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Implementation of 3D spatial planning through the integration of the standards

Dogus Guler

Department of Geomatics Engineering, Istanbul Technical University, Istanbul, Turkey

Correspondence
Dogus Guler, Department of Geomatics Engineering, Istanbul Technical University, Istanbul, Turkey.
Email: gulerdo@itu.edu.tr

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Abstract

To plan future land use, zoning plans (i.e., spatial plans) are prepared to get the most out of land for both the public and the government. These plans manifest which facilities can be built and where they can be built on land based on defined requirements such as building height and road length. The Land Administration Domain Model (LADM) is well-known and widely used standard for describing Rights, Restrictions, and Responsibilities (RRRs) with respect to land and buildings. The next version of the standard will contain the Spatial Plan Information (SPI) part to enable better land-use planning. Three-dimensional (3D) land-use planning has gained attention to delineate detailed requirements inclusively and allow different spatial analysis that provides a basis for decisions in the planning. Data standards pertaining to 3D geoinformation are vital to put into practice 3D spatial planning. To this extent, CityJSON is proposed for the effortless and efficient use of 3D city models. This article thus first aims to extend the CityJSON schema based on the proposed SPI part of the LADM such that it allows modeling, storing, visualizing, and utilizing the features and attributes required for the implementation of 3D spatial planning. Then, the usability of the proposed extension schema is demonstrated by the real-world use cases that benefit from the exemplary CityJSON files that are created based on approved zoning plans in the country.

The results of this study show that there is an important opportunity coming from the integration of international standards that enables semantic information along with their spatial counterparts within 3D spatial planning.

1 | INTRODUCTION

There is an ongoing migration from rural areas to urban areas. To meet the needs of the growing number of citizens in terms of liveability, accessibility, and sustainability, the number of complex and multi-layered buildings and facilities in the cities is increasing rapidly (OECD/European Commission, 2020). Therefore, the planning and monitoring as well as the efficient management of urban areas has become highly challenging. Challenges to the sustainable development of cities that create environmentally friendly, socially inclusive, and economically thriving living areas are related to different disciplinary fields such as land management, land administration, public administration, city management, and urban planning (Sachs et al., 2019).

Due to the population growth in the urban areas, the cities expanded horizontally and more importantly vertically (United Nations, 2015). For this reason, the importance of land management that aims to enable efficient use of both underground and aboveground land and related Rights, Restrictions, and Responsibilities (RRRs) has significantly increased in recent years. Land Administration Systems (LASs) that deal with the effective implementation of land management benefit from four functions namely land use, land value, land development, and land tenure (Enemark et al., 2014). These systems generally utilize two-dimensional (2D) spatial data with their semantics even though the RRRs are described in a way that contains specifications related to the 3rd dimension. In this regard, the increasing complexity of the built environment triggered societal, economic, and environmental problems that are subject to land administration (Rajabifard et al., 2019). Given that the utilization of 2D data is insufficient in solving existing problems that hinder the sustainable development of the countries, it is therefore aimed to improve the LASs globally such that they have the capabilities to encompass and manage three-dimensional (3D) data (Guler et al., 2022; Kalogianni et al., 2020).

Spatial planning (i.e., land use planning) that land administration exploits as a driving force deals with how to use the land most efficiently. It is one of the key instruments for the development and effective governance of countries (United Nations, 2008). Efficient planning regarding how to use the land is a pivotal issue in the context of land administration. This is because promoting sustainable development is highly affected by efficiently practicing land administration. It can be noted that spatial planning studies in urban areas are particularly troublesome since there is a need for complex analysis results that support zoning plans (Stewart & Janssen, 2014). These zoning plans (i.e., land use plans) should be prepared by taking a great number of factors into account; for example, biodiversity and ecosystem services, environmental protection, energy efficiency, societal justice, and environmentally friendly transportation. The analyses that enable the scientific basis for the mentioned factors require a good amount of spatial data that provides rich and accurate semantic and locational information (Koski et al., 2021). The use of 2D might be insufficient in planning the urban areas completely because the current urban areas need to be planned by considering the 3rd dimension, which is directly related to the cadastral RRRs (Atazadeh et al., 2017). Because of this, the need for 3D spatial planning that provides planning requirements and specifications as 3D is evident (Šiško et al., 2022; van Oosterom et al., 2020; Xia et al., 2016). On the other hand, the requirement for a common conceptual basis for practicing land administration and accordingly LASs is met with the publication of the Land Administration Domain Model (LADM) ISO 19152:2012 (ISO, 2012) as an

International Standardization Organization (ISO) standard. Because of the increasing need for 3D spatial planning, the next edition of LADM will contain a spatial plan information part.

It should be also underlined that there is a growing need for 3D city models for efficient land and urban management. Considering that cities can contain highly complex objects such as high-rise buildings, whether these models can be efficiently visualized and used with respect to the different applications becomes even more important. For example, the analyses regarding the urban form change require 3D spatial data these days so as to cover the changes in urban areas completely (Domingo et al., 2023). Regarding the efficient use of 3D urban data, international geospatial data models that allow creating the 3D models of geographic objects in the built environment are of significance in terms of enabling data interoperability between various applications for which different stakeholders and agencies are responsible (Guler & Yomralioglu, 2021). In this sense, CityGML (OGC, 2021b) has significant recognition as an official Open Geospatial Consortium (OGC) standard for storing and exchanging 3D city models. The current version of CityGML 3.0 is designed in a way that it has more integration with other international standards such as LADM. What is more, CityJSON (OGC, 2021a) is developed as a JavaScript Object Notation (JSON)-based encoding of the CityGML data model in order to ensure the efficient use of 3D city models through providing compatibility with recent software development and database management approaches.

There is a strong connection between spatial (urban) planning and the building permit issuing. The important issue is that the compliance checking within building permitting contains the checks of the designed buildings with respect to the spatial plans (i.e., land use plans) that express how the land should be used based on the conditions that are defined. These conditions provide the framework for the sustainable development of urban areas. It is essential to highlight at this point that there is an increasing trend for the digitalization of building permitting in order to increase the efficiency of the processes that are utilized within the building permit issuing (Noardo et al., 2022). This digitalization mainly benefits from the digital building, city, and land use plan data. Accordingly, the existence of 3D spatial plans formatted in the standardized data model becomes more important to facilitate the mentioned digitalization. The complexity of the built environment forces spatial planning to be implemented in 3D to meet the different requirements that are defined in the laws and regulations and for which 3D analysis and data are needed, for example, identification of the noise, shadow, wind, solar energy levels, and disaster-prone areas. Further, 3D visualizations are now considered as a default data basis for spatial planning studies. There is also a connection between building permitting and land administration. This is because the cadastral information is needed during the compliance checking to be sure that the designed building respects the cadastral RRRs (Guler & Yomralioglu, 2022). This issue triggers countries for transition to 3D LASs in practice to support the sustainable development of urban areas by wholly covering the activities related to cadastral management such as 3D spatial planning and digitalization of building permitting. Given that 2D representations are insufficient for delineating the cadastral RRRs regarding legal spaces in the built environment and designing the buildings/facilities by using digital modeling technologies in 3D is gaining increasing adoption worldwide, there is an urgent need for semantically rich and standardized 3D geoinformation that enables us to carry out compliance checking of a 3D digital model that represents a new design based on the specific conditions in the current zoning plans in the context of 3D spatial planning. This article, therefore, aims to extend the CityJSON core data model in a way that provides 3D models as compatible with the Spatial Plan Information (SPI) part of the LADM in order to facilitate the implementation of the 3D spatial planning. The next subsections provide the literature review on related topics and report the contributions of this study respectively. Section 2 provides background including the relationship between spatial planning and land administration, used standards namely LADM and CityJSON, and data requirements. Section 3 explains the research methodology of the study. The proposed CityJSON extension is detailed in Section 4. The subsequent section presents the results of the article and demonstrates the use cases to show the practicability of the proposed extended schema in the article. Section 6 provides the discussion and the last section concludes the article.

1.1 | Literature review

In recent years, 3D urban models have gained more attention since they are used to provide a scientific basis for decisions regarding the built environment. Energy modeling, specifically solar energy potential estimation is one of the widely used examples for the applications from which the 3D building models are benefited (Chen et al., 2019; León-Sánchez et al., 2021). For instance, Han et al. (2022) propose a methodology that reveals and examines the rooftop solar photovoltaic potential in urban areas in terms of the suitable aspect and slope degrees by using the LoD1 and LoD2 3D building models. Schröter et al. (2018) suggest the use of 3D city models in estimating flood loss in order to obtain spatially explicit risk information. Moreover, exemplary use cases show that 3D city models can be more beneficial than commonly used 2D spatial data in urban/spatial planning studies. Herbert and Chen (2015) examine and address the usefulness of 3D visualizations over 2D by creating a prototype including 3D building visualizations and conducting surveys and interviews with respect to this prototype. It can be also mentioned that there is an increasing interest in the use of 3D visualizations in urban planning (Guo et al., 2017; Lindquist & Campbell-Arvai, 2021; Wu & Chiang, 2018; Wu et al., 2010). In this regard, Chassin et al. (2022) conducted research aiming to reveal the user perspectives with respect to the 3D visualizations that are used for participatory urban planning. Koziatek and Dragićević (2017) develop a model enabling the spatio-temporal simulations in 3D regarding the vertical development of cities and conclude that the developed tool has the potential for a decision-making process with respect to urban planning. Furthermore, the use of 3D GIS in urban planning education is strongly proposed since 2D data has limitations with regard to representing and analyzing the complex built environment (Yin & Li, 2010). The building permit issuing encompassing land use plan checking is another significant topic within spatial planning. This topic triggers the implementation of 3D spatial planning because the checking regarding the new buildings in the complex building environment could not be carried out efficiently by using only 2D data. For this reason, researchers investigate the usability of 3D spatial models for the different use cases in checking such as noise, shadowing (Emamgholian et al., 2022), and protected areas (Tezel et al., 2021).

When it comes to the spatial data standards for creating 3D models, there is a growing interest in the CityJSON data model in the literature. For example, Peters et al. (2022) propose a methodology that enables the reconstruction of the 3D models formatted in CityJSON and they create the CityJSON files for 10 million buildings in the Netherlands using the proposed methodology. Labetski et al. (2023) provide an approach that measures the morphology of the urban areas in 3D and create the open dataset containing CityJSON files that encompass 3D metrics that are calculated by using the provided approach. Biljecki (2020) analyses the current status regarding the generation of 3D building models by using the OpenStreetMap data in Southeast Asia. As a result of the study, 3D building models that are generated and formatted in CityJSON are shared as open datasets. Nys and Billen (2021) develop a simplified database schema based on NoSQL technology to store the 3D city models specifically CityJSON models and demonstrate the two use cases namely urban green infrastructure and energy performance of buildings. Furthermore, to enhance the applicability of the CityJSON standard, several works have been done regarding extending the CityJSON core module. Some of these works are conducted by the CityJSON core team (OGC, 2022). For example, the CityGML Noise Application Domain Extension (ADE) that is developed to bring analysis capabilities regarding the noise into the CityGML data model is converted to the CityJSON extension. In addition, a CityJSON extension that enhances the core model of CityJSON such that it supports the point cloud data is proposed (Nys et al., 2021). This extension aims to improve the conformality of CityJSON with CityGML 3.0 which contains the point cloud module. Wu (2021) extends the core module of CityJSON for using 3D city models in checking the building designs in the context of urban planning. Vitalis et al. (2019) extend the CityJSON core module for representing the geometric information of city models in a more lossless way as well as providing rich topological information regarding the objects in the models. Recently, Tufan (2022) created a CityJSON extension including objects and attributes that support energy-related data and analysis. This extension is developed based on the previously proposed CityGML Energy ADE. In addition, Mohd Hanafi et al. (2022) present the applicability of the CityJSON files that cover the RRRs on the buildings. In the study, *_AbstractBuilding* feature is enriched with the attributes of the features within the Malaysian LADM-based country profile. Vaienti et al. (2022) propose a CityJSON extension to model the temporal changes of the cities in 3D for historical studies.

Land administration functions include land use planning in the context of promoting sustainable development. LADM is the prominent international standard that enables one to conceptually model the spatial and non-spatial features that take part in practicing land administration. To support the land administration paradigm completely, it is shared that spatial planning will be included in the next edition of LADM (Lemmen et al., 2019). In this regard, Indrajit et al. (2020) encompass a specific focus on enhancing the LADM in a way that comprises the features related to spatial planning is conducted. In connection with this study, they share the content of the SPI part developed within the revision of the LADM. As a follow-up study, Indrajit et al. (2021) created an LADM-based country profile for Indonesia such that it covers the recently developed SPI part and implemented this country file in a database by using the current spatial plan data of the country. It is shown in the mentioned study that 3D spatial planning can be achieved by converting the 2D data into 3D spatial data that is compatible with the SPI part.

1.2 | Contributions of this study

The literature review reveals that the need for 3D models in spatial planning is evident globally. At this point, it should be highlighted that the practicability and efficient usage of 3D models are highly related to whether they are created based on the standards. It can be also underlined that to the best of the authors' knowledge, there is no specific study focusing on the implementation of 3D spatial planning using the spatial data standards that enable the creation of 3D city models. In light of this information, the present research contributes to the existing body of knowledge for the following reasons;

- This article extends the CityJSON core module such that it enables the creation of the interoperable 3D models encompassing the semantic and geometric information regarding the implementation of 3D spatial planning in practice.
- Given that most works in the literature regarding 3D spatial planning are limited to conceptual representation, this study goes beyond the state-of-the-art by showing the feasibility of the conceptual model through the use cases that utilize the CityJSON files that are created based on the extended schema.
- By means of the integration with the CityJSON standard, the present study provides a scientific basis on how to utilize the newly proposed SPI part of the LADM standard for facilitating the implementation of 3D spatial planning.
- By demonstrating the use cases that contain the checking of different restrictions regarding cadastre and zoning, this article shows the potential benefit that could result from the interplay between 3D spatial planning and 3D land administration.

Further, the results will provide strong evidence for how to increase the efficiency of analogous building permitting by means of the use cases benefiting from digitalization. Thus, there will be a strong potential to exploit the economic benefits that result from the digitalization of building permits. The prospective scientific impacts have also particular contributions to reaching the 11th SDG namely "Sustainable Cities and Communities" by enabling the implementation of 3D spatial planning as integrated into digital building permits. The results will also affect the citizens' lives since urban areas will be able to be modeled, planned, and transformed based on beneficial requirements such as renewable energy levels and environmental regulations with respect to the built environment that will support sustainable urban development and smart cities.

2 | BACKGROUND

2.1 | The relationship between spatial planning and land administration

The land management paradigm should be mentioned first. This paradigm considers the tenure, value, use, and development of the land in an integrated manner. The four counterparts regarding the land are also considered as efficiently implemented by the societies having organizational capabilities and fundamental in the context of the land management paradigm. In this connection, modern land administration focuses on cadastral maps and cadastral registration as the foundational components. Figure 1 presents the land management paradigm that enables the implementation of the land administration functions in a way that they are in concordance with the land policy frameworks and land information infrastructures of a country for effectively supporting sustainable development (Williamson et al., 2010).

As can be seen from Figure 1, the land management paradigm aims for the efficacious implementation of LASs in the country context. In addition to this, whereas sharing experiences is a requirement for designing a LAS, identifying the recent trends is also a requirement for developing and implementing a specialized LAS for the country. A global perspective can provide these requirements. Figure 2 accordingly shows the global land administration paradigm in which the four functions of land administration namely land tenure, land value, land use, and land development are connected to make the land market efficient and land use management effective (Williamson et al., 2010).

As can be seen from Figure 2 managing the use of land is one of the important land administration functions that promote sustainable development. Land use planning is described by FAO as "*the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land use options*." (FAO, 2022). It is also important to mention at this point that practicing land use planning differs based on the levels of the application area. These levels are local, regional, and national. Whereas the context of land use planning is highly related to strategies and objectives of the countries at the national level, the management of land use is controlled by the regional administration depending on the functions of the administration. Local administrations conduct land use planning by taking specific preferences regarding the application area into consideration. Spatial planning enables to control of land use and related activities. These activities are principally associated with a number of sectors such as water management, transportation, agriculture, and environmental

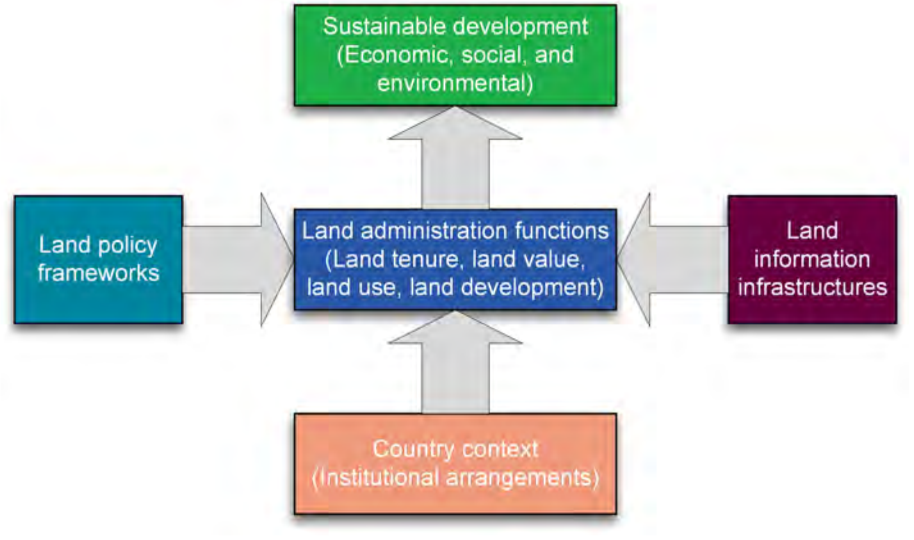

FIGURE 1 Holistic land management paradigm (adapted from Enemark et al. (2005)).

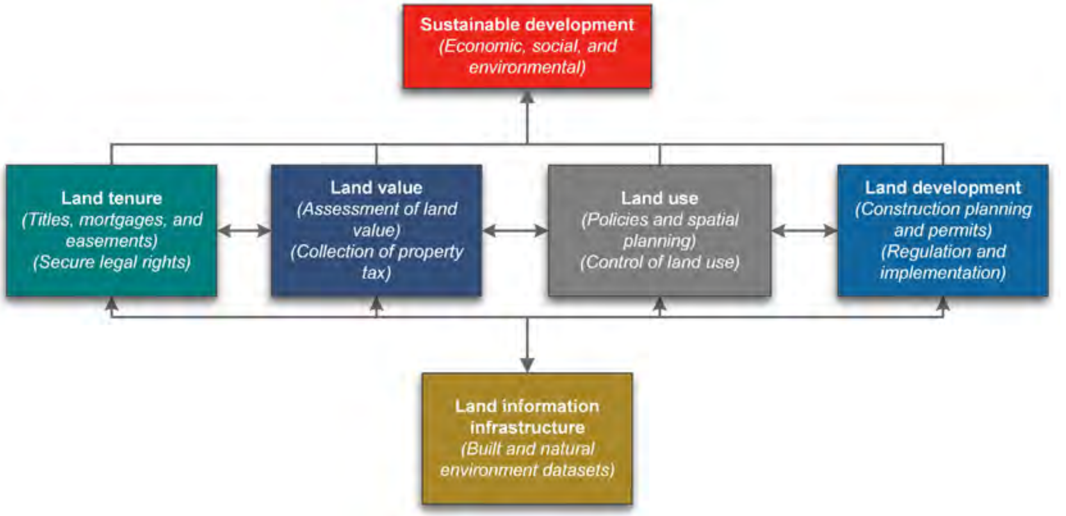

FIGURE 2 Globally adaptable land administration perspective (adapted from Enemark et al. (2005)).

conservation. It is evident that controlling land use also encompasses the related RRRs. In this regard, land administration significantly benefits from the implementation of efficient spatial planning since it utilizes land use information as well as RRRs related to this information.

2.2 | Standards

2.2.1 | Land Administration Domain Model

LADM is an ISO standard that provides a common ontology for activities regarding land administration. The conceptual models are developed within the LADM standard. The first edition of the LADM was published in 2012. This edition of the standard includes the three main packages as *Party*, *Administrative*, *Spatial Unit*, and one sub-package of *Spatial Unit* as *Surveying and Representation*. *Party* package provides the features that are used to model different parties who can be involved in the land administration-related activities. *Administrative* package enables the modeling of basic administrative units within land administration alongside its related RRRs. *Spatial Unit* package is composed to allow modeling of the specific administrative units that need to be delineated spatially. *Surveying and Representation* sub-package encompasses the features that provide geometrical modeling specifications for features in the *Spatial Unit* package. This sub-package contains the *LA_BoundaryFaceString*, *LA_BoundaryFace*, and *LA_Point* features and the geometry types of these features are *GM_MultiCurve*, *GM_MultiSurface*, and *GM_Point*, respectively. These geometry types are obtained from the ISO 19107 “Geographic Information—Spatial schema” (ISO, 2003) standard that provides the spatial modeling specifications for geographic objects. With the publication of the first edition of LADM, scholars from a wide range of countries created country profiles based on the conceptual model within LADM such that they meet the requirements of the land administration practices in a specific country (e.g., Adad et al., 2020; Radulović et al., 2019; Vucic et al., 2017). In the meantime, the work for the second edition of the LADM standard continues. In this regard, the next edition of the standard will encompass the Valuation Information (Part 4) (Kara et al., 2020) and SPI (Part 5) (ISO/TC 211, 2021). This means that the second edition of LADM will provide the conceptual basis with regard to the two important land administration functions namely land value and land use.

The content of the SPI part that will be included in the next edition of the LADM standard is shared through scientific papers (Indrajit et al., 2020, 2021). The main classes of the SPI extension of the LADM are *SP_PlanBlock*, *SP_PlanGroup*, and *SP_PlanUnit*. *SP_PlanGroup* feature is used to represent the spatial plans (i.e., land use plans) at the national and regional levels. These levels correspond to scales between small and medium. *SP_PlanBlock* is suitable to model the spatial plans covering the cities. *SP_PlanUnit* feature enables the delineation of spatial units in the zoning plans at the largest scale. The linkage between the SPI part and other parts of the LADM is also provided with the aim of integration within the LADM. Another reason for this linkage is to enable the modeling of the different RRRs related to spatial plan units. Figure 3 accordingly illustrates the relationships between the features in the SPI and *Administrative* packages of LADM.

As can be seen from Figure 3 the *SP_PlanUnit* feature has a relationship with *LA_RRR* feature in the *Administrative* package. It is thus possible to model the spatial units and their related RRRs within the spatial plans. The features of the SPI part are associated with the geometry features in the *Surveying and Representation* package of the first edition of LADM. *SP_PlanUnit* and *SP_PlanBlock* features can have geometries as *LA_BoundaryFaceString* and *LA_BoundaryFace* feature types.

2.2.2 | CityJSON

CityGML is an OGC standard that allows modeling the different objects such as buildings, vegetation, road, and tunnel in the built environment in 3D in a standardized way. CityGML data model contains a number of modules

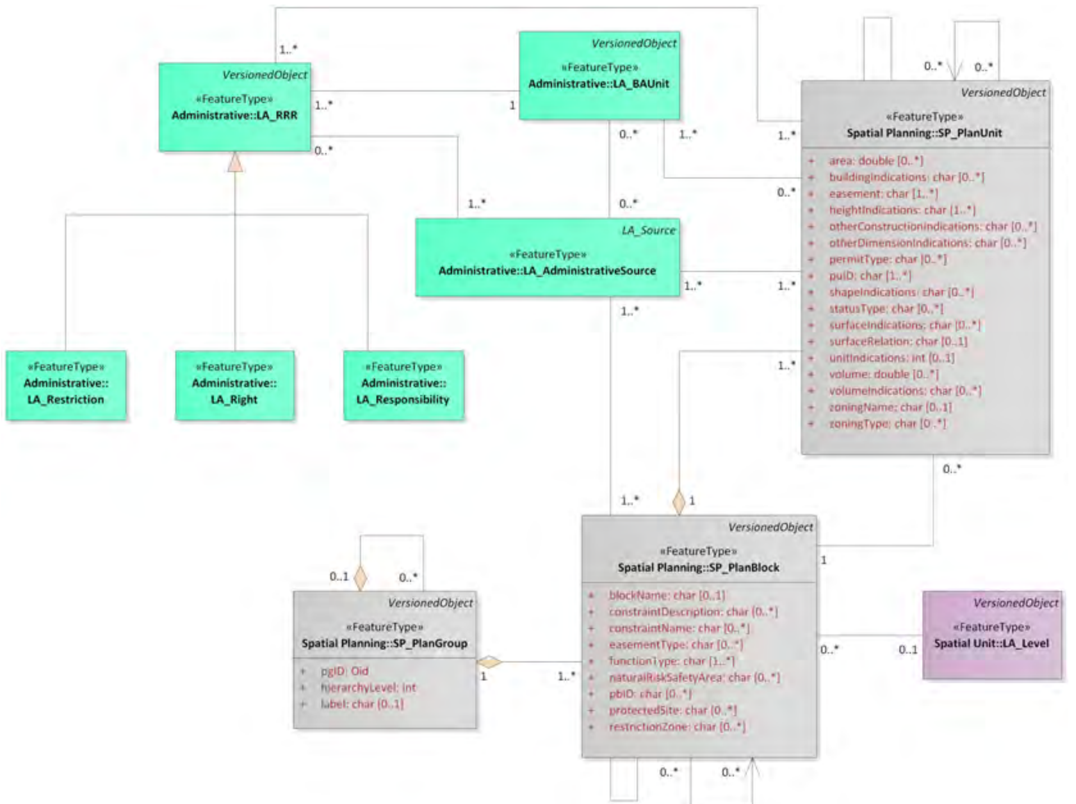

FIGURE 3 The classes of SPI part and their relationship with other classes of LADM regarding RRRs (adapted from Indrajit et al. (2020)).

that provides modeling specifications for these objects. The data model enabling the data exchange is based on the Extensible Markup Language (XML)/Geography Markup Language (GML) formats. CityGML also includes the level of detail (LoD) concept that allows modeling of the 3D geographic objects depending on requirements for the specific application in which these objects are used. With the publication of CityGML (2.0) in 2012 by OGC as an official standard, the interest in creating 3D city models based on the CityGML data model increased. It is nevertheless observed that there are some drawbacks that might hinder the efficient exchange and usability of CityGML-based models. Possible reasons for these drawbacks in the sense of practicability are revealed (Ledoux et al., 2019):

- There are a couple of software that offer comprehensive capabilities for reading, writing, and editing CityGML datasets.
- The number of created and stored CityGML datasets is not at the level that enables efficient data exchange.
- The size of the CityGML files can be large which makes the processability of these files difficult.

In order to enhance the efficient usability of 3D city models formatted in the CityGML standard, CityJSON is proposed as an encoding for the CityGML data model. CityJSON is based on JSON to tackle the disadvantages owing to using XML/GML for encoding. In other words, JSON-based encoding has a flatter structure than the XML-based encoding approach which results in a hierarchical structure. Other advantages of JSON over XML are simplicity, smallness in the file size, and easiness in code writing, human understanding, and parsing. GML-based modeling might also have problems in terms of software development because there are multiple variations to define the same geometry.

The first version of CityJSON covers the CityGML 2.0 data model. In the meantime, CityGML 3.0 is approved as an official version by OGC, and after that CityJSON is also updated such that it covers the encodings for the modules in the latest version of the CityGML. What is more, CityJSON is approved as an official OGC community standard. The latest version of CityJSON is conformant with most of the CityGML 3.0 data model. In CityJSON, the city objects can be at two different levels. While the city objects in the first level can exist by themselves, second-level city objects can only exist if they have parents. For example, *Building* is the first-level city object and can exist by itself and is associated with seven second-level city objects (e.g., *BuildingPart*, *BuildingStorey*, and *BuildingUnit*) that must be children of a city object in *Building* type.

CityJSON also has an extension mechanism through a specific JSON file that is created to contain the modeling details with regards to extending the core data model. Any CityJSON file can be validated regarding whether it is compatible with the proposed CityJSON extension. Three different ways are offered to extend the CityJSON core data model:

- City objects in the core model can be enriched by adding new complex attributes.
- New properties can be added to the root of a document.
- New city objects can be created or existing city objects can be extended, and new geometry types can be defined.

2.3 | Data requirements

Spatial data is highly significant for land use planning since it provides a solid basis for making decisions and preparing land use specifications in a data-driven manner. Population, housing, transportation, economics, utilities, facilities and services, health and safety, environment, land and property, urban development, and plans policies are the common data requirements for land use planning according to literature (Nedovic-Budic et al., 2004). As mentioned before, there is a need for a sustainable built environment for a high number of people in a limited space. This forces spatial planning activities in living areas -specifically, urban areas- to benefit from 3D geoinformation as an important data source (Dühr et al., 2021). The added features into the SPI part of LADM provide an adequate basis for the relationship between prepared spatial plans in the different levels of detail. The attributes of these features such as area, volume, permit type, and building indications are also sufficient to prepare 3D spatial plans that cover the required specifications for land use planning. To benefit from the interoperability and easily extendibility advantages of the standardized 3D geospatial data and provide 3D-enabled zoning plans, these features can be integrated to core schema of CityJSON standard.

3 | METHODOLOGY

Figure 4 shows the research methodology that is followed in the study. As can be seen from the figure the first step is to create a conceptual model for the CityJSON core model based on the SPI part of the LADM standard. This conceptual model is formed in a way that covers the necessary features and attributes for spatial planning purposes. It can be noted at this point that the methodology covers the use of CityJSON standard because its core schema can be readily extended for specific purposes and CityJSON files composed in line with the extended schema can be imported to and used in different software/tools efficiently. Another reason is that the nearly perfect match with CityGML 3.0 schema encourages practitioners to implement CityJSON files for different application areas in urban management such as energy simulations. It is benefited from the LADM standard to extend the CityJSON schema because it provides a solid data background for spatial planning in the context of the implementation of 3D land administration.

The next step is to compose the CityJSON extension file representing the created conceptual model. There are certain rules with respect to extending the core schema that is provided by the developers of the CityJSON standard. These rules are followed when composing the extension file in the present study. The features, their attributes, and their data specifications, and the relationships between the features are defined in the composed extension file. This file is saved in JSON format similar to the CityJSON core schema files. In the next step, it is focused on the spatial data that are used to demonstrate the usability of the proposed extension. The first part of this step involves obtaining the spatial data pertaining to the zoning plans. In the country, the information belonging to the zoning plans is stored and shared in the central system. The GML data of the zoning plans can be

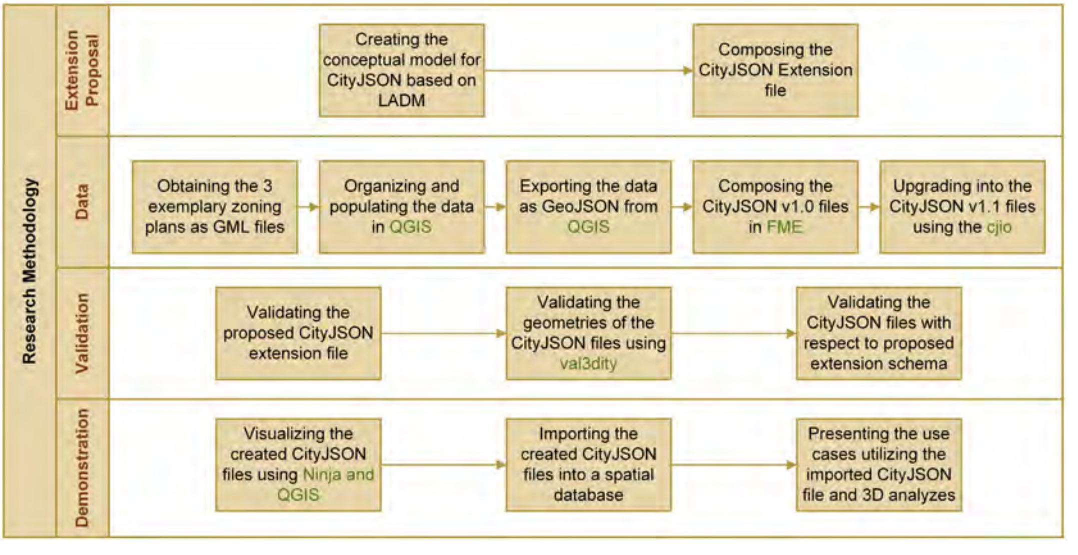

FIGURE 4 Research methodology of the present study.

downloaded in this system. The data schemas including the specifications on how to compose the GML data are provided by the ministry in order to obtain the digital data of the prepared zoning plans in an interoperable manner. To show the feasibility of the proposed extension, three zoning plans that are officially approved and shared by the ministry are selected and their GML data are downloaded from the central system.

As shown in Figure 4 the next part is to organize and populate the data pertaining to the exemplary zoning plans in the QGIS software. First, GML data consisting of different land use classes as separate layers in the zoning plan is converted to the GeoJSON file. Second, the layers related to +*PlanUnit* feature in the proposed extension are merged into a layer and its attributes are organized and populated. In addition, two layers corresponding to +*PlanBlock* and +*PlanGroup* features are created separately. The spatial join approach is used to obtain semantic information regarding the children and parent relationship between these features and their corresponding layers. By means of this approach, the layers corresponding to the plan unit, plan block, and plan group can have attributes that store the names/IDs of the children and parent features. For example, a layer corresponding to a plan block has to have two attributes for its children and parent separately. Three different layers namely plan unit, plan block, and plan unit are created for each of the exemplary zoning plans. These layers are exported as GeoJSON files when they are ready. Whereas the values of some attributes such as plan type are obtained from the downloaded GML files, some of them such as the maximum height are populated as arbitrary so as to demonstrate the usability of the CityJSON files that are created based on the proposed extension. Figure 4 illustrates that the next step with regard to data is to compose the CityJSON files by using the exported GeoJSON files. FME software (version 2022.1) that can be used as licensed freely for academic/scientific purposes is exploited to create the CityJSON files. Figure 5 shows the created FME workspace that requires GeoJSON files corresponding to the plan unit, plan block, and plan group as inputs and then creates a CityJSON file containing +*PlanUnit*, +*PlanBlock*, and +*PlanGroup* features through the input files.

In the first part of the workspace, *AttributeCopier* transformers are used to populate the feature ID namely *fid*, *parents*, and *children* attributes pertaining to plan unit, plan block, and plan group features in the CityJSON file. For example, whereas all mentioned attributes match the transformer related to the plan block, the transformer regarding the plan group has only *fid* and *children* attributes. In the next part of the workspace, the features in the GeoJSON files are extruded based on their *maxHeight* values through the *Extruder* transformer. After, the workspace sets geometry into features for the 3D representation and then writes/composes a CityJSON file based on the defined and matched values in the CityJSON writer corresponding to the attributes in the proposed extension. The workspace that can be seen in Figure 5 is openly shared as a template for reproducibility. The current version of FME supports the writing of the CityJSON files in version 1.0. However, the validations of the extended schema files and CityJSON files with respect to these files can be utilized by using CityJSON files in version 1.1. For this reason, the composed CityJSON files in version 1.0 are upgraded to version 1.1 through *cjio*

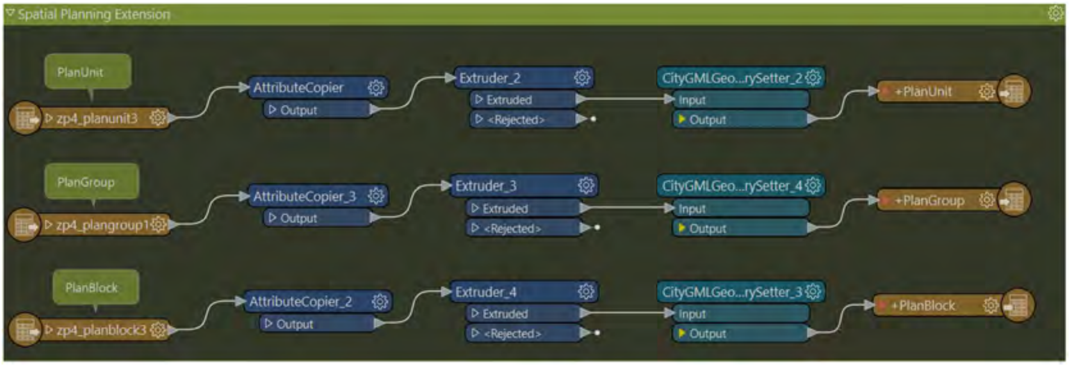

FIGURE 5 The content of the FME translator for creating the CityJSON files compatible with the proposed extension.

that is a free, small software package shared by the developers of the CityJSON standard for manipulating the CityJSON files (https://github.com/cityjson/cjio). The next steps of the methodology include the validation of the created files in the present research and the demonstration of the developed model through visualizations of the output CityJSON files and the use cases that utilize these files. Detailed information on mentioned steps is given in Section 7.

4 | EXTENSION PROPOSAL

Figure 6 illustrates the conceptual model that represents the relationship between the features in the core schema of the CityJSON and the proposed features corresponding to the features in the conceptual model of the SPI part (see Figure 3). The proposed features namely *SP_PlanUnit*, *SP_PlanBlock*, and *SP_PlanGroup* are defined in the proposed extension schema as +*PlanUnit*, +*PlanBlock*, and +*PlanGroup* respectively. As can be seen from Figure 6 the proposed features are modeled as a subclass of *_AbstractCityObject* feature in the core schema. Additional attributes such as *zoningSubType* and *planType* are also added to the proposed features to provide complete semantic information regarding spatial planning. Moreover, the attributes such as *pbID* in the *SP_PlanUnit* feature and *pgID* in *SP_PlanBlock* are provided to allow modeling the information regarding children and parent in the CityJSON file. In other words, *pbID* stores the information on the parent of the +*PlanUnit* instance and children of the +*PlanBlock* instance. Figure 6 also shows the code lists for the different attributes such as *zoningSubType*, *zoningType*, and *easement*. The values in these code lists are obtained from the GML files of the exemplary zoning plans. The relationships between the proposed features in the conceptual schema are also provided in the extension file. For example, *SP_PlanBlock* should have an association with only one *SP_PlanGroup* instance and *SP_PlanGroup*

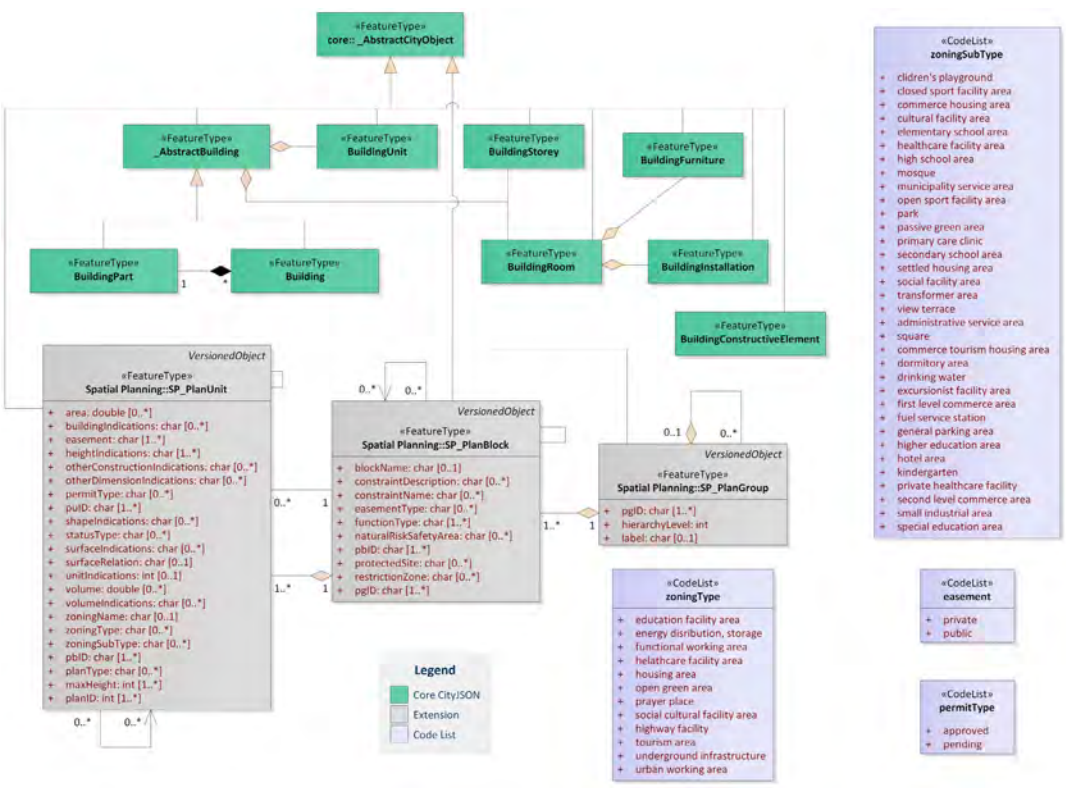

FIGURE 6 The conceptual model of the proposed CityJSON extension.

should have an association with at least one *SP_PlanBlock*. This relationship is defined in the extension file as the “children” property is mandatory for *+PlanGroup* instances and the “parents” property is mandatory for *+PlanBlock* instances.

5 | DEMONSTRATION AND RESULTS

It can be mentioned that the first result of the present research is the CityJSON extension file that is created based on the SPI part of the LADM standard for 3D spatial planning purposes. This file is shared openly via the GitHub repository to be used in various use cases by different researchers. As detailed in Figure 4 the research methodology includes the validation step. In this regard, the first validation is carried out for the proposed CityJSON extension file. The information within the official website of CityJSON is followed during the validation stage. Based on this, it is ensured using an online validator tool that the proposed extension file is syntactically valid. The validation result that shows the created CityJSON scheme is valid can be found in the GitHub repository. The GeoJSON files corresponding to the GML files of the exemplary zoning plans can be shared as second results within the study. Figure 7 illustrates these GeoJSON files in the projected coordinate system (EPSG:5254).

Table 1 lists the file sizes of the created GeoJSON files. As can be observed from Table 1 the file sizes of the GeoJSON files corresponding to plan units of Zoning Plans 1 and 3 are bigger than the others since these zoning plans have large coverages so that they contain a great number of plan units. In addition, Table 1 highlights that the file sizes of the GeoJSON files corresponding to plan blocks and plan groups of all exemplary zoning plans are similar to each other because the blocks in all zoning plans are in similar numbers and all zoning plans contain only one plan group feature. The mentioned GeoJSON files can be accessed from the GitHub repository.

The next results are the CityJSON files that are created using the prepared GeoJSON files. Three CityJSON files contain the attributes of *+PlanUnit*, *+PlanBlock*, and *+PlanGroup* based on the conceptual model that can be seen in Figure 6. As detailed in Figure 4 the geometries of the created CityJSON files are validated using a *val3dity* tool (Ledoux, 2018) that can be run as a web application and checks whether 3D primitives are valid according to specifications in ISO 19107. Based on the tool, it is found that the geometries of three CityJSON files corresponding to exemplary zoning plans are 100% valid. The validation results that show that every 3D primitive in created CityJSON files is valid can be found in the GitHub repository. Table 2 lists the number of features that are proposed in the extension with regard to zoning plans as well as the file sizes of the created CityJSON files. This means that Tables 1 and 2 itemize that the number of the plan groups is the same and the plan blocks are similar. It can be seen that Zoning Plan 1 has the highest number of plan units. Zoning Plans 3 and 2 follow it respectively.

The next results of the present study are related to the validation of the created CityJSON files with respect to the proposed CityJSON schema extension. These validations are carried out using the official validator tool that is shared by the developers of the CityJSON standard (https://validator.cityjson.org/). It is found that all created CityJSON files are 100% valid with respect to the proposed extension schema. The validation is carried out based on the following criteria: JSON syntax, CityJSON schemas, Extensions schemas, parents_children_consistency, wrong_vertex_index, semantics_arrays, duplicate_vertices, extra_root_properties, and unused_vertices. The validator first checks whether the CityJSON file is syntactically valid in terms of JSON data structure. It then controls whether the CityJSON file is compatible with the official core schema of CityJSON. Next, the validator checks the compatibility of the CityJSON file based on the extended schema that is provided with an external link such as a GitHub raw file. It also checks whether the feature instances in the CityJSON file contain any consistency regarding parent and children relationship. The validator also provides consistent results regarding the use of the vertices in the CityJSON file. The validation results pertaining to created CityJSON files can be found in the GitHub repository.

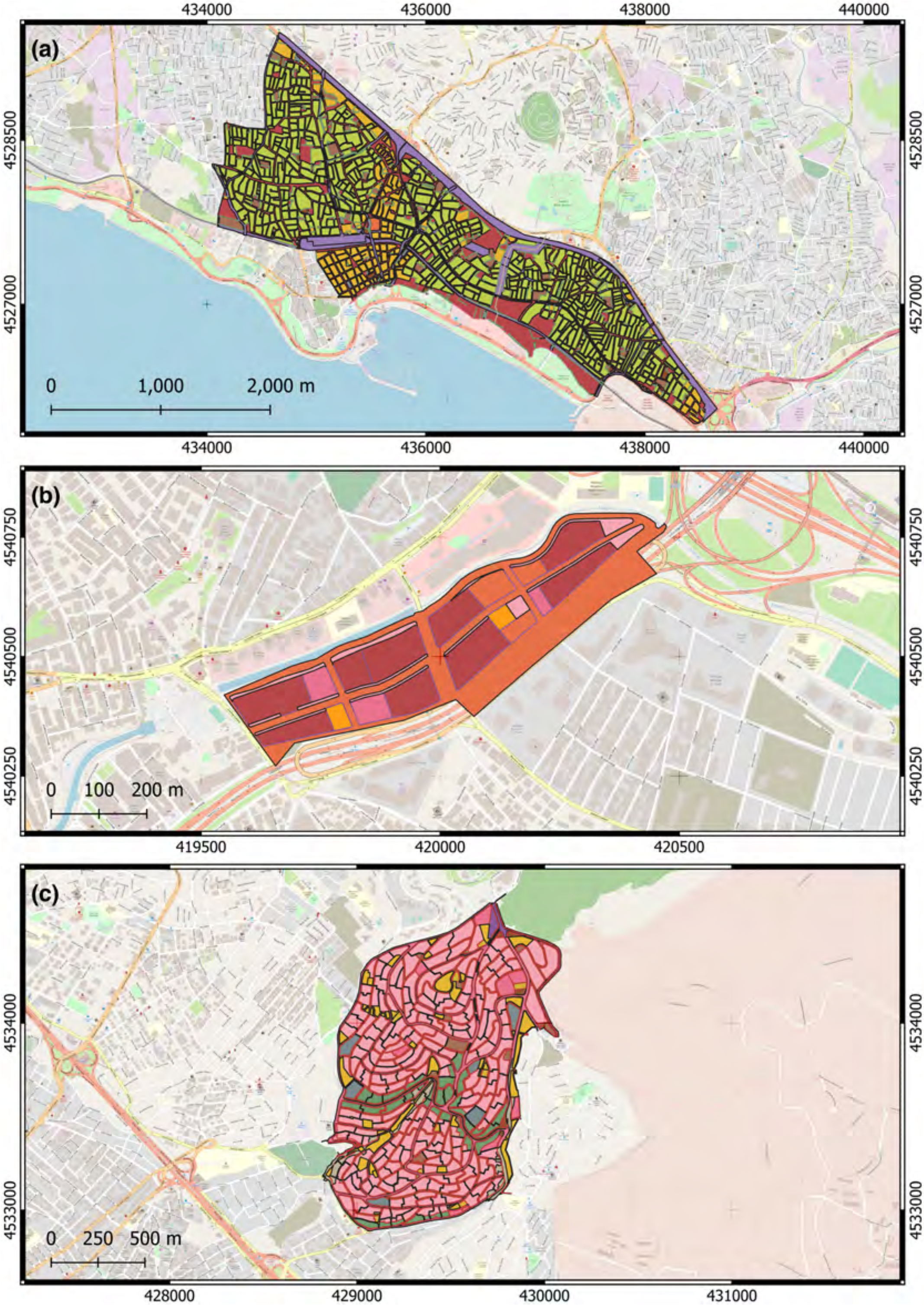

FIGURE 7 Maps presenting the GeoJSON files of plan units, plan blocks, and plan groups belonging to the exemplary zoning plans: (a) Zoning Plan 1; (b) Zoning Plan 2; and (c) Zoning Plan 3.

TABLE 1 The file sizes of the GeoJSON files.

Feature type	Plan name	File size (kB)
Plan Unit	Zoning Plan 1	1290
Plan Block	Zoning Plan 1	60.6
Plan Group	Zoning Plan 1	11.2
Plan Unit	Zoning Plan 2	63.4
Plan Block	Zoning Plan 2	18.7
Plan Group	Zoning Plan 2	5.3
Plan Unit	Zoning Plan 3	1050
Plan Block	Zoning Plan 3	37.0
Plan Group	Zoning Plan 3	12.3

TABLE 2 The file sizes and the coverage areas of the created CityJSON files and the numbers of the features within them.

Plan name	*+PlanUnit*	*+PlanBlock*	*+PlanGroup*	Total feature	File size (kB)	Area (km^2)
Zoning Plan 1	902	7	1	910	1370	5.13
Zoning Plan 2	29	8	1	38	78.2	0.18
Zoning Plan 3	469	6	1	476	1320	1.47

The next results are the visualizations of the created and validated CityJSON files to show the usability of the extended schema. The visualizations of the mentioned files are utilized in two different platforms namely *Ninja* and QGIS. *Ninja* is a web application that enables the visualization of the CityJSON files (https://ninja.cityjson.org/). Accordingly, Figure 8 presents the visualization of the CityJSON files that are corresponding to the zoning plans. It can be seen from Figure 8a that the +*PlanUnit* instance named PlanUnit691 is selected and its attributes are listed. As mentioned before, there is a children and parent relationship between the +*PlanUnit*, +*PlanBlock*, and +*PlanGroup*. Regarding this, Figure 8a reports that the PlanUnit691 instance has a parent as the PlanBlock7 instance. Figure 8b shows the visualization regarding the PlanBlock1 instance from the CityJSON files corresponding to Zoning Plan 2. As can be observed from Figure 8b, the PlanBlock1 instance has both children and parent. Whereas the parent of this instance is PlanGroup1, its children are PlanUnit1, PlanUnit2, PlanUnit3, PlanUnit4, and PlanUnit5. Figure 8c presents the visualization of the PlanGroup1 instance belonging to Zoning Plan 3. This instance has only children because of the association that is illustrated in Figure 6. It is apparent from Figure 8a–c that the numbers of the features of CityJSON files corresponding to zoning plans are the same as in Table 1.

Another result regarding the visualization is carried out in QGIS by means of the plugin called "CityJSON Loader" that enables to import of the CityJSON files and visualization of them as 3D (Vitalis et al., 2020). It can be noted that the QGIS versions starting from 3.0 allow 3D visualizations by default. In this connection, Figure 9 illustrates the 3D visualizations of the +*PlanUnit* instances of the CityJSON files corresponding to the exemplary zoning plans. Figure 9a–c present the Zoning Plans 1, 2, and 3 respectively. The CityJSON files are visualized based on the *zoningSubType* attribute. The color codes that are shared for visualizing the zoning plans by the ministry of the country are used. As shown in these figures, the different land use types in the zoning plans have various values for the *maxHeight* attribute expressing the maximum height that the prospective buildings or facilities can have.

Table 3 lists the information on three use cases that are presented to demonstrate the applicability of the extended schema within 3D spatial planning practices. These cases are implemented by using the created

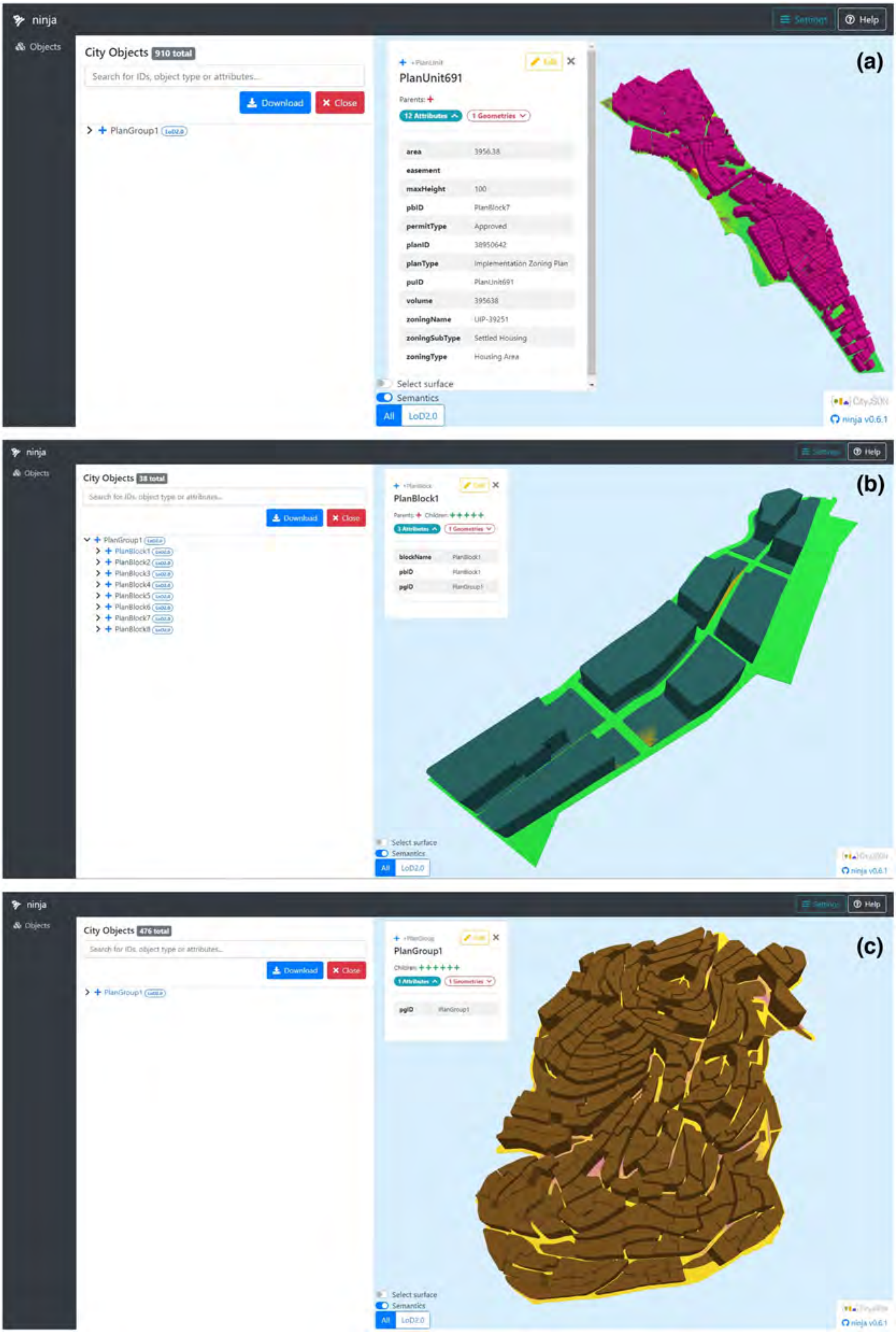

FIGURE 8 The visualization of the CityJSON files that are created based on the exemplary zoning plans in *Ninja*.

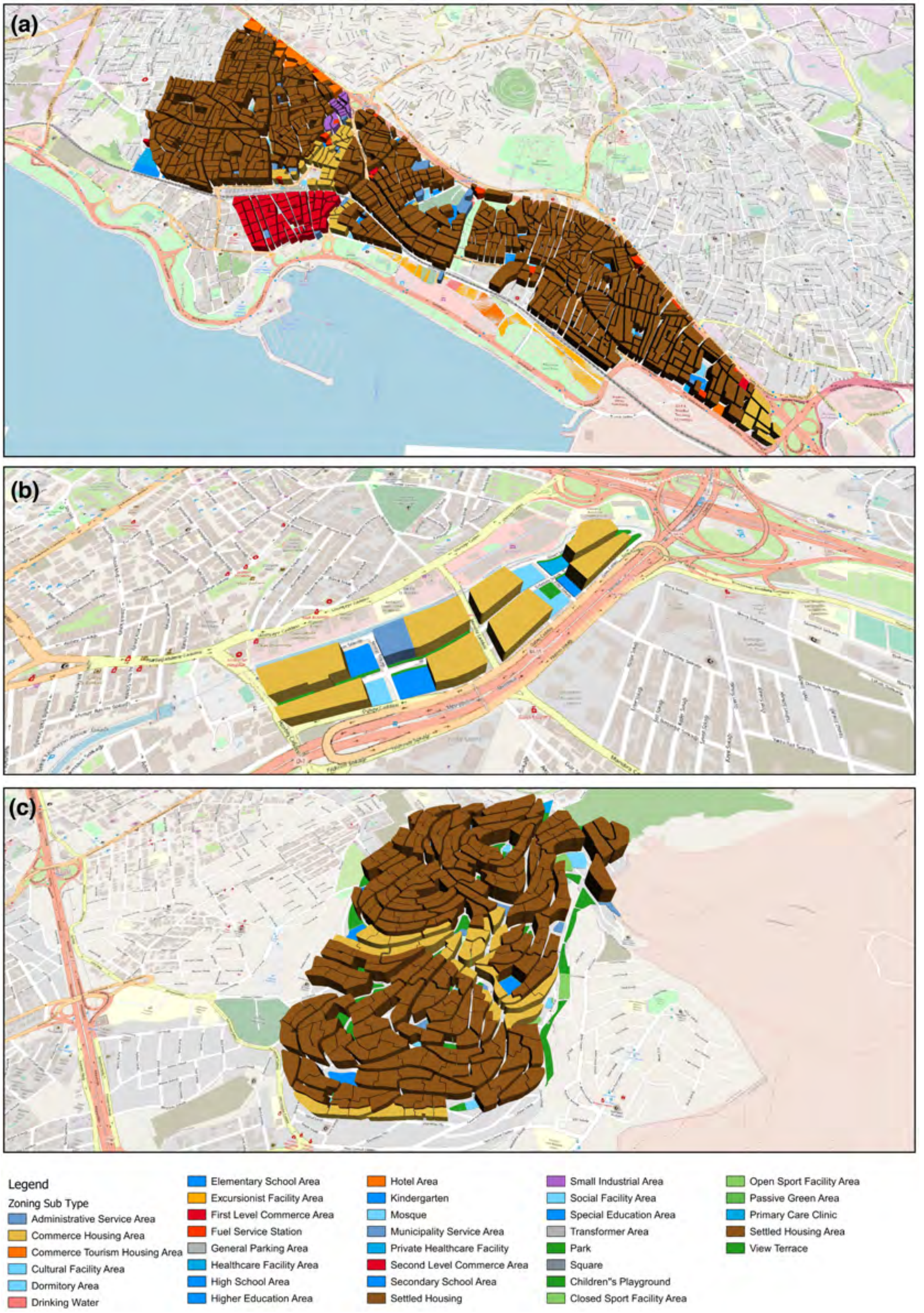

FIGURE 9 The visualization of the CityJSON files that are created based on the exemplary zoning plans in QGIS.

CityJSON file of Zoning Plan 1 and exemplary datasets that are composed regarding different objects such as buildings, roads, and housing estates in the built environment. These datasets are imported to a PostgreSQL database containing PostGIS and SFCGAL extensions in order to utilize spatial functions that support 3D (PostGIS, 2023).

5.1 | UC1

Table 4 shows the SQL query that enables to implement UC1 in the spatial database. The methodology behind the Query 1 can be sorted as follows:

1. Selecting the plan unit instance and its related information from the spatial plan table and the building instance from the building table when these instances are intersected;
2. Creating the solid geometries of the selected plan unit and building instances;
3. Calculating the volume of the intersected geometry between created solid geometries, and selecting this intersected volume and volume of the selected building instance; and
4. Checking the difference between volumes of the intersected geometry and the building. If the difference is equal to zero, it is written correctly into a column otherwise false. In other words, if there is a difference, this means that the building instance exceeds the borders of the maximum height that is defined in the corresponding spatial unit instance.

ST_3DIntersects provides a Boolean result whether the geometries of the inputs are intersected and *ST_MakeSolid* creates solid geometries of the inputs. *ST_Volume* calculates the volume of the solid geometries and *ST_3DIntersection* results in the geometry of intersected parts between the inputs. Figure 10a shows the

TABLE 3 The use cases and their contents.

Use case ID	The content of the use case
UC1	Checking the compliance of the maximum height of the designed building project according to the approved spatial plan
UC2	Checking the compliance of the designed road project regarding restrictions in the approved spatial plan and finding the geometries of the intersected parts belonging to the road
UC3	Checking the compliance of the designed house estate project regarding restrictions containing minimum distance (e.g., 100 m) in the approved spatial plan

TABLE 4 The query for UC1.

Query 1

```
create table check1 as
with tab1 as (select a.geom as geom_sp, a.fid as fid_sp, b.geom as geom_bu, b.fid as fid_bu from public."spatial_plan"
    a, public."building2" b where ST_3DIntersects(a.geom, b.geom)),
tab2 as (select ST_MakeSolid(d.geom_sp) as geom_sp_sol, ST_MakeSolid(d.geom_bu) as geom_bu_sol from tab1 d),
tab3 as (select ST_Volume (ST_3DIntersection (a.geom_sp_sol, a.geom_bu_sol)) as inter_vol, ST_Volume (e.geom_bu_
    sol) as bu_vol from tab2 a, tab2 e)
select * from tab3;
alter table check1 add dif numeric(10), add checking varchar(10);
update check1 set dif=bu_vol-inter_vol;
update check1 set checking=case when dif<=0 then 'correct' else 'false' end;
```

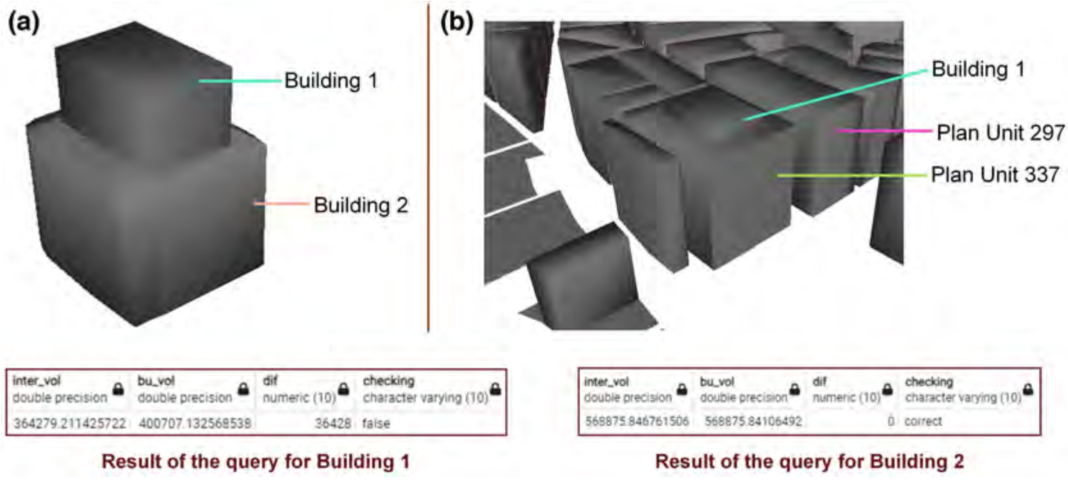

FIGURE 10 The demonstration of an example regarding UC1.

visualization of two building instances that have different heights namely 110 and 70 m. As can be seen from Figure 10b these building instances are located in Plan Unit 337 instance that expresses the maximum construction height as 75 m. Figure 10 also presents the query results for Buildings 1 and 2. As expected, the query provides a false result for Building 1 as its height is 110 m and the query result for Building 2 is correct in terms of checking designed building height based on the plan unit instance in the spatial plan.

5.2 | UC2

The query for UC2 that is shown in Table 5 finds the intersected geometries between the designed road project and corresponding plan unit instances by intersecting the solid geometries and checking the compliance of the project based on whether there is a restriction or not.

Figure 11a,b show the plan unit instances and road project respectively. As can be seen from Figure 11c there are intersections between the road project and these plan unit instances. Figure 11d illustrates the intersected geometries between road and plan unit instances that express restriction. The query result in Figure 11 contains the four plan unit instances even tough road intersects with five plan unit instances. This is because Plan Unit 337 does not include any restrictions.

5.3 | UC3

The logic of Query 3 that can be used to implement UC3 and shown in Table 6 is to check and select the house instances that are located in the specified distance with the restricted areas that are defined in the spatial plan. The query utilizes *ST_3DDWithin* that provides a Boolean result whether the distance between the geometries of the inputs is larger than the specified distance as input with the solid geometries of the plan unit and house instances.

As shown in Figure 12, the demonstration regarding UC3 includes the designed buildings in a housing estate and the plan units that have several attributes indicating the planned land use class such as green area.

In this example, it is assumed that there should be at least a 100 m distance between the designed building and the restricted area in the spatial plan according to the zoning regulation. As a result of Query 3, three houses are

TABLE 5 The query for UC2.

Query 2
create table check2 as select a.fid as plan_unit, a.easement, ST_3DIntersection(ST_MakeSolid (a.geom), ST_MakeSolid (b.geom)) as geom_inter from public."spatial_plan1" a,public."road" b where ST_3DIntersects(a.geom, b.geom) and a.easement!='';

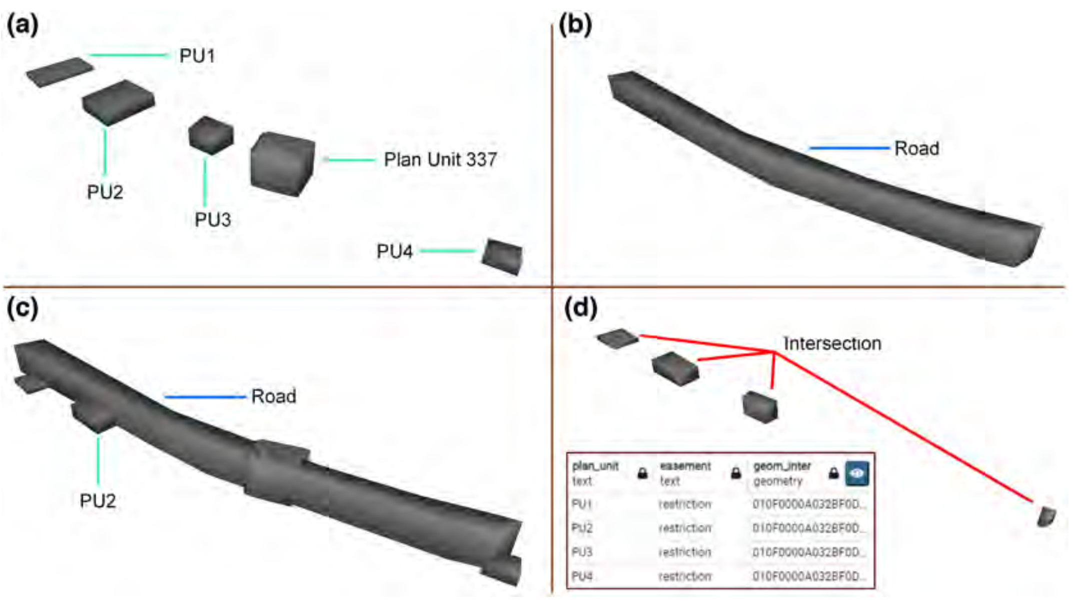

FIGURE 11 The demonstration of an example regarding UC2.

TABLE 6 The query for UC3.

Query 3
create table check3 as select a.fid, a.easement, b.zoningname as house_name, b.geom, ST_3DDWithin(ST_MakeSolid (a.geom), ST_MakeSolid (b.geom), 100) as checking from public."spatial_plan1" a, public."housing" b where a.easement!='' and ST_3DDWithin(ST_MakeSolid (a.geom), ST_MakeSolid (b.geom), 100)='true' order by b.zoningname; update check3 set checking='false' where checking='true'; select geom, house_name, checking, string_agg(fid, ', ') as plan_units from check3 group by house_name, geom, checking;

selected since they are located in the specified distance with restricted areas. Query result also provides which house is located within the which plan units as can be seen from Figure 12. Since the Plan Unit 337 instance does not contain any restriction, it is not selected in Query 3.

6 | DISCUSSION

This research provides the extension for the CityJSON core schema so as to enable and facilitate the applicability of 3D spatial planning that significantly benefits from 3D geoinformation models. The extension is developed conceptually based on the SPI part that will be included in the next edition of the LADM standard that aims to

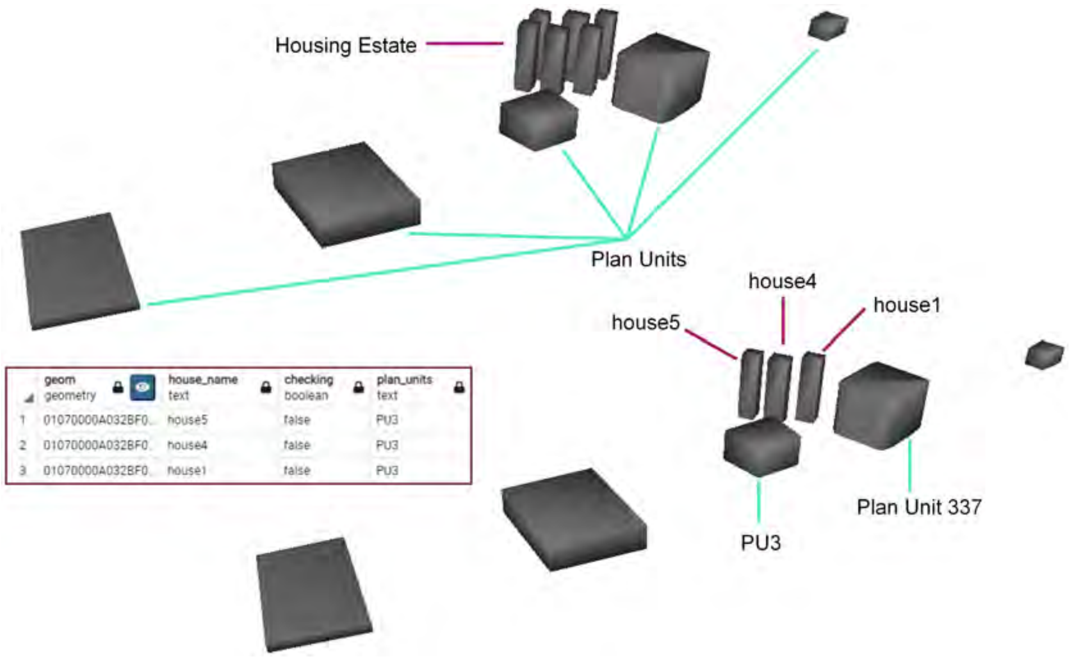

FIGURE 12 The demonstration of an example regarding UC3.

promote sustainable land administration through providing the conceptual schemas, in order to provide the scientific basis for the content of the proposed extension. In doing so, the present study makes an important contribution to increasing the usability of the CityJSON standard because the zoning plans can now be prepared such that they contain 3D geometric and semantic information on how to use land. This contribution fits for the purposes behind the development of the CityJSON standard. Specifically, the purpose that aims to enable to be easily extended the core schema of the standard and to be used the data that is created based on the extended schema without needing any extra effort regarding the software upgrade. It can be highlighted that putting into practice the mentioned purpose is of great importance for implementing 3D spatial planning in terms of several aspects.

It can be mentioned as the first aspect that the 3D visualizations can be efficiently exploited in the studies related to urban planning by means of CityJSON data that is created in line with the extended schema. This is because the mentioned data enables interoperability between various applications so that they are readily utilized by the stakeholders who are involved in urban planning. The second aspect is related to building permitting that encompasses checking the suitability of the designed buildings according to approved zoning plans (i.e., spatial plans). It is evident that a great number of applications for getting a building permit include multilayered building designs. For this reason, it is necessary to have the spatial data representing the approved zoning plans as 3D in order to utilize the spatial analyses regarding the different criteria such as specified distance with restricted areas in the compliance checking within the building permit issuing. The need for the mentioned spatial data can be fulfilled by the CityJSON data that is created by considering the extended schema. The applicability of 3D spatial planning in the context of 3D land administration can be mentioned as the third aspect. As touched on in the introduction section that the LASs are evolving into systems that are able to store and manage the 3D spatial data to meet the needs of the built environment having high complexity in the sense of sustainable land management. In this connection, the evolution of the LASs comprises the support of the 3D spatial planning since using the 2D data for representing the different RRRs that might be in underground and aboveground remains insufficient. These RRRs can be efficiently delineated through the CityJSON data corresponding to the approved zoning plans. The present study also contributes to the implementation of the LADM standard by providing CityJSON extended schema based on the conceptual model within the SPI part, creating the CityJSON data compatible with this schema, visualizing the created data, and demonstrating the use cases with these data. The mentioned contribution is in line with the aim of facilitating the implementation of the LADM standard which is planned to be achieved by providing a part specific to the implementation within the second edition. The applicability of the developed model regarding the second and third aspects is demonstrated by the use cases that cover the possible real-world cases related to building permitting and 3D land administration, for example, compliance checking with respect to cadastral restriction that is defined in 3D. It is important to note that the CityJSON files that are created based on the extended schema are utilized to carry out different queries that include 3D spatial analyses such as intersection.

Several issues can be mentioned from a technical point of view. Providing spatial data schema is significant to obtain interoperable zoning plans that cover 3D spatial information with semantics in order to enable the sustainability of the operation of the software/tools that are used to implement different applications in practice regarding urban management such as compliance checking within building permit issuing. The important issue is that jurisdictions should carry out comprehensive examinations regarding the spatial data requirements that 3D-enabled zoning plans should encompass because these requirements differ depending on the regulations that are mainly prepared based on the official development plans of the countries/jurisdictions. As shown in this article the CityJSON core schema can be extended readily based on identified requirements. The opportunity for the validation of the extended schema and also the CityJSON files that are composed based on this schema is an important basis for that the proposed approach can be transferred into different study areas and its adoption can go beyond the context of the case studies in the present study.

It is noteworthy to mention several additional issues that are related to the usability of different spatial data types in the data preparation and manipulation stages. The validation of semantic information should be taken into account to prepare 3D spatial data corresponding to zoning plans in the context of urban land administration (Asghari et al., 2023). As mentioned before, information regarding children and parent is stored in the proposed features. For example, a +*PlanBlock* instance in Zoning Plan 1 contains 283 +*PlanUnit* instances as children. This information could be stored in the field of the GeoJSON files rather than shapefiles because the character limit belonging to fields of the shapefiles remains insufficient. Another issue is related to the data transformation within FME software. The EPSG code pertaining to the GeoJSON files could not be selected from the default list in the software when importing these files so that a transformer is used to add the correct information regarding EPSG code into imported files. However, a shift is observed in the created CityJSON files. Because of this, the CityJSON files are created without doing any transformation with regard to the coordinate system. Instead, the correct EPSG codes are added to the CityJSON files after exporting them from the FME software. There is also an issue that is related to the difference with regard to the visualization capabilities of the used platforms. Whereas *Ninja* does not allow for visualization of the feature types that are proposed in the extended schema namely +*PlanUnit*, +*PlanBlock*, and +*PlanGroup* using different colors, the created CityJSON files can be visualized based on the different attribute values with the user-defined color scheme in QGIS as can be seen in Figure 9.

7 | CONCLUSIONS

To sum up, this article provides the scientific basis for the implementation of 3D spatial planning that is a current topic within the urban planning context. This is achieved by demonstrating the applicability of the developed conceptual model that is prepared based on the integration of two international standards namely LADM and CityJSON such that it fulfills the needs of 3D spatial planning in terms of the semantic and spatial information. The outputs of the present study give a significant contribution to putting 3D land administration encompassing the realization of 3D spatial planning into practice. In this regard, another contribution related to 3D spatial planning is to facilitate the digitalization of building permit issuing that includes compliance checking depending on the approved zoning plans. It can be also highlighted that the value of this study lies in providing the used data in the study openly in order to enable the reproducibility of the applied research methodology.

Future studies can focus on the adaptability of the proposed approach in different jurisdictions to facilitate the implementation of 3D spatial planning. The more condensed integration with building permitting can be also investigated by demonstrating the additional real-world use cases. This is because there is a growing interest in the digitalization of building permitting that can benefit from zoning plans that are prepared as standardized spatial data in 3D. Automation can be mentioned as a limitation of the current study. In this regard, developing a web application that enables to implementation of additional use cases by utilizing the 3D-enabled zoning plans and 3D digital building/facility models (e.g., BIM) more automatically can be a topic of future studies. Including underground in the developed model is also one of the possible future study topics because there is a need for 3D spatial plans to efficiently benefit from underground space for sustainable management of urban areas. In addition, this issue is related to 3D land administration that should cover the legal registration and management of underground space in terms of cadastral RRRs.

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CONFLICT OF INTEREST STATEMENT

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

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available at https://github.com/geospatialstudies/spatial-planning.

ORCID

Dogus Guler https://orcid.org/0000-0002-3191-103X

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