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Key words: Land Administration, Spatial Plans, Digital Permitting, LADM, IFC, BIM

SUMMARY

This research explores the integration of IFC with LADM Part 5 Spatial Plan Information (ISO DIS 19152-5) to standardize BIM-based permit checking processes, focusing on a case study from Estonia. Land Administration Systems (LAS) are crucial in spatial development, managing land-related information. Rapid urbanization necessitates efficient space management, promoting the adoption of digital technologies in the Architectural, Engineering, and Construction (AEC) sector. The integration of Geographic Information Systems (GIS) and Building Information Modelling (BIM) presents opportunities for enhanced collaboration and data management. The main aim is to enhance efficiency, interoperability, and standardization in the compliance checks between different plan levels (e.g., Detailed Plan vs Mater Plan) by incorporating LADM Part 5 into digital frameworks. Traditional permit processes are often manual, time-consuming, and prone to errors. By integrating LADM Part 5 with IFC data, this research aims to create a standardized approach that not only improves data management and facilitates seamless information exchange but also maximizes industry and technical support to ensure compliance with international standards.

The methodology involves several key steps. First, a country profile for Estonia using LADM Part 5 is developed, tailored to the specific needs of the Estonian LAS. This profile integrates with PLANK, the Estonian spatial plan database, incorporating how Estonia acquires, stores, and requires data in their spatial plans. Next, a PostgreSQL database is created to store this profile. Pilot Detailed Plan datasets encoded in IFC format are then imported into the database using FME scripts, mapping the data to relevant sections. This integrated database supports digital permitting processes, specifically plan compliance checks between different levels of spatial plans. Throughout the research, the country profile is refined based on the optimizations of the database, driven by the specific requirements of the input data processed through FME scripts. Given that LADM is a standardized model, the database enforces specific data structures, ensuring processed data is valuable and relevant. The FME scripts facilitate this process, ensuring the data extracted from the database is standardized and user-friendly. Constraints such as maximum building height restrictions are pre-processed and stored within the database, enabling users to access this information without manually reviewing raw plan data. Later, the database was sampled using pilot datasets, with the tools

and scripts made available on the research’s GitHub repository. After storing the spatial plan data in the database, data can be directly accessed by scripts designed to execute compliance checks between Detailed Plans and Master Plans, as shown in the Estonia case study. Although developing these specific checks is beyond this research's scope, the work was structured to integrate smoothly with the processes used in the Estonia case study.

Preliminary findings show that combining LADM with IFC improves data representation, enhances interoperability, and establishes a consistent standard for compliance checks between Master and Detailed Plans. This research contributes to developing standardized, reliable, and efficient permit checking systems, with important implications for urban planning and land management.

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1. INTRODUCTION

Spatial development and rapid urbanization necessitate efficient Land Administration Systems (LAS) to manage and govern land-related information. The integration of Geographic Information Systems (GIS) and Building Information Modelling (BIM) presents new opportunities for enhanced collaboration and data management in the Architectural, Engineering, and Construction (AEC) sector. Traditional permit processes are often manual, time-consuming, and prone to errors. Utilizing digital technologies and standards can enhance the efficiency, transparency, and reliability of these processes. This research aims to improve the compliance checking and permitting process by incorporating the Land Administration Domain Model (LADM) Part 5: Spatial Plan Information with IFC.

Despite the potential benefits, translating complex urban regulations into a machine-readable format for automated permit checks remains a challenge. This research addresses this challenge by integrating LADM Part 5 with IFC to create a standardized approach for BIM-based permit checking. The research focuses on developing a country profile for Estonia using LADM Part 5, creating a PostgreSQL country profile database, and importing Detailed Plans encoded in IFC formats to the database. The Estonia case study serves as a reference point for developing and assessing the implementation.

The study follows a Design Science Research approach (Hevner & Chatterjee, 2010), involving three main stages: reviewing existing literature and standards to define the problem and gather knowledge; developing a conceptual model for integrating LADM and BIM, and mapping relevant data for the Estonia case study; implementing the model, creating an FME script and a PostgreSQL database, and continuously refining the model based on feedback and assessment results. This methodology ensures a structured approach to addressing the research questions and developing a practical solution for automated permit checking.

The paper is structured as follows: Section 2 presents the related research on LADM Part 5 and BIM-based permits. Section 3 details the case study of Estonia, including the development of the country profile and the database implementation. Section 4 discusses the integration process and the results of applying the model to the case study. Section 6 evaluates the system's effectiveness and compliance with international standards, while Section 7 concludes the research and outlines potential directions for future work.

2. RELATED RESEARCH

2.1 LADM Part 5 and its Implementations

The Land Administration Domain Model (LADM), provides a comprehensive framework for land administration, systematically recording and disseminating information about land ownership, value, use, and the relationship between people and land(Simon Hull et al., 2024; UNECE, 1996). In its latest revision, LADM has evolved into a multi-part standard known as LADM Edition 2. Among its various parts, Part 5 focuses on integrating land registry and planned land use information into a single conceptual model (Lemmen et al., 2023).

LADM Part 5 supports planning hierarchies, organizes plan units in a plan block, provides extensible code lists for spatial functions, supports permit registration related to relevant plan units, and allows open dissemination and clear 2D and 3D visualization of plan information. This integration ensures a comprehensive approach to land management by linking land tenure with spatial information (Indrajit et al., 2020). The primary goal is to document the rights, restrictions, and responsibilities (RRRs) associated with spatial plans, ensuring compatibility with data from land tenure, value, and development activities (Indrajit et al., 2021).

LADM country profiles are tailored versions of the standard that align with specific local land administration needs and systems. For instance, the Indonesian country profile integrates spatial planning information with land administration, addressing dynamic land use and urban planning needs (Indrajit et al., 2020). The Malaysian profile integrates 2D and 3D cadastral registration systems, enhancing information interoperability and supporting the National Spatial Data Infrastructure (SDI) (Zulkifli et al., 2014). These country profiles demonstrate the flexibility and adaptability of LADM to different national contexts, facilitating efficient land administration adapted to their specific requirements.

2.2 BIM-based Permit Checks

Building Information Modelling (BIM) creates a 3D representation of an asset with both physical and functional information. BIM serves as a shared knowledge resource for decisions throughout a facility's life cycle, from conception to demolition (Kubba, 2012). It incorporates various dimensions, such as 4D (time), 5D (costs), and 6D (asset management), and uses an object-oriented and information model to distinguish between elements like walls, doors, and windows.

BIM-based Model Checking (BMC) automates the building permit process by using algorithms to process BIM data and verify compliance with relevant building regulations. This approach increases the speed and accuracy of permit verification by supporting human decision-making and automating time-consuming and error-prone tasks (Beach et al., 2020; Gade et al., 2018). Traditional permit processes involve manually checking plans for compliance, which is time-consuming and prone to errors. BMC replaces this manual process with automated checks, ensuring that BIM models comply with regulations and standards. The use of BIM for building permits offers several advantages, including enhanced data representation, interoperability, and standardization. Combining BIM data with LADM Part 5 aims to create a standardized approach for permit checking. BIM data, encoded in the Industry Foundation Classes (IFC) file format, serves as a universal language for exchanging information across different software applications (Industry Foundation Classes (IFC), n.d.).

IFC data can be mapped to LADM Part 5 classes, ensuring a comprehensive approach to spatial planning and permit checking. Combining various data models can enhance the functionality and interoperability of digital permitting systems.
It should be noted that, the IFC files used in the Estonia case study, representing Detailed Plans, were specifically created for this research in collaboration with Future Insight and Estonia. Currently, Estonia primarily uses 2D data such as CAD for spatial plans. Despite this, IFC, being a widely adopted standard in the AEC industry, provides a robust framework for representing and exchanging building information. This makes it a suitable choice for this research, allowing for the seamless integration of Detailed Plans and spatial data into the LADM database. The integration of IFC in this pilot project was aimed at investigating the potential future use of 3D data in urban planning and permit checks, even though it is not yet the standard practice in Estonia. This exploration serves as a theoretical step towards possibly combining IFC data with existing 2D practices, paving the way for the future development in Estonia.
In summary, combining LADM with IFC enhances data representation, promotes interoperability, and facilitates the creation of standardized permit checking systems.

3. CASE STUDY: ESTONIA

This research is conducted in collaboration with Future Insight B.V. 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. This project is a follow-up project of Future Insight for automated BIM-based building permit checks, which laid the foundation for automated BIM-based permit checks in Estonia. The primary objective is to develop a prototype for plan compliance checks between Detailed Plans and Master Plans using IFC models and integrating with the Estonian e-construction platform. The project aims to address the need that Detailed Plans align with higher-level zoning regulations before the building permit issuance phase. This process occurs early in the planning lifecycle in Estonia and is designed to tackle any inconsistencies or non-compliance with zoning regulations before any construction begins. This helps ensure that the initial plan is compliant, reducing potential issues in later stages of the construction and registration processes.
The digitization of the planning process in Estonia advanced significantly with the introduction of PLANK in 2022, a centralized database mandated by the Spatial Planning Act. This regulation ensures that all established spatial plans from the 79 municipalities are accessible in digital form, containing the necessary digital information and meeting spatial data quality standards. PLANK's main goals include reducing the burden on municipalities, ensuring up-to-date plans, dissemination with stakeholders (including citizens) and facilitating the collaborative use of planning data with other information systems. The database features automatic validation checks that verify the validity and integrity of plans, allowing only validated plans to be shared and displayed. However, these checks are limited to 2D data and do not include compliance checks between different plan levels (e.g., Master Plan vs. Detailed Plan). Additionally, plans are only registered in PLANK after the planning procedure, whereas having plan data available throughout the planning process would be more beneficial.

This highlights the need for a mechanism capable of handling both 2D and 3D data to ensure adherence to regulations throughout the planning process.
The project began with desk research and interviews with key stakeholders to understand the challenges in Estonia's planning processes. The findings highlighted the need for better standardization, collaboration, and the adoption of 3D planning, as most of the existing planning data were in 2D formats, lacking interoperability. To address these issues, the project focused on integrating IFC as a standardized format for spatial plans, ensuring compatibility with Estonia's e-construction platform. Furthermore, the prototype developed utilized Clearly.HUB for data management and FME Flow for orchestrating checks, integrating Master Plan and object data from the city of Tallinn and the Land Board of Estonia.
Additionally, the project identified and implemented seven key compliance checks using IFC-based Detailed Plan data and other spatial datasets. Afterwards, these automated checks enabled assessing the compliance between Master and Detailed Plans specifically, with the results visualized through Clearly.HUB.

4. IMPLEMENTING ISO19152:5 – SPATIAL PLAN INFORMATION IN ESTONIA

The methodology for creating the LADM country profile follows a three-step process: first, establishing an initial mapping based on LADM Part 5 classes; second, iteratively refining the profile through expert feedback and integration with national databases like PLANK; and finally, validating and optimizing the profile with real-world data to ensure its practical applicability and conformance to international standards.

4.1 Current situation in Estonia

Estonia's land administration and spatial planning system is governed by the Planning Act, adopted on January 28, 2015, and came into force on July 1, 2015[1]. 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 Estonian spatial planning system is structured into a hierarchical framework involving various levels of spatial plans, seen in Figure 1.. At the top of this hierarchy are national spatial plans, which provide key guidelines and strategies for the country's development. National Plans, including the National Spatial Plan (NSP) and National

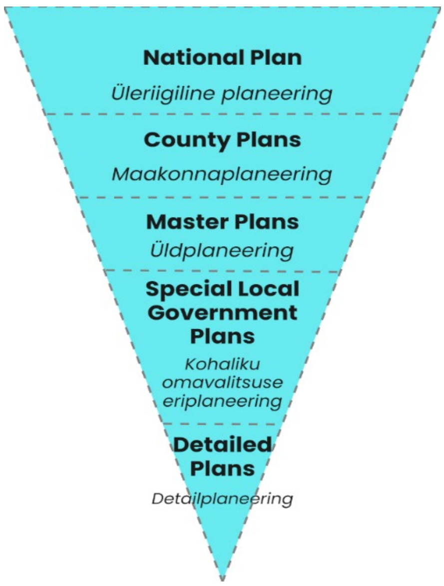

Figure 1. Spatial plan hierarchy of Estonia.

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

Designated Spatial Plans (NDSPs), set guidelines to help regional and local plans develop in a coordinated manner, ensuring that all plans support national priorities. The NSP, currently "*Estonia 2030+*"[2], outlines country-wide development principles and is managed by the Ministry of Regional Affairs and Agriculture.
At the local level, spatial planning involves County-wide Plans, Master Plans (also referred to as Comprehensive Plans in the Estonian context), and Detailed Plans. The Ministry of Regional Affairs manages County-wide Plans, while municipalities handle Master and Detailed Plans. Additionally, all local plans are reviewed by the Ministry to ensure alignment with national guidelines.
The **National Plan** provides a broad, long-term vision for the spatial development of Estonia. "*Estonia 2050*,"[3] initiated on January 5, 2023, aims to define 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 .
The **County Plan** focuses on regional spatial development, balancing local and national needs, and provides guidelines for municipal planning. These plans integrate various sectoral interests and regional characteristics, influencing the preparation of municipal Master Plans. For example, the *Jõgeva County Plan*[4] outlines spatial development according to the vision and development trends agreed upon during the creation of the national plan "Estonia 2030+".

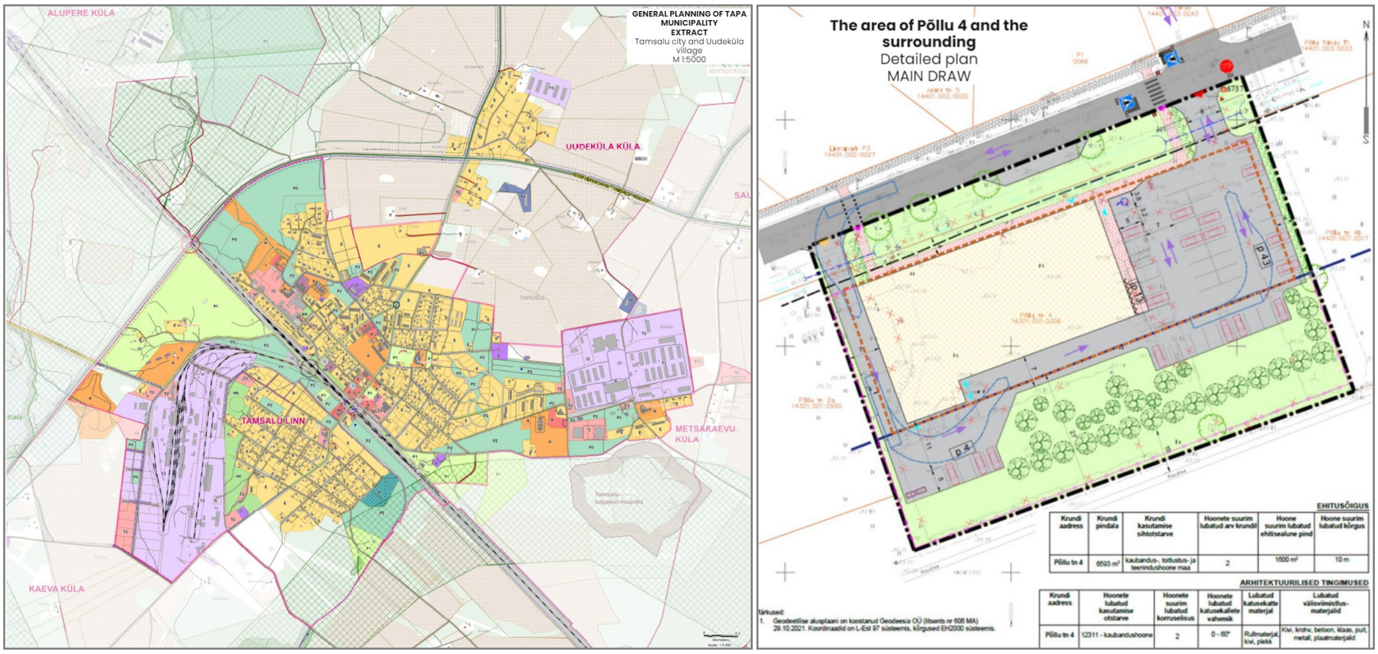

Figure 2. Tapa Parish Master Plan (left) showing Tamsalu town and Uudeküla village (scale 1:5000), and Põllu tn 4 Area and Surroundings Detailed Plan (right), illustrating land use and development specifics (scale 1:500). Figures by Kerttu Kõll, Janne Tekku, and Piret Põllendik with Entec Eesti OÜ, and Laura Andla

[2] https://eesti2030.files.wordpress.com/2014/02/estonia-2030.pdf
[3] https://riigiplaneering.ee/en/national-spatial-plan/national-spatial-plan-2050/national-spatial-plan-2050
[4] https://planeeringud.ee/plank-web/#/planning/detail/10100015

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[5]. An example of a Master Plan is the *Tapa Parish Master Plan*[6] (seen in left side of Figure 2), which outlines spatial development principles for *Tamsalu* town and *Uudeküla* village.

Detailed Plans 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*[7] (seen in right side of Figure 2), which specifies construction rights and land use changes for a commercial building.

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. These plans ensure significant projects are planned in suitable locations without hindering other activities. Established by the planning law effective from July 1, 2015, SLGPs expire if not implemented within five years, making them suitable for near-term development rather than long-term strategic planning.

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)[8] becomes important. As it ensures that the potential environmental impacts of various plans are thoroughly evaluated and addressed.

In Estonia, the SEA process applies differently depending on the type of plan. 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, they typically do not require a separate SEA process. Master Plans, being more localized, often require a specific SEA to address the direct and indirect impacts of proposed developments. Detailed Plans generally do not require an independent SEA but must comply with the SEA findings and recommendations from Master Plans.

4.2 LADM Part 5 Country Profile Development at a Conceptual Level

The By developing a country profile, the specific needs of Estonia's LAS can be addressed, allowing spatial plans and permit checks to be effectively integrated into the broader national infrastructure.

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[5] https://planeerimine.ee/ruumiline-planeerimine-2/kov-planeeringud/
[6] https://planeeringud.ee/plank-web/#/planning/detail/20100048
[7] https://planeeringud.ee/plank-web/#/planning/detail/30100010
[8] https://environment.ec.europa.eu/law-and-governance/environmental-assessments/strategic-environmental-assessment_en

The general layout of LADM classes and attributes might not always completely meet the needs of a country planning to utilize LADM. The country profile development involves creating or omitting classes, attributes and 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 mapping all cadastral information, or a targeted approach focusing on specific parts based on the country's needs (Kalogianni et al., 2019). This research focuses on spatial data and permitting, making LADM's Part 5: Spatial Plan Information package the basis for the new Estonia country profile.
Furthermore, the final country profile will be assessed according the abstract test suite (ATS) of *ISO 19152:5* in Section 5: Evaluation and Discussion. Major sources that affected each country profile version are the following:

- **Version 1:** Data layer requirements
- **Version 2:** Data layer requirements + PLANK requirements and metadata
- **Version 3:** Data layer requirements + PLANK requirements and metadata + real data

The development of the Estonia-specific LADM profile evolved through three major iterations. The first version introduced new Estonian-specific classes ("EST") to represent different plan types, with attributes based on existing Estonian Plan data layer requirements (details are available with the authors).

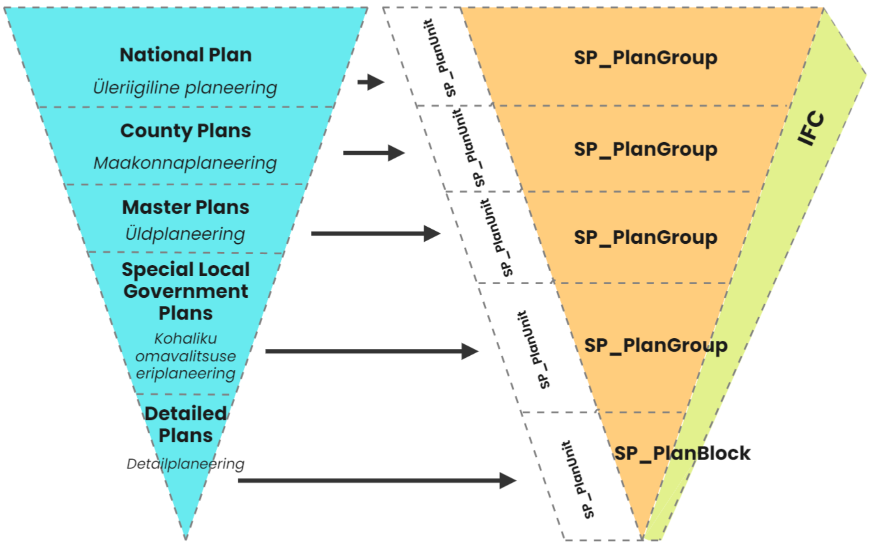


Figure 3. Mapping of Estonian spatial planning levels to LADM Part 5 classes.

The initial approach focused on translating Estonian attribute names and creating separate classes to explore the overlap with LADM Part 5 concepts. As the profile progressed, redundant attributes were eliminated, and LADM attributes were mapped to Estonian data.
The second version integrated feedback from Estonian Ministry experts and incorporated the database model from PLANK, Estonia's spatial plan database. This update significantly impacted the profile by reducing attribute redundancy, integrating metadata from PLANK, and creating code list classes for attributes specific to Estonia.

The final version of the profile (full UML diagram seen in Figure 19) introduced real data representations and optimized the model for practical use. This included incorporating real-life data, technical adjustments encountered while building the PostgreSQL database, and loading spatial data via FME. The final result is a comprehensive profile that accurately reflects the management of Estonian spatial planning data, aligning both technical and conceptual requirements.

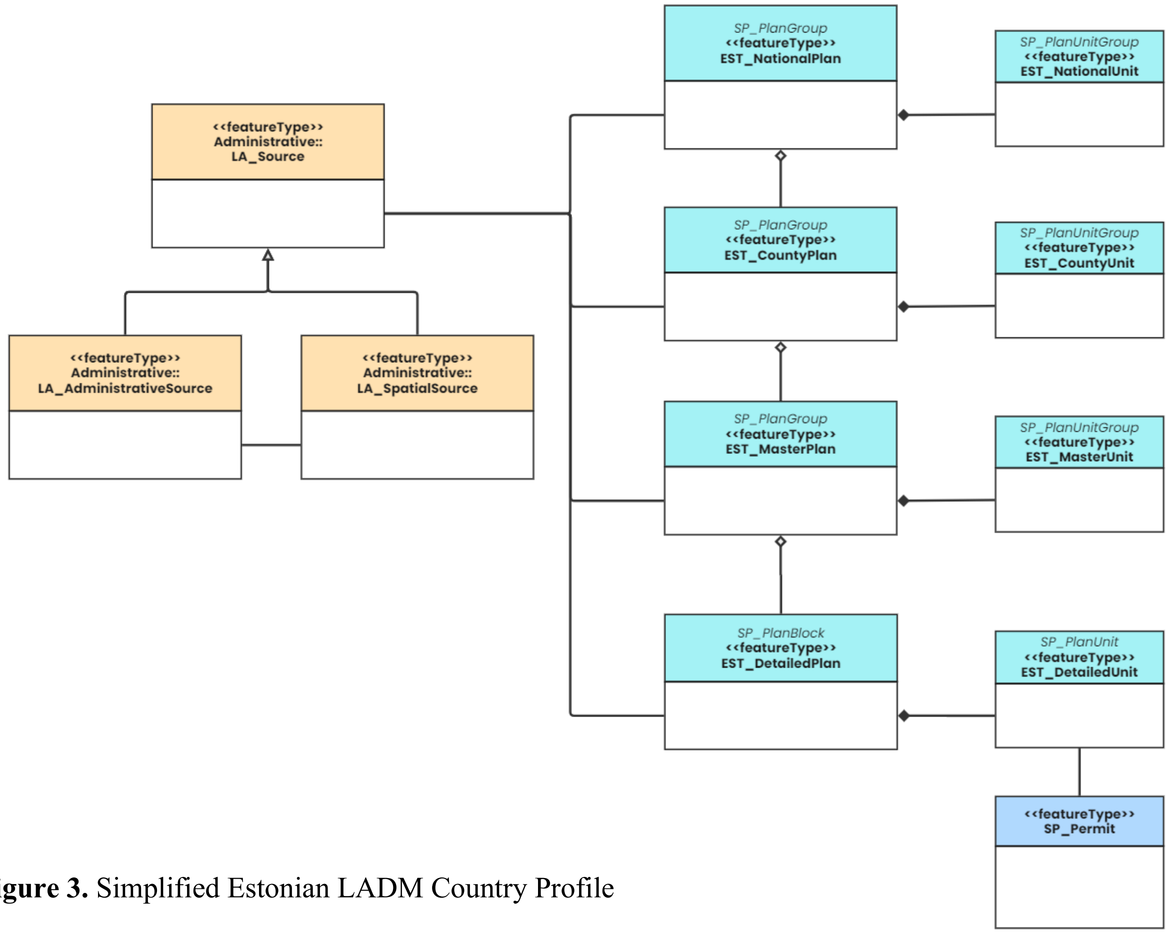


Figure 3. Simplified Estonian LADM Country Profile

The general model is presented in Figure 4. Details in the left part (seen in orange classes, detailed in Figure 5) 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, detailed in Figure 6) represents the different country profile classes, their units and relationships with each other. Part 5 classes as super classes for country profile classes, such as allowing *EST_DetailedPlan* to inherit attributes from *SP_PlanBlock* and the *VersionedObject* class in addition to its own specific attributes. Main plan classes (*EST_NationalPlan, EST_CountyPlan, EST_MasterPlan, EST_DetailedPlan*) have an "aggregation" relationship vertically with each other, representing conceptual geometry aggregation rather than strict composition. This allows for flexibility in spatial plan representation as in reality multiple smaller scale plans are not always represented by one higher scale geometry. Additionally, each plan class is associated with a unit class (e.g., *EST_DetailedPlan with EST_DetailedUnit*) to represent detailed elements with specific functions like a building or a park area, facilitating detailed information storage and easy retrieval. This hierarchical and granular approach ensures each unit within a plan can be individually addressed for comprehensive planning and management. Finally, Part 5's *SP_Permit* class is linked to *EST_DetailedUnit*, representing the most granular level of information in the model, building scale data.

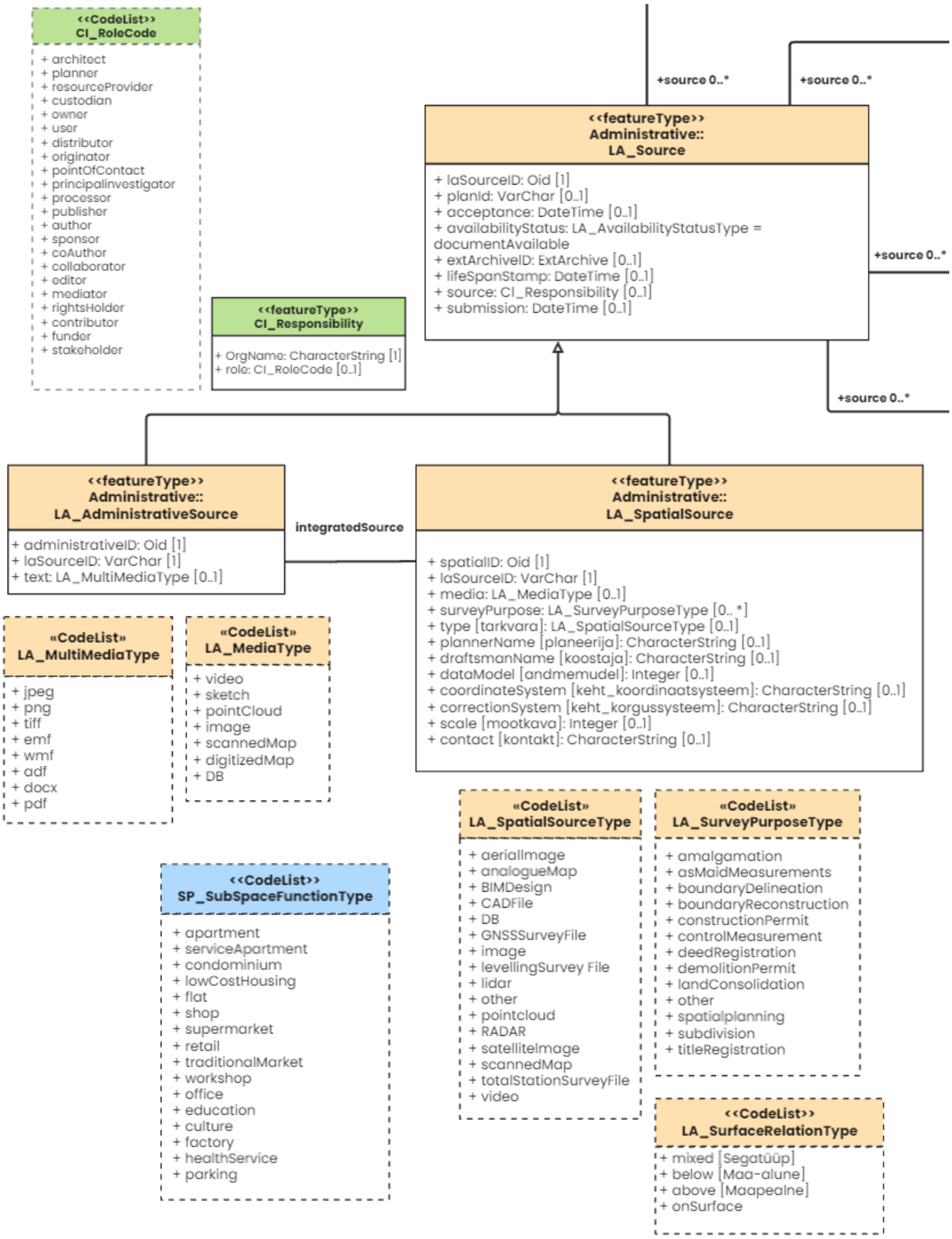


Figure 4. Representing and storing information about the source data and metadata

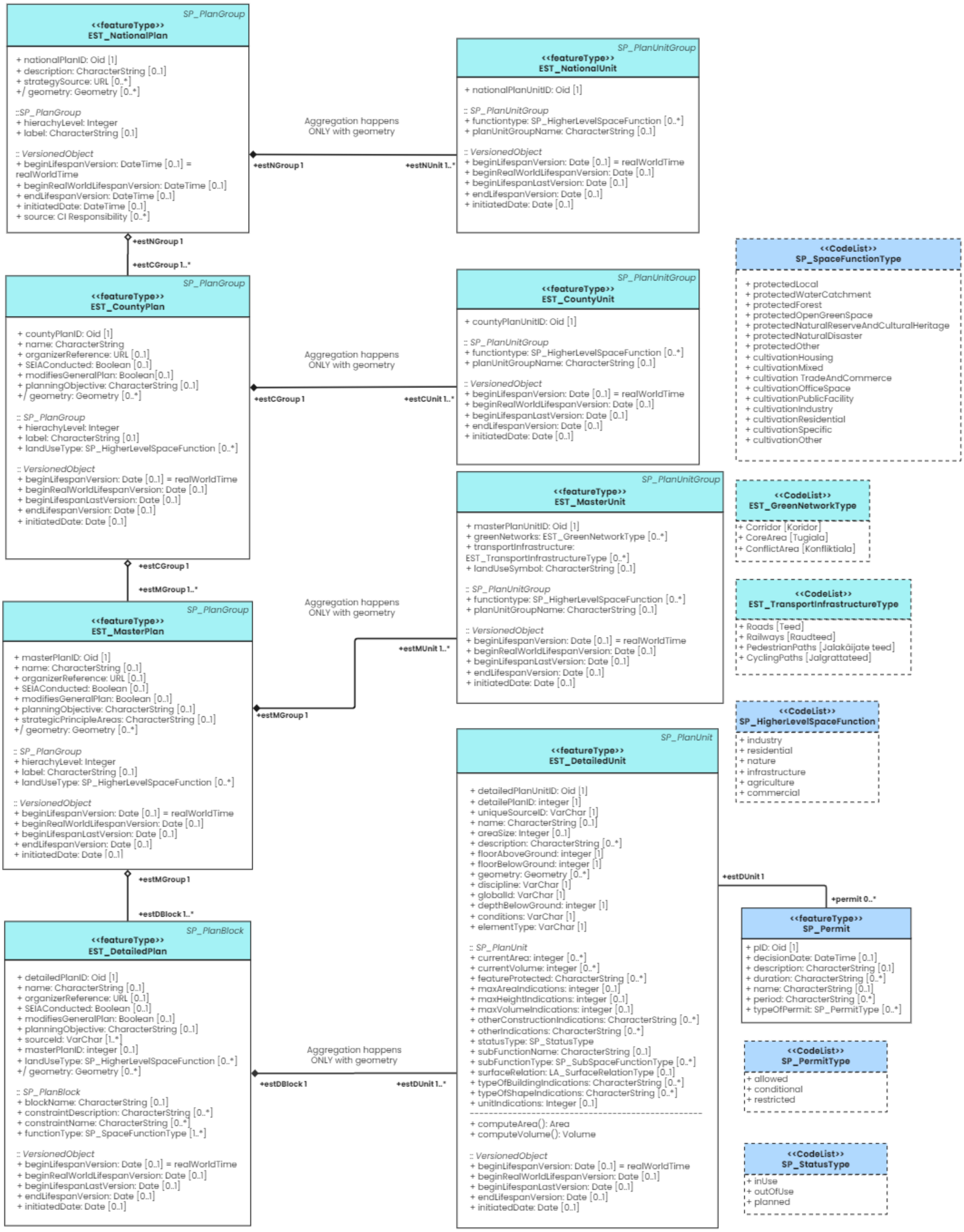


Figure 5. Plan classes and their units.

5. LADM PART 5 COUNTRY PROFILE IMPLEMENTATION IN DATABASE

The The implementation of the LADM database began by selecting PostgreSQL with the PostGIS extension as the database software due to its robustness and support for spatial data types. The initial step in developing the database involved creating the feature classes' of the country profile as separate tables. These tables serve as the primary repositories for all imported data. Key feature classes include *EST_NationalPlan, EST_CountyPlan, EST_MasterPlan, EST_DetailedPlan, EST_NationalUnit, EST_CountyUnit, EST_MasterUnit, EST_DetailedUnit,* as well as original LADM classes, such as *SP_Permit, LA_Source, LA_AdministrativeSource,* and *LA_SpatialSource*, where no changes were needed.
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 additional foreign key attributes were added to the unit tables. Figure 7 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.

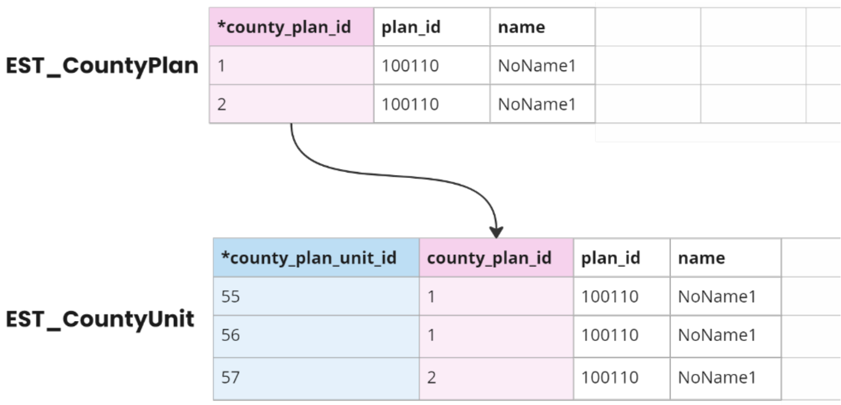


Figure 6. EST_CountyPlan and EST_CountyUnit relationship in the database

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*. Figure 8 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. The codelist tables 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.
Furthermore, to optimize the database, some sequences, triggers, views, and functions were implemented.

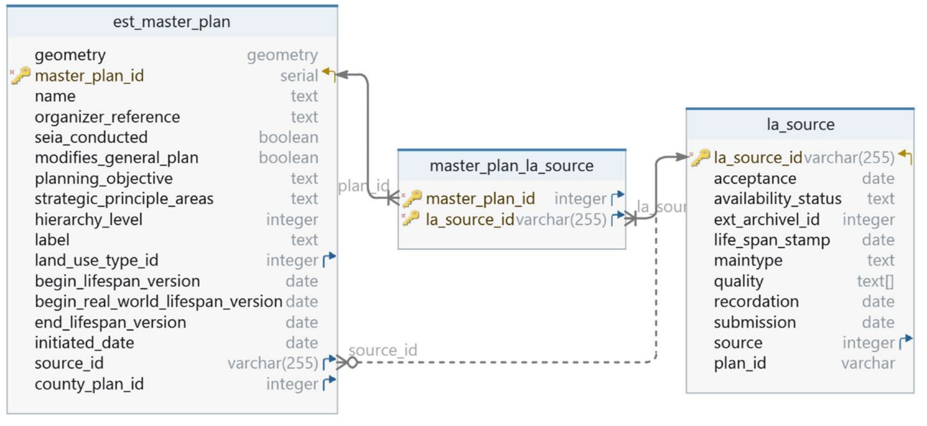


Figure 8. Example of primary and foreign key relationships in the master_plan_la_source table

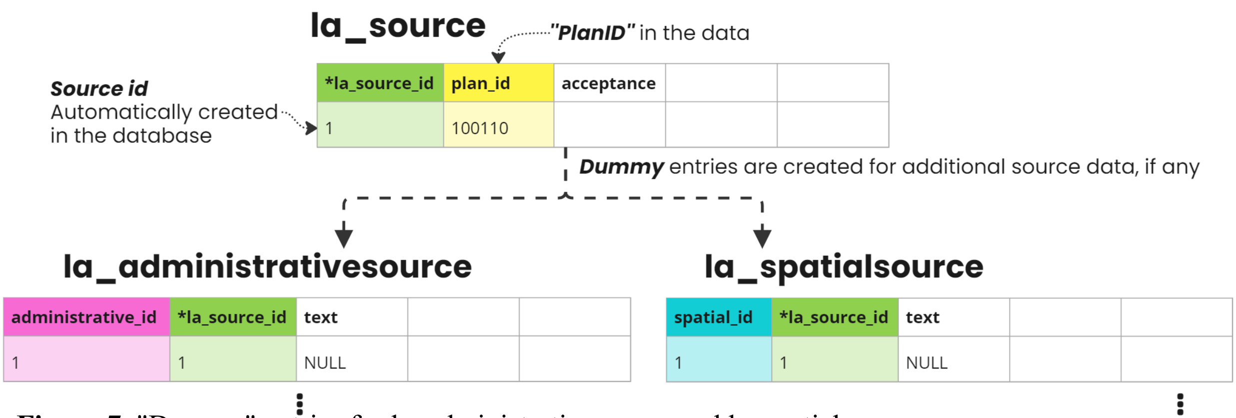


Figure 7. "Dummy" entries for la_administrativesource and la_spatialsource

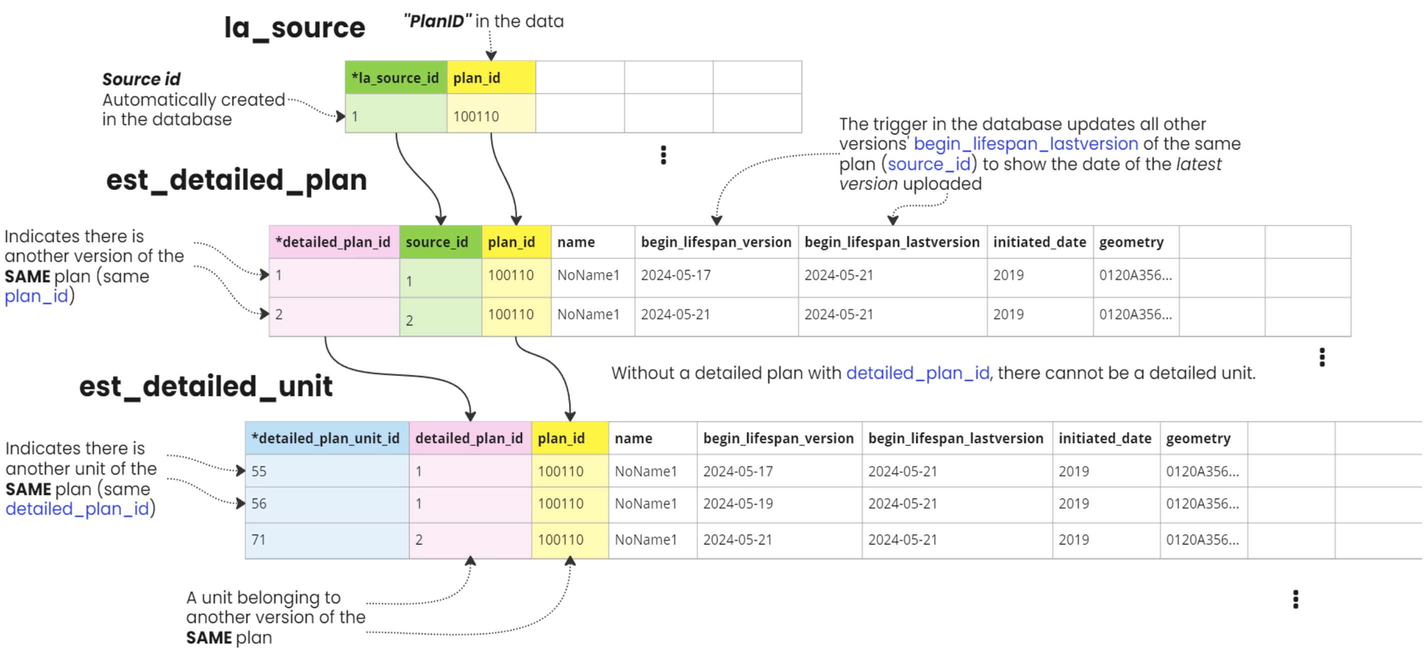


Figure 10. Example of how the versioning in the database works

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 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.

The database also contains several trigger functions to enhance efficiency and maintain data integrity. 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 mechanism can be seen in Figure 9.

For versioning, both the database and FME script were utilized. The upload date (**begin_lifespan_version**) is added through the FME script before uploading to the database. An attribute for the last version (**begin_lifespan_lastversion**) was added to every plan and unit table to manage different versions. Functions named with the plan levels (e.g., *update_d_plan_beginlifespanlastversion*) update the begin_lifespan_lastversion field, ensuring all records with the same plan_id reflect the most recent date. During the import process, **begin_lifespan_version** and **begin_lifespan_lastversion** are set to the current date to mark records as the latest version. Initially, complex logic caused infinite loops and errors, but refining the logic solved this. The trigger *trg_update_d_unit_lifespan* activates after an insert or update, ensuring accurate versioning without errors. The same logic applies to other plan and unit tables. Figure 10 illustrates an example scenario demonstrating how the versioning works in the database.

To further enhance the database's legibility further, 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.

Most functions and triggers were created during the testing phase using FME to import data, allowing realistic optimization for Estonian data requirements. This iterative process was crucial for finalizing the database setup. A database dump script for deploying the database from scratch and a reset script to clear all records except codelist values are available on GitHub[9]. These scripts ensure the database's integrity during testing and development.

Figure 11 illustrates the overall system architecture for both the database and the import process. The steps with a white background indicate the procedures followed for the project by Future Insight. The figure also shows that the initial starting point remains consistent to facilitate better integration with the actual project pipeline. Once the database was established, FME scripts were developed to handle the importation of spatial data.

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

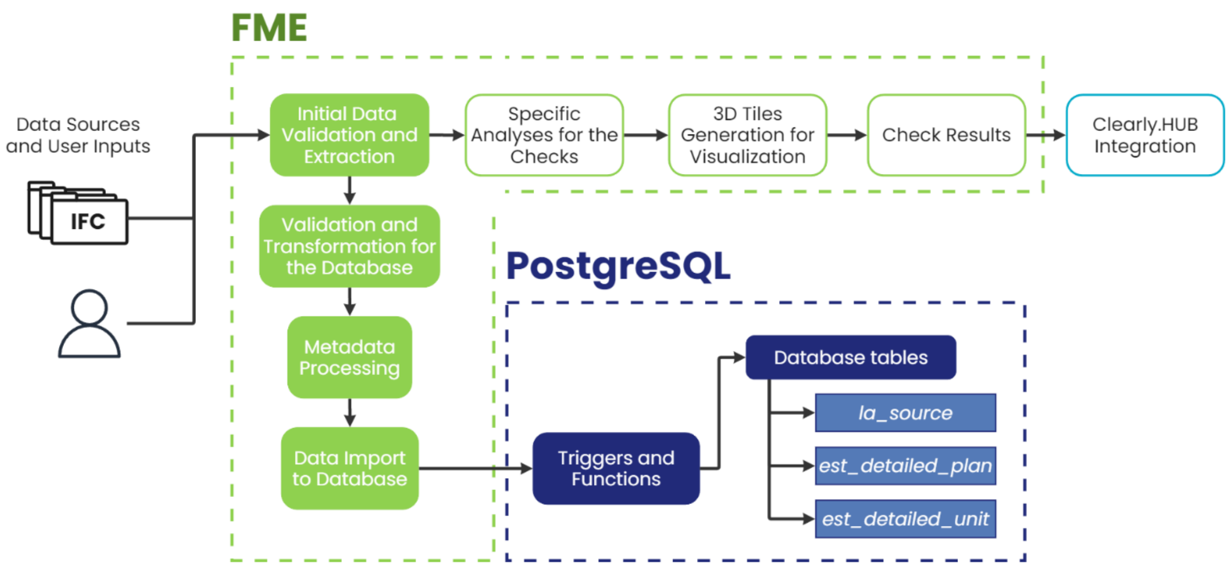


Figure 8. Overall system architecture of the process

The import process begins with the preparation of IFC data, 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 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 of data for the checks.

The process can be divided into two main parts. The first part involves general data extraction and initial validation methods for the IFC data. 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. The second part of the process handles the necessary data transformations and additional data extraction mechanisms needed to comprehensively represent the data in the LADM profile. This phase includes transforming the data to meet specific schema requirements and finally importing the transformed data into the new PostgreSQL database.

Additionally, various *User Parameters* were created to make the FME workflow more generic and flexible for various input data. Key parameters include database connections, source dataset paths, and domain-specific (also reffered as *discipline* in the research and case study) property sets and their syntax.

Figure 12 shows detailed explanation of the general FME workflow. After the IFC files are read, the data's *IfcPropertySet* and *IfcAnnotation* are compared against each other. The aim is to only keep the matched discipline records with a property set and exclude everything else. A "*discipline*" represents specific thematic categories (i.e. layering) within the Estonian IFC data, such as public spaces, landscaping, building zones, access routes, utility conditions, plot areas, land use types, and transportation networks. Next, the script checks if the *plan_ala* or *dp_krunt* is in the kept disciplines. These layers represent the planning area and the plot area, respectively and according to Estonian layer requirement, it is mandatory that every plan data must have both layers.

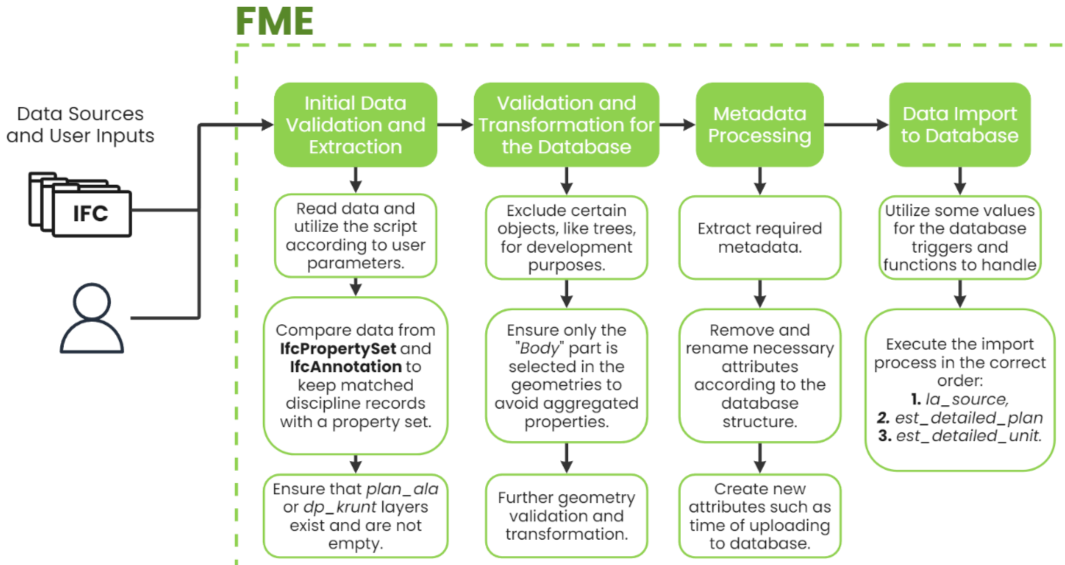


Figure 9. Detailed process of the FME scripts that are utilized for importing data to the database

After the initial data extraction and validation, the second stage (i.e., "Validation and Transformation for the Database" in Figure 12) of the script begins with excluding some objects from the records for development purposes, like trees. To avoid any relevant data loss during the import, these objects will be included again in the end, right before importing the data into the database.

Following the exclusion of some elements, the final data extraction and transformation before the LADM part focuses on geometries. When reading IFC files in FME, the "*Body*" geometry often includes aggregated property information. To ensure predictable and clean geometry data for the database storage, it is important to avoid these aggregates and extract only the "*Body*" part of the geometry. This ensures that the extracted geometries are consistent and free from unwanted aggregation. After the geometry validation, 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. 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 first table in the database to import information into is the *la_source* table. As previously explained, 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.

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 13 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.

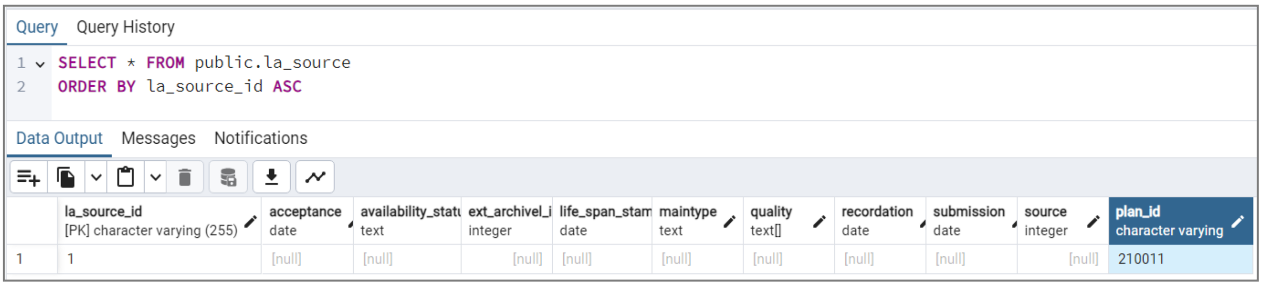


Figure 10. Example entry to the la_source table using the pilot data, Põhi.

The order of the script's import to the database is crucial, even after the *la_source* table. The correct import sequence for a spatial plan 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 established during the database creation, which state that one or more plan units cannot exist without the plan existing first. Additionally, there are technical constraints in the database to enforce this rule. Therefore, the script's execution order meticulously conforms to these constraints.

After the data is imported into the *la_source* table, the script continues with the 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 unit elements in terms of geometry, required necessary transformations to merge these units into one geometry. 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. These steps ensured that the final

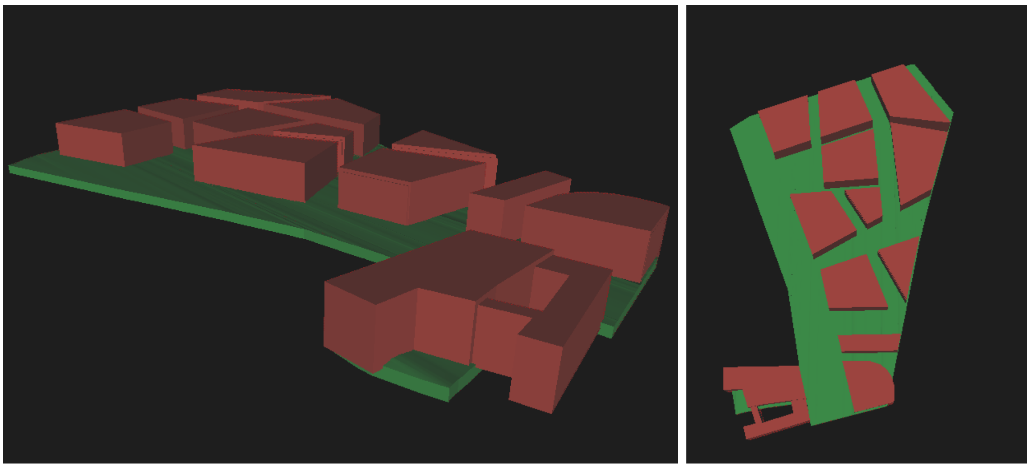


Figure 11. Final Geometry Product for est_detailed_plan table

mesh visually reflected the entire plan area in 3D. Figure 14 shows an example of the final geometry product that is to be uploaded to the *est_detailed_plan* table.

After forming the plan geometry, the current date and time are added as an attribute, representing the *begin_lifespan_version* in the plan tables to indicate the upload time. 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 15 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.

After importing the necessary information into *est_detailed_plan*, the script prepares and transforms data for the *est_detailed_unit* table. An SQL query executed in the FME script ensures that the later imported data is recognized as units of the same plan by retrieving the most recently imported Detailed Plan's ID from the *est_detailed_plan* table from the database. This allows the corresponding units to be linked to the specific plan with a foreign key. Therefore, the source, plan, and its units should be uploaded together to maintain data integrity, although this constraint can be optimized for more flexibility in the future development of the research.

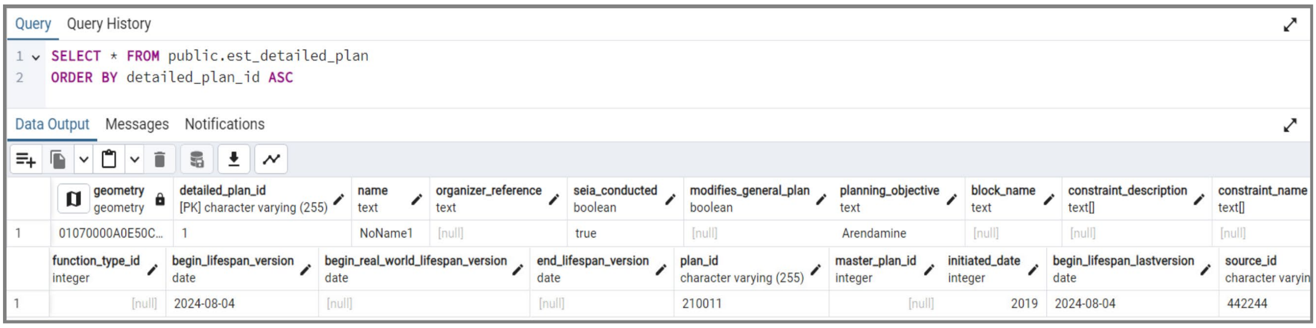


Figure 12. Example entry to the est_detailed_plan table using the pilot data, Põhi

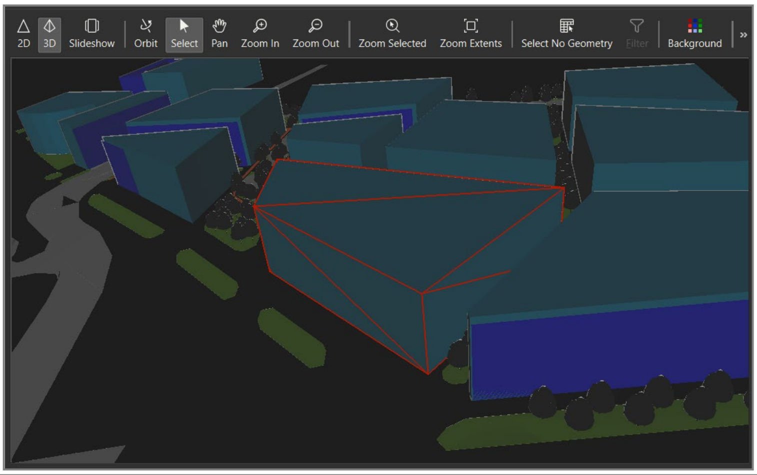
Moreover, testing mechanisms were implemented to categorize codelist values. For example, the *la_surface_relation* codelist table, illustrates a mechanism for categorizing incoming data. This was tested with flexible methods, such as automatically recognizing and labeling vegetation elements as "on surface" or comparing the depth below a building with the floors above and below it. For instance, if an element is below ground, it is assigned a value of code id "2," which the codelist table maps as code label "below." This ensures that the incoming data matches the predefined codelist values set by the country profile and 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 16 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 below.

To test the accuracy of the imported results compared to the raw input IFCs, 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 is to input the *detailed_plan_id* into the reader, so it only reads the plan units of the specific plan requested. For versioning, this query can be made more specific to isolate the requested plan and the version available in the database.

The results, seen in Figure 17, showed that the geometries accurately reflected the original pilot dataset, and the metadata was 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 issue with 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, developing custom scripts to store and apply styles separately from the geometry data could also be a potential solution, although it would make the process more complex.

Referring to the initial system architecture in Figure 11, the updated system architecture in Figure 18 demonstrates how the process of reading the Estonian spatial data previously uploaded to the database can be implemented into the case study project with Future Insight for the prototype of seven compliance checks. In this updated system, Estonian plan data can be directly read from the database, transformed into 3D Tiles, and then used to develop and execute the checks, with the results visualized in Clearly.HUB. This approach enhances scalability, as the database (and country profile) is designed to handle and store comprehensive plan data from various levels.



	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...

Figure 13. Example unit geometries stored as individual records with specific metadata

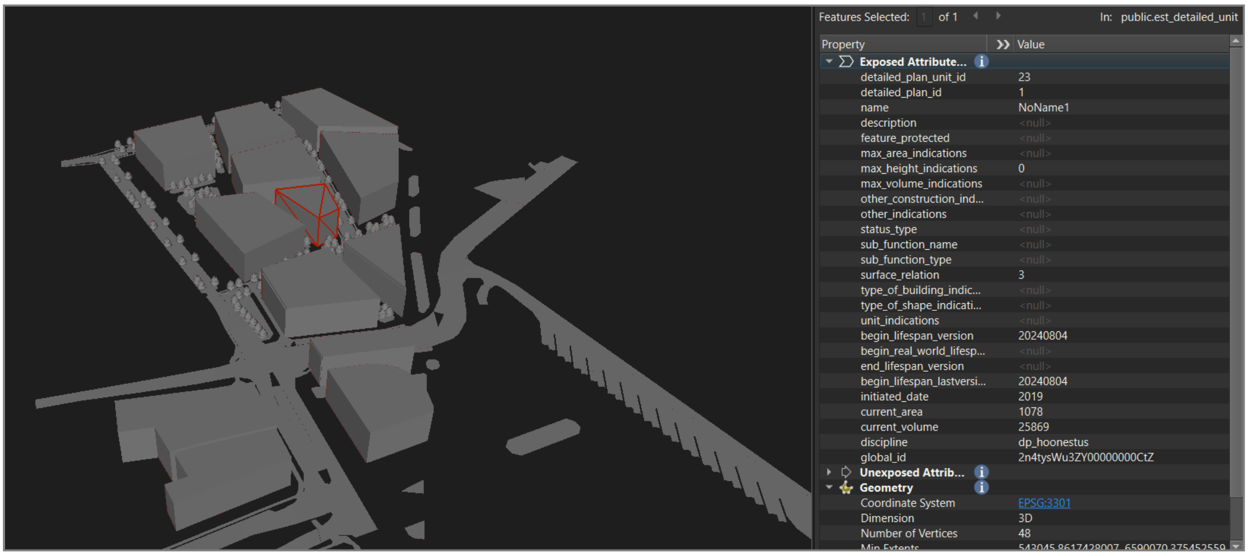


Figure 15. Read geometries and metadata from the database

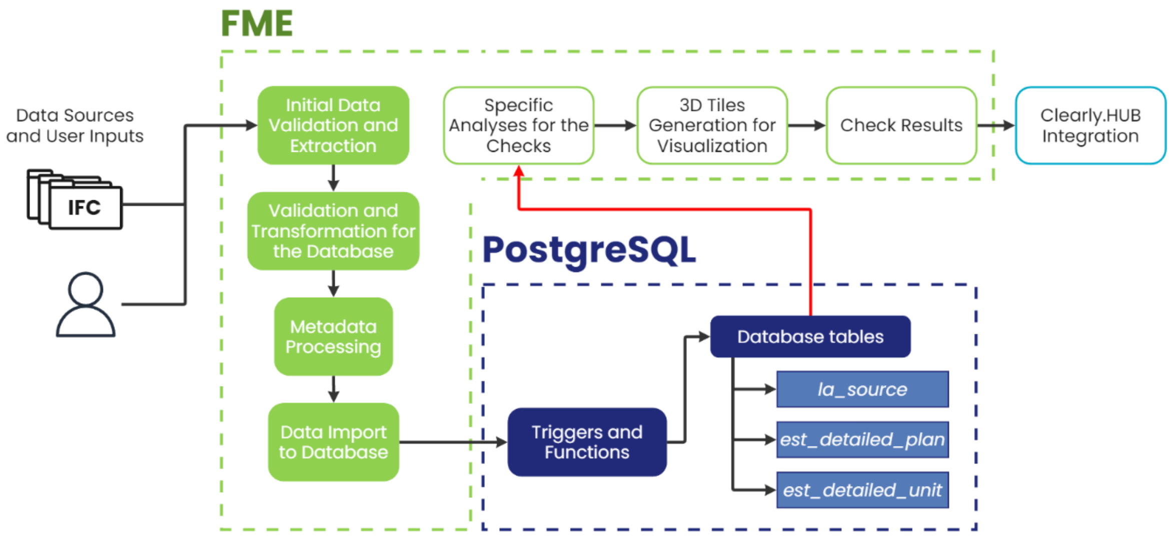


Figure 14. Updated system architecture diagram representing how to implement the LADM database process into the case study project with Future Insight

The FME scripts developed for extracting and loading plan information also extract metadata (not currently needed for the seven checks) to fully represent the plan in the database. By reading previously uploaded plan data from the database, the compliance check process becomes simpler and shorter. Specifically, this would eliminate the need for the hefty extraction and transformation processes, developed specifically for the required information for the checks. Since the database is designed to represent the plan data comprehensively, the required information for the checks and more is directly accessible from the database, provided the plan data contains it.
Additionally, users can access different versions of the uploaded plans directly from the database and easily compare the compliance check results for each version. Further

optimizations with larger datasets will enhance both the FME scripts and the database, making the process more scalable and efficient for Estonia. This would also simplify the development of additional compliance checks in the future. The implications, benefits and constraints of this approach are all summarized in Section 6: *Evaluation and Discussion.*

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5. EVALUATION AND DISCUSSION

It is crucial to assess of the Estonia-specific LADM profile, along with the developed database and FME scripts' effectiveness, limits and compliance with international standards. This section first assesses the LADM implementation using the ATS provided in Annex A of *ISO 19152:2012(E)*. It then discusses the practical implications, benefits, and constraints of the developed system.

The ATS is a standardized set of tests provided by *ISO 19152:2012(E)* to ensure that implementations of the LADM conform to specified conformance levels.

The Estonia profile has been developed to comply with level 2 conformance of ISO 19152:2012(E). According to the ATS, level 2 conformance requires the implementation of basic and common classes, which include core classes in Part 5. 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.

6. CONCLUSIONS AND FUTURE WORK

This research has successfully developed a country-specific LADM profile for Estonia, integrated with the PLANK database, and demonstrated the potential of using IFC within the prototype solution for compliance checks among Estonian spatial plans. By achieving Level 2 conformance with the ATS of ISO 19152:2012(E), the Estonia's LADM profile has proven effective in addressing both the national requirements while adhering to international standards. Additionally, the case study involving the company Future Insight and organizations from Estonia highlighted the practical benefits of this integration, including the ability to directly read and process spatial data for compliance checks, reducing manual intervention and potential errors. However, certain assumptions made during the development of the FME scripts and database shall be revised in future work to enhance scalability and flexibility.

One 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 to retrieve the unique plan ID from the PostgreSQL database. 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 one after another, the units of the first plan cannot be imported from the FME script without manually retrieving and using the plan ID from the database. Additionally, the script's reliance on predefined discipline names for filtering IFC data is based on a limited set of pilot datasets used within the case study. In a broader context, variations in discipline naming conventions could create challenges. Thus, for scalability reasons, the script should be tested and optimized with a wider range of Estonian datasets to ensure accurate operation.

Future work could focus on refining these assumptions and enhancing the system's scalability. Another point to consider is performance optimization. Performance testing with larger datasets will be crucial to ensuring efficiency and identifying any further areas for optimization. Addressing these factors will improve the overall model and tools developed, making the system more scalable and robust for compliance checking.

As digitized permit checks are an emerging domain, and the case study with Future Insight demonstrates a state-of-art prototype, the ongoing development of these checks will likely influence the evolution of the LADM model used. While this research concentrated on integrating IFC data due to its prevalent use in the AEC industry and the specific pilot dataset employed in the case study, future work should also explore additional data formats such as CityGML. CityGML's potential for representing urban features and integrating spatial plan information could be particularly beneficial for smaller-scale spatial plans, making it a valuable consideration for further development.

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BIOGRAPHICAL NOTES

Simay Batum is a Geomatics MSc student at Delft University of Technology, Netherlands. With a background in Urban Planning and Landscape Architecture, she is passionate about integrating advanced geospatial technologies into the AEC sector to drive data-driven and sustainable urban development. Her current research focuses on LADM modeling, geospatial encodings, and data analysis, contributing to innovative projects in urban planning.

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Marjan Broekhuizen holds a degree in social geography and planning, and a MSc in Geographical Information Management And Applications (GIMA). She has great experience in GIS and data management, specialized in working with FME for building BIM/IFC based permit checks. Currently, she works at Future Insight B.V. as a data specialist.

Christopher Raitviir is the Head of Digital Construction in Tallinn Strategic Management Office. He is leading digitalization of built environment life cycle processes in the City of Tallinn from urban planning to facility management and giving his experience to development of Tallinn Digital Twin. Previously he has been working in a research group in the Tallinn University of Technology on the project of "Digitalization of building life cycle using BIM processes" and developed Estonian BIM-based building permit process when working for the Ministry of Climate. Christopher has a Master of Science degree in civil engineering and is currently doing his PhD on the topic of "Synchronization of Information Flows of Digital Twins in Construction".

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APPENDIX

Figure 19. Final Estonia LADM Part 5 Country Profile's UML model