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

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Date of P2: January 24, 2023

Nomenclature

This Chapter includes a list of abbreviations and common terms used throughout the report.

Frequently Used Abbreviations & Terms

AEC	Architectural Engineering and Construction
BIM	Building Information Modelling
BMC	BIM-based Model Checking
CAD	Computer Aided Design
CityGML	City Geography Markup Language
DSR	Design Science Research
EHR	Estonian Building Registry
FME	Feature Manipulation Engine
GIS	Geographic Information Systems
IdS	Information Delivery Specification
IFC	Industry Foundation Classes
ISO	International Organization for Standardization
LADM	ISO 19152 Land Administration Domain Model
LADM Part 5	Land Administration Domain Model Part 5: Spatial Plan Information
LAS	Land Administration Systems
LIS	Land Information Systems
NIBS	The National Institute of Building Sciences
OGC	Open Geospatial Consortium
PLANIS	Planning Procedure Information System
RPIS	Ruumilise planeeringu infosüsteem (Spatial Planning Information System)
TCG	Tallinn City Government

Contents

1. Introduction

In the ever-changing realm of urban development, Land Administration Systems (LAS) play a pivotal role in the management and the governance of land. They also provide a country's infrastructure for implementation of its land related policies and strategies (Williamson et al. 2008). LAS deal with vast amounts of supporting data, which are more commonly set as centralized database systems. These include Land Registry, Cadastral systems, Land Information Systems (LIS), Land Tenure Systems, Land Use Planning Systems and many more.

As rapid urbanization and developments in the spatial disciplines advance, the reliability and efficient management of space has become a crucial aspect for sustainable development (Dželalija and Roić 2021). To improve the management, transparency, and the efficiency of the Land administrative processes, utilizing the system towards digitalization is becoming more of a noticeable trend (Rodima-Taylor 2021). This shift has led architects, urban planners, and regulatory bodies to increasingly turn towards 3D modelling as a way for collaboration and accessing spatial data through digital platforms.

The use of digital technologies in AEC (Architectural Engineering and Construction) sector has been attracting greater recognition throughout the past decade. The advancement of technology and the worldwide political, social, and economic drive to create burgeoning applications for smart, digital cities are some of the fundamental triggers of this (Sabri and Witte 2023). The latest advancements in both hardware and software have paved the way to recognizing the potential that digitalization offers for workflows and data management across a wide range of industries (Noardo et al. 2022), together with the use of standards. Due to digitalization, one of the most profound transformations in the spatial sector comes from the synergy of Geographic Information Systems (GIS) and Building Information Modelling (BIM). The integration of GIS and BIM, demonstrated in Figure 1, welcomes a revolutionary period in AEC domain by providing collaborative workflows that cover information from individual building level to city-level. The new integrated workflows, characterized by shared data and interoperability, potentially provides complimentary data for LAS (Kalogianni et al. 2020a). This approach also highlights the importance of accessible, effective, and efficient collaboration between different disciplines, also drawing a new focus to life-cycle approach towards data re-usability.

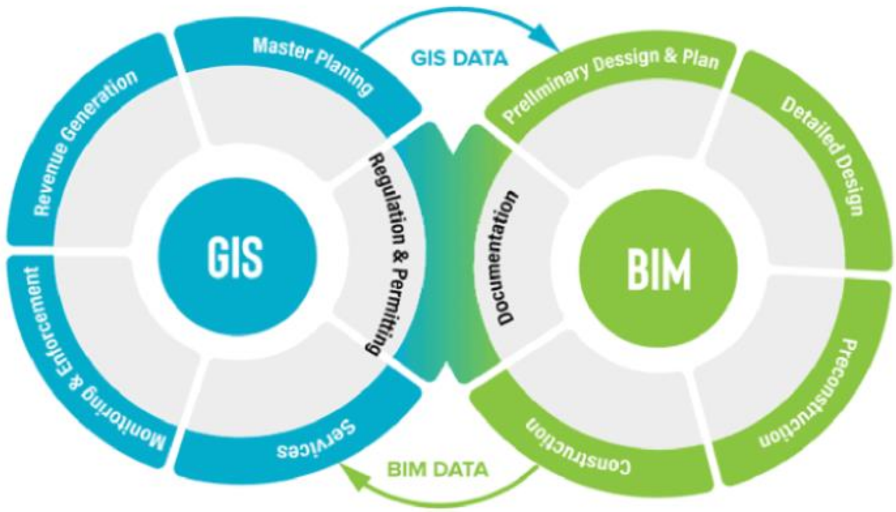

Figure 1. Integration of GIS and BIM. (Image credit: John Victor)

The integrated GIS-BIM workflows produce valuable outputs, often in the form of BIM data encoded in the Industry Foundation Classes (IFC) file format (widely used for exchanging BIM data, also ISO 16739-1:2018 (ISO 2018)). This development has created a potential opportunity to utilize BIM data as input for LAS, (Kalogianni et al. 2020a; Alattas et al. 2021; Broekhuizen, Kalogianni, and van Oosterom 2021; Kalogianni et al. 2020b), particularly through the automation of digital processes and the incorporation of data related to buildings and the built environment (Noardo et al. 2022). One example of this is conducting automated checks for building permits using BIM.

BIM-based Model Checking (BMC) is a coined term to define the grouping of concepts that focuses on processing BIM data and uses various algorithms to further process the extracted information (Gade, Hansen, and Svidt 2018). Previous work have resulted in prototyped solutions of using BIM as a way to automate BMC in the building permit process ("BIM-Based Building Permit Process Automation Seminar" 2020). The benefits of this approach include increased speed and accuracy in permit verification by supporting human decision making and automating time-consuming and error-prone works.

The traditional permit process all around the world usually involves submitting physical or digital plans to local authorities for approval and waiting for the compliance check against the relevant building regulations (Beach, Hippolyte, and Rezgui 2020). The process is mainly done manually and thus, is time-consuming and prone to errors. By using BIM models and BMC, instead of humans manually going through plans, computer algorithms can check BIM models for compliance. Figure 2, illustrates the processes both traditional permitting and BIM based permitting.

One of the limitations of using BIM models for permitting comes from the challenges associated with translating intricate urban regulations into a machine-readable format. Notably, the challenges encountered in this process are not surprising. This complexity emerges from the fact that the utilization of pre-processing algorithms and workflows for BIM data in the context of building permits is a relatively new field, emerged only in the last decade. Despite the fundamental idea behind the creation of BIM models, which is rooted in a holistic approach fostering a unified foundation for semantic attributes across diverse disciplines, the digitalization of building permits lacks a standardized understanding of semantic attributes (Noardo et al. 2022; 2020). Consequently, the existing approaches to create digitalized permit checks remain localized, relying on manual adaptation to the specific ontology of the local administrative system.

Given the difficulties associated with manually modifying the BMC algorithms to comply with complex urban regulations, the need for a standardized approach becomes evident. Recognizing this need for standardization, the ISO 19152 LADM, (Land Administration Domain Model)(ISO 2012, 19), emerges as a supportive solution, as it serves as an infrastructure for efficient LAS.

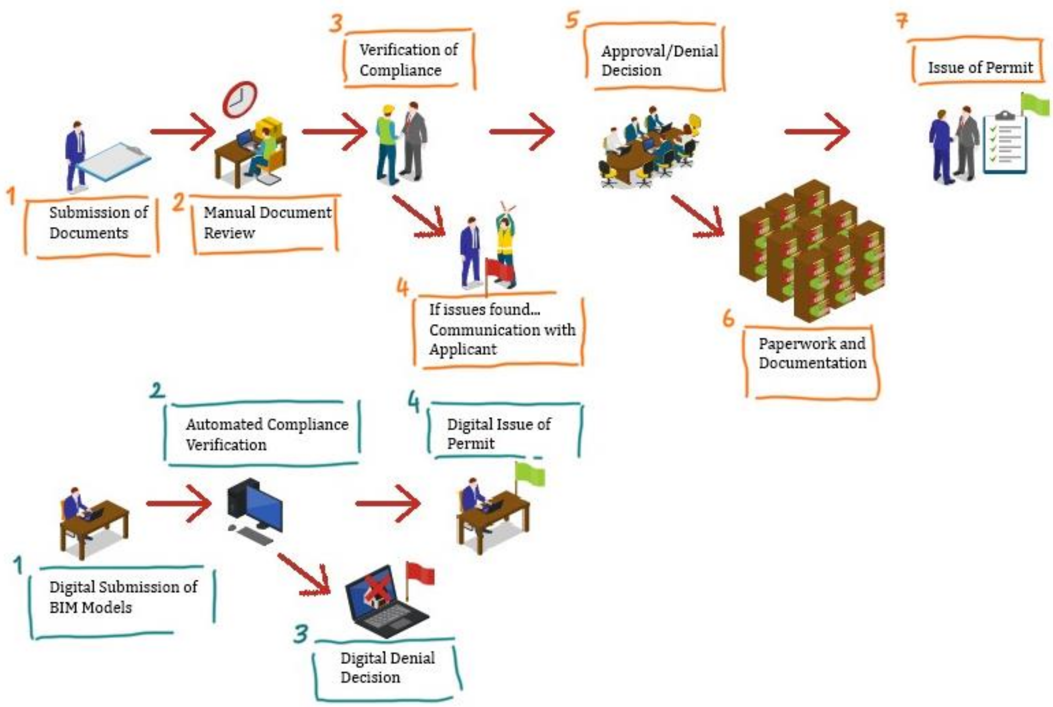

Figure 2. Traditional permitting compared to BIM based permitting

2. Related Work

To better understand the mechanism and theory behind BIM-based building checks, this section presents an overview of the previous research and methods related to the scope of the thesis. First, a brief description of the main concepts used in the thesis, i.e., LADM, BIM and CityGML is given. Then, an overview of the relevant research is introduced.

2.1. BIM (Building Information Model)

In the past, 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 and 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 Building Information Models (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 retooling BIM.

BIM is a process used to create a 3D representation of an asset with both physical and functional information. According to NIBS (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 don't distinguish between their elements, BIM incorporates 4D (time), 5D (costs) and 6D (asset management) too. Unlike CAD, BIM utilizes an object-oriented and information model, providing a classifiable differentiation of individual elements such as "walls", "doors", and "windows" as distinct objects with their unique features.

Information in a BIM model can be shared through a mutually accessible online space referred to as a CDE (Common Data Environment)(Ozkan and Seyis 2021), and the data collected is referred to as an 'information model'. Figure 3 shows 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 logistics, 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) and Construction Operations Building Information Exchange (COBie), facilitating exchange among different platforms.

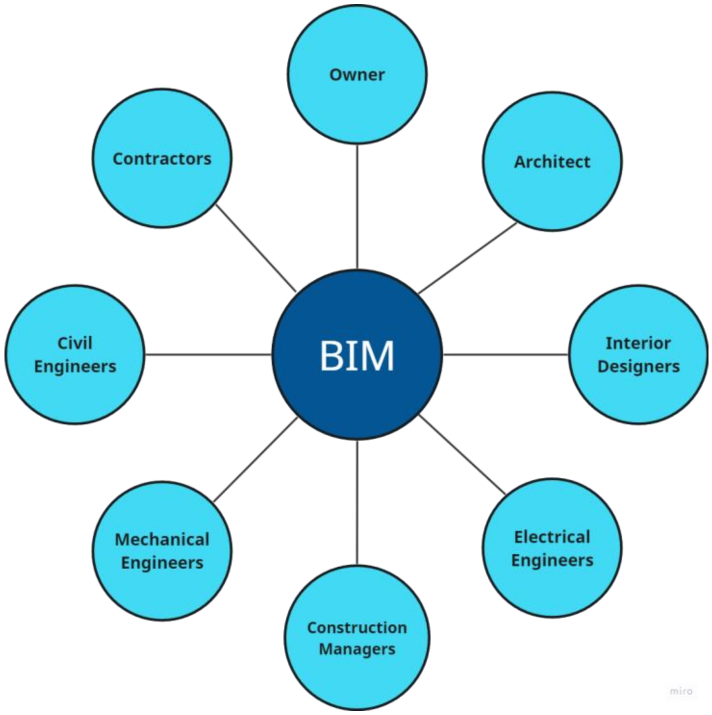

Figure 3. Relationship of BIM to the various stakeholders and project team members.

2.2. ISO 19152 LADM (Land Administration Domain Model)

The Land Administration Domain Model (LADM) is an ISO standard, ISO19152:2012 serving as an infrastructure for efficient LAS. It provides a mutual ontology to promote shared information (Van Oosterom and Lemmen 2015). LADM should be viewed as a descriptive standard rather than a strict implementation method for organizing spatial and non-spatial data associated with 3D cadastral properties (Lemmen, Van Oosterom, and Bennett 2015).

Currently, the standard is under revision within ISO TC211 and the second edition consists of 6 parts, which are currently under development (Kara et al. 2023):

Part 1 - Land Administration Fundamentals
Part 2 - Land Registration
Part 3 - Marine Space Geo-regulation
Part 4 - Valuation Information
Part 5 - Spatial Plan Information
Part 6 - Implementations

LADM Part 5 is the most related one with the scope of this research. Part 5 aims to integrate land registry and planned land use information on the same conceptual model and allow shared usage of both datasets. It will support planning hierarchy, organize plan units in a plan block, provide extensible code list values for the spatial (sub)functions of the plan, support permit registration related to the relevant plan unit, allow open dissemination and clear 3D visualization of plan information, and so on (Kara et al. 2022).

Part 5 will contribute to the need for a clear way to store the urbanistic rules and make them available for processing. Integrating LADM into the BIM base building permit process would be a strategic solution to the possible limitations of the application. This integration can provide seamless validation of one spatial plan against another plan (e.g., detailed plan against a master plan), and LADM itself can contribute by being a consistent data standard throughout the spatial life cycle rather than the creation of new, unstandardized data in every phase. Finally, using LADM in the pipeline would foster interoperability and enhance communication within different LAS modules, which LADM provides for the project's future development.

2.3. Comparative Analysis of IFC and OGC CityGML

The research will investigate the integration of LADM Part 5 from two encodings: City Geography Markup Language v3 (CityGML v3) and Industry Foundation Classes (IFC). The choice of encoding standards play a critical role in determining the efficiency and effectiveness of the permit-checking process. Both encodings will be compared by data representation, semantic interoperability, compatibility with LADM and strategic selection for specific permit processes.

2.3.1. OGC CityGML

CityGML is a widely used, open standard data model exchange format developed by the Open Geospatial Consortium (OGC). It is employed as a GML application schema for the Geography Markup Language 3 (GML3), an ISO standard (ISO 19136:2007) by OGC (OGC 2012). The data model offers a standardized way of encoding and exchanging semantic data about building usage, material composition, and energy efficiency in addition to the geometric characteristics of infrastructure and buildings. The standardized data model establishes agreements on names, promoting consistency and compatibility across diverse datasets. Moreover, users can customize the data model for particular domains or applications using Application Domain Extensions (ADEs), which expands the capabilities of CityGML and increases its adaptability to accommodate a broad range of use cases.

2.3.2. IFC

Industry Foundation Classes (IFC) is an open standard data model exchange format developed by buildingSMART International ("Industry Foundation Classes (IFC)," n.d.). It is an open, ISO 16739-1 standard (ISO 2018) that serves as a vendor-neutral and interoperable file format for sharing information throughout the building lifecycle. IFC serves as a common language that allows interoperability among various BIM tools, enabling seamless collaboration and information exchange. The IFC schema includes a comprehensive set of data that covers elements such as building geometry, spatial relationships, materials, and other relevant attributes.

2.4. BIM-based building permit checks

Building permits that are based on BIM models can be obtained by submitting BIM models rather than 2D drawings (plans and other related items), and automated code compliance checks can be performed instead of manual reviews. This makes the process cost-efficient and time-saving. In addition to these, it omits the possibility of human errors since the reviewing process would be fully automated (Ullah, Witt, and Lill 2022).

Rule-based systems are primarily used in the building permitting process to verify that building designs follow the regulations. These guidelines depend on vendor-specific standards (Fauth and Seiß 2023) or building codes from the government. Four steps form the basis of Eastman et al.'s (2009) automatic rule-based checking of building designs (Figure 4).

1. First, human interpreters translate regulations into a language that machines can understand.
2. Then, the designed model has to be made ready for the checks before the translated rules are implemented.
3. That is, a semantic model has to 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 ("Information Delivery Specification IDS," n.d.; Gragnaniello et al. 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 accomplishing this have been explored in academic research. Appendix Table 1, presents the contributions related to rule interpretation and digitalization of city and building regulations (Noardo et al. 2022).

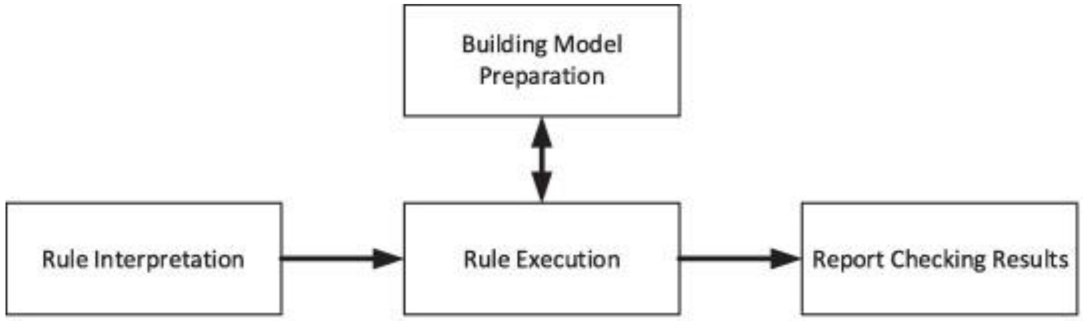

Figure 4. The functionalities of a rule system. Figure by Eastman et al. (2009).

Furthermore, several studies have been conducted in the last decade that delves into the possible application of BIM for building permits . The findings of the studies (Noardo et al. 2022; Ullah, Witt, and Lill 2022; Beach, Hippolyte, and Rezgui 2020) 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 (Noardo et al. 2022; Ullah, Witt, and Lill 2022; Beach, Hippolyte, and Rezgui 2020). According to a study (Ullah, Witt, and Lill 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.

Using IdS for checking compliance of IFC models is possible and promises successful results (Gragnaniello et al. 2024) however, for encodings like CityGML (which might be a more tempting option to consider for larger scale checks such as zonal checks), this creates ambiguity in the required information for the checks to be carried out. Since the information of required data is not inherently included in IFC and CityGML, it must be added. This is where LADM can be in use. In addition to this, the strategic integration of LADM Part 5 into the BIM-based building permit process, is expected not only to enhance interoperability, but also to strengthen communication within different LAS modules provided by LADM, setting a solid foundation for the project's future development.

3. 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 do CityGML and IFC encodings of LADM Part 5 Spatial Plan Information (ISO19152-5) compare in supporting BIM-based permit checking? A case study in Estonia."

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

1. *How can LADM Part 5 be used CityGML data models by developing ADEs?*
2. *How can LADM Part 5 be used with IFC data models through extensions or other schema mechanisms?*
3. *To what extent can the inclusion of LADM contribute to the efficiency of automated permit checking processes in both CityGML and IFC, impacting accuracy and speed, and are there specific differences in spatial planning information?*
4. *What is the current state of permit checking in Estonia using CityGML and IFC models, and how does the proposed solution compare to the existing permit checking processes in Estonia?*
5. *Do the existing tools recognize the product of the collaboration of LADM Part 5 with CityGML/IFC encodings, and how do these standards compare in terms of effectiveness for supporting permit checking processes?*

4. Methodology

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

1. LADM is integrated into the 3D building models (BIM) that are already encoded in CityGML and IFC
2. Their performance is assessed concerning BIM-based permit checks

The Estonia case study is used as a reference point throughout the development process of the thesis, utilizing the concurrently developed BIM-based permit check project as a robust testing mechanism. The research was conducted using Design Science Research (DSR) approach (Hevner and 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.

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. 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. The main contributor of DSR is the Design Cycle, where the actual construction, evaluation, and refinement of the artifact take place according to received feedback from each loop (Hevner and Chatterjee 2010).

In this context, taking Alattas' approach (Alattas 2022) as an example of implementing DSR in his work, a DSR approach was developed for the thesis. It consisted of a three-staged approach to answer research questions aimed at guiding the thesis, Figure 5 shows this process and the connections between steps.

The first stage covers the preliminary level, involving a review of existing literature studies to understand the current state of research. Additionally, standards central to this thesis, such as LADM, IFC, and CityGML, will be examined for the upcoming integration step in the research. This, along with feedback from the application domain, will form the initial problem definition. After defining the problem, existing research on specific concepts like BIM-based permit checks and LADM integration will be explored technically to initiate the second stage, the conceptual level. In the last step of the first stage, knowledge from LADM will be utilized to contextualize the country profile mapping for the Estonia case study in the next step.

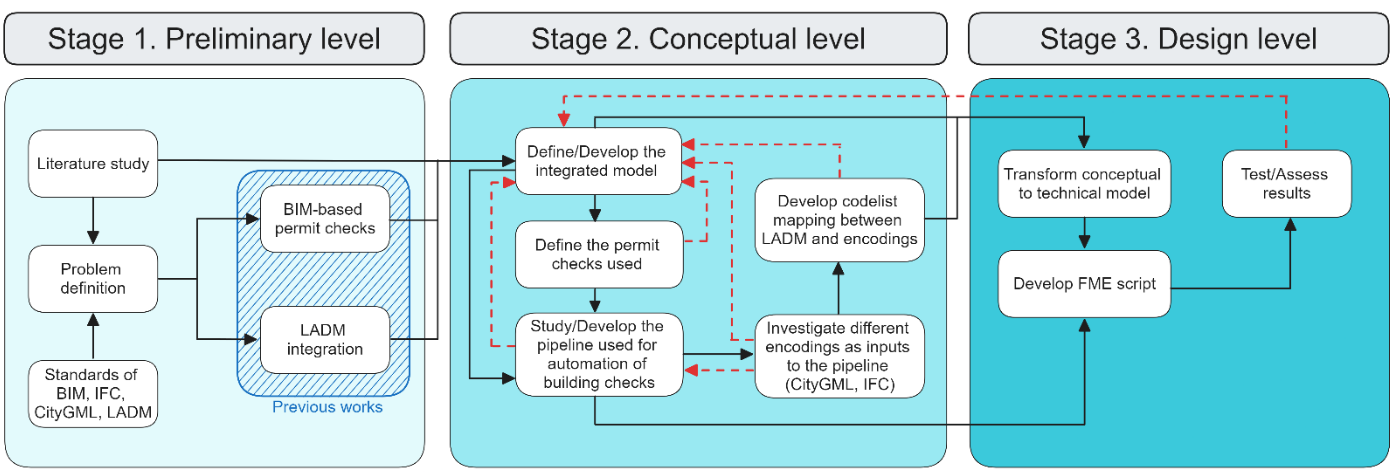

Figure 5. Research methodology

The second stage involves a conceptual level of initial development for the prototyped solution to the problem. Using the outputs and required knowledge from stage 1, the first step attempts to define and develop an integrated model for LADM and BIM automation. This step requires the functional usage of all features of the standards used in the research to initiate codelist mapping for semantic interoperability. Defining the connection between standards leads to the investigation of mapping building permits to LADM in the context of the selected Estonia project, which specifies the specific permits used. Using the case study as a tool for investigation also provides an opportunity to observe the ontology transformation between localized building permits and machine language. The last step of this stage explores different encodings for the created pipeline and develops a technical model, introducing the final stage, the design level.

The final stage covers the transformation of the conceptual model to a technical model. During this step, the technical model is considered an implementation model that helps discover its limitations or weaknesses. Additionally, the transformation involves the development of an FME script, which contributes to the overall automation process. This step is crucial as the process undergoes review and improvement in a feedback loop.

Furthermore, a MosCoW diagram, Figure 6, was created to define the areas of research coverage and specify the goals that fall outside the scope of the thesis.

Figure 6. MosCoW diagram for the research.

5. Case study: Estonia

The thesis is conducted in collaboration with Future Insight BV company 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 based on the initial project of Future Insight for automated BIM-based permit checks, started in 2018, which laid the foundation for the following advancements.

The first project's (2018) objective was to develop the software solution for BIM-based building permit processes in the Estonian Building Registry (EHR) ("BIM-Based Building Permit Process," n.d.). Developed BIM module would be integrated into the building permit application process on the Estonian Spatial Planning Information System platforms, PLANIS and RPIS (planned to be replaced by PLANIS in 2018)(ERR 2019). This module was fully integrated into the platform's user interface and operated on the online platforms. The project successfully implemented an extension to the EHR, introducing a suite of BIM-based compliance checks for building permits. This enhancement enables users to upload IFC files and run various compliance checks, such as assessing if the fire escape routes are sufficient (Figure 7).

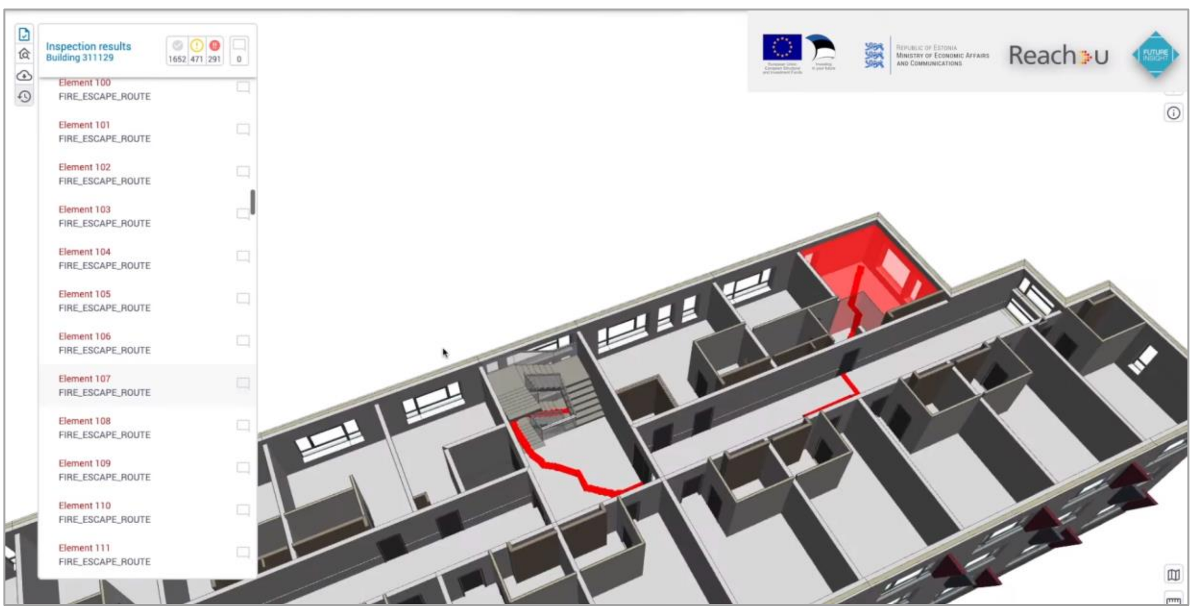

Figure 7. Fire route check through the implemented module (Image credits: Future Insight B.V.)

Building on the experiences and challenges encountered in the 2018 project, the current Estonia project focuses on expanding the capabilities of the previous BIM module, particularly in terms of scalability and the ability to run more extensive checks. The current project builds upon the concepts explored in the 2018 project, with a notable shift in focus. Instead of conducting compliance checks for BIM building designs, the emphasis is on evaluating less detailed Spatial Planning Information Models that represent Estonian detailed plans. These models are then compared against the requirements outlined in the master plan. Additionally, the current project seeks to improve the scalability of the BIM service and address hosting challenges by proposing a more scalable and efficient solution (Future Insight Group B.V. 2023).

With this project, Estonia stands out in adopting BIM-based permit-checking systems globally, among other pioneer municipalities of countries such as Norway, Finland, Singapore, Austria, Sweden, Denmark, and the Netherlands.

6. Time planning and Practical Aspects

The research is conducted in collaboration with the ongoing Estonia project at Future Insight B.V. The work schedule is segmented between tasks at the company and tasks at school. Based on the required responsibilities to achieve the research goals, a Gantt chart was made, shown in Figure 8.

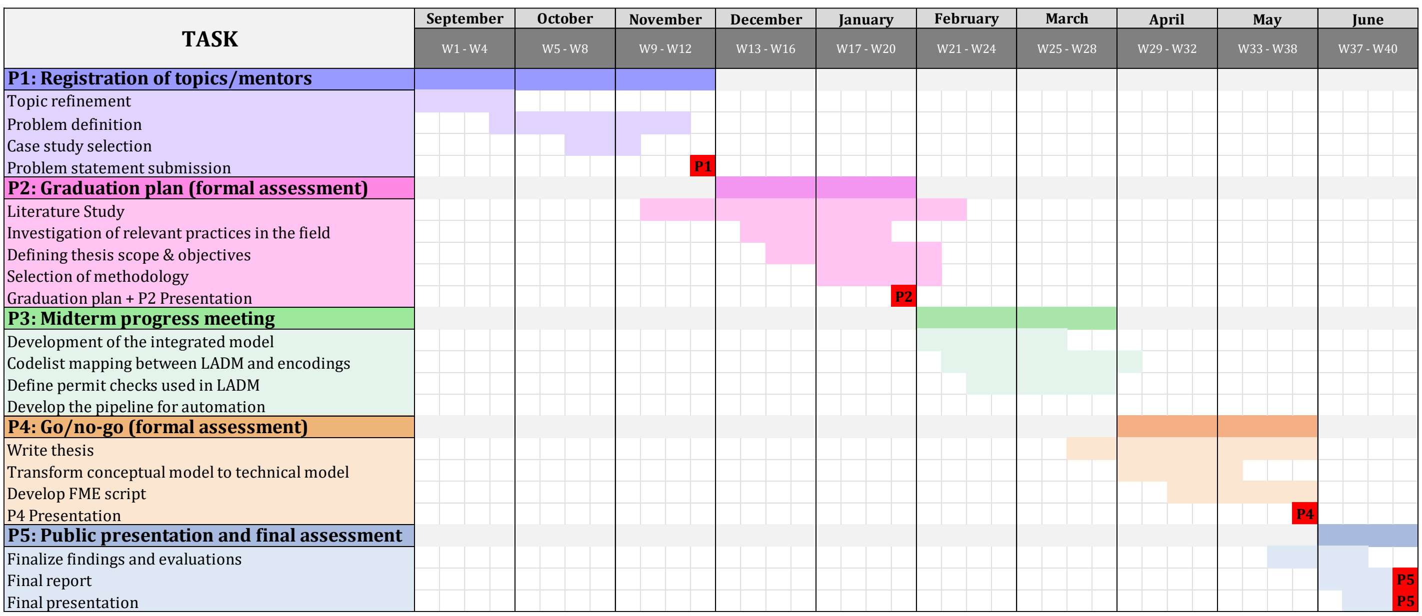

Figure 8. Gantt chart of roadmap for the research

7. Tools and datasets used

7.1. Tools

For efficient codelist mapping and modeling, FME (Feature Manipulation Engine) will be employed, facilitating the integration of LADM with associated encodings. For handling Building Information Models (BIM), especially in terms of storage and visualization, tools such as Clearly.BIM will be used. Additionally, the use of an open-source (Java) library like CityGML4j is planned to enhance the manipulation and processing of CityGML data. Furthermore, considering the storage options for CityGML data, alternatives like 3DCityDB, based on PostgreSQL and accessible through tools like pgAdmin, will be evaluated. The most suitable storage solution will be selected throughout the process and employed to ensure optimal data management and accessibility. GIS software like QGIS/ArcGIS is considered to be used for reading and altering GIS data. Finally, Enterprise Architect (EA) will be utilized for reading and creating UML diagrams.

7.2. Datasets

The datasets 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. The Masterplan 2030 for the Old City Harbour area was finalized in 2017, and the area continues to undergo development ("Old City Harbour Development," n.d.). In addition to the detailed plans, an elaborate 3D detail plan is available for the area, Figure 9 (Future Insight Group B.V. 2023). However, it is important to note that there is currently no standardized representation of planning elements in IFC entities.

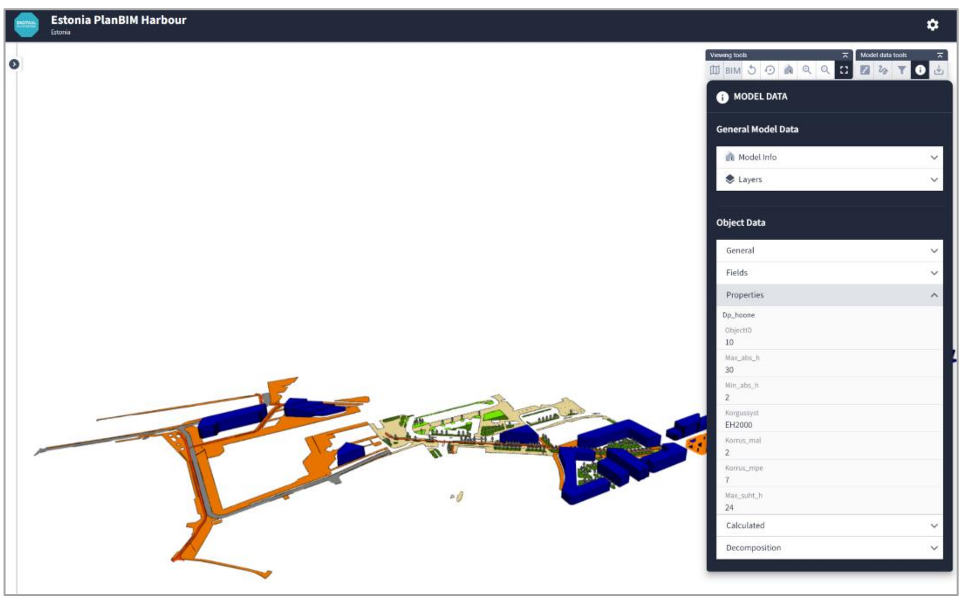

Figure 9. IFC file of the detailed plan of Tallinn Harbor area. (Image credits: Future Insight B.V.)

In addition to this the data of the National Broadcasting Building will be used. This test data includes a detailed plan and a detailed design of the building, both in IFC formats. Finally, a master plan data will be used to compare the detailed plans against the requirements outlined in the master plan.

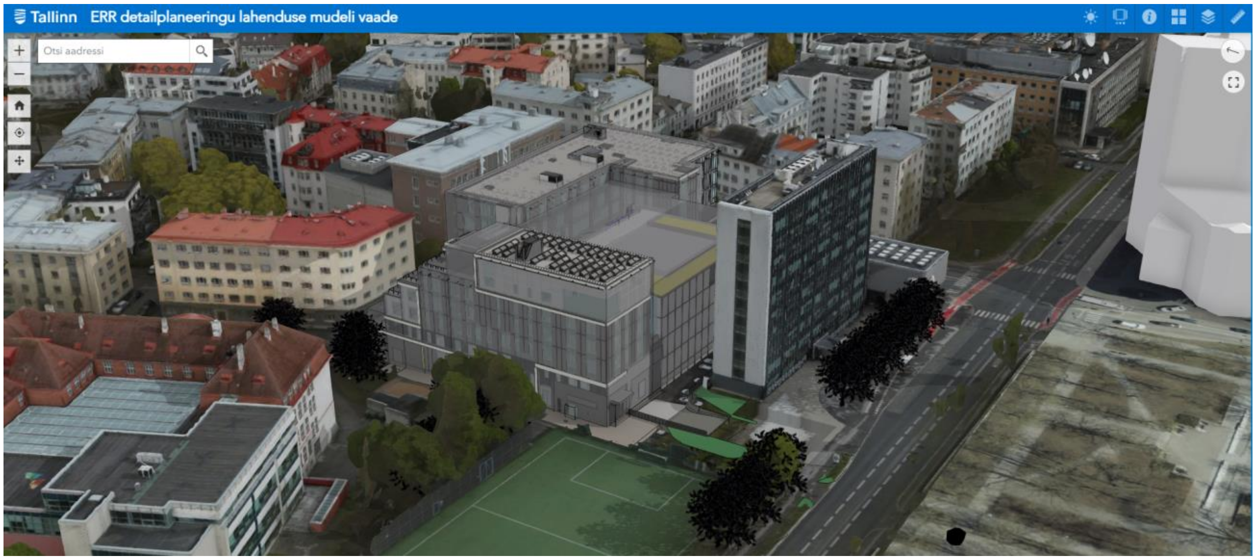

Figure 10. Visualization of the 3D Detailed Plan combined with 3D Data of the City of Tallinn. (Image credits: www.tallinngis.maps.arcgis.com)

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9. Appendix

Table 1. Contributions related to rule interpretation and digitalization of city and building regulations. Table 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 a 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