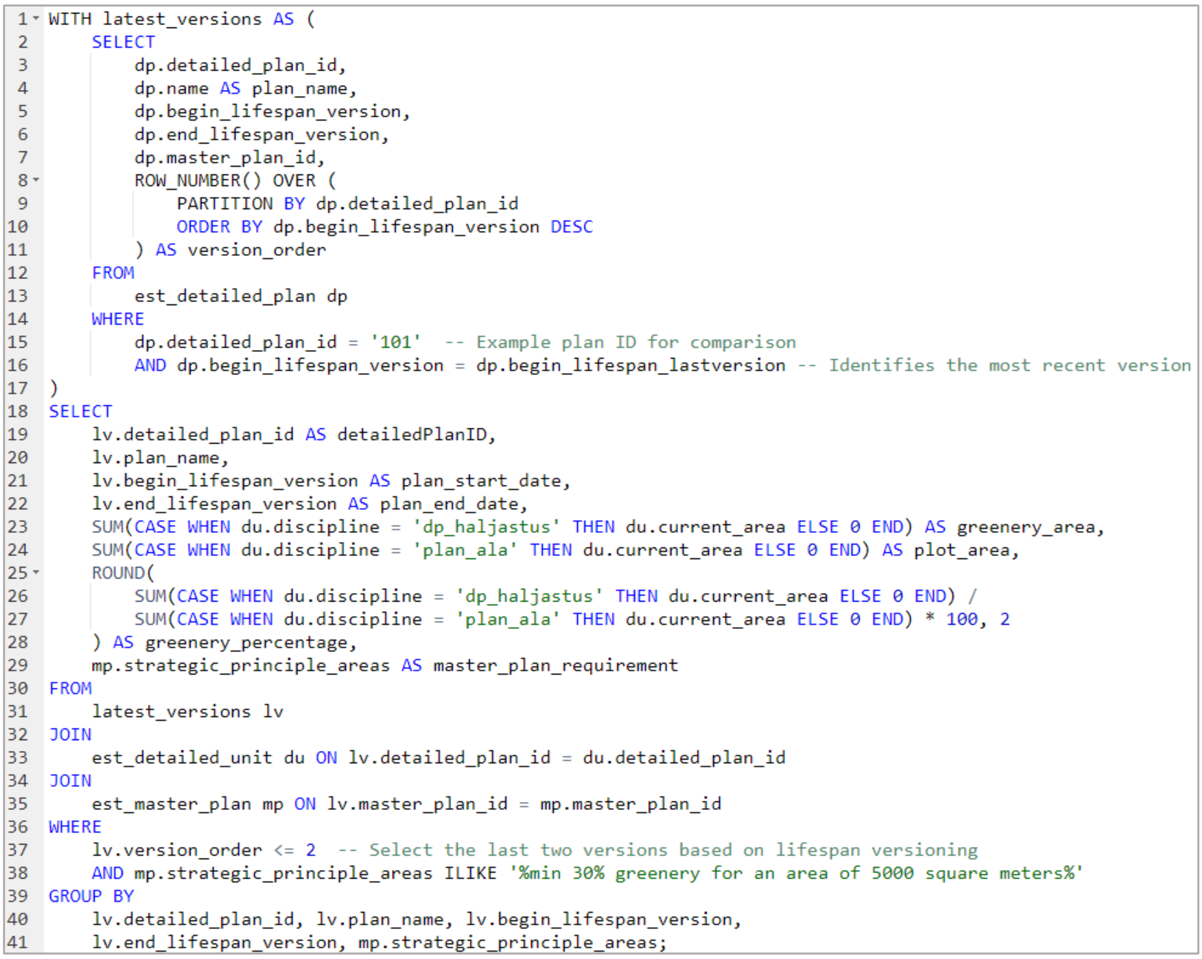


Figure 79. Classes and attributes needed (highlighted in yellow) to execute the greenery compliance check in the database.

The compliance check process can be automated within the LADM database using a SQL query. This query calculates the percentage of the greenery area within the Detailed Plan, checks whether it meets the minimum threshold set by the Master Plan and compares different versions of the Detailed Plan to observe any changes in compliance over time. Below is an example SQL query (Figure 80) that demonstrates how this check can be executed:



```
WITH latest_versions AS (
    SELECT
        dp.detailed_plan_id,
        dp.name AS plan_name,
        dp.begin_lifespan_version,
        dp.end_lifespan_version,
        dp.master_plan_id,
        ROW_NUMBER() OVER (
            PARTITION BY dp.detailed_plan_id
            ORDER BY dp.begin_lifespan_version DESC
        ) AS version_order
    FROM
        est_detailed_plan dp
    WHERE
        dp.detailed_plan_id = '101'  -- Example plan ID for comparison
        AND dp.begin_lifespan_version = dp.begin_lifespan_lastversion -- Identifies the most recent version
)
SELECT
    lv.detailed_plan_id AS detailedPlanID,
    lv.plan_name,
    lv.begin_lifespan_version AS plan_start_date,
    lv.end_lifespan_version AS plan_end_date,
    SUM(CASE WHEN du.discipline = 'dp_haljastus' THEN du.current_area ELSE 0 END) AS greenery_area,
    SUM(CASE WHEN du.discipline = 'plan_ala' THEN du.current_area ELSE 0 END) AS plot_area,
    ROUND(
        SUM(CASE WHEN du.discipline = 'dp_haljastus' THEN du.current_area ELSE 0 END) /
        SUM(CASE WHEN du.discipline = 'plan_ala' THEN du.current_area ELSE 0 END) * 100, 2
    ) AS greenery_percentage,
    mp.strategic_principle_areas AS master_plan_requirement
FROM
    latest_versions lv
JOIN
    est_detailed_unit du ON lv.detailed_plan_id = du.detailed_plan_id
JOIN
    est_master_plan mp ON lv.master_plan_id = mp.master_plan_id
WHERE
    lv.version_order <= 2  -- Select the last two versions based on lifespan versioning
    AND mp.strategic_principle_areas ILIKE '%min 30% greenery for an area of 5000 square meters%'
GROUP BY
    lv.detailed_plan_id, lv.plan_name, lv.begin_lifespan_version,
    lv.end_lifespan_version, mp.strategic_principle_areas;
```

Figure 80. SQL query to be performed for the greenery compliance check.

To give an example scenario, a hypothetical plan titled “*Central Park*” will be considered to validate the compliance check mechanism within the LADM database. The plan, identified by **detailed_plan_id** = *'101'* represents the Detailed Plan *Central Park* in the database. The Master Plan, which governs the broader development objectives, requires a minimum requirement of 30% greenery within a specified area in the plan for sustainable urban development.

In this scenario, the Detailed Plan *Central Park* has been developed in multiple phases, and different versions of the plan have been recorded in the LADM database. For this assessment, the last two recorded versions of the Detailed Plan *Central Park* in the database are compared using the query. The query identifies these versions by selecting the latest version by using the condition **beginLifespanLastVersion** =

beginLifespanVersion, which implies that it is the latest version recorded in the database. The version right before the last version is identified by ordering the records based on the **beginLifespanVersion** dates. By comparing the two most recent versions of the plan, planners can evaluate how changes between these versions have impacted the result of the compliance check regarding the greenery requirements set by the Master Plan.

The SQL query retrieves the relevant data, calculates the percentage of greenery within each version by comparing the area of the landscape layer to the area of the plan plot, and compares these values against the Master Plan's specified requirements. The results provide insights into whether the latest adjustments to the plan continue to meet regulatory standards or if there have been deviations that require further attention.

Table 6. Example outcome of the greenery compliance check.

Detailed Plan ID	Plan Name	Plan Start Date	Plan End Date	Greenery Area	Plot Area	Greenery Percentage	Master Plan Requirement
101	Central Park	2024-01-01	2024-03-31	1500	5000	30.00	*min 30% greenery for an area of 5000 square meters*
101	Central Park	2024-04-01	2024-06-30	1400	5000	28.00	*min 30% greenery for an area of 5000 square meter*

The results displayed in Table 6 illustrate the compliance status of the last two versions of the Detailed Plan Central Park. The first version, valid from January 1, 2024, to March 31, 2024, meets the required standard with a 30% greenery ratio, aligning well with the Master Plan's requirement of having a minimum of 30% greenery in the specified area. However, the latest version, valid from April 1, 2024, to June 30, 2024, shows a reduction in the greenery area to 1400 square meters, which represents only 28% of the total plot area. This percentage falls below the minimum requirement set by the Master Plan, indicating the compliance check is not successful.

This scenario demonstrates the effectiveness of the LADM database in facilitating some compliance checks directly within the database. However, this approach is limited by three main factors. The first limitation is the visualization aspect. Since the checks are performed within the database, there are no visual outputs to support the compliance check results, unlike prototypes supported by web services such as WFS and WMS, which can provide graphical representations. The second limitation is that the information required for the checks must already be available in the database; thus, the use of APIs to access additional external sources cannot be utilized within this approach. Finally, while not necessarily a limitation, it is important to consider that this approach relies on SQL queries to execute compliance checks. The extent to which SQL can fully support the complexities of compliance checks is not fully explored.

As another example, Table 3, Check 6: "*Protected Area Requirements*", which assesses whether a Detailed Plan overlaps with protected areas such as heritage sites or flood zone was also investigated. This check can also be executed directly within the LADM database using SQL queries combined with spatial analysis provided by PostGIS. The main goal is to ensure that the geometries of the Detailed Plan do not conflict with protected areas defined in the Master Plan.

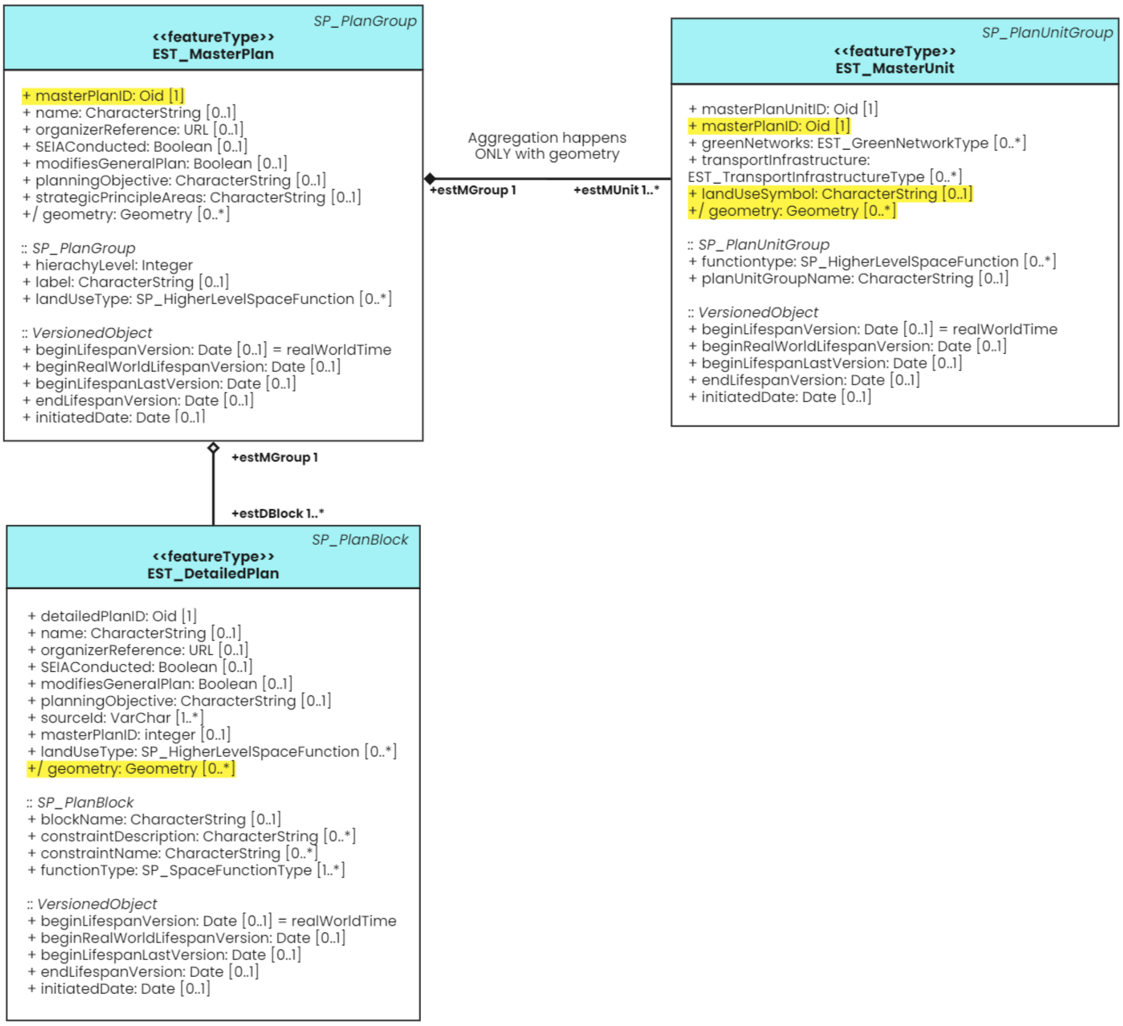
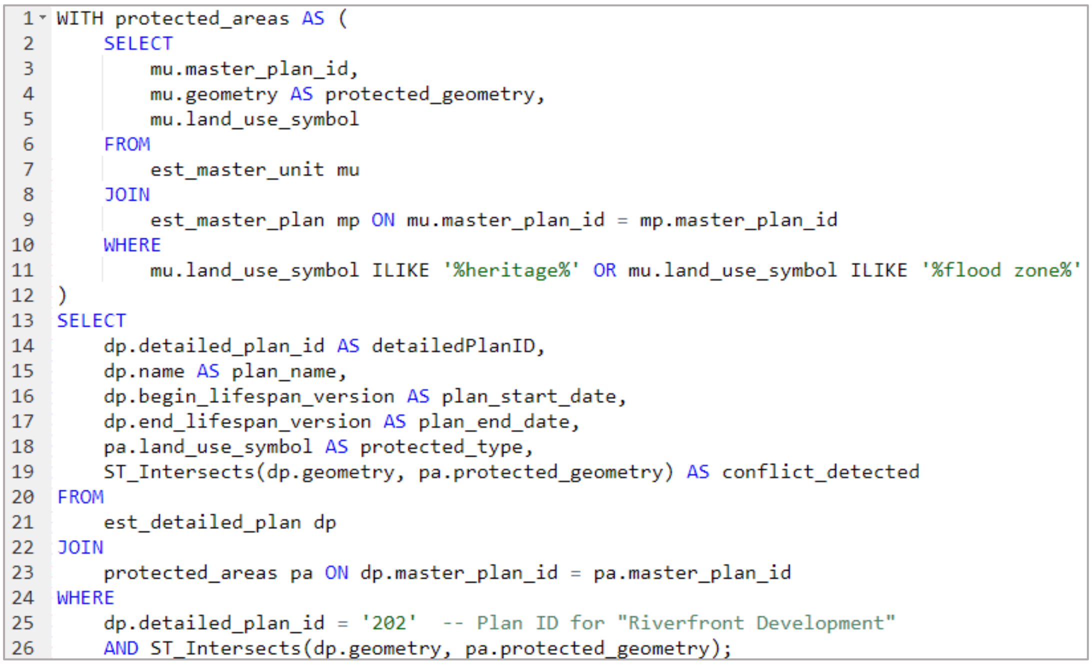


Figure 81. Classes and attributes needed (highlighted in yellow) to execute the protected areas check in the database.

To perform this compliance check, the *EST_Master_Unit* class can be queried to identify units associated with the Master Plan that are designated as protected areas, based on the **landUseSymbol** attribute. This attribute can indicate specific types of protection, such as "Heritage Site" or "Flood Zone." Once the protected areas are identified, the geometry of the Detailed Plan can be retrieved from the *EST_Detailed_Plan* class, which contains the plan's plot geometry. The spatial relationship between the Detailed Plan geometry and the protected areas is then analyzed using PostGIS functions to detect any overlaps. Figure 81 illustrates the classes and attributes required to perform the check.

The compliance check can be automated using a SQL query, utilized with PostGIS functions, to compare the geometries of the Detailed Plan and the protected areas. If an overlap is detected, the compliance check fails, issuing a warning or error indicating the conflict. Below (Figure 82) is an example SQL query that demonstrates how this check can be executed.



```sql
WITH protected_areas AS (
    SELECT
        mu.master_plan_id,
        mu.geometry AS protected_geometry,
        mu.land_use_symbol
    FROM
        est_master_unit mu
    JOIN
        est_master_plan mp ON mu.master_plan_id = mp.master_plan_id
    WHERE
        mu.land_use_symbol ILIKE '%heritage%' OR mu.land_use_symbol ILIKE '%flood zone%'
)
SELECT
    dp.detailed_plan_id AS detailedPlanID,
    dp.name AS plan_name,
    dp.begin_lifespan_version AS plan_start_date,
    dp.end_lifespan_version AS plan_end_date,
    pa.land_use_symbol AS protected_type,
    ST_Intersects(dp.geometry, pa.protected_geometry) AS conflict_detected
FROM
    est_detailed_plan dp
JOIN
    protected_areas pa ON dp.master_plan_id = pa.master_plan_id
WHERE
    dp.detailed_plan_id = '202'  -- Plan ID for "Riverfront Development"
    AND ST_Intersects(dp.geometry, pa.protected_geometry);
```

Figure 82. SQL query to be performed for the protected areas check.

To give an example scenario, the compliance check mechanism will be demonstrated using a hypothetical plan named "*Riverfront Development*". This plan, identified by **detailed_plan_id** = '*202*', represents a development project located near a river, where flood zones and heritage sites must be avoided. The Master Plan of the area includes protected zones for both flood risk areas and heritage sites, which cannot overlap with the plot geometry of the Detailed Plan. The query checks whether the geometry of Riverfront Development overlaps with any of these protected areas.

Table 7. Example outcome of the protected areas check.

Detailed Plan ID	Plan Name	Plan Start Date	Plan End Date	Protected Area Type	Conflict Detected
202	Riverfront Development	2024-02-01	2024-04-30	Flood Zone	TRUE
202	Riverfront Development	2024-05-01	2024-07-31	Residential Zone	FALSE

The results displayed in Table 7 show the compliance status of the Riverfront Development plan in relation to protected areas, such as flood zones and heritage sites. In the first version of the plan, valid from February 1, 2024, to April 30, 2024, a conflict is detected with a designated flood zone, as indicated by the "*TRUE*" result in the "Conflict Detected" column. This suggests that the proposed development area overlaps with a flood-prone area, which would violate the Master Plan's requirement to avoid such high-risk zones. As a result, this version of the plan fails the compliance check and would require adjustments to avoid the flood zone.

The second version of the plan, valid from May 1, 2024, to July 31, 2024, shows no detected conflicts with the identified protected areas. While this version checks for overlap with a "Residential Zone" (which may not be considered a conflict for protected zones), because the area does not overlap with any protected areas like heritage sites or flood zones allow this version to pass the compliance check.

As with the previous check, executing this compliance check in the database also has several limitations. First, it depends on the accuracy and completeness of the spatial data in the database; outdated or incomplete information on protected areas, such as flood zones or heritage sites, can lead to incorrect results. Additionally, the lack of visualization tools makes it harder for planners to interpret the results, as there are no graphical outputs like those offered by web services such as WFS or WMS.

Despite these limitations, utilizing LADM database for the compliance checks to be executed highlights the significant benefits of implementing LADM into the checking process. Whether used directly within the database or as a foundational data source accessed through external systems, the LADM framework offers considerable advantages in streamlining the overall process.

5.4. Investigation of 2D data

Despite Estonia's progress toward digitalization with the introduction of PLANK, the centralized spatial plan database, the country's spatial planning processes continue to rely heavily on 2D data formats such as CAD drawings and PDF files. PLANK (which has been mandatory for all municipalities since November 2022) represents a significant step forward in ensuring that valid spatial plans are accessible in a standardized digital format. However, the data submitted to PLANK is still predominantly 2D, which reflects the ongoing reliance on traditional design methods, where 3D models are primarily used for renders and visualizations—processed through tools like *Photoshop, Illustrator, Lumion*, and *Twinmotion*—but not as the core planning data.

This reliance on 2D data presents several limitations, especially when it comes to automating compliance checks and ensuring interoperability with future 3D-based systems. While PLANK performs automatic validation on the spatial plans it receives, its checks are confined to metadata and 2D spatial data integrity. As Estonia moves toward more advanced digital planning frameworks, including BIM and 3D spatial data, there is a growing need to address the shortcomings of the current 2D system.

This section will investigate the theoretical limitations of Estonia's existing reliance on 2D data by examining an established Detailed Plan uploaded to PLANK. Through this analysis, the study will demonstrate how the 2D format constrains automated compliance checking, interoperability, and the future integration of more advanced digital tools. The motivation for this investigation lies in the need to bridge the gap between the current 2D-centric practices and the anticipated shift toward 3D data models, such as IFC, which will be crucial for streamlining planning processes and enhancing the accuracy of spatial planning in Estonia.

The key questions in this investigation are the following:

1. Can the data from this example be effectively represented in the Estonian LADM Part 5 country profile and stored in the PostgreSQL database?
2. Does the data provide the necessary information about the plan that can be extracted and processed using the import scripts (FME) for automated compliance checks?

The goal is to assess theoretically whether these 2D data formats, combined with external CSV metadata, provide a sufficient basis for transitioning toward a more automated and structured planning process, or whether significant adjustments will be needed to fully align with the LADM framework.

An example from the "**Põllu tn 4 detailed plan**" (*Põllu tn 4 maa-ala ja lähiümbruse detailplaneering*)[24] will be used to analyze its compatibility with the country profile and assess the capability of the current data format for extraction and integration into a developed LADM database using import scripts. The Põllu tn 4 dataset is stored as 2D CAD drawings in DWG format, alongside separate metadata in CSV files, as well as some supporting documents in PDF format (including 3D renderings that are presented visually in PDF format rather than as structured 3D data).

Additionally, for better research and flow in the report, all the information presented regarding Põllu tn 4 will be translated to English after this point.

The data currently available in PLANK for Põllu tn 4 includes (as seen in Figure 83):

1. **2D CAD file** (**DK202**) - the main planning solution containing spatial data (DWG).
2. **Smart Data Table** (**DK401**) - metadata stored separately in CSV format, which describes some of the design elements such as plot details and construction attributes.

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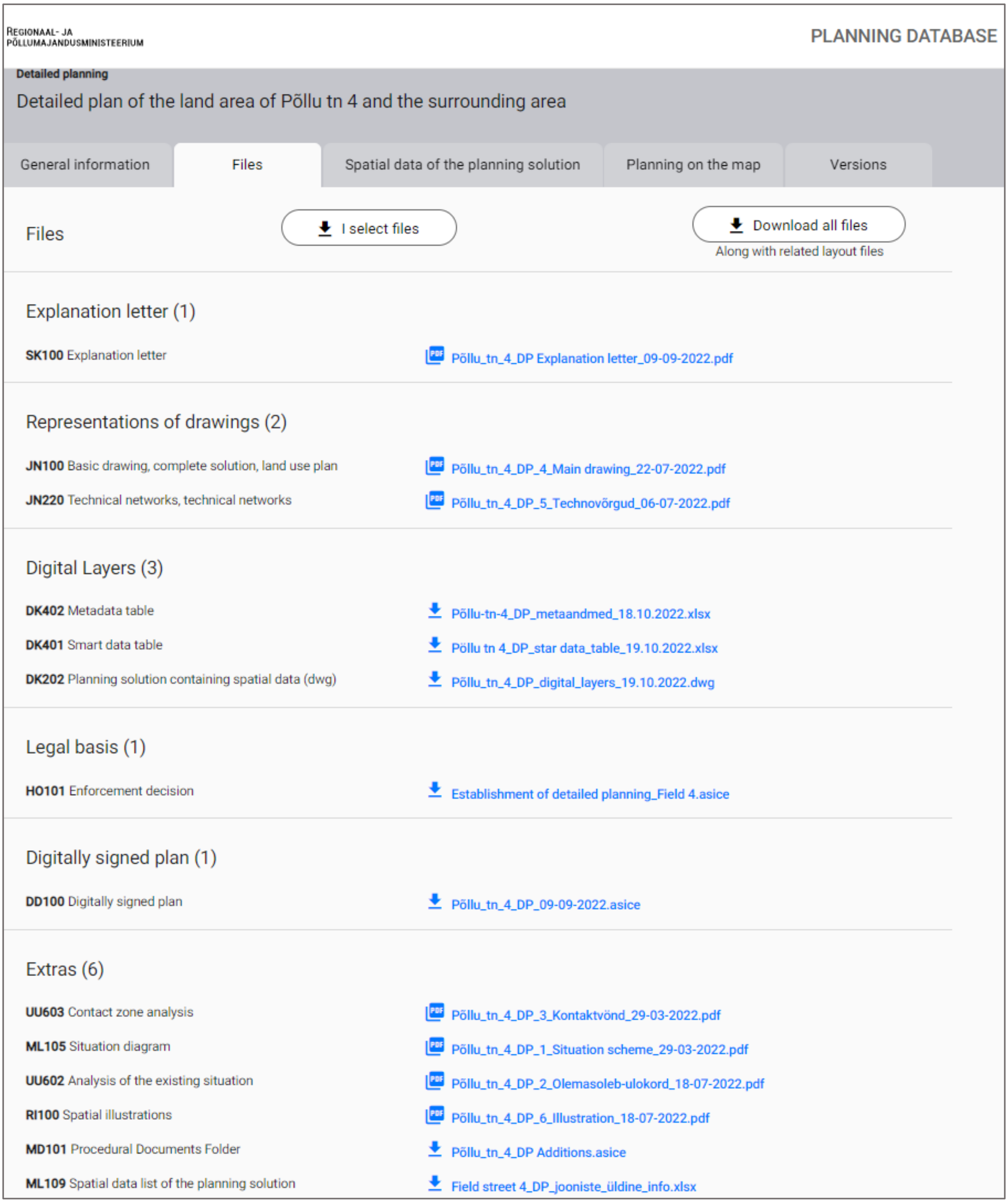
[24] https://planeeringud.ee/plank-web/#/planning/detail/30100010

3. **3D visualizations** (**PDF**) - simplified 3D renderings, primarily used for presentation purposes rather than detailed technical checks.



Detailed planning

Detailed plan of the land area of Põllu tn 4 and the surrounding area

Files

Explanation letter (1)

SK100 Explanation letter	Põllu_tn_4_DP Explanation letter_09-09-2022.pdf

Representations of drawings (2)

JN100 Basic drawing, complete solution, land use plan	Põllu_tn_4_DP_4_Main drawing_22-07-2022.pdf
JN220 Technical networks, technical networks	Põllu_tn_4_DP_5_Technovõrgud_06-07-2022.pdf

Digital Layers (3)

DK402 Metadata table	Põllu-tn-4_DP_metaandmed_18.10.2022.xlsx
DK401 Smart data table	Põllu tn 4_DP_star data_table_19.10.2022.xlsx
DK202 Planning solution containing spatial data (dwg)	Põllu_tn_4_DP_digital_layers_19.10.2022.dwg

Legal basis (1)

HO101 Enforcement decision	Establishment of detailed planning_Field 4.asice

Digitally signed plan (1)

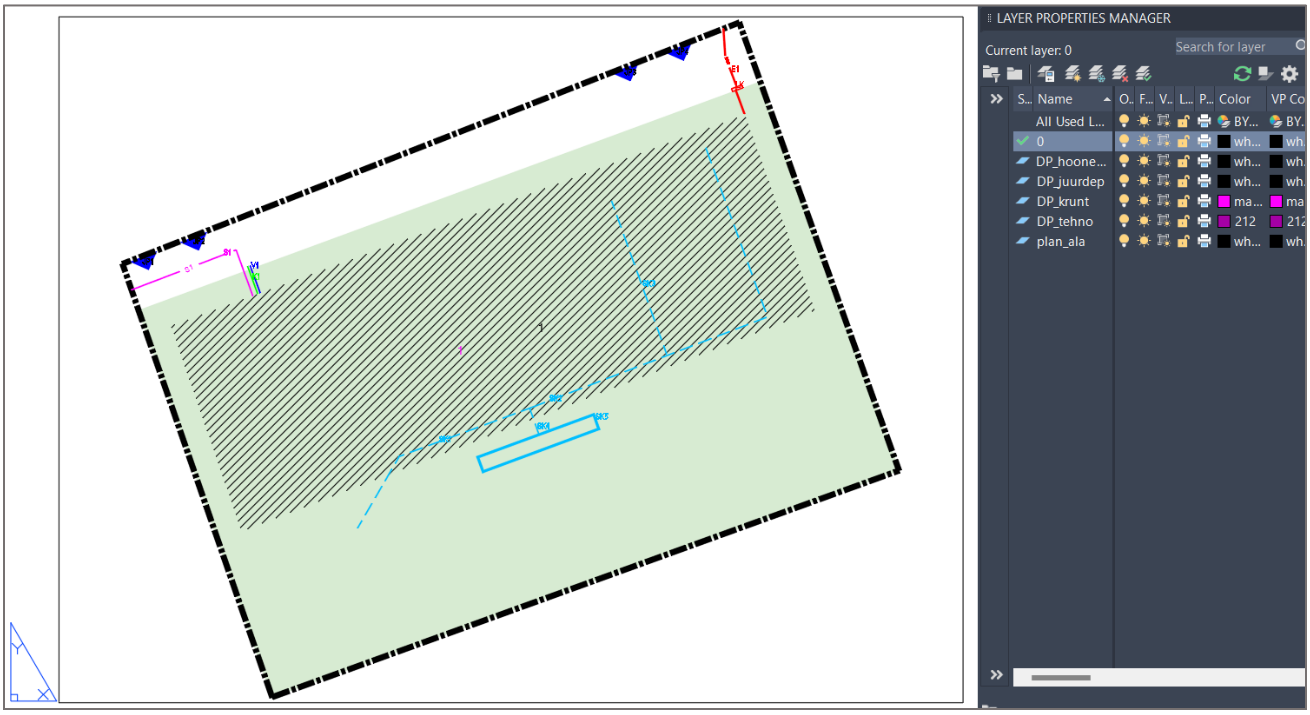
DD100 Digitally signed plan	Põllu_tn_4_DP_09-09-2022.asice

Extras (6)

UU603 Contact zone analysis	Põllu_tn_4_DP_3_Kontaktvönd_29-03-2022.pdf
ML105 Situation diagram	Põllu_tn_4_DP_1_Situation scheme_29-03-2022.pdf
UU602 Analysis of the existing situation	Põllu_tn_4_DP_2_Olemasoleb-ulokord_18-07-2022.pdf
RI100 Spatial illustrations	Põllu_tn_4_DP_6_Illustration_18-07-2022.pdf
MD101 Procedural Documents Folder	Põllu_tn_4_DP Additions.asice
ML109 Spatial data list of the planning solution	Field street 4_DP_jooniste_üldine_info.xlsx

Figure 83. Available files for Põllu tn 4 on PLANK.

Given these characteristics, the investigation will focus on the 2D data stored in this fragmented format (CAD for spatial design and CSV for metadata), assessing its theoretical limitations and its compatibility with the LADM framework. Additionally, it will examine whether significant adjustments are needed for this data to align with the automated compliance-checking workflows.



LAYER PROPERTIES MANAGER

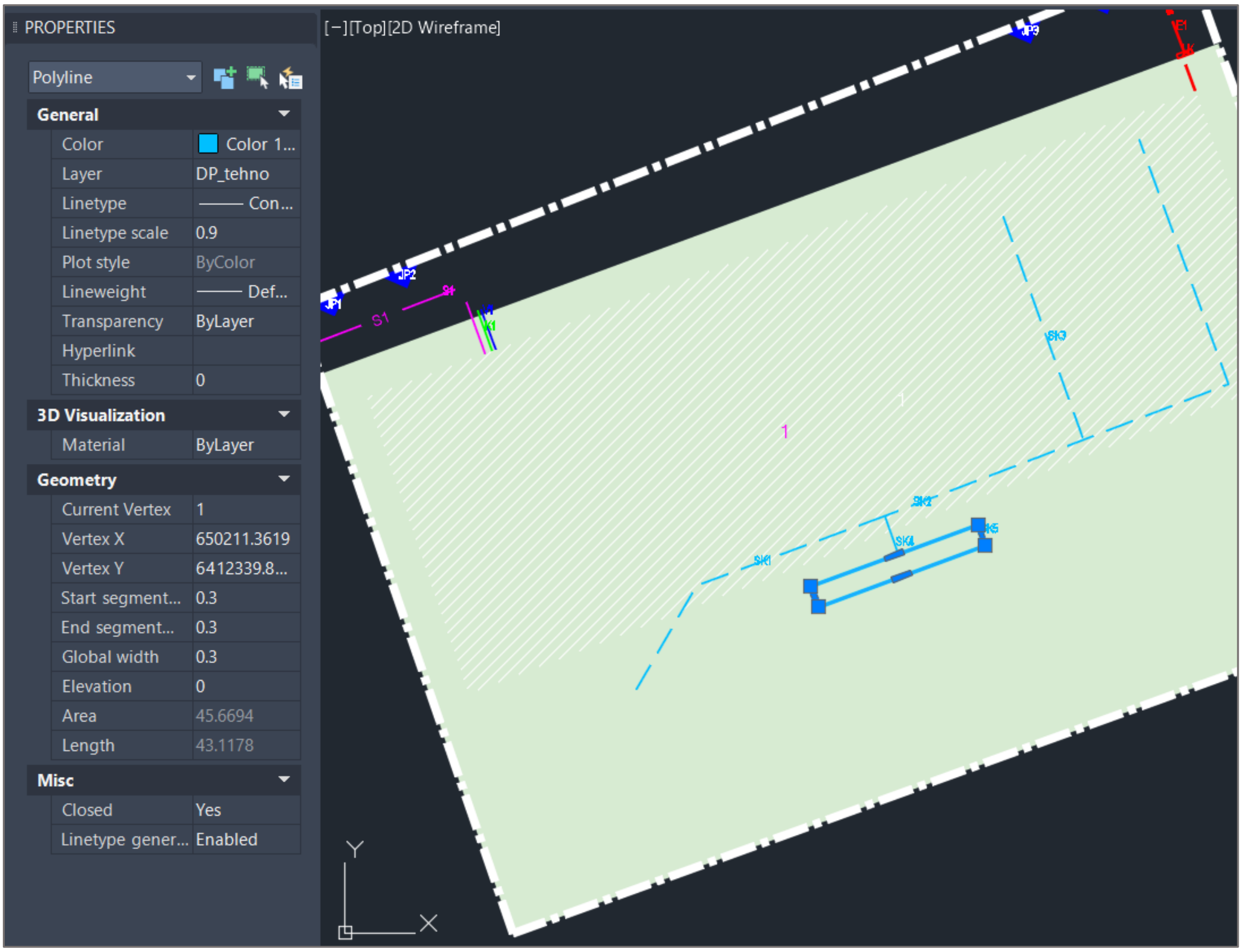
Current layer: 0

S...	Name	O..	F...	V...	L...	P...	Color	VP Co
	All Used L...	💡	☀	▢	🔓	🖨	BY...	BY.
✓	0	💡	☀	▢	🔓	🖨	■ wh...	■ wh.
▱	DP_hoone...	💡	☀	▢	🔓	🖨	■ wh...	■ wh.
▱	DP_juurdep	💡	☀	▢	🔓	🖨	■ wh...	■ wh.
▱	DP_krunt	💡	☀	▢	🔓	🖨	■ ma...	■ ma
▱	DP_tehno	💡	☀	▢	🔓	🖨	■ 212	■ 212
▱	plan_ala	💡	☀	▢	🔓	🖨	■ wh...	■ wh.

Figure 84. Snippet from the DWG file showing the overall layout of the plan and associated layers.

The DWG file of the plan was investigated first. Figure 84, shows a snippet from the file with the plan data and its layers shown. To understand how the data is presented in more detail, objects in the plan were selected with the metadata they represent. Figure 85 shows a snippet of that. For the selected element in the DWG file, it becomes apparent that the available information is primarily focused on visualization rather than detailed metadata about the design or spatial attributes. As shown in Figure 85, the element is categorized within the "*dp_krunt*" layer, indicating its association with a specific thematic category (such as a land plot or building block). However, beyond this basic categorization, most of the information relates to the visual representation of the element, including aspects like line weight, transparency, color, and other properties used to define its appearance within the CAD drawing.

This lack of detailed metadata presents a challenge for the integration of the DWG data into more structured frameworks like the LADM Part 5 country profile, where spatial plans require a more robust description of elements such as plot attributes, zoning regulations or unit metadata. The 2D CAD file only provides the geometric layout and basic visualization details, while the critical semantic information—such as land use, building heights, or functional classifications—must be sourced from separate files, such as the CSV metadata file or external documentation.



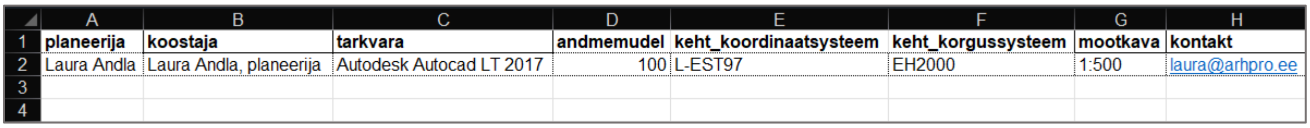
PROPERTIES

Polyline

General	
Color	Color 1...
Layer	DP_tehno
Linetype	Con...
Linetype scale	0.9
Plot style	ByColor
Lineweight	Def...
Transparency	ByLayer
Hyperlink	
Thickness	0
3D Visualization	
Material	ByLayer
Geometry	
Current Vertex	1
Vertex X	650211.3619
Vertex Y	6412339.8...
Start segment...	0.3
End segment...	0.3
Global width	0.3
Elevation	0
Area	45.6694
Length	43.1178
Misc	
Closed	Yes
Linetype gener...	Enabled

Figure 85. Example of selected metadata for an object in the DWG file (AutoCAD display).

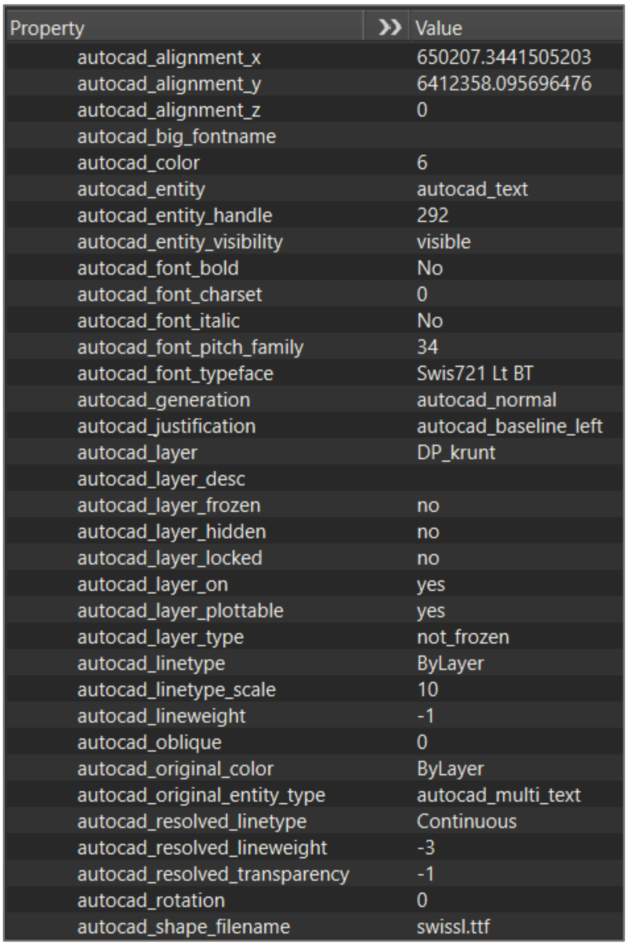
To gain more concrete insights into the DWG file, the data was imported into FME to examine all its attributes. Figure 87 shows a snippet of the attributes read for the "*dp_krunt*" layer. As was evident in AutoCAD, the metadata appears to only relate to the visual aspects of the drawing, such as styling and layout, and does not provide valuable information about the design itself, such as zoning requirements or land use.



	A	B	C	D	E	F	G	H
1	**planeerija**	**koostaja**	**tarkvara**	**andmemudel**	**keht_koordinaatsysteem**	**keht_korgussysteem**	**mootkava**	**kontakt**
2	Laura Andla	Laura Andla, planeerija	Autodesk Autocad LT 2017	100	L-EST97	EH2000	1:500	laura@arhpro.ee
3								
4								

Figure 86. Snippet from the DK402 Metadata Table, showing key information such as the planner, software used, coordinate system, height system, and contact details..

Next, the related CSV files were examined, beginning with "**DK402, the metadata table**". Figure 86 displays this metadata, which includes key information such as the architect and author. This information is planned to be represented in the LADM country profile as part of *LA_SpatialSource* and *LA_AdministrativeSource* classes (visible in Figure 46). This metadata improves upon the 3D IFC datasets used earlier in the research, which did not contain such details. The fact that PLANK mandates the inclusion of this information (even if in external CSV format) enables its integration into the LADM database and ensures the automation process benefits from having relevant details available.

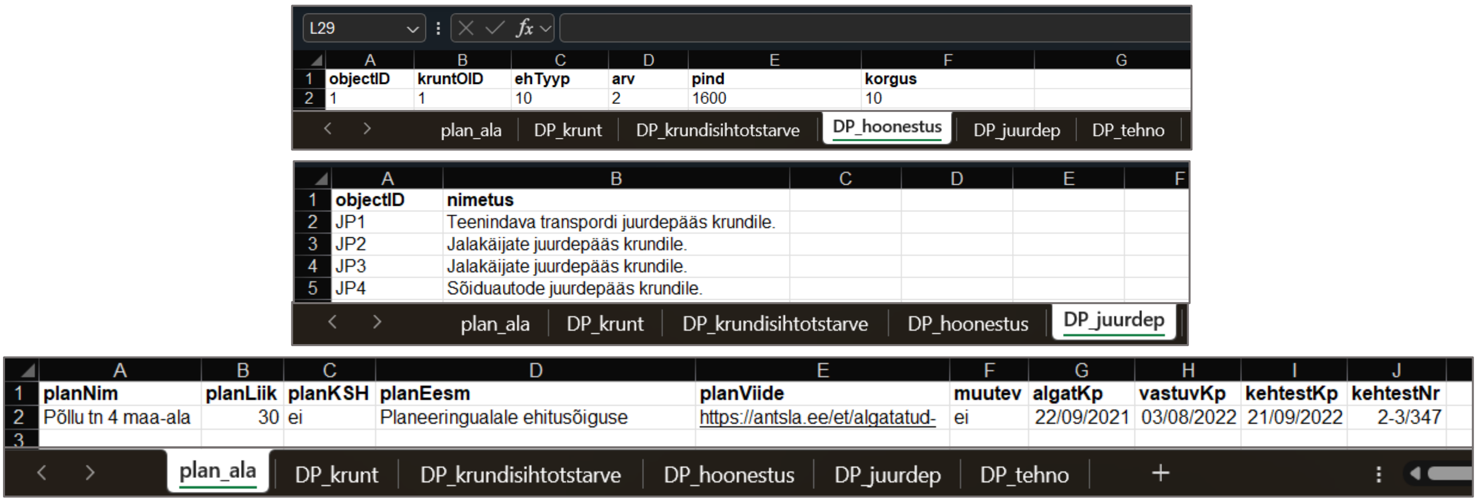


Property	Value
autocad_alignment_x	650207.3441505203
autocad_alignment_y	6412358.095696476
autocad_alignment_z	0
autocad_big_fontname	
autocad_color	6
autocad_entity	autocad_text
autocad_entity_handle	292
autocad_entity_visibility	visible
autocad_font_bold	No
autocad_font_charset	0
autocad_font_italic	No
autocad_font_pitch_family	34
autocad_font_typeface	Swis721 Lt BT
autocad_generation	autocad_normal
autocad_justification	autocad_baseline_left
autocad_layer	DP_krunt
autocad_layer_desc	
autocad_layer_frozen	no
autocad_layer_hidden	no
autocad_layer_locked	no
autocad_layer_on	yes
autocad_layer_plottable	yes
autocad_layer_type	not_frozen
autocad_linetype	ByLayer
autocad_linetype_scale	10
autocad_lineweight	-1
autocad_oblique	0
autocad_original_color	ByLayer
autocad_original_entity_type	autocad_multi_text
autocad_resolved_linetype	Continuous
autocad_resolved_lineweight	-3
autocad_resolved_transparency	-1
autocad_rotation	0
autocad_shape_filename	swissl.ttf

Figure 87. A snippet of attributes read from the "dp_krunt" layer in FME.

The next file to be reviewed is "**DK401, the Smart Data Table**", which contains further essential metadata about the design elements and spatial attributes of the plan.

In the snippets from the DK401 Smart Data Table shown in Figure 88, it is clear that the data is somewhat similar to the metadata contained in the 3D IFC pilot datasets. However, the key difference lies in how the data is stored and represented. In the 3D IFC datasets, nearly all relevant information, including geometric and semantic data, is embedded directly within the IFC files, which also include 3D representations of the design elements. On the other hand, in the current 2D-based planning methods, the metadata is split across external CSV files, such as the DK401 table, rather than being included within the design file itself. This fragmentation of data between the DWG files and CSV tables highlights the limitations of the current system in terms of data integration and efficiency. The current approach requires additional steps to combine the geometry with its associated metadata for automated processes like compliance checks.



	A	B	C	D	E	F	G
1	objectID	kruntOID	ehTyyp	arv	pind	korgus	
2	1	1	10	2	1600	10	

	A	B	C	D	E	F
1	objectID	nimetus				
2	JP1	Teenindava transpordi juurdepääs krundile.				
3	JP2	Jalakäijate juurdepääs krundile.				
4	JP3	Jalakäijate juurdepääs krundile.				
5	JP4	Sõiduautode juurdepääs krundile.				

	A	B	C	D	E	F	G	H	I	J
1	planNim	planLiik	planKSH	planEesm	planViide	muutev	algatKp	vastuvKp	kehtestKp	kehtestNr
2	Põllu tn 4 maa-ala	30	ei	Planeeringualale ehitusõiguse	https://antsla.ee/et/algatatud-	ei	22/09/2021	03/08/2022	21/09/2022	2-3/347
3										

Figure 88. Snippet from the DK401 Smart Data Table showing metadata associated with various design elements in the Detailed Plan, stored externally from the DWG file..

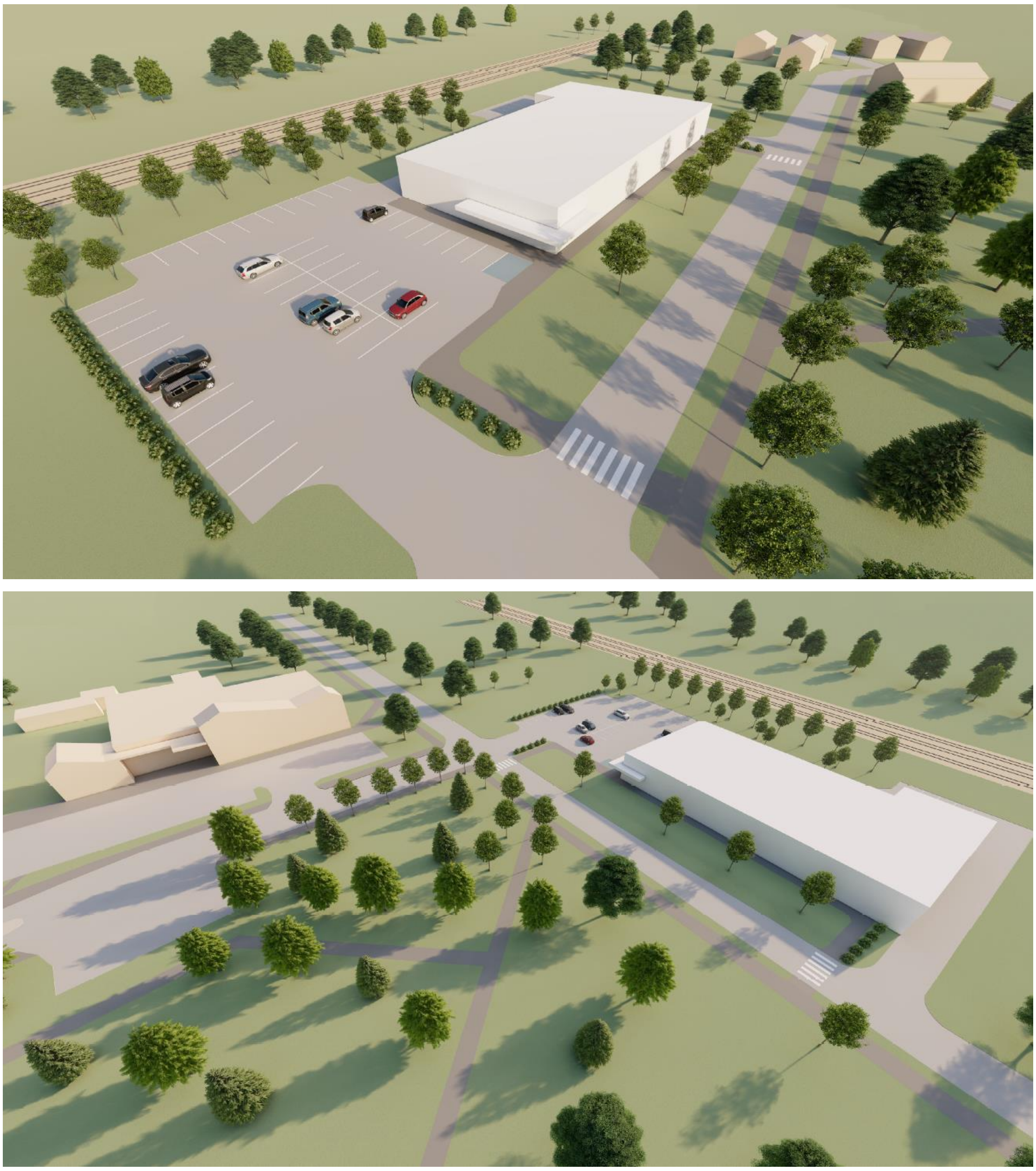


Figure 89. 3D renders of the planned development from the "RI100 Spatial Illustrations" PDF file.

The final element examined was the “**RI100 Spatial Illustrations**” PDF, which contains 3D renders of the detailed plan, as shown in Figure 89. While these renders provide an aesthetically pleasing representation of the planned development, they do not carry the technical information necessary for compliance checks or integration into the LADM database. The renders are primarily used for visualization purposes, and although creating these 3D models requires effort, the lack of integration with the actual plan data and metadata results in an inefficient process. From a technical standpoint, these renders add little value beyond presentation and do not contribute to automating compliance checks or improving the structure of spatial data in Estonia's planning framework.

The investigation into the **Põllu tn 4 detailed plan** and its associated 2D data has revealed several key insights regarding the limitations and challenges of Estonia's current reliance on 2D CAD drawings and fragmented metadata storage in CSV files.

These findings provide answers to the two key questions raised at the beginning of this section:

1. **Can the data be effectively represented in the Estonian LADM Part 5 country profile and stored in the PostgreSQL database?**
   The analysis has shown that while the basic geometrical layout from the DWG files can be stored in the LADM database, the lack of embedded semantic information within the DWG file itself presents a significant limitation. Metadata required for compliance checks, such as zoning rules, building heights, and land use, is scattered across separate CSV files (like DK401 and DK402), making it difficult to ensure seamless integration into the LADM Part 5 framework without additional and manual processing of these fragmented data sources. While the external metadata in CSV format could be incorporated into the LADM framework, it would require the development of tailored import scripts to map the information properly, indicating that the current format is not immediately ready for automated compliance checking.

2. **Does the data provide the necessary information for automated compliance checks and extraction using FME import scripts?**
   The current state of the data does not fully support an efficient extraction and compliance-checking process. While some metadata is provided in the CSV files, critical spatial attributes and technical details necessary for compliance checks (e.g., zoning requirements, heights etc.) are missing from the CAD file itself, and must be manually associated with the geometric data from external sources. The separation of geometry and metadata necessitates additional steps to combine and link these elements in automated workflows, complicating the automation process. Furthermore, while 3D renders are provided, they lack the technical details required for compliance checks, limiting their value to aesthetic visualization rather than functional verification.

In conclusion, the reliance on 2D data formats and fragmented metadata storage in Estonia’s current spatial planning system presents several challenges that must be addressed as the country moves towards more advanced digital frameworks. The data available in PLANK can theoretically be adapted for integration into the LADM Part 5 country profile and subsequent automated compliance checking; however, significant adjustments to the current workflows would be necessary. This includes implementing richer semantic information directly within the planning data, streamlining metadata management, and reducing reliance on external CSV files.

6. Assessment and Evaluation

This chapter provides a comprehensive evaluation of the Estonia-specific LADM profile, alongside the developed database and FME scripts. The main focus is to assess their effectiveness, limitations, and compliance with international standards.

Starting with the Estonia country profile, to ensure conformance to the LADM standards, the assessment will follow the Abstract Test Suite (ATS) outlined in Appendix A of *ISO 19152:2012*. The ATS is a model-based testing mechanism composed of abstract test cases designed to evaluate the conformance of specific implementations with a standard. It cannot be executed directly against the model because it provides high-level, conceptual test cases rather than executable scripts or concrete test procedures. It's important to note that while *ISO 19152:2012* does not yet encompass Part 5, the upcoming *DIS 19152-5* (2024) draft addresses it. Therefore, the assessment will begin with the current ATS for *ISO 19152:2012* and later another assessment will be made according to the *DIS 19152-5* (2024) to guarantee the profile's compatibility with both versions.

Table 8. Conformity levels of the abstract test suite of ISO 19152:2012 and their requirements.

Conformance Level	**Requirements**
Level 1 (Basic)	Implementation of the basic class(es) and the core class(es) of LADM.
Level 2 (Common)	Implementation of the basic class(es) and common class(es) of LADM, including level 1 requirements.
Level 3 (High)	Implementation of the basic class(es) and all other class(es) of LADM, including level 1 and 2 requirements. Specific classes required include: - LA_BoundaryFace - LA_LegalSpaceBuildingUnit - LA_LegalSpaceUtilityNetwork - LA_Mortgage - LA_RequiredRelationshipSpatialUnit - LA_Responsibility

The Estonia profile has been developed to comply with level 2 conformance of *ISO 19152:2012*, as Table 8 displays. According to the ATS for *ISO 19152:2012*, level 2 conformance requires the implementation of basic and common classes, which include core classes in Part 5 according to the scope of the research. These classes have been inherited by the new Estonian plan and unit classes to include attributes specific to Estonian requirements, such as "*landUseType*" for *EST_DetailedPlan* and "*strategicPrincipleAreas*" for *EST_MasterPlan*, ensuring that national requirements are addressed while maintaining the LADM's integrity. The profile also includes comprehensive metadata attributes and predefined codelist values to maintain data integrity with PLANK. Overall, in the scope of the research, the Estonia-specific LADM profile achieves level 2 conformance, meeting the necessary requirements and providing a robust framework for managing spatial plan data in Estonia.

Following the initial assessment with *ISO 19152:2012*, the Estonia-specific LADM profile was also evaluated using the ATS from *DIS 19152:5 (2024)*. This suite assesses the profile's compliance to specifically LADM Part 5 as a standard and its ability to disseminate and visualize plan information effectively. It also examines support for participatory monitoring, organization of plan units, and extensible code lists for spatial subfunctions. Additionally, the ATS reviews the management of hierarchical planning structures and the system's capability to register permits and link them to relevant plan units.

Table 9. Evaluation results for Estonia LADM profile according to DIS 19152:5 (2024) ATS.

	Test Case	Purpose	Result
1	Core LADM Conformance	Verify alignment with core LADM standards (19152-1 and 19152-2).	Conformant
2	Plan Information Dissemination	Assess ability to disseminate and visualize spatial plans (2D/3D).	Conformant
3	Plan Information Monitoring	Verify support for participatory plan monitoring and feedback.	Conformant
4	Plan Unit Block Relationship	Check organization of plan units and blocks according to accepted standards.	Conformant
5	Spatial Subfunction	Confirm extensibility of code lists for spatial (sub)functions.	Conformant
6	Plan Group Hierarchy	Assess support for hierarchical planning structures from national to local levels.	Conformant
7	Permit Registration	Verify support for permit registration and linking to plan units.	Partially Evaluated (theoretically conformant)

Table 9 summarizes the evaluation of the country profile based on the ATS of DIS 19152:5 (2024). The profile was confirmed to be conformant with the core LADM standards, effectively supporting dissemination and visualization of spatial plans, participatory monitoring, organization of plan units, and extensible code lists for spatial functions. It also successfully manages hierarchical planning structures. The permit registration functionality, while theoretically supported, was not practically tested due to the research focus on compliance checks rather than permit management.

By achieving Level 2 conformance with the ATS of *ISO 19152:2012* and six "conformant" and one "not evaluated" with the ATS of *DIS 19152:5 (2024)*, Estonia's LADM profile has proven effective in addressing both the national requirements while adhering to international standards.

Regarding the performance assessment of the LADM PostgreSQL database and FME scripts, practical evaluation was limited due to the lack of sufficient data. Testing the FME script’s import capabilities and the database’s performance required large and diverse Estonian plan datasets, which were not available for this research. As a result, performance testing could not be conducted, and the evaluation continues with relying on a theoretical assessment of the tools' limitations instead. One aspect to be evaluated was the effects of certain assumptions made during the development phases which contributed to some limitations and scalability issues in the process.

One significant assumption involves the order of data imports in the FME script. Currently, after importing Detailed Plan data into the *EST_DetailedPlan* table, an SQL query is made within FME script to retrieve the unique plan ID from the PostgreSQL database, as previously illustrated in Figure 71. This ID is then used to establish a foreign key relationship for uploading the corresponding unit data to the *EST_DetailedUnit* table. However, if two different plans are imported into the *EST_DetailedPlan* table sequentially, the units of the first plan cannot be imported from the FME script without manually retrieving and using the plan ID of the first plan from the database. This acts both as a constraint and a limitation for the process. On one hand, it ensures that unit data can only be imported when the associated plan data exists in the database, providing control over the import process. On the other hand, it introduces a limitation, as manual entry of the specific plan ID is required if the import order changes.

Another crucial assumption was the script’s reliance on predefined discipline names[25] for filtering IFC data, which was based on a limited set of pilot datasets used in the case study. In a broader context, variations in discipline naming conventions could present challenges. For scalability reasons, the script should be tested and optimized with a wider range of Estonian datasets to ensure accurate operation. To address this limitation, a machine learning approach was introduced to enhance the script's adaptability.

Although not the primary focus of this research, this approach was explored for optimization purposes. It enhances the FME script by predicting and categorizing Estonian discipline names in the IFC data. The model, trained on synthetic data, helps recognize and validate spatial layers and plan naming conventions, ensuring correct ontological distinctions. Its predictions are then integrated into the pipeline,

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[25] In this context, "*disciplines*" are Estonian layer names representing categories in spatial plans, aligned with national regulations and PLANK (e.g., dp_avalik for public spaces, dp_haljastus for landscaping).

streamlining the processing of Estonian Detailed Plans and their import into the database. The main Python script, ***main.py***, automates the entire process, including database creation, machine learning execution, and FME script operation, requiring only basic user input.

This method optimizes the workflow and increases the scalability of the FME script. The relevant scripts and files can be found in the main research's GitHub repository under the folder "*ML_4_Estonia*". To further enhance scalability in handling various Estonian naming conventions, the model could be trained with larger real and synthetic datasets that better reflect the diversity of Estonian planning data.

Additionally, the following provides a brief evaluation of the pilot datasets used in this research. It is important to remind again that the IFC files representing Detailed Plans, created specifically for this research in collaboration with Future Insight Group and the Ministry of Climate (*Kliimaministeerium*) of Estonia, were tailored for research purposes. The primary reason for this customization is that Estonia predominantly relies on 2D data formats, such as CAD, for spatial planning processes. As of now, there is no officially established approach to using IFC models for spatial plans in Estonia. Therefore, the IFC files were customized to include specific disciplines and attributes relevant to compliance checks and the needs of this research.

However, while this customization was essential for simulating how Detailed Plans could be processed in 3D for automated compliance checks, it introduces certain limitations. The tailored nature of these files means that the results of this research are somewhat theoretical and may not fully reflect the real-world complexity or diversity of planning data in Estonia. The absence of standardized IFC planning models in Estonia could limit the broader applicability of the findings until such standards are adopted. Furthermore, the lack of metadata in these IFC files—despite mandatory requirements outlined in Appendix D of Estonian regulations—also posed a challenge during the development of the scripts and database.

In conclusion, while these tailored datasets enabled the prototype's development, their limitations emphasize the need for standardization. Standardizing IFC data in Estonia would enhance the effectiveness of compliance checks across different plan levels and pave the way for future optimizations and additional functionalities in the LADM pipeline.

7. Conclusion and Future Directions

This chapter presents the conclusions and findings derived from the study. To summarize the research findings, the research questions posed at the beginning will be revisited and addressed. First, the sub-research questions will be discussed, leading to an answer to the main research question. General conclusions will then follow. Later, recommendations for future work will be provided in section 7.1, outlining potential areas for continued research and improvement. Lastly, reflections on reviews from external academic and professional experts, along with a critical reflection on the research, are presented in Appendix F.

Research Sub-Question 1

How can LADM Part 5 be effectively utilized with IFC data models through extensions or other schema mechanisms?

A country profile developed from LADM Part 5, can be effectively integrated with IFC data models of spatial plans by utilizing the inherent flexibility and interoperability of both standards. IFC serves as a widely used open standard for exchanging building level and spatial information, while LADM Part 5 focuses on representing the spatial planning and land use, providing a standardized framework for handling necessary information. These can specifically be expressed as the spatial units, plan blocks, and plan hierarchies that LADM Part 5 already offers.

The integration of LADM Part 5 with IFC can be achieved by mapping relevant classes between the two models. For instance, the *IfcBuilding* class from IFC aligns with the *SP_PlanUnit* class in LADM Part 5, allowing building-level data to be incorporated into spatial plans. Similarly, *IfcSite* can be mapped to *SP_PlanBlock* for organizing larger spatial units. However, this mapping requires careful use of the IFC data model as proposed by the IFC standard. In practice, as seen in the Estonia case study, the way data is stored in IFC does not always align with the theoretical schema. This is primarily due to the underdeveloped use of IFC models for planning purposes in Estonia compared to its more mature application in design models. To exemplify, most of the pilot datasets used to develop the country profile, scripts and the database didn't necessarily store the "building" information in the *IfcBuilding* class but as *IfcBuildingElementProxy.* This ambiguity and variability in how IFC data is applied necessitated the development of a country profile, scripts, and database tailored to the specific datasets used in the study.

Following the initial mapping of relevant classes and attributes between the IFC data and LADM Part 5, FME scripts were used to automate the extraction, transformation, and loading (ETL) of IFC data into the LADM-compliant PostgreSQL database.

Research Sub-Question 2

What theoretical advantages and challenges would arise from using CityGML data models with LADM Part 5?

CityGML offers several theoretical advantages when integrated with LADM Part 5. It provides a flexible framework for representing urban features across multiple scales through its Levels of Detail (LoD), which makes it highly suitable for various urban planning tasks. Similar to IFC integration, CityGML can be utilized for LADM Part 5 through mapping of the relevant classes and attributes. For example, in theory, CityGML's thematic modules, such as *Building* and *LandUse*, align well with LADM Part 5's *SP_PlanUnit* and *SP_PlanBlock* classes. This enables LADM to capture semantic, geometric, and topological information that CityGML offers. Furthermore, CityGML's ability to represent detailed zoning and land use regulations—particularly for high-level spatial plans like County or National Plans—adds substantial value, especially when compared to IFC, where higher-scale zoning information is less frequently represented.

However, there are also challenges associated with using CityGML with LADM Part 5. One key limitation is that CityGML is generally not used for AEC products like BIM, which limits its applicability in detailed spatial plan representations. Additionally, while CityGML efficiently handles broad urban planning tasks, its detailed modules (e.g., the *Building* module) may not provide the same granularity as IFC when representing specific plan details. In some cases, new classes and attributes might also need to be added to LADM to fully represent certain thematic areas covered by CityGML, such as transportation or vegetation, which do not have direct mappings in LADM Part 5.

Thus, while CityGML provides a robust framework for certain aspects of spatial plans, particularly at larger scales, challenges arise in applying it to more detailed plans or specific thematic areas. These would require careful adaptation and potential extensions to LADM Part 5. In theory, integrating CityGML-LADM for higher-level plans (e.g., Master, County, and National Plans) with IFC-LADM for Detailed Plans would yield the most efficient results in the context of this research, particularly for compliance checks and permitting processes.

Research Sub-Question 3

To what extent can the inclusion of LADM Part 5 contribute to the efficiency of automated compliance checking processes using IFC, impacting accuracy and speed, and what potential differences could exist if CityGML were used?

Theoretically, integrating LADM Part 5 into automated compliance checking processes with IFC can significantly enhance both accuracy and speed. LADM Part 5 offers a structured, standardized framework for managing spatial plans, simplifying data integration and validation. This approach eliminates the need to repeatedly extract spatial information from datasets for each check. By mapping IFC data to LADM Part 5, spatial units, plan hierarchies, and plan blocks can be efficiently captured and analyzed within a standardized system. Additionally, the FME script and database store only the relevant data, including both absences and actual values. This allows authorities to directly verify the presence of necessary data, thereby improving the accuracy of compliance checks by reducing ambiguity in data, creating a streamlined process.

However, the full assessment of accuracy and speed remains theoretical, as the final integration has not yet been fully implemented in Estonian systems, with the current output of the case study with Future Insight is a prototype solution featuring seven checks and three datasets. To truly assess its effectiveness, the system must be applied to real-world digital planning workflows in Estonia, which would require adopting IFC as a standard in the AEC domain. Furthermore, once these theoretical aspects are addressed, it will be essential to test large datasets representing Detailed Plans against the final prototype to effectively measure speed and accuracy.

On the other hand, when comparing the potential use of CityGML instead of IFC, theoretical differences arise again. CityGML, with its broad urban planning and zoning capabilities, might be more effective for high-level spatial plans (e.g., National or County Plans) but could face challenges with compliance checks that require detailed information. IFC, on the other hand, is more suited to capturing detailed building-level information, making it better aligned with LADM Part 5 for detailed plan integration. Therefore, the use of CityGML would likely affect both accuracy and speed differently, depending on the level of detail required. Usage of CityGML could be more efficient with broader zoning checks but may introduce inefficiencies or inaccuracies when dealing with more granular, detailed spatial data.

Research Sub-Question 4

What is the current state of compliance checks between spatial plans in Estonia using IFC models, and how does the proposed solution compare to the existing checking processes in Estonia?

Compared to most countries, Estonia is highly advanced in BIM-based checking systems, having developed a system that is recognized globally as a model for such implementations. However, the current application of IFC models in Estonia's spatial planning remains underdeveloped compared to its use in building design. The primary focus of the IFC format has been on mostly buildings, with less attention given to its use in the planning process. For example, spatial planning usually involves larger areas with lower levels of detail, whereas IFC is primarily structured for the detailed design of individual building elements like walls and doors, as part of BIM models.

Additionally, many planning datasets in Estonia are still in 2D CAD or GIS formats rather than 3D plan information models. This reliance on 2D data limits their interoperability and the potential for advanced applications like automated compliance checks. Some plans are not even digitized, existing only as paper or PDF documents, further complicating automation efforts. While open standards like IFC and CityGML offer opportunities for compliance checks and later permitting, the current use of the IFC format lacks specific entities tailored to urban planning, creating challenges for further adoption.

The theoretical investigation into the *Põllu tn 4 detailed plan* in section 5.4 provided additional insights into these limitations. The investigation revealed that while the 2D DWG files capture basic geometric layouts, they lack embedded semantic information essential for compliance checks, such as zoning rules, building heights, or land use data. This metadata is instead stored externally in CSV files, which fragments the data and complicates integration into automated workflows, such as those based on the LADM framework. Additionally, the 3D renders included are primarily for visualization purposes and lack the technical detail required for compliance checks, further highlighting the inefficiencies of the current system.

The reliance on 2D data not only limits the ability to automate compliance checks but also undermines the potential of more integrated digital planning frameworks. The investigation points to the need for better data models that combine both geometric and semantic information, ideally stored within a unified framework such as LADM Part 5. These models would improve data integration and make automated compliance checking more effective. As Estonia progresses toward more advanced digital frameworks, such as BIM and 3D spatial data, addressing the limitations of the current 2D system will be crucial to ensuring a smoother transition.

The findings suggest that to maximize the potential of automated compliance checks, Estonia must focus on three key areas:

1. **Standardizing IFC for Planning** (**Proposed 3D Approach**)
   The first recommendation is based on the proposed shift toward 3D models using the IFC format, which is currently underdeveloped in the planning domain. The IFC model should be standardized for use in spatial planning, just as it is for building design. For example, in building models, a door is consistently registered as *IfcDoor*. Similarly, elements in spatial planning models, such as roads or sidewalks—typically represented at a broader scale with less detail—should be stored within a standardized framework. This consistency will help create a unified understanding for plan information models and support the future integration of 3D data in compliance checks.

2. **Consistent Naming and Semantics**
   It is crucial to strictly standardize the naming conventions and semantics of Estonian data while allowing some flexibility where needed. For instance, a plot layer/entity in an Estonian Detailed Plan should always be named "*dp_krunt*" rather than variations like "*krunt*" or other derivatives. This would ensure that automated systems can accurately read and interpret the incoming planning models (regardless of their format).

3. **Standardized Models in Databases for Further Usage**
   Increasing the functionality of planning models for further applications requires the implementation of a standardized model in the planning databases. This would allow other disciplines, such as in LAS, to leverage the existing planning models for various applications, including compliance checking and more. The integration of **LADM Part 5** into this process, as proposed by the research, supports this by developing an Estonian country profile and a LADM database for storing and managing spatial plans. This proposed solution aligns with the centralized PLANK database, ensuring compatibility with existing platforms and workflows, and prepares Estonia for future advancements in automated processes.

In summary, while the focus of this research has been on the use of 3D IFC data for compliance checks, the theoretical investigation into Estonia's existing 2D data system highlighted significant gaps and limitations. The current fragmented approach, with CAD drawings and metadata stored externally in CSV files, poses challenges for automation and integration. This research has demonstrated that while 3D IFC data presents a more robust solution, there is potential for adapting existing 2D data systems, provided that key gaps—such as the lack of embedded semantic information—are addressed. LADM Part 5 serves as a critical steppingstone in this transition, offering a standardized framework through the new LADM-compliant database, which is equipped to handle various types of spatial data and present them in a more unified way.

Research Sub-Question 5
How effectively can LADM Part 5 (ISO/DIS 19152-5) represent Estonian spatial plan information and support its utilization for compliance checks?

LADM Part 5 (ISO/DIS 19152-5) can represent Estonian spatial plan information effectively, though several customizations were necessary to align with the specific requirements of the Estonian system. The development of the Estonia's LADM profile involved adapting the core classes and attributes of LADM Part 5 to fit national needs, incorporating new attributes and relationships where necessary. Initially, the profile used standard LADM Part 5 classes as a foundation, but as the profile developed it became clear that additional attributes and classes were needed to fully represent the

Estonia planning data.

The profile underwent several iterations, each refining the representation of Estonian spatial data. Significant updates included the integration of metadata from the Estonian spatial plan database, PLANK, which provided crucial details like plan initiation dates, versioning, and uploader information. This allowed for a more accurate reflection of how spatial plans are managed and updated in Estonia. The final version of the profile inherited attributes from LADM Part 5 classes and focusing on more detailed and practical representation of the plan data. The final profile ensured that all relevant spatial information was captured without loss by incorporating specific Estonian attributes while removing redundant and unnecessary ones.

The overall insight gained from the research showed that LADM Part 5 can be utilized effectively for representing spatial plans of Estonia, particularly for Detailed Plans. While the focus of this research was on Detailed Plans due to IFC data, the methodology and framework developed for compliance checks can be extended to other types of spatial plans, such as county or national plans. LADM Part 5 aligns well with the general idea of spatial plan hierarchies, from higher scales to lower, and offers a robust structure for representing and managing various plan levels. Some existing attributes were not used to fully represent the Estonian data; however, their existence might be useful for profiles of other countries to represent their data. A significant factor in the development of the country profile was the collaboration with Estonian professionals, who provided feedback during the development phases. This ensured that the profile also aligns with the existing data and platforms in Estonia.

For the compliance checks, the integration of LADM Part 5 with Estonian spatial plan information has demonstrated its capability to enhance the efficiency of automated processes. By using the structured framework of LADM Part 5, the compliance checking system benefits from a standardized approach that streamlines data validation and integration. This results in more precise checks against spatial plans, ensuring that all relevant attributes and relationships are accounted for in the database. Although this research primarily focused on Detailed Plans, the approach is flexible enough to be applied to other plan types within the Estonian planning hierarchy.

However, the practical application of this approach is still in its early stages, as the current prototype has only been tested with limited datasets (three main IFC data introduced in Section 3.6) and checks (7 checks seen in Table 3). To fully assess the effectiveness of LADM Part 5 in real-world scenarios, it is crucial to implement the system across broader datasets and in actual compliance-checking workflows. While the research shows promising results, further testing is required to determine how well LADM Part 5 can manage the complexities and scale of real-world spatial planning data beyond Detailed Plans.

7.1. Recommendations for Future Work

Throughout the research, several limitations, and areas with possibilities for further development have been identified, pointing to potential future research directions that could progress the findings and expand their practical application. While the current work demonstrates promising results, there are still challenges to address and new opportunities to explore based on this groundwork. This section outlines key areas where future work could provide meaningful contributions to the field.

Broader Implementation and Further Testing: A key area for future research involves scaling up the current prototype to test it with a broader range of datasets and in real-world permitting workflows. This will help validate the effectiveness of the integration between LADM Part 5 and Estonian spatial planning data. Testing larger and more complex spatial datasets will also show how well the current framework handles diverse types of data, plan hierarchies, and real-world. challenges. In addition, applying the system in actual permitting processes will expose potential bottlenecks, inefficiencies, or gaps that need to be addressed. Further testing will also provide insights into how scalable the solution is and whether further optimization is necessary to handle Estonian datasets.

IFC Integration for Plan Information: While the integration of LADM Part 5 with IFC-encoded plan information models has showed feasibility, there are still areas that require refinement. Future research could focus on improving the mapping of classes and attributes between IFC and LADM Part 5, particularly addressing the discrepancies between the theoretical data schema and the way information is stored in practice. The current application of IFC models in Estonia's spatial planning is underdeveloped thus, compared to IFC encoded design models, there is no established standard for representing urban-scale data in IFC models. This creates a need for developing more advanced mapping strategies and refining the FME scripts used to automate data extraction, transformation, and loading (ETL). Future efforts could aim to increase the robustness and flexibility of these scripts, while minimizing variability and ensuring compatibility between IFC data and LADM Part 5. Moreover, the standardization of IFC data usage in planning—similar to its application in building models—will be essential for creating more seamless workflows in spatial planning.

Exploring CityGML Integration: Future research could investigate the integration of CityGML with LADM Part 5 in greater depth. While CityGML provides a detailed framework for representing urban environments, its compatibility with LADM Part 5 for spatial planning and zoning purposes remains largely unexplored. Future work could focus on evaluating the potential of CityGML for high-level planning and zoning compliance checks, as well as examining how CityGML complements IFC in representing different aspects of spatial plans.

Standardization and Digitization of Estonian Plans: Standardizing models and establishing consistent naming conventions across Estonian spatial planning data is a critical step for improving data interoperability and automation in compliance checking. Future research should explore creating a standardized framework that facilitates the digitization and uniform representation of planning elements. This will enhance the ability to compare spatial data at different levels, enable better integration with LADM Part 5, and streamline the automated permit-checking process. Developing shared vocabularies and data structures will also help ensure that datasets are more easily exchanged between various platforms and stakeholders.

Integrating other LADM Standards: While this research has focused primarily on LADM Part 5, future studies could explore the integration of other parts of the LADM standard, such as LADM Part 1 (Generic Conceptual Model), Part 2 (Land Registration), Part 3 (Marine Geo-regulation), and Part 4 (Valuation Information). Understanding how these standards interact with spatial planning data could open new possibilities for more comprehensive land administration systems.

Other Countries: Extending the scope of this research to other countries could further demonstrate the applicability and adaptability of the LADM Part 5 in real-life. Each country has unique spatial planning processes, regulations, and datasets, which may present different challenges and opportunities for integrating LADM. By applying this research to different contexts, future work could uncover insights into how LADM Part 5 can be tailored to support diverse planning systems.

More Compliance Checks: While this research has demonstrated certain aspects of automated compliance checking, future work could expand the scope of the checks that can be automated. The development of advanced algorithms to support these checks would improve the thoroughness and reliability of compliance verification in the process while standardizing the whole system.

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System.

Appendices

Appendix A

Table 10. Contributions related to rule interpretation and digitalization of city and building regulations, by Noardo et al. 2022.

Entry	Description	Progress	Country
Van Berlo et al. (2013)	Proposes the storage of spatial planning information in 3D based on CityGML and the Dutch zoning data. It is also proposed the conversion of such a dataset to IFC by means of FZK viewer.	Executing	The Netherlands
MacitIlal and Günaydın (2017)	Method to formalize and code building regulations.	Closing	Turkey/Int
Lee et al. (2015)	Develops a software that allows users to export selected rules in building codes as computer-readable format by benefiting from created database. The classification of texts in building code is done manually.	Executing	South Korea
Beach and Rezgui (2018)	Proposes an approach that allows to encode building regulations into executable format using RASE strategy and ifcOWL.	Executing	UK/Int
Zhang and El-Gohary (2016)	Propose a new method, based on semantic natural language processing (NLP) techniques and machine learning techniques, for extending the IFC schema to incorporate Compliance Checking-related information, in an objective and semi-automated manner.	Closing	USA
Song et al. (2018)	Natural Language Processing to interpret and formalize regulations	Executing	South Korea
Song et al. (2019)	Describes the KBimCode translator, which translates KBimCode into an executable code of specific rule checking software, named KBimAssess.	Executing	South Korea
Nisbet et al. (2009)	Require 1 is a tool that support the coding analysis of Building Regulations based on the RASE methodology.	Validating	UK, USA
Park et al. (2016)	Describes the definition of KBimCode Language and demonstrates its actual use case.	Executing	South Korea
Park and Lee (2016)	Explains the KBimCode used as a base for checking compliance to regulations in BIM.	Closing	South Korea
Kim et al. (2017)	Classifies objects and properties in regulations related to building permit from the Korean Building Act and adds them to an object-name database to facilitate later use in KBimCode.	Closing	South Korea
Lee et al. (2016)	The paper describes a translation of the Korean building act into a computer-readable language.	Executing	South Korea
Zhang and El-Gohary (2017)	Develops an integrated system that transforms building codes into logic rules using NLP and allows for automatic checking of these rules by using EXPRESS data.	Validating	USA/Int
Zhang and El-Gohary (2020)	Proposes a machine learning-based approach to automatically match the building-code concepts and relations to their equivalent concepts and relations in the Industry Foundation Classes (IFC).	Executing	USA
Noardo et al. (2020)	Explores the building permit use case in collaboration with the municipality of Rotterdam. The interpretation and formalization of regulation for building height, overhang and tower ratio is proposed as preliminary results.	Executing	The Netherlands
Nawari (2012)	Examines the challenges in the computer-readable representation of building codes and standards to link them to BIM.	Conception and Initiation	Int

Table 11. LADM country profiles (2012-2020). Table by Kalogianni et al. (2021).

Country	References
Benin	Mekking et al. (2020)
Brazil	(Paixao et al. 2015; Dos Santos et al., 2013; Purificação et al.,2019)
Cabo Verde	Andrade et al. (2013)
China	(Guo et al., 2011; Zhuo et al., 2015; Xu et al., 2019)
Colombia	(Jenni et al., 2017; Morales et al., 2019; FAO, 2020a)
Croatia	(Vucic et al., 2017, 2013; Mađer et al., 2018)
Cyprus	Elia et al. (2013)
Czech Republic	Janečka and Souček (2017, 2016)
Ethiopia	Kebede et al. (2018)
Greece	(Psomadaki et al., 2016; Kalogianni et al., 2017)
Honduras	Koers et al. (2013)
Hungary	ISO (2012)
Indonesia	(ISO, 2012; Budisusanto et al., 2013; Indrajit et al., 2020)
Israel	(Felus et al., 2014; Adi et al., 2018)
Japan	ISO (2012)
Kenya	(Kuria et al., 2016; Karamesouti et al., 2018)
Korea	(ISO, 2012; Jeong et al., 2012; Kim et al., 2013; Lee et al., 2015)
Malaysia	(Zulkifli et al., 2019, 2014; Rajabifard et al., 2018; Hanafi and Hassan, 2019)
Mongolia	Buuveibaatar et al. (2018)
Montenegro	(Radulovic et al., 2015; Govedarica et al., 2018)
Morocco	Adad et al. (2020)
Mozambique	Balas et al. (2017)
Nigeria	(Abidoye et al., 2017; Babalolaa et al., 2015)
Nicaragua	FAO (2020a)
Poland	(Góźdź et al, 2014; Bydłosz, 2015; Góźdź and Van Oosterom, 2016)
Portugal	ISO (2012)
Queensland, Australia	(ISO, 2012; Karki, 2013)
Republic of Srpska	Govedarica et al. (2018)
Russian Federation	(Elizarova et al., 2012; ISO, 2012)
Saudi Arabia	Alattas et al. (2020)
Scotland	Reid (2019)
Serbia	(Radulovic et al., 2019, 2017; Govedarica et al., 2018)
Singapore	(Soon et al., 2016; Yan et al., 2019)
South Africa	(Tjia and Coetzee., 2013; Tjia, 2014)
South Korea	(Lee et al., 2015; Kim, Heo, 2017)
The Netherlands	(ISO, 2012; Kara et al., 2019)
Trinidad & Tobago	Griffith-Charles and Edwards (2014)
Turkey	(Alkan and Polat, 2017; Kara et al., 2018a)
Victoria, Australia	(Aien et al., 2012; Kalantari and Kalogianni, 2018)
Vietnam	(Le et al., 2012)

Appendix B

Relevant BIM-based Initiatives for Permit Checking

While the primary focus of this research is on compliance checks between spatial plans before the permitting phase, it is valuable to examine BIM-based permit checks, as they are more widely researched and provide useful insights into automated compliance checking methods. Both processes involve executing compliance checks against models, with the key difference being the types of models and the motivation for the checks. Compliance checks between spatial plans typically use plan information models, which reflect more comprehensive spatial frameworks, whereas BIM-based permit checks utilize design or building models to ensure that specific projects adhere to regulations. Although the motivation behind these checks differs, the underlying principles of verifying alignment with regulations remain consistent.

BIM-based permit checks have potential in the building permitting process by leveraging rule-based systems to verify that building designs comply with relevant regulations. These guidelines depend on vendor-specific standards or building codes from the government (Fauth & Seiß, 2023). Four steps form the basis of Eastman et al.'s (2009) automatic rule-based checking of building designs (Figure 90).

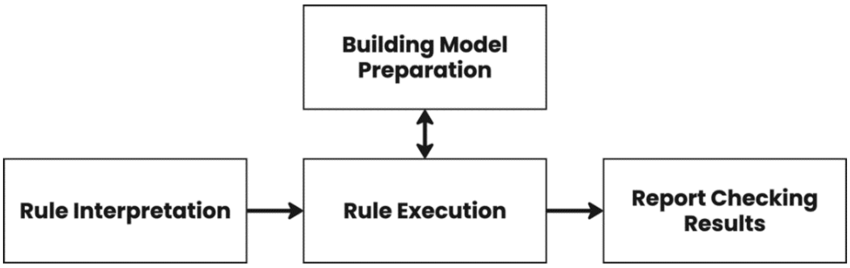

Figure 90. The functionalities of a rule system. Figure adapted from Eastman et al. (2009).

1. First, human interpreters translate regulations into a language that machines can understand.
2. Then, the designed model must be made ready for the checks before the translated rules are implemented.
3. That is, a semantic model must supply the data that is checked in the rule.

   For example, this can be done by Information Delivery Specification (IdS) checks in the case of BIM models in IFC format (Gragnaniello et al., 2024; *Information Delivery Specification (Ids)*, 2024). In this context, it is crucial to distinguish between IdS *as a comprehensive document* outlining the specifics of information requirements and structure within a BIM model, and IdS *checks*, which are implemented through an XML-based file format. The IdS checks in this case involve using the

XML-based format to assess the compliance of the IFC model with the conditions outlined in the IdS document.

4. Lastly, the results of the checks are displayed.

The first step in this complex process involves the classification of rule interpretation and digitalization of city and building regulations for permit reasons. Various approaches to accomplish this have been explored in academic research. Appendix A Table 10 presents the contributions related to rule interpretation and digitalization of city and building regulations (Noardo et al., 2022).

Furthermore, several studies have been conducted in the last decade that investigate the possible applications of BIM for building permits. The findings of the studies (Beach et al., 2020; Noardo et al., 2022; Ullah et al., 2022) emphasize the complex nature of digitalization, extending beyond technical challenges to include mindset shifts, scalability concerns, and interoperability issues. The mentioned findings highlight the complexity of incorporating BIM into building permit procedures, necessitating a refined methodology to tackle technical difficulties and wider organizational dynamics (alignment with the organizational structure and processes of the companies).

Various prototypes and frameworks for BIM-based building permit processes have been introduced in these studies, but there has been a notable gap in research regarding how regulatory/administrative bodies can successfully implement them (Beach et al., 2020; Noardo et al., 2022; Ullah et al., 2022). According to a study (Ullah et al., 2022) conducted in Estonia by Tallinn City Government (TCG) to explore the factors affecting the adaptation of a BIM based building permit process, the necessity for a structured and clear framework for the translation of the contents of codes and guidelines to a machine-readable language becomes evident. The study's results emphasize the need for a standardized structure for the representation and exchange of land administration information.

The ACCORD project (2025), which intends to construct a comprehensive and interoperable system for automated building permit checking, is an example of recent achievements in this field. AEC3PRO, an ontology created to capture the building and regulatory domain knowledge required for automated permit checking, is central to this project. AEC3PRO includes the BCRL (Building Code Rule Language), a formal language for encoding building regulations and rules (ACCORD: BCO Ontology and Rules Format, 2023). Complex building codes may be seamlessly translated into a machine-readable format with the integration of AEC3PRO and BCRL. This initiative demonstrates the ongoing efforts to bridge the gap between BIM-based models and regulatory compliance through advanced technological solutions. However, while initiatives like AEC3PRO and BCRL aim to significantly advance the automation of permit checks, they do not inherently include all the necessary information for compliance and comprehensive representation of LAS, stressing the continuing need for a framework like LADM.

In this context, using IdS (*Information Delivery Specification (Ids)*, 2024) for checking a BIM that is encoded in IFC, conforms to specific information delivery standards is feasible and has shown promising results (Gragnaniello et al., 2024). However, it's important to note that IdS checks are predominantly semantic. This means they validate the presence and correctness of data according to specified standards, but do not verify geometric accuracy or more complex aspects of the model.

The necessity for LADM arises because neither IFC nor CityGML inherently includes all the required information for comprehensive compliance checks, whether for spatial plans or building permits. LADM provides a structured framework for integrating additional data, ensuring that both geometric and semantic aspects are accurately represented. By integrating LADM Part 5 into BIM-based workflows, whether for spatial plan compliance checks or building permit checks, interoperability between different LAS modules is improved. This facilitates seamless data exchange and ensures that information is standardized across both planning and permitting processes. As a result, while BIM-based permit checks offer valuable insights for automation, LADM helps fill gaps that IFC and CityGML alone cannot address. Ultimately, this integration supports more effective and consistent land administration, laying the groundwork for both higher-level compliance checks and future advancements in automated building permit systems.

In the recent years, several initiatives have been developed to streamline the building permit process using BIM models. The following part will be an exploration on the existing research and prototypes relevant to the context discussed in previously, focusing on how these initiatives can provide valuable insights for improving compliance checks between spatial plans and for future automation in the permitting process.

ACCORD (2022-2025)

ACCORD is a Horizon Europe initiative aimed at automating building permit and compliance processes through the use of BIM and additional data sources. The project is developing a Semantic Framework to be showcased in five real-life projects across Europe, specifically in Finland, Estonia, Germany, the UK, and Spain. (*ACCORD*, 2024). These demo projects primarily focus on automated BIM-based building permits, with special attention to environmental compliance (ACCORD: Framework and User Requirements Specification, 2023). ACCORD focuses on creating a rule formalization tool, which allows regulations to be standardized into a rule representation format and stored in a ruleset database. Additionally, the project aims to develop Compliance

Checking Microservices to support various use cases, all accessible through open standardized APIs. These APIs enable integrated dataflows between building permitting, compliance, and other information services.

CHEK (2022-2025)

The CHEK project is another EU-funded Horizon Europe initiative which started in October 2022. CHEK aims to provide a methodology and technological tools to advance the digitization of building permits and automate compliance checks for building projects. CHEK involves a comprehensive study of the current building permit processes across several municipalities in Europe, including Ascoli Piceno (Italy), Lisbon and Vila Nova de Gaia (Portugal), Prague (Czech Republic), Skopje (North Macedonia), and South Tyrol (Italy) (CHEK: Digital Building Permit Process Map, 2023). The project aims to develop a standardized digital building permit process that integrates BIM and GIS tools. This new process plans to increase the efficiency of building permit issuance, ensuring compliance with regulatory standards through semi-automated checks. The project identifies common stages in the BIM-based building permit process, such as information collection, pre-checking, BIM validation, submission, automated rule-checking, visual review, approval and issuance, construction, as-built update, and final update to the city model.

RAVA3Pro (2021-2023)

RAVA3Pro is another initiative that emphasizes the use of advanced rule-based validation techniques for building permit applications. Funded by the Ministry of Environment of Finland and the project involves 23 cities. It aims to automate the compliance checking of BIM-based building permits. The project focuses on developing national property sets, use cases, and checking rules for the BIM-based building permit process. It includes piloting automated code checking solutions using cloud-based platforms like *Cloudpermit* and Trimble *ePermit* and integrating these solutions with the National Built Environment Information System (RYTJ) (Kallinen, 2023). The project's goals include automating the checking of BIM-based building permits against regulations, establishing a cloud-based information exchange and communication platform, and creating national requirements for IFC files and use cases. The project also involves piloting the use of IFC files for urban planning and zoning measurements, as well as developing national IFC checking rules for the building permit process.

BIM Based permit check – Estonia (2018-2021)

The BIM Based Permit Check project in Estonia, initiated by the Ministry of Economic Affairs and Communications of Estonia and Future Insight Group, aimed to advance the digitalization of the building permit process by integrating BIM-based workflows. It involved assessing existing building permit procedures and proposing improvements to increase efficiency and compliance accuracy. The focus was on developing a proof of concept (PoC) for using BIM in permit checking, which included creating and testing conceptual frameworks for future real-world applications (Future Insight Group, 2021). During the project, particular emphasis was placed on using open standards, specifically IFC models. Integration with the National Building Register (EHR) was also a crucial aspect, facilitating seamless data exchange and interoperability between systems. Multiple pilot projects were conducted across various municipalities to assess and validate the developed concepts. Even though just a PoC, the project demonstrated significant potential for improving the efficiency and accuracy of the building permit process and laid the foundation for further development.

Appendix C

Interview Questions

1. Introductions: Name, company, function, consent
2. What does the current planning process look like from your point of view?
3. What is your role within this process?
4. Which software do you use in this process?
5. Are you using any of the following products in the planning process?
    a) EHR 3D Twin
    b) PLANK
    c) Land-Board Geodata
    d) BIM product
    e) Any local municipality data platform or a geoweb
    f) Other products not mentioned yet
6. Which data do you use in this process? And where do you get this data?
7. Which data would help in the planning process but is not available/takes too much time to gather at the moment?
8. What part of the process takes the most time?
9. Are there any parts in the process that are prone to human error in your opinion?
10. Are there certain steps in the process for which you think this would be suitable?
11. What data (2D/3D) would be needed to make this feasible and is this data already available?
12. What would be the effect (in sense of time/money) of the addition of a BIM check on this step in the process?
13. How ready do you think the market is for the introduction of BIM checks in the planning process?
14. How could the BIM checks be integrated into the current processes?
15. What do you think are the bottlenecks for using the BIM checks in practice and in legislation?

(All questions belong to Future Insight Group)

Appendix D

Table 12. Estonian Master Plan data layer requirements[26]. (Translated to English)

Core Layer Name	Name	Division Layers	Mandatory	Spatial Data Requirements	Smart Data	Point	Line	Surface
plan_ala	Planning Area	-	Mandatory	-	Mandatory	-	-	Allowed
yp_arhVoistlus	Area with Mandatory Architectural Competition for Detail Planning	Allowed	-	-	-	Allowed	-	Allowed
yp_DPKoKo	Area with Mandatory Detail Planning	-	-	-	-	-	-	Allowed
yp_EKV	Construction Prohibition Zone Increase or Decrease	Allowed	-	-	-	-	-	Allowed
yp_jaade	Waste Management	Allowed	-	-	-	Allowed	-	Allowed
yp_juurdep	Access	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_kaldaehitis	Water and Shore Construction	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_kallasrada	Shore Path Closure and Modification	Allowed	-	-	-	-	Allowed	Allowed
yp_KKTingimus	Area with Environmental Condition Set by Master Plan	Allowed	-	-	-	-	-	Allowed
yp_KOVKultparand	Local Cultural Heritage or Heritage Conservation Object	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_KOVLoodus	Local Government Nature Conservation Proposal	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_maakas	Land Use Purpose	Allowed	-	-	-	-	-	Allowed
yp_maapar	Land Improvement Systems	Allowed	-	-	-	-	-	Allowed
yp_maavara	Restriction from Mineral or Mining	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_ORME	Construction with Significant Spatial Impact	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_puhke	Recreation and Leisure Area	Allowed	-	-	-	-	-	Allowed
yp_rand	Beach	Allowed	-	-	-	-	-	Allowed
yp_rohev	Green Network	Allowed	-	-	-	-	-	Allowed
yp_strateegia	Strategic Principle Areas	Allowed	-	-	-	-	-	Allowed
yp_sund	Need for Expropriation in Public Interest	Allowed	-	-	-	Allowed	Allowed	Allowed

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[26] https://www.riigiteataja.ee/aktilisa/1211/0202/2002/RM_m50_lisa3.pdf#

yp_tehno	Technical Construction	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_tiheas	Dense Settlement Area	-	-	-	-	-	-	Allowed
yp_tingimus	Condition Set by Master Plan	Allowed	-	-	-	-	-	Allowed
yp_transp	Transportation Construction or Area	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_vaartMaastik	Valuable Landscape	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_vaartMiljoo	Valuable Milieu	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_vaartPollum	Valuable Agricultural Land	Allowed	-	-	-	-	-	Allowed
yp_vaartRohe	Valuable Green Area	Allowed	-	-	-	-	-	Allowed
yp_vaartVaade	Valuable Views	Allowed	-	-	-	Allowed	Allowed	Allowed
yp_veehaare	Water Intake	Allowed	-	-	-	Allowed	-	Allowed
yp_yleujutus	Flood Area or High-Water Limit	Allowed	-	-	-	-	Allowed	Allowed

Table 13. Estonian Master Plan data attribute requirements[27]. (Translated to English.)

Layer Name	**Attribute (Column Name)**	**Data Type**	**Explanation**	**Mandatory**	**Condition for Mandatory**
yp_EKV	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
yp_jaade	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
yp_juurdep	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
yp_kaldaehitis	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.

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[27] https://www.riigiteataja.ee/aktilisa/1211/0202/2002/RM_m50_lisa6.pdf#

	tingimus	text	Conditions.	-	-
yp_KOVKultparand	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
	voond	integer|fraction	Width of the protection zone.	-	-
yp_KOVLoodus	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
	voond	integer|fraction	Width of the protection zone.	-	-
yp_maakas	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	tingimus	text	Land use conditions.	-	-
	tahis	text	Symbol for main purpose.	-	-
	juhtots	text	Main purpose.	-	-
yp_maapar	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
yp_maavara	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
yp_ORME	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
yp_puhke	objectID	integer|text	Object identifier.	Mandatory	-

	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.	-	-
yp_rand	objectID	integer|text	Object identifier.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-
	nimetus	text	Object name.	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Conditions.		

Table 14. Estonian Detailed Plan data requirements[28]. (Translated to English)

Core Layer Name	Name	Division Layers	Mandatory	Spatial Data Requirements	Smart Data	Point	Line	Surface
plan_ala	Planning Area	-	Mandatory	-	Mandatory	-	-	Allowed
dp_arhVoistlus	Area Requiring Architectural Competition	Allowed	-	-	-	-	-	Allowed
dp_avalik	Area Planned for Public Use	Allowed	-	-	-	-	Allowed	Allowed
dp_haljastus	Landscaping and Maintenance	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_hoonestus	Building Area	Allowed	Mandatory	Building area must be entirely within the plot connected to the annotation data	-	-	-	Allowed
dp_juurdep	Access	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_KKTingimus	Environmental Condition Area	Allowed	-	-	-	-	-	Allowed
dp_KOVLoodus	Local Government Nature Conservation Proposal	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_krunt	Plot	-	Mandatory	The spatial shape of an object cannot be a collection of surfaces. At least one geometry per layout.	Mandatory	-	-	Allowed
dp_krundiSihtotstarve	Plot Purpose	-	Mandatory	-	Mandatory	-	-	-
dp_maapar	Land Improvement System	Allowed	-	-	-	-	Allowed	Allowed
dp_servituut	Easement Need	Allowed	-	-	-	Allowed	Allowed	Allowed

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[28] https://www.riigiteataja.ee/aktilisa/1211/0202/2002/RM_m50_lisa3.pdf#

dp_sund	Need for Acquisition in Public Interest	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_tehno	Technical Construction	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_tingimus	Condition Set by Plan	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_transp	Transportation Construction or Area	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_vaartloodus	Natural Value	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_vaartMiljoo	Milieu Value	Allowed	-	-	-	Allowed	Allowed	Allowed
dp_vaartPollum	Valuable Agricultural Land	Allowed	-	-	-	-		Allowed

Table 15. Estonian Detailed Plan data attribute requirements[29] . (Translated to English.)

Layer Name (Worksheet)	Attribute (Column Name)	Data Type in Column	Explanation	Filling Rules	Mandatory	Condition for Mandatory
plan_ala	planLiik	integer|text	Plan type identifier	Values from plan type classifier	Mandatory	-
	sysID	integer	Planning identification number in database	-	Conditionally Mandatory	Required if number is reserved or if changes are submitted
	kovID	text	ID or identifier of the planning activity organizer	-	Conditionally Mandatory	Required if issued by the planning activity organizer
	muutev	text	Modifying a more general plan	yes\nno	Mandatory	-
	planEesm	text	Main objective of the plan, similar to the establishment decision	-	Mandatory	-
	planID	integer	Cadastral administrator's planning identification number	-	Conditionally Mandatory	Required if issued by the cadastral administrator
	planKSH	text	Strategic environmental assessment conducted during the process	yes\nno	Mandatory	-
	planNim	text	Plan name as given in the establishment decision	-	Mandatory	-
	planViide	text	Web link to the plan at the organizer's website	-	Conditionally Mandatory	Required if a public web link to the plan is available
	algatKp	date	Date of plan initiation	-	-	-
	vastuvKp	date	Date of plan acceptance	-	-	-

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[29] https://www.riigiteataja.ee/aktilisa/1211/0202/2002/RM_m50_lisa4.pdf#

dp_vaartPollum	objectID	integer|text	Object identifier	Unique within the base layer at least	Mandatory	-
	jaotuskiht	text	Distribution layer for GIS formats	-	-	-
	tingimus	text	Description of conditions	-	-	-
dp_vaartMiljoo	objectID	integer|text	Object identifier	Unique within the base layer at least	Mandatory	-
	jaotuskiht	text	Distribution layer for GIS formats	-	-	-
	nimetus	text	Object name	-	Conditionally Mandatory	Mandatory if distribution layers are not used
	tingimus	text	Description of conditions	-	-	-
dp_vaartLoodus	objectID	integer|text	Object identifier	Unique within the base layer at least	Mandatory	-
	jaotuskiht	text	Distribution layer for GIS formats	-	-	-
	nimetus	text	Object name	-	Conditionally Mandatory	Mandatory if distribution layers are not used
	tingimus	text	Description of conditions	-	-	-
dp_transp	objectID	integer|text	Object identifier	Unique within the base layer at least	Mandatory	-
	voond	integer|fraction	Width of the protection zone	Unit: meter	-	-
	jaotuskiht	text	Distribution layer for GIS formats	-	-	-
	kujaTing	text	Conditions of the corridor, such as spacing	Unit: meter	-	-
	nimetus	text	If all road and street elements are presented on one layer, it is mandatory to indicate which object it is	-	Conditionally Mandatory	Mandatory if distribution layers are not used
	tingimus	text	Description of conditions	-	-	-
dp_tingimus	objectID	integer|text	Object identifier	Unique within the base layer at least	Mandatory	-
	jaotuskiht	text	Distribution layer for GIS formats	-	-	-
	nimetus	text	Object name	-	Conditionally Mandatory	Mandatory if distribution layers are not used
	tingimus	text	Description of conditions	-	-	-
dp_tehno	objectID	integer|text	Object identifier	Unique within the base layer at least	Mandatory	-
	korgus	integer|fraction	Relative height above ground	Unit: meter	-	-
	korgusAbs	integer|fraction	Absolute height	Unit: meter	-	-
	maxKorgAbs	integer|fraction	Maximum allowed absolute height	Unit: meter	-	-
	maxKorgus	integer|fraction	Maximum allowed relative height above ground	Unit: meter	-	-

	maxSygavus	integer|fraction	Maximum allowed depth in meters is relevant for buildings or significant public interest facilities	Unit: meter	-	-
	minKorgAbs	integer|fraction	Minimum allowed absolute height	Unit: meter	-	-
	minKorgus	integer|fraction	Minimum allowed relative height above ground	Unit: meter	-	-
	minSygavus	integer|fraction	Minimum allowed depth in meters is relevant	Unit: meter	-	-
	sygavus	integer|fraction	If depth in meters is relevant	Unit: meter	-	-
	voond	integer|fraction	Width of the protection zone	Unit: meter	-	-
	jaotuskiht	text	Distribution layer for GIS formats	-	-	-
	kujaTing	text	Conditions of the corridor, such as spacing	Unit: meter	-	-
	nimetus	text	Object name	-	Conditionally Mandatory	Mandatory if distribution layers are not used
	tingimus	text	Description of conditions	-	-	-
dp_haljastus	objectID	integer|text	Object identifier.	Unique at least within the core layer.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-	-
	nimetus	text	Object name.	-	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Description of land use and building conditions.	-	-	-
	kujaTing	text	Corridor conditions, e.g., spacing.	Unit: meter	-	-
dp_arhVoistlus **dp_juurdep** **dp_KKTingimus** **dp_maapar** **dp_KOVLoodus**	objectID	integer|text	Object identifier.	Unique at least within the core layer.	Mandatory	-
	jaotuskiht	text	Classified distribution layer for GIS formats.	-	-	-
dp_servituut **dp_avalik dp_sund**	nimetus	text	Object name.	-	Conditionally Mandatory	Mandatory if no distribution layers are used.
	tingimus	text	Description of land use and building conditions.	-	-	-
	tingimus	text	Conditions.			

Appendix E

Reflection on Key Lessons and Recommendations Based on the Case Study

The project *"Detailed analysis of the use of the information model of the plan and creation of a prototype solution"* of Future Insight Group with Estonia's Ministry of Climate not only developed a prototype for automating compliance checks but also provided valuable insights into the existing situation and areas for improvement in Estonia's spatial planning process. Based on these findings, several key lessons and recommendations were identified by Future Insight to make the system more efficient, standardized, and scalable (Future Insight Group, 2024):

1. **Standardization and Central Availability**: The adoption of 3D data in Detailed Plans is not yet standard, and agreements are needed on central availability and standardization of such data to enable automation on a larger scale.
2. **Regulation Interpretation**: Translating planning rules into automated checks requires collaboration to ensure clear and accurate interpretation of regulations, which is critical for creating reliable automated verification processes.
3. **Simplicity in Visualization**: Visualizing check results can quickly become complex. It's important to maintain simplicity and standardization in visualizations, focusing on core messages to avoid confusion.
4. **Consistent Delivery of Check Results**: Clear agreements should be made about the format of check results (e.g., ID, description, result) and use of standard formats like 3D Tiles or CityGML databases for storing results to ensure scalability and flexibility.
5. **Consistent Color Associations**: Using common color associations such as green (pass), yellow (warning), and red (fail) helps users easily interpret check results. Reference layers should be kept neutral to ensure the results are highlighted.
6. **Streaming and Zooming**: Streaming formats like 3D Tiles enhance the ability to zoom into check results, making it more efficient. Future improvements could allow for more specific toggling of check results to make them clearer.
7. **Validation of Objects Before Checking**: Ensuring that objects are validated before running checks improves the reliability of results. IFC model designers should validate models to ensure optimal check outcomes and prevent disputes.
8. **Collaboration with IFC Model Designers**: Collaborating closely with IFC model designers helped improve the checks and provided insights into potential requirements for future IFC models, making the process more adaptable.

9. **Clear Interpretation of Rules for Accurate Checks**: The accuracy of check outputs depends heavily on how the rule is interpreted. Iterating through checks with the project team helped ensure a common understanding of rule interpretation and check results.
10. **Standardization of Master Plan Requirements**: Standardizing Master Plan requirements (e.g., greenery percentages, building distance) will improve the scalability and reliability of automatic checks by providing consistent data inputs for detailed plans.
11. **Alignment of Plot Data**: Matching plot data between IFC models and WMS services remains a challenge, and improving the alignment of these datasets would enhance the accuracy of checks.
12. **Unique Object Identifiers**: The use of unique Object IDs across all disciplines and layers is essential to avoid confusion during checks. Using *GlobalID* or prefixed *ObjectID* ensures proper identification of objects.
13. **Future Exploration of IFC Entities and 3D Formats**: While the current prototype used *IfcBuildingElementProxy* and *IfcAnnotation*, future exploration of more specific IFC entities or alternative formats like CityGML could improve the handling of planned zoning objects and expand the use of 3D data.
14. **Database Integration for Scalability**: Importing IFCs into a PLANK or LADM database after validation and running checks from the database could improve long-term scalability, version control, and data management for the checks.

Appendix F

Reflection on Reviews and Research Insights

In this section, the reviews from external academic and professional experts are reflected upon and addressed. Following this, the author's critical reflection on the research in general will be presented.

Review 1: *What is the research about—interoperability of different types of spatial plans, or automated checks of detailed architectural and engineering plans submitted for a building permit?*

Comment 1: The thesis focuses on the interoperability of different types of spatial plans and their automated compliance checks before the permitting stage. The scope is limited to compliance checking between higher-level spatial plans (such as Master Plans) and lower-level plans (such as Detailed Plans), and some checks requiring only Detailed Plans for local rules. These checks ensure the plans adhere to broader regulations. While the research draws on techniques often used in automated checking for building permits (Appendix B), the focus remains on spatial plans, not detailed building design or permit plans. The overlap in methodologies may have caused confusion, but this research addresses the gap that exists *before* the permitting process, ensuring spatial plans comply with various regulatory levels.

Review 2: *Can you elaborate on Estonia's transition to 3D IFC data and its practical implications for the compliance checks?*

Comment 2: Estonia is in the early stages of transitioning from 2D spatial planning to the use of 3D data in formats like IFC. Traditionally, spatial plans have been managed as 2D CAD drawings for design (3D for renders), often supplemented by separate textual documents, such as Excel sheets, which makes interpretation and application cumbersome. The stakeholders interviewed in the case study highlighted the difficulties that arise from the lack of structured, reusable data and the inconsistencies between 2D drawings and accompanying documents. As 3D data becomes more widespread, there is a clear need for standardized approaches to ensure that this data can be effectively used across municipalities and planning departments. The transition to IFC format is particularly promising, as it offers a more detailed and structured representation of spatial plans, enabling more precise compliance checks for parameters like building heights and distances. However, this shift will require concerted efforts in standardization, training, and collaboration across different sectors.

The research contributes to this developing setting by demonstrating how IFC-encoded 3D spatial plans can be integrated with the LADM Part 5 framework to streamline compliance checks. By providing a standardized approach, it helps pave the way for more efficient and accurate planning processes, supporting Estonia's goal of adopting 3D spatial data.

Review 3: Can you e*laborate on how the main challenges that the spatial planning community currently faces are going to be resolved by the research?*

Comment 3: The spatial planning community in Estonia currently faces several critical challenges, many of which were highlighted in the stakeholder interviews. These include the lack of standardization across different municipalities, the reliance on 2D plans that often lack sufficient detail for compliance checks, and the difficulties associated with interpreting various formats of planning data, which often leads to inefficiencies and errors. One major issue raised was the cumbersome nature of managing spatial plans in multiple formats (e.g., 2D CAD drawings, text documents, spreadsheets), which complicates cross-departmental collaboration and compliance checks (investigated in section 5.4).

This research addresses these challenges by introducing LADM Part 5 as a standardized framework specifically designed for spatial plans. LADM Part 5 promotes seamless interoperability between different plan types and data formats, ensuring consistency across various planning levels (e.g., Master Plans, Detailed Plans) and between national and local regulations. By integrating 3D IFC models with LADM, the research helps move beyond the limitations of traditional 2D planning, offering a more detailed and structured representation of spatial data that can be used for automated compliance checks. This shift will allow spatial planners to conduct more precise, efficient, and consistent checks across different municipalities and planning departments.

Moreover, during the interviews conducted for the case study, stakeholders highlighted the need for improved data exchange and collaboration between various planning authorities. By implementing LADM Part 5, the research lays the groundwork for a unified approach to storing, managing, and validating spatial plans. This framework will enable Estonia's spatial planning community to tackle issues related to data inconsistencies and lack of collaboration, ultimately leading to more transparent, accurate, and efficient planning processes. In the long term, this contributes to Estonia's digitalization efforts and helps set the stage for future developments in automated compliance checks.

Review 4: *Why was Estonia selected as a case study and not another country?*

Comment 4: Estonia was chosen as a case study for several strategic reasons. Despite the absence of a 3D planning system or an established LADM country profile, Estonia's position as one of the most advanced digital societies makes it an ideal candidate for testing new digital frameworks. The country is known for its ambitious digital initiatives, including e-governance and innovative solutions in various sectors, which align well with the research objectives. Estonia is actively pursuing future developments in spatial planning, particularly in digitalizing its planning processes, which provided an excellent opportunity to introduce LADM Part 5 for compliance checking.

Additionally, Future Insight, the company collaborating on this research, was already engaged in a project focused on automated compliance checking for spatial plans in Estonia. This ongoing work presented a valuable real-world context for applying and testing the framework developed in the thesis. By building on this existing groundwork, the research could leverage real data and processes in Estonia, allowing for meaningful contributions that could benefit both the academic community and Estonia's planning authorities.

Although other countries, such as the Netherlands, have more developed 3D spatial planning systems or LADM profiles, the novelty of LADM Part 5 related to spatial plans means that its application is still in its early stages globally. Estonia's lack of an existing profile and 3D system actually provided more flexibility to explore how a country profile could be developed from scratch and integrated into its planning framework. In contrast, countries with established profiles might have offered less opportunity for innovative, foundational work for integrating LADM Part 5 with their existing profiles. Thus, this makes the case study both relevant and forward-looking, with the potential for Estonia to serve as a model for other countries in the future.

Review 5: *The implementation phase presents that LADM can work for a theoretical case in Estonia for one type of plan (Detailed Plans). How is this relevant to the research?*

Comment 5: The relevance of the LADM implementation for Detailed Plans in Chapter 5 lies in its contribution to ensuring interoperability between spatial plans at various planning levels. While the research primarily focused on encoding Detailed Plans in IFC, Master Plan data was also provided as WFS and WMS services. However, the use of WFS/WMS data for Master Plans and the integration of compliance check scripts with the LADM database were outside the primary focus of the study, which centered on BIM-based 3D spatial data.

Despite this, the LADM profile and database were designed to accommodate both

Master and Detailed Plans, ensuring that the necessary attributes and structures for compliance checks across different planning levels were integrated into the system. This also aligns with the Estonian centralized database PLANK, providing the structural foundation for performing checks between these levels. In the future, WFS/WMS data formats can be integrated into the import scripts to extend the research and include additional plan types.

While Chapter 5 did not investigate the direct integration of compliance check scripts or the importation scripts for the Master Plans, the research proposes a new pipeline that simplifies the process by utilizing the LADM-based database as the starting point. The initial checking scripts, which were more specific to the dataset and checks required, would need to be adapted to use the LADM database as the source of input data. This adjustment sets the stage for standardized, streamlined and scalable compliance-checking process.

Furthermore, as demonstrated in section 5.3, some compliance checks can be directly executed within the database using SQL queries. This allows for efficient validation and returns results in a tabular format rather than 3D visualizations. While this approach reduces the graphical representation of the checks, it significantly simplifies the process and provides faster results for certain types of compliance queries.

The key advantage of the approach suggested in the research is that the cumbersome data extraction and validation scripts would no longer be required. Once the spatial plans are imported into the centralized LADM database, the compliance check scripts can directly access validated and structured data, streamlining the entire process. Although the final results of the compliance checks or visualizations would not change, this new pipeline would significantly reduce complexity, improve efficiency, and simplify scalability. Therefore, the research provides a practical starting point for implementing more efficient compliance checks and sets the stage for future developments involving both Master and Detailed Plans.

Review 6: *What are the advantages of 3D data in compliance checking? Additionally, what was the motivation behind selecting BIM/IFC as the focus of the research?*

Comment 6: The shift to 3D data brings significant advantages in compliance checking, particularly when it comes to accurately representing the spatial relationships and complexities of detailed plans. One of the primary advantages is the ability to capture both geometric and semantic information in a more structured and integrated way. 3D models, especially those based on the IFC format, enable detailed visualization and provide the necessary information for conducting precise compliance checks. These models contain rich geometric and semantic data, such as building heights, distances, and spatial relationships, which can be easily extracted and validated against planning regulations. This level of detail and integration is difficult to achieve with traditional 2D methods, where such information may need to be gathered or manually processed.

Furthermore, 3D data allows for more automated processes by embedding metadata directly into the model. This reduces the reliance on fragmented external data sources like CSV files, as highlighted in the investigation of Estonia's existing 2D system in section 5.4. With 3D models, both the geometric and semantic data are stored together, streamlining the validation process and making it easier to automate compliance checks.

The motivation for selecting BIM/IFC as the focus of this research stems from its widespread adoption in the AEC sector and its potential for enabling interoperability across different platforms. IFC, as an open standard, supports detailed data exchange and is already used extensively in building design (as highlighted previously in section 0). By extending its application to spatial planning, the research aimed to leverage the rich semantic and geometric capabilities of IFC to improve compliance-checking workflows. Additionally, the growing global interest in BIM for urban planning made IFC a logical choice for exploring how Estonia could advance its digital planning framework.

In the context of Estonia, where much of the spatial planning data is still in 2D, the introduction of 3D models offers an opportunity to bridge the gap between current practices and future digital developments. While the research focused on 3D IFC data for Detailed Plans, it also recognized the limitations of the current 2D-based system. The LADM-based framework proposed in the research provides a foundation for integrating both 2D and 3D data in the future, allowing for a more unified and scalable approach to spatial plan management and further compliance checking.

Reflection on the Research

The study focused on integrating LADM Part 5 with spatial plan data, particularly in automating compliance checks between different levels of plans and local rules when necessary. The methodology proved effective in achieving the primary objective of streamlining the compliance checking process. The research deliberately focused on Detailed Plans encoded in IFC format, while Master Plan data, provided as WFS/WMS services, was outside the scope of the implementation phase due to its format and the research's emphasis on BIM/IFC data. This left the integration of WFS/WMS services for Master Plans open for future exploration.

Despite this scope limitation, the research contributes significantly by demonstrating how automated compliance checks can improve both efficiency and standardization in early spatial planning processes. By focusing on Detailed Plans, the study provides a practical starting point for implementing automated checks while also laying the foundation for future integration of Master Plans. Although the implementation was specific to Estonia, the methods and results offer broader applicability, with the potential for adaptation to other jurisdictions seeking similar improvements in their spatial planning processes.

The ethical considerations of automating compliance checks were also an important aspect of this research. While automation enhances efficiency, it may raise concerns regarding transparency and accountability. The decision-making processes behind the checks must be clear and accessible to stakeholders to avoid creating an opaque system. Additionally, while automation reduces manual errors, human oversight remains crucial, particularly in complex cases where automated systems might lack the necessary context. Balancing these elements ensures that the implementation of such systems is both efficient and ethically responsible.