12 Integrating 3D Geodata-Based Spatial Plans into 3D Land Administration for Digital Building Permits

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Introduction

The increased urban population rate requires more efficient planning of cities. Land use planning significantly benefits from spatial data when making decisions because different kinds of spatial analyses are needed to support these decisions scientifically. Land use planning is also a crucial factor in implementing sustainable land management due to the need for robust land development (Emamgholian et al., 2024). There is also a notable interrelation between land use planning and land management because of cadastral rights, restrictions, and responsibilities (RRRs). RRRs are a main component of land management, and some parts of RRRs, especially restrictions, are defined within land use planning. Land management is technically realised by means of land administration systems. These systems commonly encompass the cadastral and registry information together based on two-dimensional (2D) spatial datasets. However, there is a significant intention to practise land administration systems such that they can store and manage data representing RRRs in three-dimensional (3D), in order to address the challenges posed by the complexity of buildings and the built environment. For instance, efficiently planning underground spaces requires 3D data pertaining to both existing structures and ownership information of the subsurface (Guler, 2024).

Spatial planning involves information on how developments can be implemented based on specific regional specifications. These specifications may include land use, allowable building heights, and road widths. They are represented through spatial plans at different scales. These plans serve as the foundation for planning and building permit applications, which are an essential mechanism for controlling the alignment of new developments and ensuring sustainability and safety in urban areas. Currently, digitalisation is being widely adopted in different sectors, such as construction, to improve the effectiveness of procedures. Digital building permitting, which promotes automation through the use of digital, machine-readable data instead of manual processes, is a popular research topic (Noardo et al., 2022). Building Information Models (BIMs) are the main resource for obtaining digital data on designed buildings and facilities. On the other hand, digitalisation involves storing spatial plans as

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geographic datasets that cover spatial information and semantics. In some countries, such as Germany, this is already happening (Zahid et al., 2024). Specifically, these plans must be created and validated based on developed data standards from the geoinformation domain. The main idea behind this development is exchanging standardised digital data representing spatial plans between different applications. Simulating these plans with their geometries and attributes that encompass different land- and building-related restrictions in 3D could facilitate the implementation of digital building permitting. Therefore, this chapter presents how the core schema of the geoinformation standard can be extended to create 3D spatial data that depicts land use plans. This increases the usability of these plans for further applications, such as urban simulations and compliance checking within building permitting.

The chapter is structured as follows: the next section provides background information on related standards and studies. Then, the methodology is explained. The "Results" section explains how the datasets are created and provides demonstrations. The "Discussion" section presents insights regarding the applied methodology and the obtained results. The final section concludes the chapter with recommendations for future studies.

Background

Standards

Enabling the reusable data models relies on the well-established data standards that promote interoperability. The 3D modelling of the built environment covers two fields, namely Building Information Modelling (BIM) and 3D Geographic Information Systems (GIS). BIM has more focus on digital representation and management of buildings/facilities. Regarding this, Industry Foundation Classes (IFC) is the main open standard that paves the ways of exchanging digital models in an interoperable manner.[1] 3D semantic city models are beneficial for implementing efficient decision-making regarding different fields of applications in the built environment. In this regard, CityGML provides a data model for the 3D modelling of physical objects and logical spaces in urban areas with their semantics through different data themes such as building, construction, and land use.[2] The standard provides a foundation for modelling on these themes but its core model can be extended with feature classes and attributes for specific needs of the various fields/sectors such as land registry and cadastre and energy modelling through Application Domain Extension (ADE) mechanism. In addition, another standard called CityJSON is proposed as the JavaScript Object Notation (JSON)-based encoding of the CityGML core model in order to improve the implementation of CityGML-based data since there might be some inefficiencies because of the complex and hierarchical structure of Geography Markup Language (GML) (Ledoux et al., 2019). CityJSON v2 is the latest version of the standard and is compatible with CityGML v3, which is the latest version. CityJSON has also an extension capability that can be utilised based on the identified conditions by the developers of the standard. The standards above address 3D urban modelling, covering both physical objects and logical spaces. In addition, there are data models for enabling interoperable spatial data infrastructures such as Infrastructure for Spatial Information in Europe (INSPIRE).[3] It covers different data themes, and Data Specification on Land Use is directly related to land use planning. It covers different feature classes for representing the spatial plan information through standardised spatial data. Further, the Land Administration Domain Model (LADM) provides a conceptual model for modelling of land registry and cadastral activities. The next version of the standard will contain a specific part titled Spatial Plan Information (SPI) that encompasses the conceptual model for representing the spatial plan objects in the context of land administration practices (Kara et al., 2024). This conceptual model is developed by considering the related, existing models such as INSPIRE. XPlanung is a data standard that was developed to enable the beneficial and lossless transformation of different types of spatial plans digitally within Germany. It covers modelling of the feature types and the relationships using Unified Modelling Language (UML), and XPlanGML is the GML-based encoding of the standard that is provided by adopting ISO 19118 and ISO 19136.[4]

Related Studies

There exist studies focusing on the use of the SPI part of the LADM standard for integrating spatial plan objects within land administration practices. For example, Poulaki et al. (2024) provided a conceptual model based on this part in Greece's spatial planning context. Similarly, Yılmaz and Alkan (2024) redesigned the SPI part for the Turkish planning system and presented a demonstration of 2D spatial data based on the content of feature classes in the conceptual model.

The control of land use suitability represents a critical component of spatial planning, particularly within the context of building permit processes. However, the use of only 2D spatial data proves insufficient for conducting effective evaluations in complex urban environments. This limitation has led to the growing demand for digitalising permit workflows, thereby necessitating the development and utilisation of 3D spatial plan data.

In response to these challenges, recent research has explored the applicability of 3D spatial models in a range of spatial suitability assessment scenarios, including noise exposure, shadow analysis, and the identification of protected areas (Emamgholian et al., 2024; Tezel et al., 2021). These studies emphasised the importance of 3D data models in supporting digital building permitting procedures. Moreover, the growing complexity of urban environments requires the explicit consideration of the third dimension in planning processes, which is strongly associated with the concept of cadastral RRRs. Relying solely on 2D data may fall short in adequately supporting spatial planning decisions, reinforcing the need for a 3D spatial planning approach that can address multi-level planning requirements and spatial characteristics (Guler & Yomralioglu, 2022; Šiško et al., 2022).

Despite these advancements, the literature addressing the integration of 3D data in planning and permitting remains limited. However, Guler (2023) focused on integrating the SPI component of the LADM into the CityJSON core model. They presented 3D visualisation of spatial plans that are generated as CityJSON format. In Estonia, research has examined the feasibility of producing zoning plans based on the SPI part of the LADM using IFC-based building models as part of a national initiative to digitalise building permitting with BIM (Batum et al., 2024). In Germany, researchers have proposed a linkage between the XPlanung spatial planning standard and the CityGML data format, aiming to establish interoperability between planning and 3D urban models (Zahid et al., 2024).

A growing area of interest within 3D spatial planning involves underground space planning, which has become increasingly critical in addressing urban challenges stemming from surface-level land use constraints. In this sense, 3D property information and cadastral restrictions are vital for planning in subsurface contexts. Although fewer studies exist compared to those focused on aboveground modelling, important research has demonstrated the feasibility of modelling underground legal spaces in 3D (Döner et al., 2011; Kim & Heo, 2017). More recent efforts have investigated the interoperability of CityGML and IFC standards for such purposes (Ramlakhan et al., 2023; Saeidian et al., 2023). Guler (2024) conducted a study exploring the use of the CityJSON format to represent cadastral RRRs in 3D, such as underground condominium units and restrictions related to subsurface heritage structures. Additionally, recent research has indicated that incorporating underground information within the SPI part of the LADM may enhance spatial planning responses to climate change (Kawasaki Tarozzo et al., 2024).

In light of this information, this chapter aims to provide integration between XPlanung and CityJSON by creating an extension covering a feature type for further applications. For this reason, it shows the usability of the extension by creating and visualising a CityJSON dataset based on 2D plan data and demonstrates how a designed building can be enriched using this dataset.

Methodology

As shown in Figure 12.1, the methodology starts with a review of related developments. In this sense, the XPlanung is selected as an exemplary data model, which is one of the comprehensive data models for generating and sharing land use plans in a standardised and digital manner.

XPlanung data model covers a number of modules that contain feature types for comprehensively modelling the content of the spatial plans. For example, FPlan (Flächennutzungsplan), which means land use plan, is utilised for creating spatial data corresponding to the land use information regarding different use type areas such as urban development, waste disposal, mineral

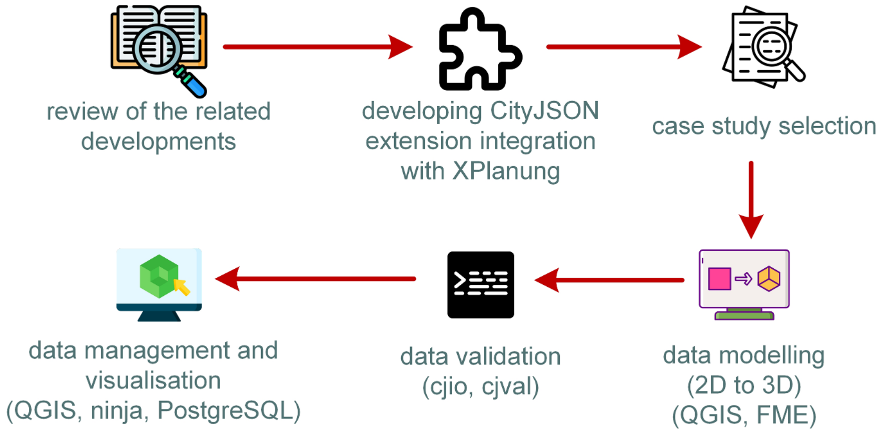


Figure 12.1 Methodology of this study.

resources, sports facilities, nature conservation, and green spaces. This module and its subsections indicate the land use type; however, elaborations on zoning are modelled through BPlan (BebauungsPlan), which means development plan.

The idea of matching some feature types and attributes within the XPlanung data model and CityGML was previously presented by Zahid et al. (2024). They, for example, associated the BP_PartialBuildingAreaSurface (BP_BaugebietTeilFläche) feature type that covers land use specifications with the LandUse object within the CityGML core model. The authors also proposed relations between attributes of BP_FestsetzungenBaugebiet (BP_Building-AreaDeterminations) and different CityGML feature types such as Building and BuildingUnit. These attributes encompass various restrictions on how designed buildings can be built. This chapter selects the BP_Ueberbaubare-GrundstuecksFlaeche (BP_BuildableArea) class to demonstrate how land use plans can be modelled through 3D urban model standard and be demonstrated regarding different restrictions. This class is selected because it delineates a specific part of the land parcel where the buildings can be constructed, and thereby it is related to the land administration context. Therefore, the CityJSON extension is developed based on the BP_UeberbaubareGrundstuecksFlaeche class and their selected attributes for demonstration purposes. The upper-level city objects such as Building, Tunnel, and Transportation are all subclasses of _AbstractCityObject within the CityJSON core schema. Hence, a new city object called +BP_UeberbaubareGrundstuecksFlaeche is modelled as a subclass of _AbstractCityObject. In the next step, an exemplary development plan (BPlan) is selected and then converted to CityJSON dataset. After that, created CityJSON dataset is validated based on both the specifications of the standard and compatibility with the developed extension. In the last stage, the visualisation of created CityJSON dataset is provided via different tools, and a case through the PostgreSQL system is presented to show the usability of the proposed approach.

Results

There exist test datasets that are shared within the website of XPlanung.[5] Therefore, exemplary BPlan data in GML format is selected among these datasets. Figure 12.2(a) shows the representation of the selected development plan. The dataset covers different sub-layers that encompass the classes within XPlanung, for example, BP_PartialBuildingAreaSurface (BP_Baugebiet TeilFläche), BP_BuildingBoundary (BP_BauGrenze), and BP_GreenArea (BP_GruenFlaeche). Figure 12.2(b) illustrates the BP_UeberbaubareGrundstuecksFlaeche class within the aforementioned dataset which is exported in the Geo Package format for data conversion and modelling process. This data also contains a number of attributes aligned with the data schema within XPlanung, for example, Z (maximum number of aboveground storeys) and ZU (maximum number of underground storeys). The EPSG 25832 is used for coordinate system consistency throughout data conversion processes.

As mentioned before, a CityJSON extension file, which is a JSON file, is created to be able to represent the BP_UeberbaubareGrundstuecksFlaeche class in CityJSON format. In addition, some attributes that are related to the BuildingUnit class of CityJSON schema are included within the extension

Figure 12.2 (a) BPlan test data and (b) 2D spatial data representing the BP_UeberbaubareGrundstuecksFlaeche class.

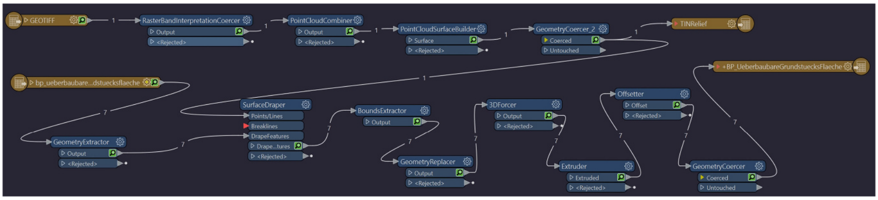


Figure 12.3 FME workbench for creating 3D CityJSON dataset.

in order to delineate the restrictions within the BP_UeberbaubareGrundstuecksFlaeche class for designed buildings. An exemplary plan is then converted to CityJSON dataset through the created workbench within FME[6] software (Figure 12.3). This software enables the amending of different types of spatial and non-spatial data together and also transforms these data into desired data formats. To obtain a 3D model that is compatible with the elevation of the surface, the OpenDTM-DE dataset with 1 m resolution is included in the workbench. This open dataset is compiled by using the high-resolution terrain models that are provided by the federal states in Germany and can be accessed through a website.[7] The availability of this dataset enables two beneficial issues regarding modelling. First, the TINRelief object within CityJSON covering the extent of the exemplary development plan is created. Second, this terrain dataset is used to obtain height values for each feature within BP_UeberbaubareGrundstuecks Flaeche dataset, which is shown in Figure 12.2(b). By doing so, the objects within CityJSON can be created by having real-world height values. BP_UeberbaubareGrundstuecksFlaeche instances are extruded using the h attribute that represents the maximum allowed building height in the development plan. The workbench writes two types of city objects, namely TINRelief and +BP_UeberbaubareGrundstuecksFlaeche, as shown in Figure 12.3.

The proposed extension file is created based on the specifications of CityJSON v2. Because FME exports only CityJSON v1, the dataset was upgraded to v2 after conversion. This upgrade can be done via cjio,[8] which is a Python command line interface. The validation of created CityJSON files is quite important to enable the reusability of the dataset and interoperability between the applications that use this dataset. In this sense, the created CityJSON file is successfully validated according to the different considerations, for example, JSON syntax, CityJSON schemas, and consistency between parents and children properties. The validation can be utilised within cjio with the help of cjval[9] which is a rust library and also has Python bindings. It is significant to further validate the CityJSON file and whether it is in line with the structure of the developed extension. This can also be completed through cjio. While Figure 12.4(a) shows a part of the extension file, Figure 12.4(b) illustrates the city object instances within the created CityJSON file.

Figure 12.4 (a) A section from the created extension file that covers the part of +BP_UeberbaubareGrundstuecksFlaeche class and (b) a section from instances of +BP_UeberbaubareGrundstuecksFlaeche class in the created CityJSON file.

It can be seen from Figure 12.4(a) that +BP_UeberbaubareGrundstuecks-Flaeche is structured as a subclass of _AbstractCityObject. The attributes and their types are also shown in the same figure. Figure 12.4(b) illustrates that +BP_UeberbaubareGrundstuecksFlaeche instances are modelled with CompositeSurface geometry type which is one of the permissible geometry types for this type of object within the developed extension. Figures 12.5(a) and 12.5(b) present the visualisations of different instances from different views. As seen in these figures, +BP_UeberbaubareGrundstuecksFlaeche objects have various attributes that are defined in the extension. Figure 12.5(b) demonstrates the underground storey restriction which is stored with the ZU attribute. This attribute is used within the FME workbench to bring subsurface geometry in +BP_UeberbaubareGrundstuecksFlaeche objects when creating the CityJSON file. These figures cover the TINRelief object as well.

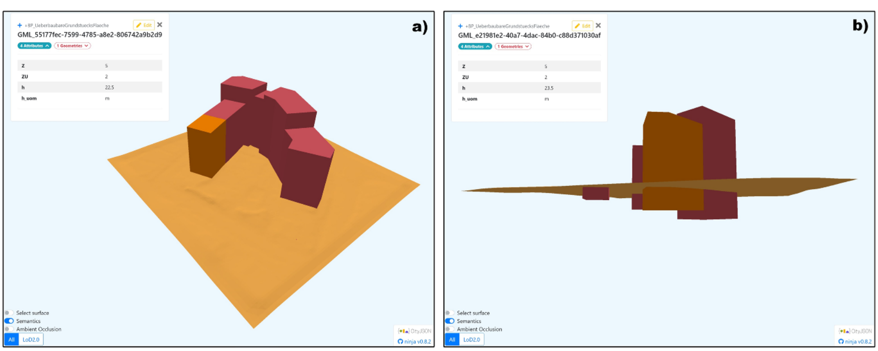


Figure 12.5 Visualisation of a +BP_UeberbaubareGrundstuecksFlaeche instance (a) an instance covering subsurface buildability restriction (b).

To simulate the usability with the created CityJSON file that is compatible with the extension, exemplary IFC dataset pertaining to a building is used. As mentioned before, extra attributes are added to the BuildingUnit class of the CityJSON schema to demonstrate the restrictions regarding the building units. Figure 12.6 illustrates the building and its defined spaces through the IfcSpace entity within IFC.

It is meaningful based on the schema specifications of IFC and CityJSON that the IfcSpace entity can be matched and used to create the BuildingUnit feature class. Therefore, a workbench is created to convert the IfcSpace instances within the building to BuildingUnit classes, as shown in Figure 12.7. For demonstration purposes, a Building feature class is also created within the workbench such that it is composed of BuildingUnit instances. It can be noted that there must exist the child and parent relationship of some object types within the CityJSON core schema. One of these relationships should be ensured between Building and BuildingUnit objects. In other words, a BuildingUnit instance must have a parent property that indicates the object ID of the related Building object. This is also enabled within the created workbench.

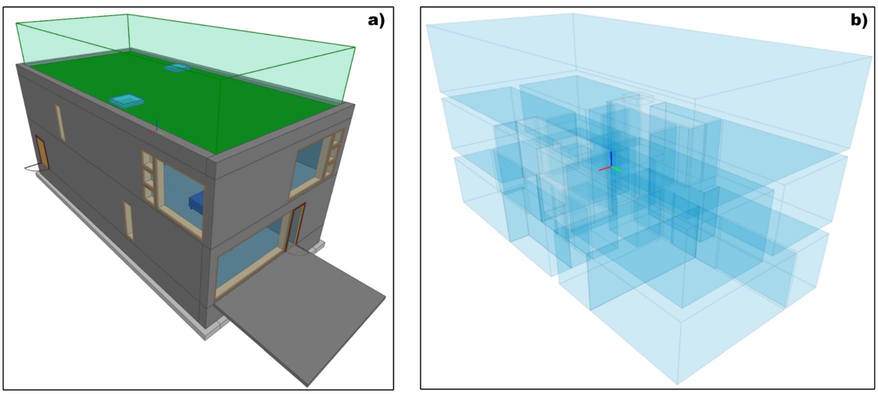


Figure 12.6 Visualisation of exemplary IFC dataset (a) and its spaces (b).

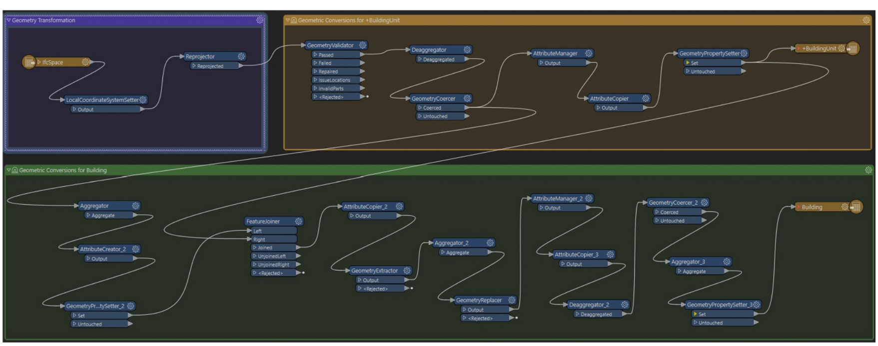


Figure 12.7 A workbench for creating BuildingUnit and Building objects within CityJSON dataset by using IfcSpace instances.

The created CityJSON dataset covering Building and BuildingUnit objects is georeferenced within the workbench for demonstration purposes. The original dataset does not include any projected coordinate system information; instead, it uses local coordinates. As mentioned before, EPSG 25832 is selected as coordinate reference system. It is therefore used to reproject the IfcSpace instances within the workbench similar to creating the CityJSON dataset pertaining to BPlan. While the Building object is generated with a level of detail (LoD)1, the BuildingUnit objects are modelled as LoD2. Similar to created CityJSON data representing BPlan, obtained datasets are also upgraded to CityJSON v2 and successfully validated through cjio. As shown in Figure 12.8, the BuildingUnit object has a parent property, and the Building instance has children property, which indicates the BuildingUnit objects that are related to the Building object within CityJSON data.

Figure 12.9 demonstrates the 3D visualisation of created CityJSON files within QGIS through the plugin. Figure 12.9(a) illustrates the plan data based on the object type, that is +BP_UeberbaubareGrundstuecksFlaeche. Figure 12.9(b) presents the visualisation of two datasets together. While BuildingUnit objects are delineated within building dataset, BPlan data is visualised based on the ZU attribute value. For demonstration purposes, the exemplary building dataset is georeferenced as close to plan data.

To enhance the content of the building model with the BPlan that is spatially related, created CityJSON files are imported into the spatial database that is stored within PostgreSQL. The plugins, namely PostGIS and SFCGAL, are enabled to store spatial data and implement the functions that provide spatial analysis in 3D. In this study, a query is executed to add the related attributes in +BP_UeberbaubareGrundstuecksFlaeche table into BuildingUnit objects where their geometries intersect in 3D. The content of this query is presented in Table 12.1.

The query first adds new attributes (i.e., h, z, and zu) to the BuildingUnit table and then identifies the attributes within +BP_UeberbaubareGrundstuecks Flaeche table that are inserted into the BuildingUnit table. This insertion is successfully executed if the geometries of two objects are intersected in 3D. This

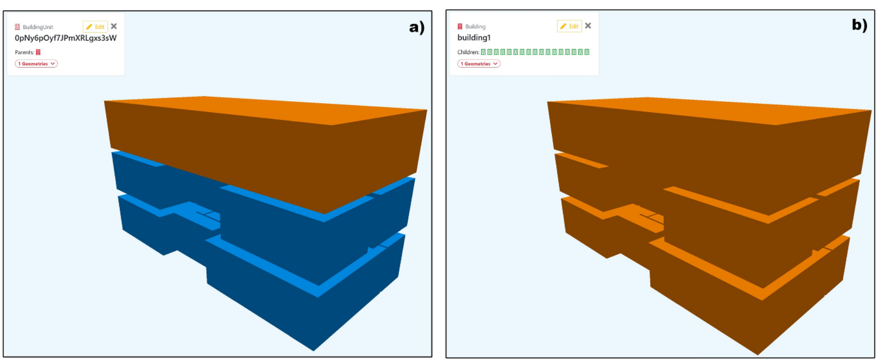


Figure 12.8 Visualisation of BuildingUnit (a) and Building (b) instances.

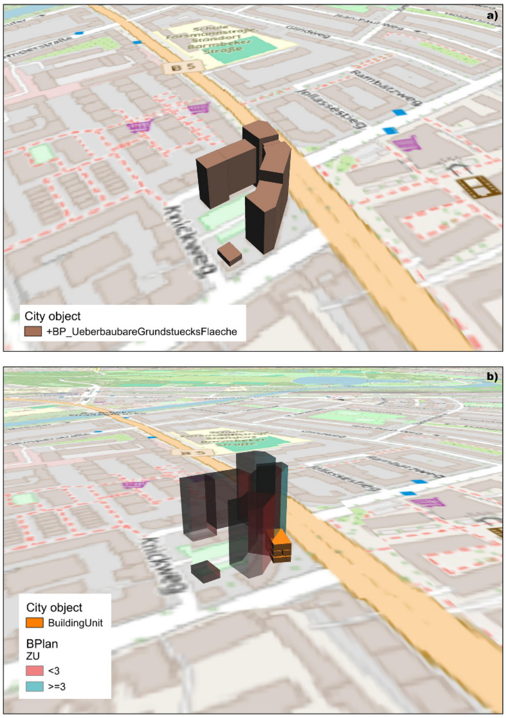


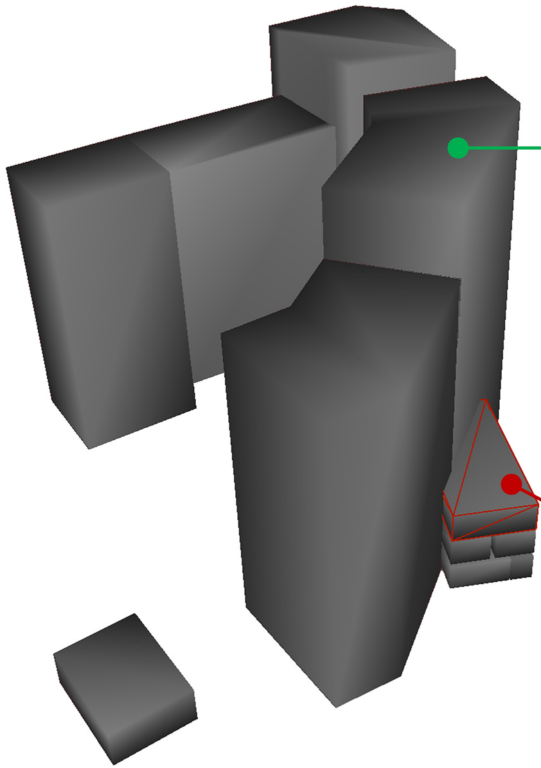
Figure 12.9 3D visualisation of plan data (a) and together with the created building data (b).

Table 12.1 Query for Inserting Different Attributes into Another Table

Query 1

```
alter table public. "BuildingUnit" add column h double precision, add column z
  double precision, add column zu double precision;
update public. "BuildingUnit" b
set h = s.h,
      z = s.z,
      zu = s.zu
from public. "+BP_UeberbaubareGrundstuecksFlaeche" s
where ST_3DIntersects(b.geom,s.geom)
```

intersection is implemented through the ST_3DIntersects function that provides true or false results depending on whether the geometries intersect. Figure 12.10 illustrates the result for Query 1. As can be seen from this figure, different BuildingUnit objects intersect with different +BP_Ueberbaubare GrundstuecksFlaeche objects in 3D. Therefore, BuildingUnit objects have different values for identified attributes. For example, in Figure 12.10, selected +BP_UeberbaubareGrundstuecksFlaeche and BuildingUnit object have the same attribute values after execution of Query 1 as they intersect.



+BP_UeberbaubareGrundstuecksFlaeche

	fid text	z bigint	zu bigint	h double precision	h_uom text	geom geometry
1	GML_55177fec-7599-4785-a8e2-806742a9b2d9	5	2	22.5	m	010F0000A0990F...
2	GML_bff033ce-687f-48fe-b27c-542b545fb292	6	3	30	m	010F0000A0990F...
3	GML_d43355f7-ac29-4763-82ea-57c2b5c4be9f	7	3	30	m	010F0000A0990F...
4	GML_e0c8b0e8-7b8c-4ead-ae77-f2f1551b9136	6	2	26.5	m	010F0000A0990F...
5	GML_e1568a2b-1768-4889-aedb-95449c029c25	4	1	22.5	m	010F0000A0990F...
6	GML_e21981e2-40a7-4dac-84b0-c88d371030af	5	2	23.5	m	010F0000A0990F...
7	GML_ea917a61-3dcc-4889-9be0-0d56cbaad94f	1	1	0.001		010F0000A0990F...

BuildingUnit

	fid text	geom geometry	h double precision	z double precision	zu double precision
1	0BTBFw6f90Nfh9rP1dlXrc	010F0000A0990F...	30	7	3
2	0BTBFw6f90Nfh9rP1dl_3S	010F0000A0990F...	30	7	3
3	0BTBFw6f90Nfh9rP1dl_CZ	010F0000A0990F...	30	7	3
4	0pNy6pOyf7JPmXRLgxs3sW	010F0000A0990F...	30	7	3
5	0BTBFw6f90Nfh9rP1dlXr$	010F0000A0990F...	30	7	3
6	2gRXFgjRn2HPE$YoDLX3FC	010F0000A0990F...	30	7	3
7	0BTBFw6f90Nfh9rP1dl_3P	010F0000A0990F...	30	7	3
8	0BTBFw6f90Nfh9rP1dl_3C	010F0000A0990F...	30	7	3
9	0BTBFw6f90Nfh9rP1dl_3A	010F0000A0990F...	23.5	5	2
10	0BTBFw6f90Nfh9rP1dlXr2	010F0000A0990F...	23.5	5	2

Figure 12.10 Demonstration of the result for Query 1.

Discussion

This chapter focuses on generating CityJSON data to represent spatial plans as 3D geoinformation. There are several reasons for selecting CityJSON. Firstly, the created data is clearer in terms of syntax thanks to the JSON formatting. This makes the resulting dataset easier to understand and amend. Secondly, CityJSON's extension mechanism allows different types of objects, attributes, and relationships specific to an application area to be modelled with minimal effort. Thirdly, the version can be updated and the resulting datasets validated openly using the provided tools. This enhances the reusability of the datasets for further applications.

It should be noted that the use of the geodata standard can be extended to different applications in several ways. One way is to match the attributes of a standard to feature types within the geodata standard. There are examples of this in the literature. The second option is to extend the core schema of the geodata standard, which is also used in this study. For example, the BP_UeberbaubareGrundstuecksFlaeche feature type within the XPlanung schema is added to the core schema of the standard as a new object type. The attributes of this object within XPlanung are also included in this new type.

As mentioned before, there are different feature types corresponding to various planning objects within the XPlanung schema. In this study, BP_UeberbaubareGrundstuecksFlaeche is selected for demonstration of the created CityJSON extension. This is because it defines the restrictions regarding the buildability of a land parcel. Therefore, +BP_UeberbaubareGrundstuecks Flaeche is one of the key elements used in compliance checking during building permitting and is related to cadastral restriction. For this reason, obtaining the 3D geodata depicting this object type can be helpful for simulating the different restrictions.

In this study, an exemplary BPlan dataset is used as input for data conversion. As in previous studies, FME software was used to create a CityJSON dataset. It is important to note that inadequate software support constitutes a significant impediment to the effective implementation of data standards. This is because, even though data standards are updated at regular intervals, software versions may not be updated to support the latest versions of the standard. A similar situation exists between FME and the CityJSON standard. In other words, while the latest CityJSON standard is version 2.0.1, the latest FME version can only read/write version 1.0.1. Since updated versions of standards may offer more accurate modelling and extension capabilities, it is notable to create datasets using the latest versions. This has been achieved for the CityJSON dataset created in this study thanks to the open-source tools provided that upgrades the dataset to the current version of the standard.

Moreover, providing an extension paves the way for obtaining 3D spatial plans, which can present land use planning content from spatial and semantic contexts comprehensively. One of the reasons for this is that both the spatial planning and the building datasets can be validated in accordance with the created extension, thereby ensuring interoperability and lossless data exchange through standardised datasets.

In addition, making spatial plans available as 3D standardised geodata can provide a useful foundation for land use planning and controlling developments in underground spaces. This study uses an exemplary CityJSON dataset that also covers restrictions regarding subsurface development, that is the number of underground storeys permitted. From a visualisation perspective, the conditions of these restrictions and the designed buildings can be investigated using this dataset. Furthermore, the designed buildings in CityJSON format can be enriched with attributes related to subsurface restrictions using the 3D spatial analysis capabilities of a spatial database. Checking designed buildings against various subsurface restrictions can also be utilised through different types of objects within the CityJSON standard, such as underground historical sites, utility networks, and ownership.

Conclusions

This chapter presents an approach for creating 3D geodatasets that represent land use plans in CityJSON format. To accomplish this, a feature type that is selected from the XPlanung standard as related to buildability within land parcel is included in the created CityJSON extension. Converting a 2D spatial plan to 3D CityJSON and validating the resulting dataset based on the extension demonstrates that standardised datasets can be obtained with minimal effort. Additionally, the case for enriching designed buildings within the borders of spatial plans with these plans' attributes through 3D spatial context is presented. Thus, 3D spatial plans can efficiently serve simulation purposes and other applications, such as building permit compliance checking.

This study uses only the +BP_UeberbaubareGrundstuecksFlaeche feature type for demonstration. However, future studies may investigate integrating other XPlanung feature types into the CityJSON extension to obtain an overarching representation of spatial plans. This would enhance the enrichment of the designed building by providing more attributes from different feature types. The created extension can also be amended to cover other attributes from the BP_FestsetzungenBaugebiet feature type, which provides values for building area determinations. Furthermore, the web-based prototype can be developed to demonstrate the usability of the created dataset for various applications, such as verifying cadastral restrictions regarding the subsurface.

Acknowledgements

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Data Availability

The data in this study can be accessed via https://github.com/geospatialstudies/3D_spatial_plans.

Notes

1 https://technical.buildingsmart.org/standards/ifc
2 https://www.ogc.org/standards/citygml
3 https://github.com/INSPIRE-MIF/technical-guidelines/tree/main
4 https://xleitstelle.de/XPlanung/ueber_XPlanung
5 https://gitlab.opencode.de/xleitstelle/xplanung/testdaten
6 https://fme.safe.com/
7 https://www.opendem.info/opendtm_de.html
8 https://github.com/cityjson/cjio
9 https://github.com/cityjson/cjval

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