

Representing the Spatial Plans as 3D Standardized Geodatasets: Demonstrations from Sweden and Türkiye

Dogus Guler^{1,*}, Jing Sun², Jenny Paulsson³

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* Corresponding author

Conflict of Interest statement

None of the authors has a conflict of interest to disclose.

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¹ Department of Geomatics Engineering, Istanbul Technical University, Istanbul, Türkiye, gulerdo@itu.edu.tr, ORCID: 0000-0002-3191-103X

² Department of Computer Science and Civil Engineering, University of Gävle, Gävle, Sweden, Jing.Sun@hig.se, ORCID: 0000-0003-2820-5801

³ Department of Real Estate and Construction Management, KTH Royal Institute of Technology, Stockholm, Sweden, jenny.paulsson@abe.kth.se, ORCID: 0000-0001-7886-5926

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Abstract

Planning practices that are crucial for ensuring the sustainability of countries evolve into approaches that significantly benefit from digital data, especially geodatasets, with the advancement of information and communication technologies (ICT). In addition, the complexity of the built environment brings about the transformation of land administration practices in a way to manage three-dimensional (3D) modeling of cadastral rights, restrictions, and responsibilities (RRR) for both above and below the land surface. Given the land development phenomenon in relation to this, there is a growing interest in utilizing the 3D models within the spatial planning to improve the efficiency and transparency of the planning processes. In this sense, this paper presents a methodology on how the 3D interoperable geodatasets that depict the land use plans can be created through defined conceptual models. The results show that the conceptual models can be formed based on the regulated land use specifications of different countries to create corresponding CityJSON extensions, and hence, 3D interoperable geodatasets representing the land use plans can be generated by validating them against these extensions. The visualization of these datasets is also presented by means of a Cesium-based prototype. By demonstrating the methodology within two countries, namely Sweden and Türkiye, this study contributes to the digital exchange of 3D standardized land use plans for digital transformation initiatives, as well as further applications such as digital building permits.

Keywords: 3D land use plan, 3D geoinformation, 3D land administration, CityJSON, digital planning, data standardization.

1 Introduction

Land is an essential resource for the sustainable development of (Williamson et al., 2010). Urban planning is of great importance to benefit from the land, as it is the main discipline and science that expresses how the land should be used in the most efficient manner (United Nations, 2008). In addition, land administration is the fundamental mechanism that provides the technical implementation of land management with regards to cadastral rights, restrictions, and responsibilities (RRR) (Dale & McLaughlin, 2000). This mechanism is realized through land administration systems that often use digital registries based on two-dimensional (2D) datasets. These systems are considered as a special form of Geographic Information Systems (GIS) (Yomralioglu & McLaughlin, 2017).

The proliferation of GIS has greatly enhanced planning practices by providing data-driven spatial analyses and supporting decision-making through various geodatasets (Geertman & Stillwell, 2020; Harris & Batty, 1993). Furthermore, the developments regarding information and communication technologies (ICT) facilitate the opportunity for digitalizing the various services and procedures in a broader context (Reis et al., 2020). This includes the digital transformation of planning that aims to promote stakeholder-inclusive, scientifically-supported, and interoperability-enabled approach through digital technologies, tools, and datasets (Batty, 2021; Batty & Yang, 2022). Accordingly, the interest in digital planning and, consequently, the benefits that result from its implementation is gaining attention (Daniel et al., 2024; Hersperger et al., 2022).

In connection to this, another interest regarding improving the planning practices encompasses integrating the subsurface space into spatial planning (Hooimeijer & Tummers, 2017; Zhao et al., 2016). Managing underground space has become increasingly important as cities face land scarcity and the need to optimize spatial resources (Broere, 2016; Hunt et al., 2016; Qin et al., 2024). Regarding this, it is important to note that the existence of three-dimensional (3D) models covering subsurface provides a fundamental data resource to make

efficient decisions when planning land use on underground space (Peng et al., 2025; Zhou et al., 2019). The interdependence between land administration and spatial planning is thus intensified in the context of digital planning (Enemark et al., 2014), particularly in managing 3D cadastral RRR below the surface (Saeidian et al., 2023a; Tarozzo Kawasaki et al., 2025). This is also related to evolving the land administration systems in a way to utilize the 3D spatial datasets regarding cadastral RRR for both aboveground and underground of the land (Guler et al., 2022; Paasch & Paulsson, 2023; Sun et al., 2023; van Oosterom et al., 2020).

In parallel, it can be underlined that the digitalization affects the building permit procedure in such a way that the Building Information Modeling (BIM) that enables digital models of buildings/facilities in 3D through object-based modeling approach are utilized as the main submission document (Noardo et al., 2022). While the Industry Foundation Classes (IFC) schema provides data interoperability, the other standards such as the Information Delivery Specification (IDS) support the efficient digital data exchange across different departments and stakeholders (buildingSMART, 2025).

Building permitting has a close linkage with both spatial planning and land administration as it includes the compliance checks that are conducted against approved land use specifications and registered cadastral RRR (Guler, 2023). On the one hand, sharing urban plans digitally is thus vital to facilitate the automation within digital building permits (Guler & Yomralioglu, 2022). On the other hand, the existence of land use plans as 3D models contributes to enhancing this automation by providing a data resource for various beneficial 3D spatial analyses from different contexts, such as buildability, noise level, and historical restrictions (Emamgholian et al., 2024). In this sense, achieving data interoperability is essential to improve the efficiency of procedures and enrich the reusability of datasets within the systems, which is also put into force with the European Union (EU) Data Act (European Commission, 2023).

In light of the outlined issues, the main aim of this research is to propose a methodology for how 3D geodatasets that represent the land use plans with their descriptions can be created through a geoinformation-based data standard. To achieve this aim in terms of demonstrating the replicability and practicability of the proposed methodology, the research objective is identified as presenting the implementation of the conceptual models through the created geodatasets in two countries, that is, Sweden and Türkiye. These countries are selected as study objects for several reasons. First, there is an interest for digitalization in these countries that is promoted by the governments. Second, this digitalization ambition encompasses the building permit and planning procedures through the use of digital data. Third, there is strong evidence in both countries regarding the standardization of plan data by means of information models.

The remainder of the paper continues with Section 2 covering background on digital planning, related standards, an overview of the current situations in the included countries, a review of related works, and the contributions of the presented research, lastly. The next section contains the methodology of the research. Section 4 expresses the results as tripartite. First, it covers the details on how the conceptual models and corresponding standard extensions are developed. Section 4.2 includes the results from the data transformation and then the Section 4.3 presents the visualizations regarding the created geodatasets. The last section discusses the content of the presented research comprehensively and concludes the paper, revealing the implications in line with the discussion.

2 Background

2.1 Digital Planning

Planning is one of the most important instruments for promoting the sustainability of urban environments. Interest in digital transformation strongly influences the planning practices. The concept of digital planning is actually not a recent approach as the discussions to

promote planning support systems (PSS) (Harris & Batty, 1993), which can be evaluated as foundation of digital planning, started with the increased usage of information technologies and digital tools such as Computer-Aided Design (CAD) and especially GIS (Geertman & Stillwell, 2020). PSS significantly benefits from the spatial data and analysis to support the decisions for creating spatial plans (Klosterman, 1997). Accordingly, it can be noted that digital planning fundamentally encompasses the use of digital data, particularly geodata. In recent years, there has been a growing trend to practice digital planning in different countries, especially in the European region (ESPON DIGIPLAN, 2021).

This interest often covers transforming the plan data into a digital format. Even though this is the first step towards digital planning, it is worth mentioning that the digital planning paradigm constitutively expresses practicing the planning procedures using ICT in scientifically-supplemented and comprehensively-participated ways (Potts & Webb, 2023). While digitalization encompasses creating PDF and similar formats on the initial level, the advanced level aims to provide the geodata representing the land use plan.

In this sense, standardizing the planning data into machine-readable form is an essential mechanism to enable interoperability between different systems, as stated in the European Interoperability Framework (European Commission, 2017). However, the existence of geodata for information exchange and interoperability remains a work in progress. This issue has been mentioned in a report in 2021, stating that no country has yet achieved a comprehensive implementation of a machine-readable planning system (ESPON DIGIPLAN, 2021). Nevertheless, for example, in Finland, information models that include the conceptual models, code lists, and information exchange rules have been developed to promote semantic interoperability in the context of digitalizing its planning system (Nummi et al., 2023).

2.2 Related Standards

In connection with the previous section, it is important to note that promoting interoperability lies in standardization. Defining and establishing the standards is the foundation of standardization. The digital plan data is closely related to standards regarding spatial information. In the European context, the Infrastructure for Spatial Information in Europe (INSPIRE) is the fundamental directive and source for enabling spatial data interoperability within different application themes such as cadastral parcels, transport networks, and land cover (European Commission, 2024). The aim is to enable and maintain spatial data interoperability throughout Europe. Accordingly, the Data Specification on Land Use provides the conceptual models that represent spatial objects and relationships utilized to model spatial plans digitally. These conceptual models basically target 2D data modeling.

Spatial plans are also a significant driving force for effective land management. For this reason, the Land Administration Domain Model (LADM), which provides conceptual models for cadastral RRR, includes the Spatial Plan Information (SPI) part within its second edition (Kara et al., 2024). This standard aims to provide a common ontology for land administration practices by means of these models. The SPI part is formed by considering other standards that include conceptual models regarding land use specifications, such as INSPIRE. This part covers the feature types representing the spatial plans at different scales, such as *SP_PlanBlock* and *SP_PlanGroup*, with a defined relationship. The most detailed object within the spatial plan is represented by the *SP_PlanUnit* feature type. LADM provides basic conceptual models, while its feature types and attributes can be modified and enhanced for specifications of the jurisdictions through country profiles, as exemplified in the literature (Kalogianni et al., 2021).

In addition, the increased multifaceted structure of the built environment necessitates creating the digital representation of physical objects and logical spaces by considering the vertical

dimension. In this sense, CityGML⁴ is the prominent geodata standard to produce semantic urban models in a 3D modeling context. It covers a number of modules, such as building, construction, and transportation, to enable modeling of the built environment in a comprehensive manner. The conceptual model covers the fundamental feature types for creating 3D models within these modules. In relation to spatial planning, the core schema of the standard includes the LandUse module that can be used to depict the objects representing the land use and land cover of the surface of the earth. It has one top-level feature type named LandUse as a subclass of *AbstractThematicSurface* that allows for creating 3D objects through GM_MultiSurface and GM_MultiCurve geometry types based on ISO 19107:2003 (ISO, 2003).

CityGML 3.0 is the latest version of the standard that is developed in a way to facilitate the integration with other standards such as LADM and IFC used in BIM. In addition, the concept that enables modeling of logical spaces, such as building subdivisions alongside physical objects such as buildings, is included in the standard with this version (Kutzner et al., 2020). CityGML is typically implemented using the Geography Markup Language (GML) as its encoding format⁵. Moreover, the CityGML standard allows for enriching the core schema of the standard by means of the Application Domain Extension (ADE) mechanism to fulfill the modeling necessities for specific application domains, such as energy demand modeling. In this way, new feature types and attributes can be added to conceptual models within different modules.

CityJSON has been further proposed as a JavaScript Object Notation (JSON)-based encoding of the CityGML data model to enhance the implementation capabilities that are impeded because of the relatively complex hierarchical structure of GML (Ledoux et al., 2019). CityJSON 2.0 is mostly compatible with the core schema of the latest version of

⁴ <https://www.ogc.org/standards/citygml/>

⁵ <https://docs.ogc.org/is/21-006r2/21-006r2.html>

CityGML 3.0. There are first and second-level city objects within the defined hierarchy of CityJSON specifications,⁶ such as *Building* and *BuildingUnit*. In other words, while first-level objects might be depicted as themselves alone, second-level objects should have a parent object to exist. For example, a *BuildingUnit* object that represents a subdivision of the building, such as an apartment unit, should have the children and parent relationship with a *Building* object. CityJSON also has extension capability of the core schema with a more flexible mechanism than CityGML ADEs. It is aimed at increasing the practicability of the CityJSON datasets that are created based on proposed extensions in a more effortless way. This means that CityJSON datasets that are created based on the developed extension and cover the new city objects and/or attributes can be utilized within the software and/or tools without requiring additional extension files or importing adjustments.

2.3 Overview of Current Situations in the Countries

2.3.1 Sweden

The planning system in Sweden includes regional development strategies for counties that encompass spatial policy goals, which are required by the government. The strategies that are determined for the development of the municipalities are included within Comprehensive Plans which the municipalities are responsible for preparing. These plans cover the whole of the municipality and may contain suggestive provisions that are not legally binding. The municipalities also create Detailed Development Plans that contain regulatory zoning specifications regarding land use for the selected area of the municipality. These plans provide restrictions and rights to land owners (OECD, 2017).

There is a governmental interest in digitalization in the country. This interest significantly affects the digitalization of public services. Digitalization also encompasses the building permit procedures. Accordingly, the Swedish National Board of Housing, Building and

⁶ <https://cityjson.org/specs/>

Planning (Boverket) has an aim for digitalizing the urban planning process to improve efficiency⁷. This aim fundamentally covers providing up-to-date and exchangeable urban planning data. In connection to this, creating plan data digitally is required at the national level by different regulations, that is Act (2010:1767)⁸ on Geographic Environmental Information and the Ordinance (2010:1770)⁹ on Geographic Environmental Information, from 2022. The main goal is to enable interoperability between different systems through standardized plan data. In this regard, Lantmäteriet (Swedish mapping, cadastral and land registration authority) provides information models that cover specifications on how corresponding geodatasets for different plans, such as the Detailed Development Plan (Lantmäteriet, 2023a) should be created. In the information model, there is an association between the objects corresponding to the Detailed Development Plan (Detaljplan) and Planning Provisions (Planbestämmelse) that complements the plan in terms of legal specifications. Geometry definitions are mandatory for both objects through the specified data type, namely *Geometri*. This data type provides geometry information with attributes and its subclasses, such as line or polygon. Both GeoJSON and GML are supported for different types of geometries. 2nd and 3rd dimensions can be selected and modeled within this data type, such as *LineString* and *Solid*.

2.3.2 Türkiye

The general framework of planning in Türkiye is initialized with two national strategic plans, namely the National Development Plan and the National Spatial Strategy Plan. Regional Plans follow these national plans to provide spatial strategies for specific regions in the country. Environmental Plans provide more land use planning and fewer spatial strategies compared to the Regional Plans, at the small scales between 1: 100 000 and 1: 25 000. Land

⁷ <https://www.boverket.se/sv/samhallsplanering/digitalisering/>

⁸ https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/lag-20101767-om-geografisk-miljoinformation_sfs-2010-1767/

⁹ https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/forordning-20101770-om-geografisk_sfs-2010-1770/

Use Zoning Plans specify the general land use types with additional information such as urban, social, and technical infrastructure areas and transportation systems for specific regions/areas with the aim of making urban spaces more livable. At the bottom, Implementation Zoning Plans elaborate the specific development regulations within the levels of parcel blocks and parcels at the scale of 1: 1 000 (OECD, 2017).

As a candidate country, the national strategies in Türkiye are significantly affected by the strategies that are implemented by the EU. In the early years, this started with the use of electronic systems and evolved into increased use of digital technologies and tools within public services. One of the important progresses is developing the national spatial data standards aligned with the INSPIRE directive, that is Türkiye National Geographic Information System (TUCBS)¹⁰. The aim is to prevent the duplicative production of spatial data by different organizations and facilitate the efficient sharing and reuse of standardized data between administrations and stakeholders throughout the country. TUCBS is coordinated by the Directorate General of Geographic Information Systems (DGGIS).

Similar to INSPIRE, TUCBS covers the data specifications for the Land Use theme, which covers the conceptual models and code lists regarding how the geodataset representing the spatial plans should be modeled. In harmony with the objectives regarding digitalization, the e-plan¹¹ system that enables managing the planning process electronically is put into practice. The system aims to collect new Implementation Zoning Plans such that they are generated in GML format and compatible with the 2D geodata standard, namely PlanGML, which is in line with the TUCBS, in order to provide data exchange regarding spatial plans digitally. In this regard, all GML files representing the Implementation Zoning Plans should be valid against to XML Schema Definition (XSD) document that is created for PlanGML.

¹⁰ <https://tucbs.gov.tr/>

¹¹ <https://e-plan.gov.tr/>

The latest national development plans in Türkiye include promoting digitalization in different sectors, particularly in the construction sector. In connection to this, it is aimed to practice an electronic project management system that enables the use of BIM models of designed buildings within building permitting, and to establish a national digital building database covering BIM/IFC models. Accordingly, the Planned Areas Zoning Regulation (PAZR) is amended in a way to ensure that BIM models of the construction projects that are aligned with defined standards by the ministry will be delivered to the authorized departments and stored in the database after validation. This amendment will enter into force on the first day of 2027¹².

2.4 Related Works

One of the key questions in literature is whether digital planning is beneficial in practice; another is whether it is implemented efficiently. In this regard, current situations in the countries with regards to the digital plan data were investigated, for example, in Denmark (Fertner et al., 2019) and Slovakia (Gergel'ová et al., 2024). In relation to this, Hersperger et al. (2022) examined how the use of digital plan data affects the planning procedures in terms of efficiency, transparency, and innovation by considering the practices within three countries. They stated that digitalization positively affects the planning procedures since it improves the efficient interaction between stakeholders and administrations. Similar to the results of this study, the outcomes mainly highlighted that digital planning are helpful for improving the planning procedures (Lin et al., 2025). The majority of these studies aimed to provide insights through interviewing the different personnel who have a role in planning procedures.

With the increasing presence of 3D models, another topic that is being researched in relation to the digitalization of planning is the use of 3D visualizations within urban planning practices. While some of this research focused on whether the 3D visualizations are helpful for citizen

¹² <https://www.resmigazete.gov.tr/eskiler/2025/03/20250311-1.htm>

participation (Chassin et al., 2022; Onyimbi et al., 2018; H. Wu et al., 2010), some studies investigated the usability and efficiency of these visualizations in terms of perception and interpretation of urban planners (Herbert & Chen, 2015). For example, Jaalama et al. (2021) stated that 3D visualizations can be used as supportive tools for communication within planning. Recently, Linkola et al. (2025) underlined that 3D geovisualization is an aidful approach for planning departments in the context of improving the collaboration of citizens in the planning process based on the results of a Finnish case study. Furthermore, Eilola et al. (2023) expressed based on their review that most of the studies are lacking in technology and its adaptations regarding 3D visualization in planning practices. In addition, creating spatial plans as a 3D model was investigated. For example, as an early study, Bos (2011) converted the 2D zoning plans in Groningen, the Netherlands, into a 3D dataset that can be visualized in Google Earth. Furthermore, how different cartographic design approaches for 3D visualization of digital plans affect the perception of persons was examined as a case study in Sweden (Judge & Harrie, 2020).

In the sense of standardization, the SPI part of the LADM standard was proposed to integrate spatial plans and cadastral RRR (Indrajit et al., 2020). Accordingly, researchers developed country profiles based on the SPI part of the LADM standard for different countries, such as Türkiye (Yılmaz & Alkan, 2024), Serbia (Radulović et al., 2025), and Greece (Poulaki et al., 2024). For example, Yılmaz & Alkan (2024) provided a case study regarding the country profile by means of a 2D spatial dataset. Furthermore, some studies aimed to use the LADM SPI part for 3D representations in order to efficiently delineate the land use plans (Indrajit et al., 2021). In this sense, Guler (2023) presented the conceptual model based on the LADM SPI part and its implementation through the CityJSON dataset. The scholar also demonstrated how a 3D geodataset can be used effectively through queries that cover 3D spatial analyses regarding the compliance checks within building permitting. Batum et al. (2025) provided a country profile for Estonia based on the LADM SPI part and created a

corresponding spatial database within PostgreSQL. They presented how the detailed plan can be integrated into this database for SQL-based compliance checks.

Moreover, the utilization of 3D datasets and 3D analyses was proposed regarding different cases, such as noise impacts, overshadowing, and protected area boundaries in the sense of land use regulation restriction checks (Emamgholian et al., 2024; Tezel et al., 2021). Zahid et al. (2024) mapped the classes within Xplanung, which is the German standard for exchanging plan data digitally, into features of CityGML to obtain 3D land use plans for urban simulations. Olsson et al. (2025) converted a 2D land cover dataset into a CityGML dataset through 3DCIM ADE to obtain semantically-enriched models for urban simulations. Grisiute et al. (2025) proposed a methodology that transforms land use plans into an ontology-driven format in which different content-based queries can be utilized to provide insights from the descriptions of the plans. Demir Altıntaş & Ilal (2021) proposed a conceptual model to create GML datasets that cover the land use specifications in zoning plans by integrating related attributes from BIM models to facilitate the automation of compliance checking. It can also be mentioned that the CityJSON core model was extended in a way to encompass the features and relationships that are beneficial for different application fields, such as energy demand modeling (Tufan et al., 2022), point cloud storing (Nys et al., 2021), historical city modeling (Vaienti et al., 2022), and design checks (Wu, 2021).

2.5 Contributions of this Study

Reviewing the literature shows that digitalization of planning procedures is considered a useful approach for contributing to the sustainability of the urban future. However, implementing digital planning requires notable advancement in technological services that are significantly fed by digital data. Beyond its impact on planning practices, digital planning is also an essential contributor to the digitalization of planning/building permitting. The important issue is that plan data should be generated in a way to align with the defined spatial data standard that promotes data exchange. Furthermore, the complex structure of the urban

areas forces the creation of 3D spatial plans where the vertical dimension should be considered, such as subsurface management. Notwithstanding, the literature is still lacking in creating 3D standardized geodatasets representing the spatial plans since many previous studies have focused on examining if/how 3D visualizations are useful for planning rather than the generation procedure of geodatasets. In addition, only a few studies concentrated on the modeling of spatial plans in which different land use specifications, such as restrictions for underground historical sites, require a 3D depiction. Considering this information, the presented research contributes to the existing body of knowledge in several ways. First, this study points out how to develop conceptual models by considering the current regulations and information models in the countries, and then expresses how to implement these models through 3D CityJSON geodatasets for two different countries. By doing so, it is shown that the methodology can be replicated in different study areas. Second, this research gives evidence on how 3D geodatasets depicting the spatial plans with their descriptions can be generated and validated by means of standard extensions in order to ensure standardization. Third, this article reveals how to model spatial plans, including land use and cadastral restrictions regarding different levels of the subsurface as 3D standardized geodatasets for practicing complete planning that encompasses above and below of land. Considering these contributions, the digitalization level of plan data is modified as seen in Figure 1.

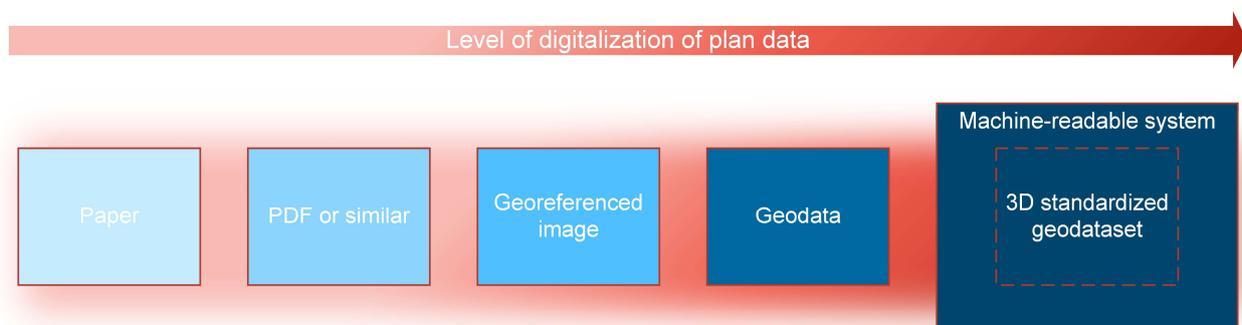


Figure 1. The different levels of digitalization of plans (adapted from ESPON DIGIPLAN (2021))

3 Methodology

The methodological framework adopted in this study consists of a sequence of steps summarized in Figure 2. The approach integrates regulatory analysis, conceptual modeling, dataset transformation, and validation to demonstrate the generation of standardized 3D spatial plan datasets.

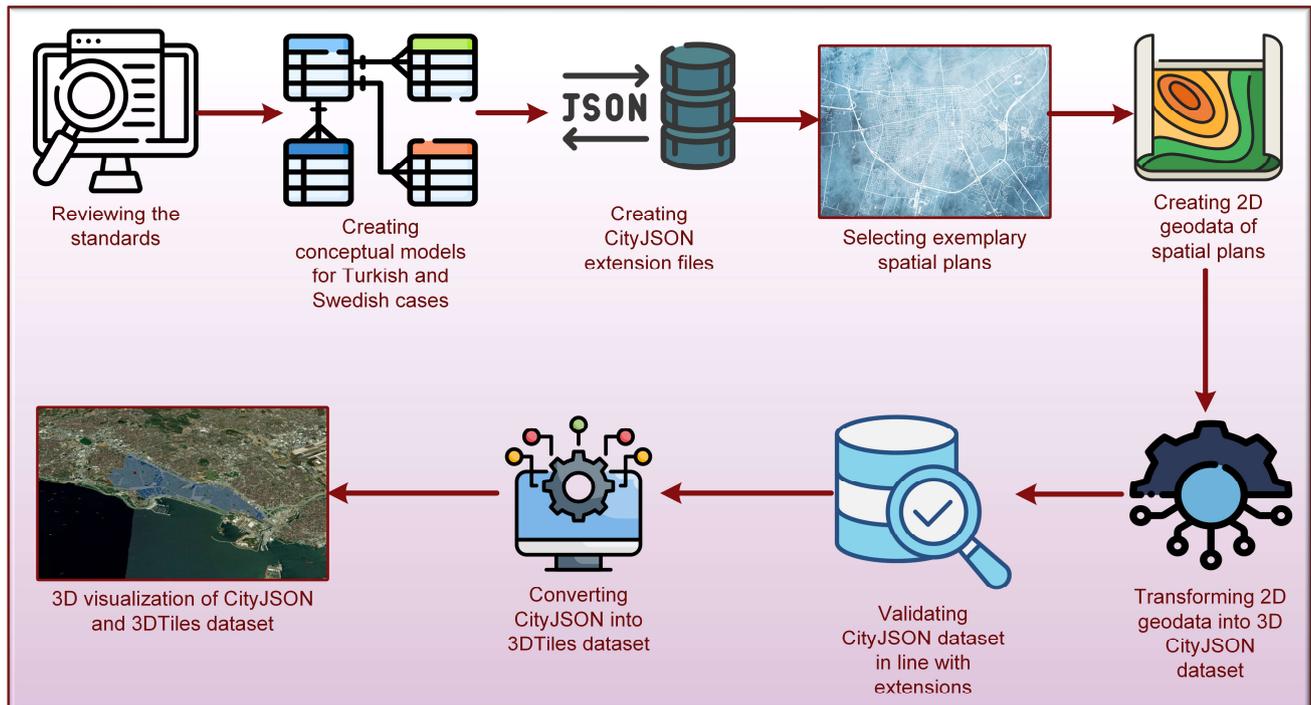


Figure 2. Research method of the study.

First, the related regulations and data standards were examined for both countries, namely Sweden and Türkiye. One of the main reasons to examine two countries in parallel is to provide strong evidence for the applicability of the proposed methodology in different study areas. In this way, the replicability of the methodology for 3D geoinformation-based representation of spatial plans can be demonstrated comprehensively. Both countries were purposively selected owing to their advanced initiatives and policy orientations toward digitalization in spatial planning and land administration. More specifically, given that there are notable research activities on 3D land administration in Sweden and Türkiye, in which these topics complement each other, examining two specific study areas by considering

regulations and practices provides a significant insight for transferring the proposed methodology into administrative areas where there is an interest in incorporating the interoperable plan data within governmental services, such as building permitting. These activities cover the extensive use of digital modeling approaches such as BIM and 3D GIS, where 3D digital plans can enhance the procedures for such services. Another reason is to point out how standard-based implementation of the conceptual models that are developed for different study areas can be achieved efficiently. This is important because the conceptual model-based methodologies might result in insufficient outcomes for other study areas in terms of realization.

The progress on the standardization of geodata within case countries is also a significant indicator to implement the developed methodology that covers the creation of 3D geodatasets. In terms of standards, the Land Use theme within TUCBS was the main reviewed resource for the Turkish case as it provides data specifications for different levels of spatial plans in 2D. The Information Model for Detailed Development Plan and regulation that is shared by Boverket was a basic source for the Swedish case since it covers detailed information for creating the spatial plans in a standardized way. Additionally, international standards such as LADM were also reviewed in the sense of spatial planning. After that, the conceptual models defining the relevant features and relationships were developed separately for each country. These models were formed based on the standard specifications of CityJSON by considering the content of the reviewed resources for the countries. CityJSON extension files corresponding to these conceptual models were formed (see Section 4.1). It can be noted that the steps between the creation of conceptual models and corresponding CityJSON extension files may be an iterative process until achieving the complete representation of the conceptual model as an extension file. This is because implementing the content of the conceptual models might be challenging due to the defined modeling specifications of the standards.

In this study, CityJSON was selected over alternatives such as IFC and CityGML ADE due to its superior balance of performance, storage efficiency, and interoperability for urban-scale applications. Unlike IFC, which is optimized for modeling individual buildings, CityJSON is more suitable for representing land use plans across large extents like districts or cities. Its JSON structure is less verbose than CityGML's GML, leading to smaller file sizes and faster processing. Furthermore, CityJSON's extension mechanism is more interoperable: unlike a CityGML ADE, which requires a separate definition file, a CityJSON extension is self-contained within the dataset, enhancing usability across tools without plugins. Finally, extending IFC is complex and can yield software-specific results, limiting interoperability (Yu et al., 2023), whereas CityJSON offers a more standardized and software-independent approach.

The spatial plans pertaining to each country were selected to demonstrate the implementation of the conceptual models. Two plans were identified for the Swedish case to cover the different land use specifications and demonstrate the creation of 3D plan geodatasets for different areas. A spatial plan that has a large extent with a great number of land use types and restrictions was used for the Turkish case. These plans were converted and organized as 2D geodatasets. Next, they were transformed into CityJSON datasets in 3D and validated against the developed CityJSON extensions. Further, these datasets were converted to 3D Tiles format for web-based visualization and exploration.

4 Results

4.1 Creating Conceptual Models and Standard Extensions

Developing the conceptual models is the first step to creating interoperable 3D digital plan datasets. These models are formed by considering the existing national information models and regulations within countries. First, the features and relationships pertaining to spatial plans are established. For Sweden, the current information model for the Detailed

code column provides standardized coding that corresponds to the mentioned formulations, such as "DP_KM_Eg_Fastighetsstorlek_Storsta_Storsta", which is used for indicating the maximum property size. As illustrated in this example, minimum property size should be coded as "DP_KM_Eg_Fastighetsstorlek_Minsta_Minsta". After determining the contents related to spatial plans, the conceptual model is designed such that it can be implemented as a CityJSON extension. This is important to prevent incompliances between conceptual models and the physical dataset.

Figure 4 shows the conceptual model that is created for Sweden. A number of rules should be followed to create the extensions for CityJSON as defined in the standard specifications. The conceptual models in this study are created by taking these rules into consideration. For example, the names of new city objects should start with the "+" sign, as seen in Figure 4, for example, *+SE_ComprehensivePlan*. While *+SE_DetailedDevelopmentPlan* is the corresponding object for detailed development plans, *+SE_PlanningProvision* is used for modeling these plans with their detailed descriptions, such as minimum property size. As can be seen in Figure 4, *+SE_PlanningProvision* object has attributes to store information regarding different property sizes, such as *propertySize1* and *propertySize2*. These attributes are formed based on the information model belonging to the Detailed Development Plan. To comprehensively store the plan specifications, complex attributes are defined in the conceptual model, for example, *propertySize*. This attribute has also sub-attributes that are defined as properties within the CityJSON extension. For instance, the plan description regarding the minimum property size in Figure 3 can be stored in this way. In other words, *propertySize* has several sub-attributes, namely *pSizeSubType*, *pSizeID*, and *pSizeValue*. They respectively correspond to property subtype (e.g., DP_KM_Eg_Fastighetsstorlek_Minsta_Minsta), identification of property size type, and defined value (e.g., 1000).



Figure 4. The conceptual model for Sweden, from which the enumerations within complex attributes are selected from different sections of the BFS.

A similar approach is used for defining the other complex attributes regarding the specifications for different contexts, such as utilization rates and heights. The enumerations within complex attributes are selected from different sections of BFS.

All feature types within Figure 4 are modeled as a subclass of *_AbstractCityObject* within the CityJSON schema. This is the core feature type from which the first-level city object types are derived. The relationships between feature types are defined as seen in Figure 4. For example, there is an association relationship between *+SE_DetailedDevelopmentPlan* and *+SE_PlanningProvision*. In other words, a *+SE_PlanningProvision* instance might have a relationship with only one *+SE_DetailedDevelopmentPlan* instance.

On the other hand, a *+SE_DetailedDevelopmentPlan* instance might have a relationship with zero or more *+SE_PlanningProvision* instance. This is because different planning provisions can be defined for a detailed development plan. Figure 5 shows the created conceptual model for Türkiye. The model consists of feature classes that can be used to represent different types of spatial plans, namely the environmental plan and the land use zoning plan. As mentioned before, the legal bindings regarding the land use specifications are defined within implementation zoning plans. Legal bindings are mostly defined for parcels, which are named zoning parcels within these plans. Sometimes, these bindings might be determined for only a parcel block in a way to affect all parcels in that block. The limitation regarding building heights is an example of this situation. For this reason, the conceptual model includes feature classes corresponding to parcels and parcel blocks, namely *+TR_Parcel* and *+TR_ParcelBlock*. These two features have a composition relationship as seen from the conceptual model. In other words, a *+TR_Parcel* instance should have a relationship with only one *+TR_ParcelBlock* instance. On the other hand, the *+TR_ParcelBlock* instance might have a relationship with one and more *+TR_Parcel* instances. *+TR_ImplementationZoningPlan* covers a number of attributes for defining the different land use types in a broader sense.

This feature type is used for defining land use types of different areas such as tourism, disaster, and protected areas. *+TR_Parcel* is the main feature type that represents the detailed land use descriptions such as *floorAreaRatio* and *footprintAreaRatio*.

It encompasses a large number of attributes to comprehensively depict the zoning information regarding the parcels such as *maxStorey* and *maxHeight*. Furthermore, some attributes that affect the content of the rules within the regulation are included within *+TR_Parcel*. For example, *isCornerParcel* defines whether the zoning parcel is at the corner or not. As shown in Figure 5, all feature classes have a number of attributes for storing the regulated definitions within the plans. The current data schema within TUCBS, namely Land Use, is considered when determining these attributes. Similar to the Swedish conceptual model, complex attributes are defined to unambiguously store the information in the plans. For example, *housingStructureDensity* has a number of sub-attributes for modeling the legislative bindings regarding zoning parcels, such as *referenceFrontSetBackDistance* and *buildingStructureType*. Also, the conceptual model contains the *+TR_Building* feature type for modeling building objects. It has a relationship with the *+TR_Parcel* feature type. In other words, a *+TR_Building* instance can have only a relationship with one *+TR_Parcel* feature type. On the other hand, a *+TR_Parcel* instance might have a relationship with any number of *+TR_Building* instance. *+TR_Building* includes several attributes, such as *measuredHeight*, that can be used for depicting the legal obligations within PAZR regarding the design of buildings. These attributes are important to digital information exchange for different applications, such as digital building permitting. *+TR_Building* is modeled as a subclass of *_AbstractBuilding* in which *BuildingPart* and *Building* city objects are derived from within the CityJSON core schema. For both countries, the corresponding CityJSON extension files for the created conceptual models are formed separately, based on the CityJSON 2.0 specifications. Each JSON file defines feature type, relationships and attributes within the conceptual models. It can be noted that the version of standard specifications may contain

differences in terms of rules regarding creating the extensions. Both JSON files are validated in terms of JSON syntax and shared in an open repository¹³ to be able to conduct the validations, as described in the following sections.

4.2 Data Transformation

Exemplary spatial plans were selected to demonstrate how the developed conceptual models can be exploited for real cases. For the Swedish cases, two detailed development plans were obtained in PDF format from the open data portal¹⁴ operated by Lantmäteriet (Lantmäteriet, 2021, 2023b). The direct links that enable to access these plans in the portal in addition to the PDF files of the plans can be also seen in the open repository of this study. The plans in PDF format were first digitized to create a 2D geodataset, and then their attributes were populated based on different plan descriptions, for example, property size. Figure 6 illustrates the created 2D geodatasets depicting the detailed development plans in the Swedish cases. The datasets were generated in GeoPackage (GPKG) format and projected in EPSG:3011 - SWEREF99 18 00, matching the coordinate reference system (CRS) of the source PDF plans. Figure 6 also shows that these datasets and digitized plans were well-matched spatially when the basemaps were considered. As seen in Figure 6a and Figure 6b, Swedish plans contain various descriptions for different parts within the plan border. For this reason, a 2D geodataset was formed in a way to represent these parts as features within a polygon type. For the Turkish case, the GML dataset of an exemplary implementation zoning plan is obtained from the e-plan database. Since there are changes in the e-plan system in terms of downloads of the spatial plans, the specific link from the system for this dataset is not available at this moment. But the dataset was openly accessible through another open repository¹⁵.

¹³ <https://github.com/geospatialstudies/spatial-planning-Sweden-Turkiye>

¹⁴ <https://detaljplaner.lantmateriet.se/>

¹⁵ <https://github.com/geospatialstudies/spatial-planning>

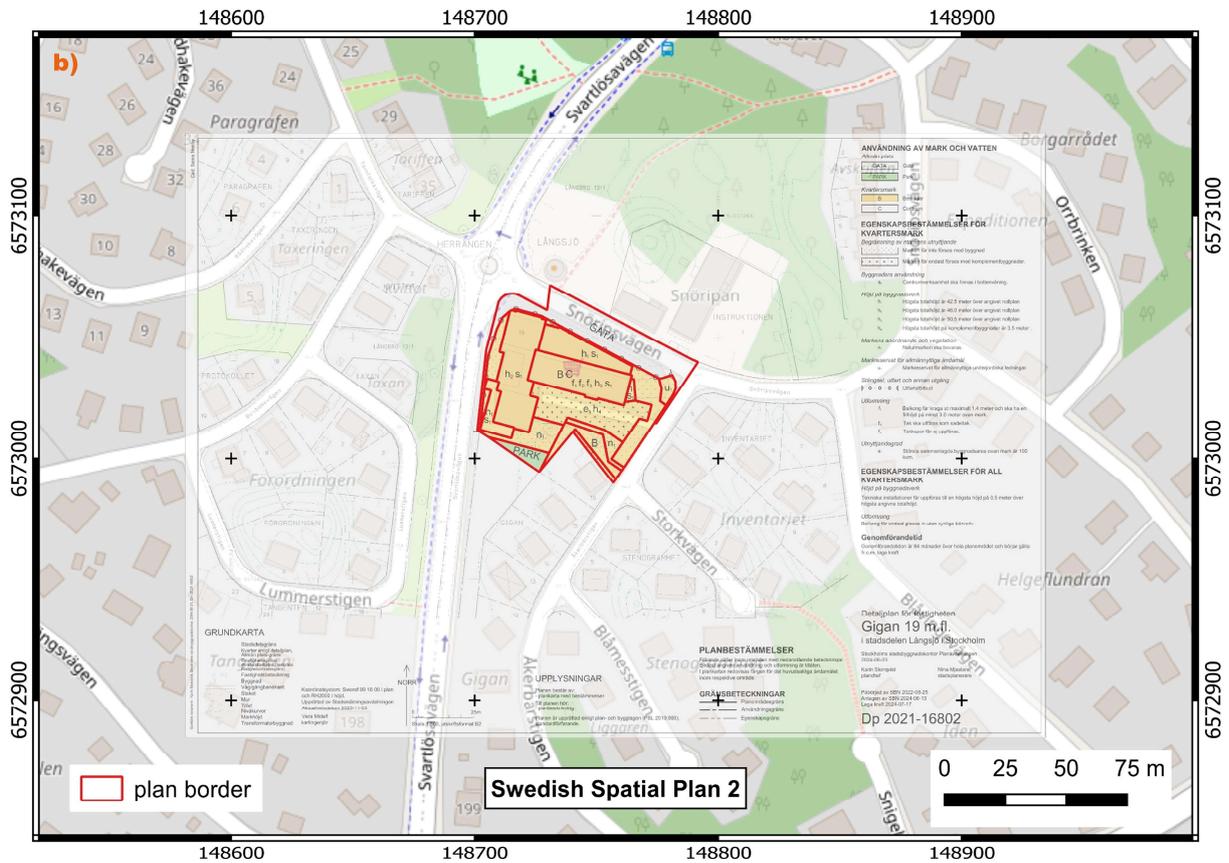
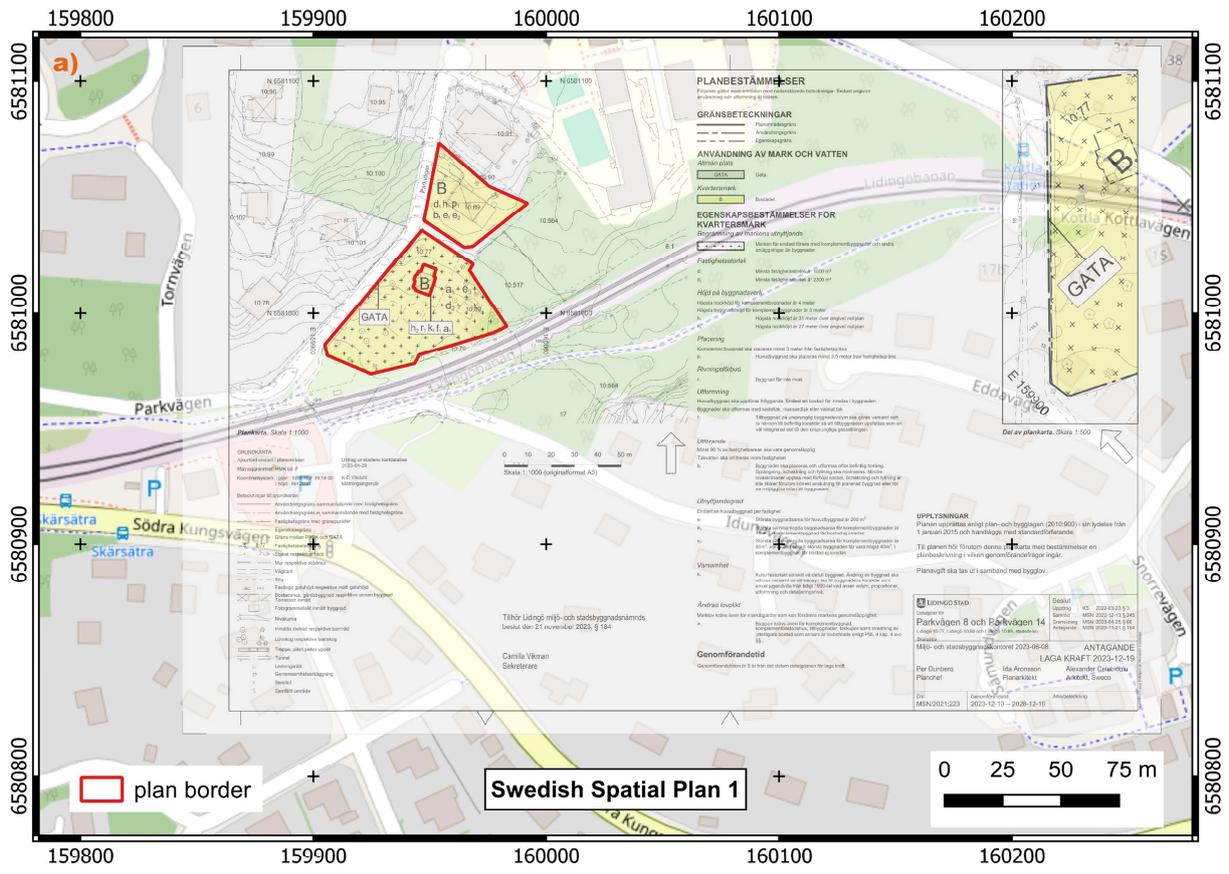


Figure 6. The maps that represent the 2D geodataset of Swedish plans with their PDFs.

These PDFs are obtained from Lantmäteriet (2023b) and Lantmäteriet (2021).

Nevertheless, the mentioned plan can be viewed in the official e-plan system with the plan code "UİP-39251". It can be also mentioned that because some attributes of this dataset are missing, they were populated with the aim of showing the usability of the proposed extension. This dataset was converted to GeoPackage format and then amended based on the content of the conceptual model to prepare for data transformation. EPSG:5254 - TUREF/TM30 was used as CRS for this dataset. Figure 7 shows the 2D geodataset that covers layers corresponding to +TR_Parcel and +TR_ImplementationZoningPlan.

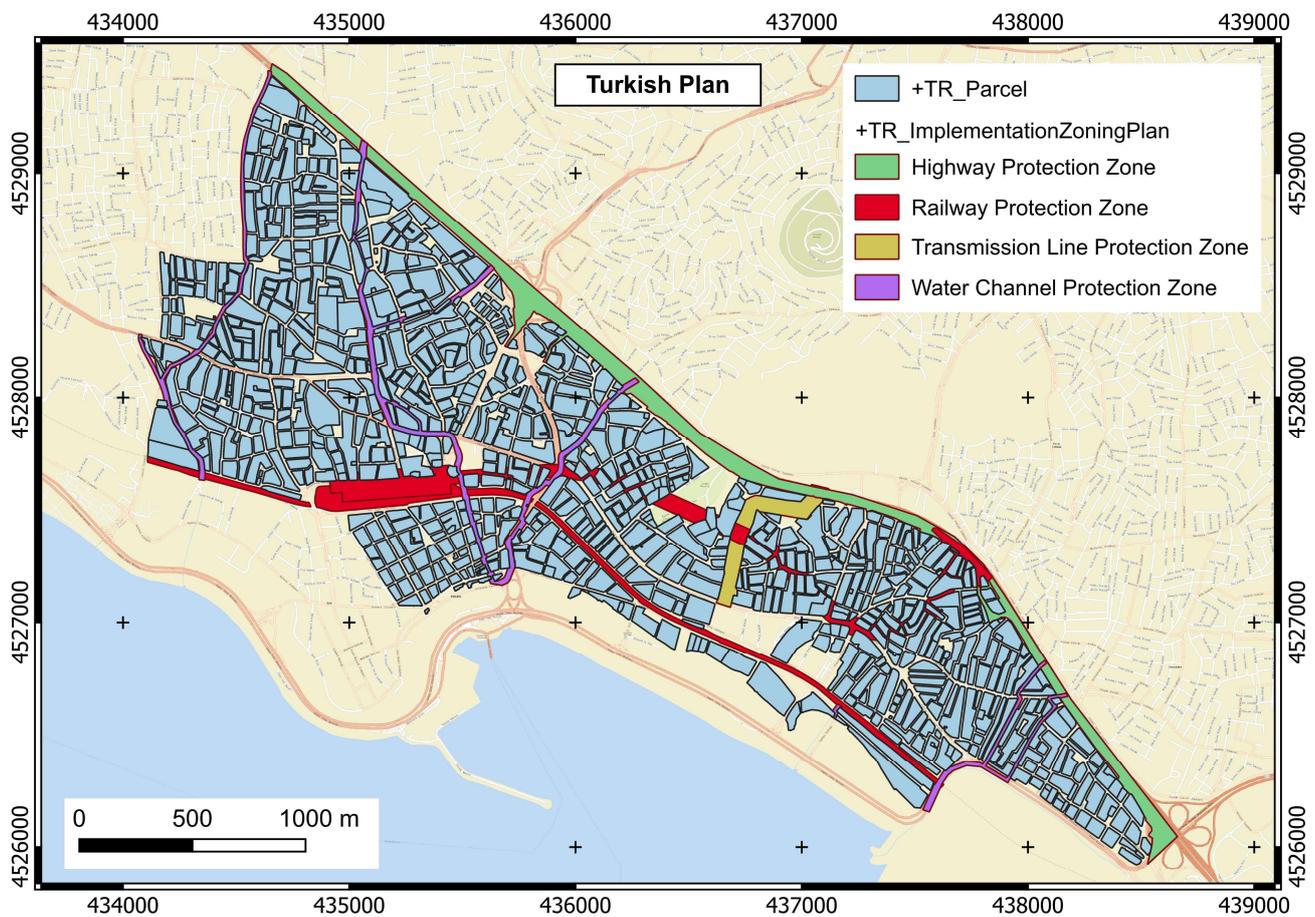


Figure 7. The map representing the 2D geodataset for the Turkish plan.

As can be seen from the figure, the selected plan encompasses different kinds of protection zones such as highway and transmission line. The data transformation from 2D geodatasets to 3D CityJSON datasets was conducted using FME¹⁶ software, which provides Extract–

¹⁶ <https://fme.safe.com/>

Transform–Load (ETL) solutions particularly for spatial datasets. Within the workbench, 2D geodatasets representing the spatial plans were used as input, and then they were extruded into 3D solids based on the descriptions regarding the heights on the plans, which are stored as attributes. By doing so, CityJSON objects that have solid geometries were produced. CityJSON writer within FME can be used to create the extra city objects defined within the extensions, alongside the core city objects of the standard, such as *Building*. FME can write CityJSON datasets with version 1.0, but the extension files are designed based on 2.0 specifications. For this reason, the produced CityJSON datasets were upgraded to version 2.0 by using the *cjio*¹⁷ tool, which allows for amending the CityJSON dataset. It is important to show whether the produced CityJSON datasets are compatible with the formed CityJSON extensions. Therefore, three datasets were validated without any errors through the official validator¹⁸ of the CityJSON. The validator checks whether the CityJSON file aligns with the core schema of the standard and also extension schemas. To do this, the created extension file is stored at an open URL (e.g., GitHub repository) and this URL is also defined within the created CityJSON dataset according to the rules for developing the extension. By doing so, the validator is able to access the content of the extension on which CityJSON dataset is developed based. The produced CityJSON datasets are public and available through the study's data repository. The validated CityJSON datasets were also converted to 3DTiles¹⁹ format, which is an Open Geospatial Consortium (OGC) standard. It is used to stream a 3D dataset through a web-based application efficiently. This transformation was performed in FME software, enabling the visualization of the spatial plans within web-based 3D environments.

¹⁷ <https://github.com/cityjson/cjio>

¹⁸ <https://validator.cityjson.org/>

¹⁹ <https://www.ogc.org/standards/3dtiles/>

4.3 Data Visualization

Figure 8 and Figure 9 present the 3D visualizations of the resulting CityJSON datasets corresponding to the Swedish plans. As shown in the figure, the *+SE_PlanningProvision* feature class has different attributes that store the regulatory information on the plans. For example, Figure 8 illustrates the instance of *+SE_PlanningProvision* with the ID 19 that contains the attribute as *propertySize*. Accordingly, the figure shows the implementation of this attribute encompassing the plan descriptions regarding property size that is depicted previously in Figure 3. Figure 9 also presents examples of the *heightOfWorks* attribute, representing the height-related provisions within the detailed development plan. This attribute includes the sub-attributes such as *hWorksID*, which allows for distinguishing cases where multiple plan section share identical height regulations.

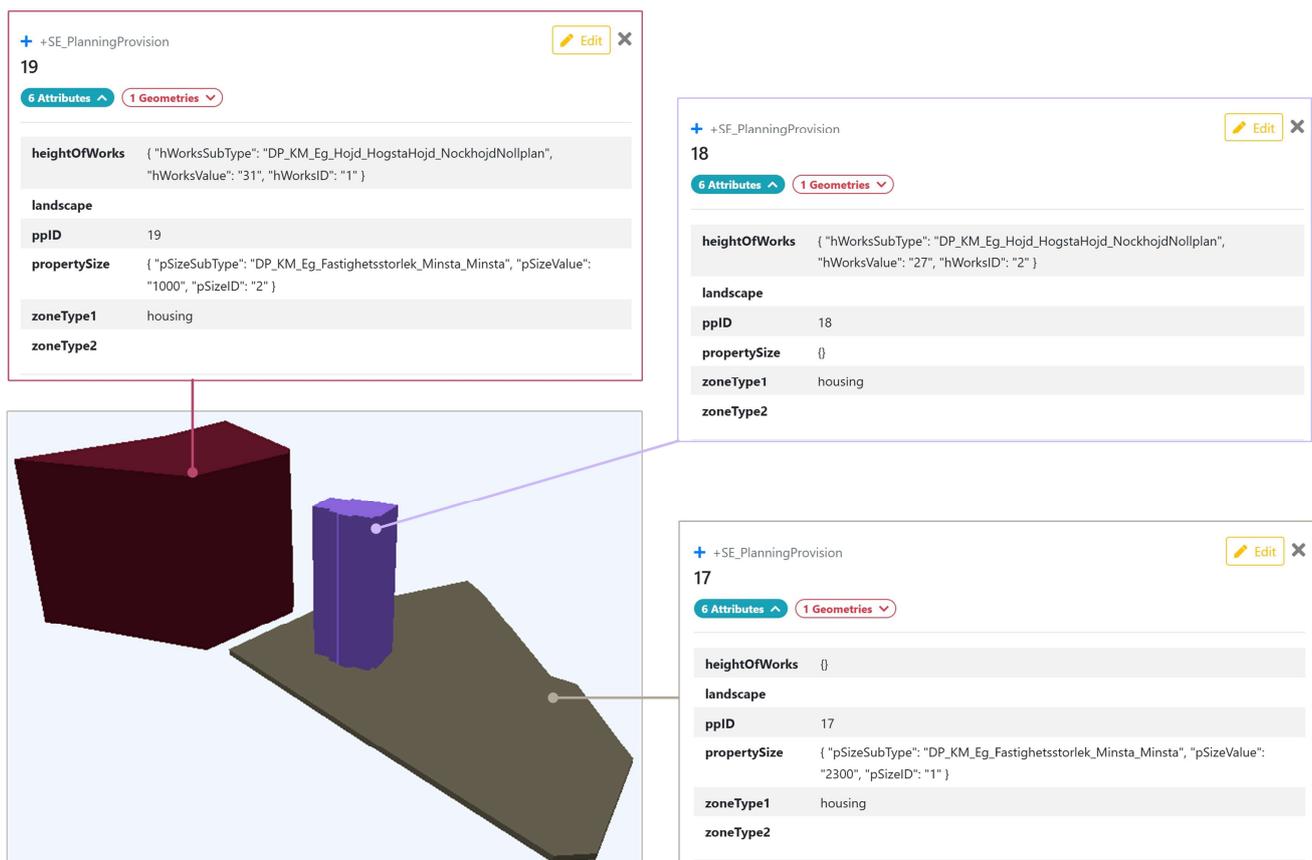


Figure 8. 3D visualization of CityJSON datasets representing the Swedish spatial plan 1.

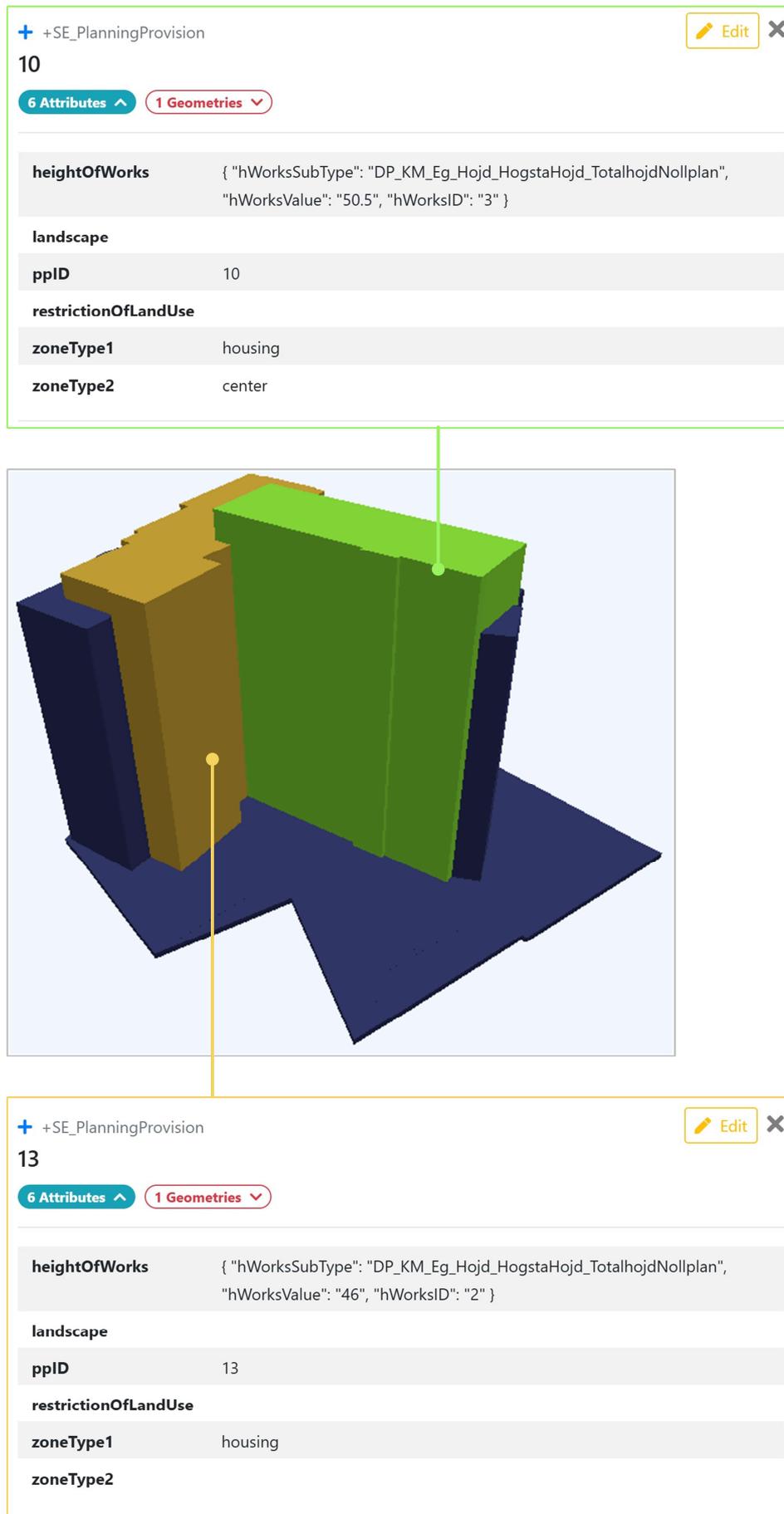


Figure 9. 3D visualization of CityJSON datasets representing the Swedish spatial plan 2.

These examples demonstrate that the attributes are fully compatible with both the conceptual model and, consequently, the Swedish regulation, namely BFS. In addition, *+SE_PlanningProvision* instances cover the information regarding the defined land-use zone types, such as residential or mixed-use areas. Figure 10 presents the 3D visualizations of the CityJSON dataset corresponding to the Turkish implementation zoning plan. As mentioned previously, different protected zone types can be delineated through the created conceptual model. In this regard, Figure 10a and Figure 10b show the implementation of this issue by means of the *newBuildRestrProtArea* attribute. For example, *+TR_ImplementationZoningPlan*'s instance with the ID of *izp1* represents the restriction regarding highway protection. In addition, Figure 10a and Figure 10b illustrate the two different protection zones that run along the subsurface, that is transmission line and the railway.

Figure 10a also shows that these protected zones overlap in some areas; however, they can be represented unambiguously thanks to the 3D solid models. In other words, the protected zones at different distances from the surface can be modeled within the produced CityJSON dataset. Figure 10 also covers the visualization of the instance from the *+TR_Parcel* feature type. For example, the instance with the ID of *PlanUnit410* presents the zoning parcel with the attributes that store zoning type and subtype that are described within the implementation zoning plan. As mentioned, there is a relationship between the parcel and parcel blocks in the Turkish zoning plans. In this regard, Figure 10 also illustrates this relationship since *PlanUnit410* has a parent object with the ID of *PlanBlock7*, and its attribute, namely *pbID* can be seen in the figure.

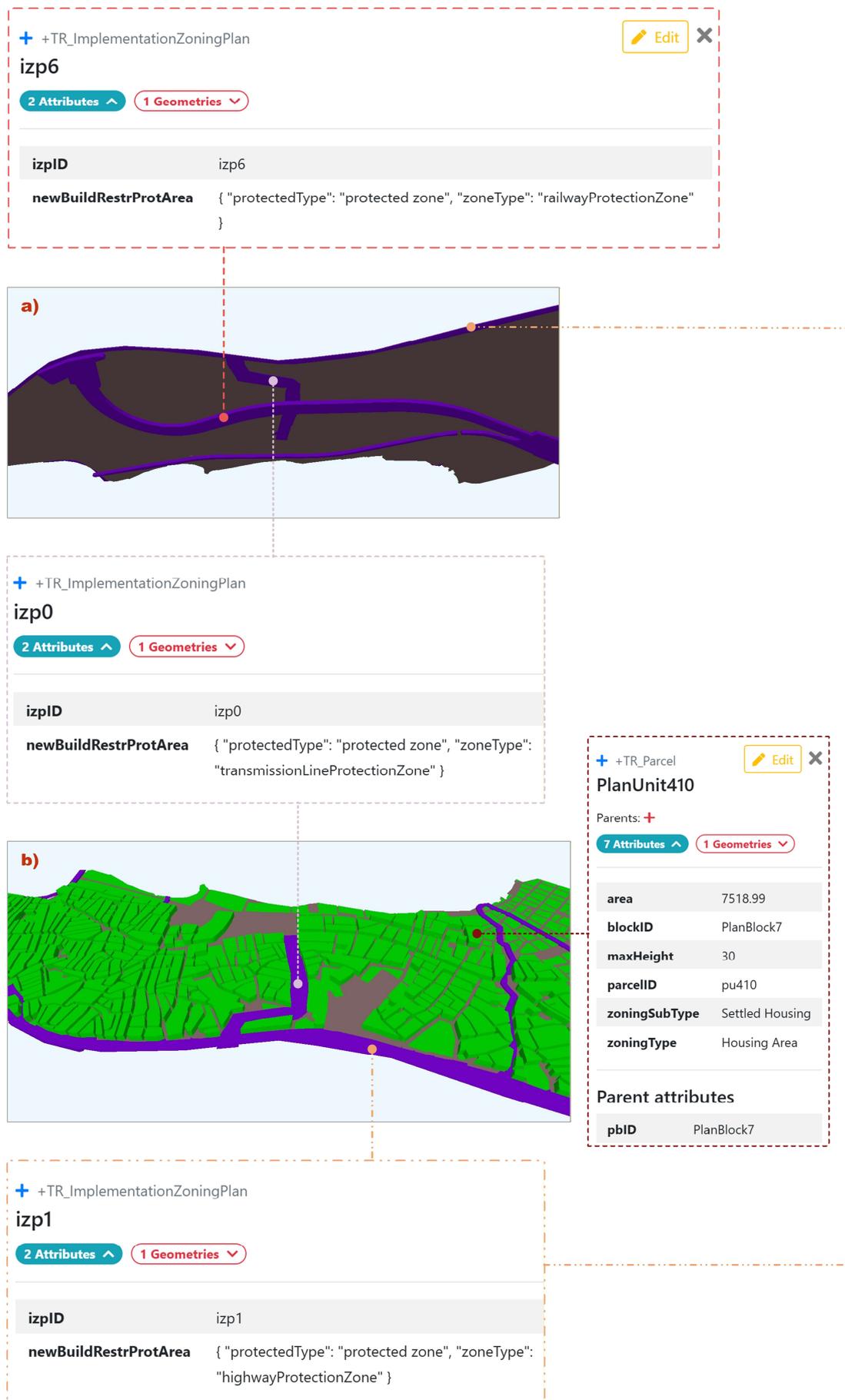


Figure 10. 3D visualization of the CityJSON dataset representing the Turkish plan from different view angles, namely bottom (a) and above (b).

Figure 11 demonstrates how the modeling information regarding city objects is stored within the CityJSON extension file and produced as CityJSON dataset. Figure 11a shows the excerpt from the CityJSON extension file pertaining to the Turkish case for the *newBuildRestrProtArea* attribute.

```

a)
{
  "newBuildRestrProtArea": {
    "type": "object",
    "properties": {
      "protectedType": {
        "type": "string"
      },
      "zoneType": {
        "type": "string",
        "enum": [
          "airportProtectionZone",
          "nuclearEnergyProtectionZone",
          "highwayProtectionZone",
          "pipelineProtectionZone",
          "waterChannelProtectionZone",
          "railwayProtectionZone",
          "subsurfaceWaterProtectionZone",
          "transmissionLineProtectionZone"
        ]
      }
    },
    "required": [
      "protectedType",
      "zoneType"
    ],
    "additionalProperties": false
  },
},

b)
{
  "izp1": {
    "attributes": {
      "izpID": "izp1",
      "newBuildRestrProtArea": {
        "protectedType": "protected zone",
        "zoneType": "highwayProtectionZone"
      }
    },
    "geometry": {
      "type": "+TR_ImplementationZoningPlan"
    }
  },
},

c)
{
  "izp6": {
    "attributes": {
      "izpID": "izp6",
      "newBuildRestrProtArea": {
        "protectedType": "protected zone",
        "zoneType": "railwayProtectionZone"
      }
    },
    "geometry": {
      "type": "+TR_ImplementationZoningPlan"
    }
  },
},

```

Figure 11. The parts from the CityJSON extension file (a) and CityJSON dataset (b, c).

As mentioned, this attribute has different properties, such as *zoneType*, since it is modeled as a complex attribute to store the plan descriptions thoroughly. Figure 11b and Figure 11c present the parts of the CityJSON dataset belonging to two city object instances with the IDs of *izp1* and *izp6*, which are visualized in Figure 10. As seen in these figures, the types of both instances are *+TR_ImplementationZoningPlan*. To show the usability of the produced 3D datasets in terms of 3D visualization purposes, a web-based prototype is developed using the Cesium JavaScript library²⁰. It is accessible openly via the link²¹. As stated in the previous section, the 3DTiles datasets are utilized within the prototype. Figure 12 illustrates the

²⁰ <https://cesium.com/platform/cesiumjs/>

²¹ <https://web.itu.edu.tr/gulerdo/plan.html>

visualizations of three exemplary plans in this prototype. The datasets are visualized by color classification based on their land use zone types.

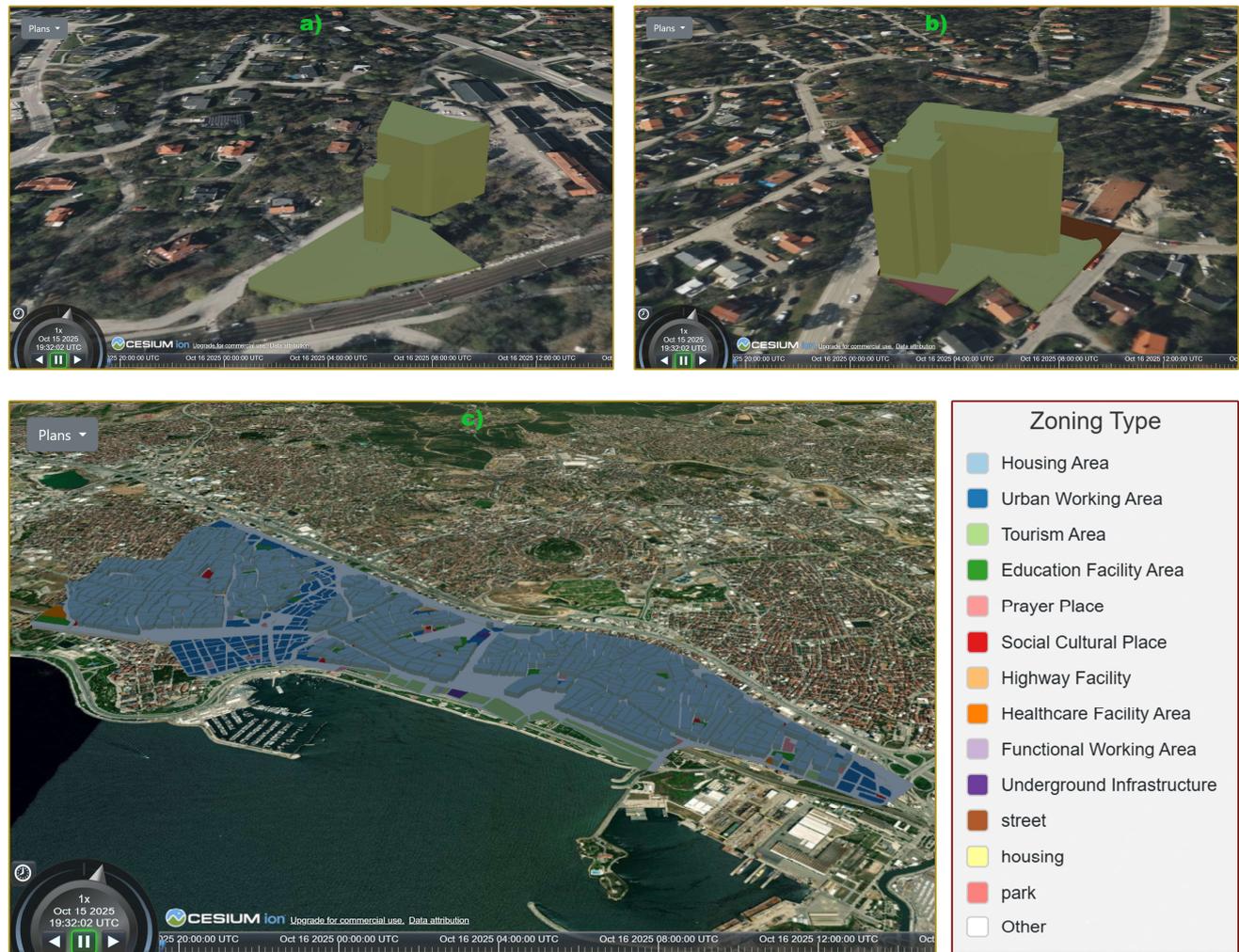


Figure 12. 3D web-based visualization of exemplary spatial plans, Swedish plan 1 (a), Swedish plan 2 (b), and Turkish plan (c).

5 Discussion and Conclusions

This study presents how land use plans can be represented as interoperable 3D geodatasets aligned with internationally recognized geospatial standards. This proposed standardization covers the identification of essential feature types, attributes, and relationships required to efficiently model land use specifications through the CityJSON data standard. The developed methodology in this research includes the creation of conceptual models for two countries, Sweden and Türkiye, by considering their current data specifications regarding representing

the land use plans digitally. Additionally, these models are implemented to produce and validate 3D CityJSON geodataset representing exemplary land use plans. The results confirmed that the proposed methodology is useful for creating a 3D geodataset corresponding to land use plans within different countries. This provides significant insights for its adoption at various administrative levels, such as municipalities in a country. In addition, the results might be beneficial for establishing interoperability regarding 3D representation of land use plans transnationally, for example, across the EU. In other words, this study contributes to realizing the Land Use specification within INSPIRE, such that it enables 3D modeling of land use specifications.

There is a continuing discussion regarding to which degree and in what ways 3D visualizations are most useful for planning practices, while there exist studies that present positive impacts of these visualizations because of increasing perception. The presented study can contribute to this discussion by providing an efficient methodology to create 3D visualizations based on interoperable geodatasets. In this way, examining the usefulness of these visualizations can be utilized by considering practicability in a more comprehensive manner. This outcome might also be beneficial for implementing digital tools within planning practices that aim to ensure the sustainability of urban areas, since efficiently managing the information flow that exploits the standardization is a requirement for these tools, as stated by Lin et al. (2025). Moreover, the results on how to generate the 3D interoperable geodataset that depicts the zoning plans provide foundational insights in terms of technological basis regarding obtaining 3D visualizations, which is mentioned as a lacking issue in the literature (Eilola et al., 2023).

The results of this research also contribute to the practice of efficient underground space planning that significantly benefits from 3D geodatasets. As illustrated in Figure 10, 3D geodatasets that represent the land use plans enable modeling of zoning specifications regarding subsurface, such as railway protected zones. In relation to this, the importance of

property rights for underground space planning has been highlighted recently as a case study on Stockholm, Sweden (Kuchler et al., 2024), which is one of the countries that are considered in this research. Therefore, the presented results do not only provide the existence of 3D land use plans covering underground space, but also pave the way for integrating information on property ownership that encompasses the cadastral restrictions into subsurface space planning through interoperable geodatasets. It thus contributes to ensuring the existence of standardized datasets, the importance of which has been highlighted in recent literature (Javaherian Pour et al., 2025; Peng et al., 2025). They are also a useful data source for practicing the 3D land administration that aims to incorporate the development of above and below the land surface (Saeidian et al., 2023b). This issue also has a significant impact on implementing digital permit procedures because the cadastral restrictions that can be unambiguously represented in 3D are notably involved in the compliance checks regarding subsurface. Given that this is not thoroughly investigated except in a few studies, such as Guler (2024), the presented research contributes to automating the control of design compatibility against zoning plans by providing 3D standardized geodatasets covering underground spaces. While the subsurface space is an underinvestigated counterpart regarding digital building permitting (Guler, 2024; Guler & Yomralioglu, 2022), the availability of interoperable geodatasets that depict the land use specifications contributes to this issue in a broader context by enabling the digital information exchange of zoning plans in 3D. Accordingly, the results provide insights in terms of establishing geodata standards for 3D land use plans for the jurisdictions where there is an aim for realizing the digital transformation, such as the countries included in this research.

In relation to this, it can be mentioned the differences regarding the modeling approach for generating the spatial plans in 3D. Creating 3D data models is often based on two domains, namely 3D GIS and BIM. It can be noted that digital building permit mainly benefits from building designs that are created as BIM models and particularly IFC datasets, which are

based on an interoperable, open data standard (Noardo et al., 2022). In connection with this, there is an interest in enabling IFC-based modeling of spatial plans that offers a solution in terms of standardizing the digital plan data (Future Insight Group B.V., 2024). However, 3D geodata standards such as CityJSON provide efficient modeling thanks to unlaborious data size for the spatial plans that have large coverage, such as the Turkish plan in this study. Nevertheless, the property sets that are necessary for storing the plan descriptions can be identified regarding the IFC schema to create the digital data for spatial plans to a smaller extent, such as the Swedish plans in this research. It can also be underlined that even if the digital spatial plans are generated through 3D GIS or BIM-based standards, they are usually imported and stored in a spatial database such as PostgreSQL to be able to implement spatial queries regarding compliance checking within building permits, as demonstrated in the literature (Batum et al., 2025; Guler, 2023).

Some issues can be mentioned in terms of a technical viewpoint. First, the data types regarding source zoning plans differ for the two countries in this study. While the land use plans in PDF format are digitized for Swedish plans, the GML dataset is able to be obtained for Turkish plans. Nevertheless, the same approach is followed to create the 2D spatial dataset that represents the exemplary land use plans with the necessary attributes. For example, the attributes that store the information regarding complex attributes, such as *heightOfWorks* within the CityJSON extension, are populated in QGIS. Within the FME workbench, a similar methodology for all plan examples is also utilized to create the corresponding CityJSON datasets. Noteworthy to mention is that even if the source data type differs, the FME workbench can be modified based on different data types to produce similar CityJSON datasets. Second, the version of CityJSON datasets is important to enable data interoperability since the systems should be able to utilize these datasets with respect to the standard's specifications. In this study, even though the FME only writes CityJSON v1 datasets currently, they were upgraded to CityJSON v2 thanks to open-source tools. These

tools are significant since they improve the practicability of the data standards by enabling the upgrade to the latest specifications. Otherwise, the gap between versions of the data specification and created datasets through various software/tools is prospective because updating the software/tool that is developed by the vendors, different from the developers of the standard, often lags behind. Third, the methodology regarding data transformation is tested through exemplary datasets that encompass different numbers of features. In other words, while the Swedish plans have 3 and 16 features respectively, the Turkish plan covers 921 features in total. This shows that the developed methodology is efficient for creating 3D standardized geodatasets with respect to the land use plans that might have a wide range of features. In connection to this, noteworthy to mention is that the proposed workflow in this study has a solid potential for its scalable implementation for large coverages such as nationwide. In this sense, the representation of a large number of buildings (approx. 10 million) within the Netherlands as the CityJSON dataset²² provides significant evidence regarding feasibility of this workflow for 3D depiction of the spatial plans in an interoperable manner (Peters et al., 2022).

Despite the contributions mentioned, some limitations can be identified. First, the conceptual models were designed in a way to cover the most commonly utilized feature types, such as *+SE_PlanningProvision* in the Swedish case, and future work could expand these to encompass the regulated specifications as a whole. Second, the database implementation of the methodology is not within the current scope, yet it represents a crucial step for real-time management and query processing of 3D datasets. Third, although a web-based prototype is developed for visualization, further improvements could enable near-real-time data upgrades through database connectivity and interactive analytical functions for 3D land use plans. To achieve this, the following steps can be examined. First, the existing database that

²² <https://3d.bk.tudelft.nl/projects/3dbag/>

stores the 2D land use plan datasets should be amended such that it allows for storing the 3D geodatasets in order to achieve the integration with developed web-based prototype. Regarding this, the type of the database that stores the 3D standardized datasets should be determined. The choices of relational types such as PostgreSQL or specialized graph databases can be investigated in this context. For example, the new version of 3D City Database (3DCityDB) allows for storing the CityGML 3.0 and CityJSON 2.0 datasets as well (Yao et al., 2025). Second, the methods of data sharing that enable reaching the land use plans can be explored. In this sense, OGC API standards²³ that are being developed for serving the geospatial datasets by supporting the modern software development requirements hold a solid potential for 3D standardized geodatasets. For example, OGC API - 3D GeoVolumes is a specific standard that aims to share the 3D geospatial datasets over the internet.

Finally, the issues mentioned can be used as a basis for structuring future studies. Another possible future research direction can be related to integrating 3D land use plans into data spaces that have a solid potential for increasing efficiency regarding data accessibility and interoperability. Data spaces can be served as an enhanced version of spatial data infrastructures (SDI) (Bacco et al., 2024; Kotsev et al., 2020). Therefore, they can improve the decision-making capabilities of the different stakeholders regarding the processes in which the land use plans are exploited, such as building design and building permitting. Noteworthy to mention is that the results of this study provide an insightful base for other countries regarding achieving the digital land use plans as 3D interoperable geodatasets. Demonstrating the developed methodology through the cases from two countries is of great importance in this sense. The conceptual models in this study can be amended in a way to meet the data modeling requirements regarding land use specifications within legal

²³ <https://ogcapi.ogc.org/>

documents of different countries. Subsequently, the corresponding CityJSON extension files can be created to ensure the standardization of generated geodatasets.

In summary, this research provides a practical and adaptable framework for modeling and visualizing 3D interoperable land use plans through standardized geodatasets. It contributes both theoretically and technically to the ongoing digital transformation of spatial planning and land administration. By bridging conceptual modeling, interoperability, and implementation, the study advances the foundation for more integrated, efficient, and transparent planning systems in the 3D digital era.

Data Availability

The data related to this study is available at <https://github.com/geospatialstudies/spatial-planning-Sweden-Turkiye>.

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