A REVIEW OF 3D SPATIAL DATA MODELS FOR SURFACE AND SUBSURFACE INTEGRATION OF SPATIAL OBJECTS

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ABSTRACT:

Three dimensional (3D) spatial data models have been known as a geographic information system platform for representing the dimensionality of spatial objects with respect to the real world. They can be used to mimmick the real-world objects above the ground, on the ground and underground. A 3D spatial data model that can integrate surface and subsurface elements will have a significant impact on engineering, spatial and urban planning, and the built environment. Such an impact includes good infrastructure development, proper planning, result-oriented installation of utilities, location-specific excavation of existing utilities, and cost-effective economy resulting from minimal damage of infrastructures. This article explores and documents the state-of-the-art with respect to 3D spatial data models specifically for the integration of surface and subsurface objects based on a thorough review of the literature in academic articles, technical reports, and web-based materials. To better understand the scope, this paper reviews the different 3D spatial modelling approach for surface spatial objects, subsurface spatial objects, and with keen focus on surface and subsurface spatial objects integration. The Open Geospatial Consortium (OGC) has played an important role in data integration and has a core space in 3D spatial data model evolution. One of the recent data models for such task is CityJSON due to its simplicity in data storage, visualization, manipulation, and data update compared to CityGML. The parameters influencing the choice of models can be attributed to the availability of data structure, applicability, exchange format and relevance. Based on the range of 3D spatial data model reviewed, a unified model is expedient for integration of surface and subsurface spatial objects.

1.1 INTRODUCTION

Three-dimensional (3D) spatial data is a three-dimensional mathematical representation of natural and human real-world objects on a map, an image, and a scene with height values (z-values), stored with geometric information (Biljecki et al., 2017). 3D spatial data modeling are series of processes that use the spatial interactions of spatial characteristics to imitate real-world circumstances within a GIS. These models allow for a wide range of applications, resulting in a requirement for a detailed representation of a specific area or even a focused model. Spatial data refer to all types of data objects or elements that are present in a geographical space or horizon. Points, lines, polygons, and other primitives of geographic and geometric data that may be modelled by position and associated with an object as metadata make up spatial data. The construction of 3D spatial data models has developed very rapidly over the past few decades (Yan et al., 2019).

A surface spatial object is the outer or uppermost layer of a tangible object or space, as the term is most commonly employed. It is the part of the object that is first experienced by an observer using their senses of sight and touch, as well as the part that interacts with other materials. The surface of an entity is filled with, spread across, or filled with perceivable qualities like colour and warmth rather than a basic geometric solid. On the contrary, subsurface spatial objects are those objects that exist below the surface. Electric gas, and telephone lines, fibre optic and television cables, water mains and sewage pipes, and other assets such as street lighting circuits, drainage systems, and flood control facilities are all part of the subsurface infrastructure, especially in urban areas (Esekhaigbe et al., 2020). The possibility of collisions between excavation equipment and buried utilities is a major concern arising from the uncertainty surrounding the type, location, and configuration of subsurface objects. Explosions and electrocutions while digging the ground to install utilities are known to cause accidents that result in injury or death to workers and site personnel. These mishaps also result in property damage, reduced excavation productivity, and disruption of essential consumer services. Such issues are more likely in the absence of good 3D spatial information (Zeiss, G. 2019; Esekhaigbe et al., 2020)

Many applications need to integrate data from inside and outside, above and below the surface, which makes 3D modelling and data management necessary (Zlatanova et al., 2012). To have a holistic digital representation of spatial objects, you need a unified 3D spatial data model. Several attempts and propositions have been made towards the integration of surface and subsurface objects via a unified or an integrated 3D spatial data model. In addition to being able to understand the surface or subsurface information that corresponds to each other's position and spatial linkages, surface and subsurface information should be unified (Kushwaha et al., 2020). Until now, data structure and standard formats have been at the heart of 3D spatial data models. This is because they

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determine the scope, applications, and useability of 3D spatial data models.

This section establishes the sequence by outlining 3D spatial data models for the integration of surface and subsurface objects; Section 2 discusses the history and previous works on 3D spatial data models; and Section 3 concentrates on the issues and challenges of 3D spatial data models. Section 4 focuses on the conclusion. A path of the previous works on 3D spatial data models is presented in the next section.

2. PREVIOUS WORKS ON 3D SPATIAL DATA MODELS

Three stages of development have so far been completed for the spatial data model. The common representations include the Geodatabase data model based on object-oriented technology and relational databases, the coverage data model based on file and database combinations, and the CAD data model known as the file system (Yao et al., 2018). A CAD data model stores geographic information as binary files and employs vectors to represent spatial information such points, polylines, and polygons as well as their shapes and colours. The second, also known as a coverage data model, is a vector data model based on geographical relationships, while the third is a data model based on relational databases and object-oriented technology.

Using an object-oriented approach, it is possible to manipulate complex objects and accurately simulate people's knowledge of geographic information in computers. As a result, the concept of object-oriented development is rapidly replacing traditional GIS development methods. The interesting component of spatial data is that they should be maintained in a spatial database system, where object relational databases are preferable to relational databases (Nguyen-Gia et al., 2017).

The main current tendency is to create object-oriented spatial data models (Li, 2020) that can attend to the geometries of spatial objects. Working with 3D spatial data models necessitates the use of both surface and subsurface spatial objects, as well as careful evaluation of the data structure's concerns and constraints (Jaljolie et al., 2018; Al Kalbani & Abdul Rahman, 2019). There is need to examine standards and data formats relevant to a 3D spatial data model.

2.1 Standards and Data Formats

For surface and subsurface spatial objects, for various time periods, and for a variety of applications, increasing 3D spatial data models are becoming accessible (Stroter *et a.l*, 2020). It is crucial to have suitable methods for standardizing and structuring the storage of such sets of 3D spatial data models.

Interoperability is at the heart of standards, which appear when many organizations need the same data format to address an issue and give instructions on how to check that the data are appropriately formatted for exchange (Liao, 2020; Muthalif et al., 2022). According to Chaturvedi *et al.* (2019), the use of free, open, and global standards such as those offered by the Open Geospatial Consortium helps promote interoperability (OGC). As a result of these standards, networked systems that provide access to data, applications, and analytical tools can be interfaced, while also being modelled and represented as data sources. Structured data must be stored, processed, and sent to various applications according to their needs. The necessity to make decisions based on the collected knowledge through the new method of gathering and processing essential 3D spatial data models of information for decision-making procedures is important for this advancement (Amović et al., 2021).

A data model, which is a knowledge of data structure, meaning, and application, is offered for the exchange of 3D data. There are several file types available. Some were developed by vendors but approved as standards due to widespread use (KML), others were developed by international organizations as standards (VRML, X3D, IFC, CityGML), and a third set of standards have become de facto standards as a result of widespread adoption by users and software providers (SHP, DXF, COLLADA, 3D PDF). The file formats were developed to fulfil a specific function, such as SHP, which maintains semantics on geometry, and IFC, which allows for realistic viewing and interaction (Zlatanova et al., 2012).

Accordingly, (Frith & Watson, 2017) said that standards must be acknowledged and upheld in order for various stakeholders to produce, collect, and keep data in a consistent manner that is appropriate for a particular purpose. CityGML has been utilized in several surface objects with different Levels of Details (LODs). An essential aspect of a 3D city model is the idea of Level of Detail (LOD)(Kumar et al., 2019; Huang et al., 2021). The idea of LODs comes from the field of computer graphics, where efficiency and richness are balanced by controlling the level of information used to represent a simulated reality (Kumar et al., 2019).

To manage 3D spatial data models, 3DCityDB, an open source 3D geodatabase system, has just been presented (Yao et al., 2018; Zadeh et al., 2019; Buyukdemircioglu & Kocaman, 2020). According to the CityGML standard, the tool suggests a system for the maintenance, examination, and display of substantial 3D city models.

A recent data model that uses the CityGML encoding is CityJSON. The CityJSON encoding allows us to avoid most of the shortcomings of the GML encoding: CityJSON files from real-world datasets are 6 times more compact on average, and their structure may be easily manipulated by many programming languages, including JavaScript (Ledoux et al., 2019).

It should be noted that the basic appropriate exchange format for 3D spatial data models is CityGML. However, a more recent development is an encoding for a subset of the OGC CityGML data model, that is, JavaScript object notation – based (JSON – based) called CityJSON. These data models in addition to geospatial software and tools serve the best interest in 3D spatial data modeling.

2.2 Software and Tools

There are a number of geospatial software and tools used to support data models. These tools perform a variety of functions. For instance, some are viewers, generators, editors, converters, storage, parsers, and API for programmers and validator tools.

There are categorized as international standards organization (ISO), widespread standards (WS), and de facto standards (DFS). Detailed description of the classification has been provided in Section 2.1.

The combination of these software and tools support is fully utilized in some exchange formats in the category of organizational standards such as CityGML, CityJSON, and IFC, while it is partially or less used in de facto standards such KML, SHP, DXF, COLLADA and 3D PDF. It is stated by Ledoux et al. (2019) that having an open standardized data format is crucial in the context of 3D models. Therefore, the place of exchange formats in the 3D spatial data model cannot be overemphasized.

CityGML and CityJSON are the most used exchange formats for 3D spatial data models, according to recent studies. Therefore, most software and tools functionalities support are utilized more in CityGML and CityJSON environment. For instance, Janečka (2019) transformed spatial objects from shapefile into CityGML via Feature Manipulation Engine (FME) and imported into the spatial database, Yao et al., (2018) use the 3DcityDB tool support for effective 3D city model administration, storage, analysis, interaction, and visualization based on the CityGML standard. 3dfier has been an essential tool for generating 3D from building footprint or 2D models as documented in (Biljecki et al., 2017; Kumar et al., 2019; Nys et al., 2020). An open – source plugin was developed by Vitalis et al.(2020) to identify all city objects, a CityJSON file is parsed, and its tree structure is examined with the city object's geometry and properties converted into QGIS features and grouped into layers in accordance with user choices. Some other supporting tools include citygmltools: a collection of tools for working with CityGML files that also supports storing and parsing CityJSON files hence it can convert CityGML files to CityJSON and vice versa (Vitalis et al., 2020). Citygml4j as a supporting tools was used for data integration (Shen et al., 2020). It is worthy to note that they are several other supporting tools that can be classified under different functionalities of viewers, generators, storage (import & export), parsers & API, validators, editors and converters etc. in exchange formats environment. The software and tool support for an exchange format influences the ultimate product of a 3D spatial data model. The support of software and tools plays an important role in the current status of 3D spatial data models with respect to surface and subsurface spatial objects.

2.3 Current Status of 3D Spatial Data Models

A comprehensive strategy for modelling 3D spatial data based on the use of 3D data as a platform is now necessary since 3D spatial data models have evolved beyond 3D visualization. For example, some cities, institutions, and governmental organizations have created 3D city models of surface spatial objects for a variety of uses and applications, with some of these models being documented in studies such as Nottingham in the United Kingdom and Shanghai in China (Girindran et al., 2020), Quebec City, Canada (Lafioune & St-Jacques, 2020), Kalasatama (City of Helsinki, 2019), 3D Geoinformation, Delft University of Technology, Delft, The Netherlands (Biljecki et al., 2017), Cesme Town of Izmir Province, Turkey (Buyukdemircioglu et al., 2018), port of Rotterdam, (Boates et al., 2018), Shenzhen and the Guangdong-Hong Kong, China (Xie et al., 2021) , Piraeus Metro Station, Greece (Perperidou et al., 2021)Los Angeles, CA, USA (Hill et al., 2021), Celje, Slovenia (Šarlah et al., 2020), Birmingham, UK Netherlands (Zlatanova et al., 2013) amongst others. Additionally, a number of significant research has been carried out in Nanaimo, Canada (Chapman et al., 2020), ETH Zurich (Yan et al., 2019), Tehran, Iran (Shahri et al., 2021), Casablanca, Morocco (Zerhouny et al., 2018), Geneva, Switzerland (Adouane et al., 2021), Delft University of Technology (Fossatti et al., 2020) , Poland (Bieda et al., 2020) etc. The 3D spatial data model to represent objects in reality and the spatial database system to store spatial data are varied (Nguyen-Gia et al., 2017). In recent years, several 3D spatial data models have been proposed (Emmitt et al., 2019). They are classified into four different approaches, namely, boundary representation (B REP), constructive solid geometry (CSG), voxel, and hybrid methods (Nguyen-Gia et al., 2017; Halik,T. 2018; Van Pham & Vinh Tran, 2019). The BREP approach describes 3D objects using main elements such as points, line, surface, and body (Olsson et al., 2018; Sun et al., 2020). The simplest depiction of a voxel contains all faces with square shapes. A voxel's complicated representation has all faces of varying sizes and forms. The voxel model is best suited for describing 3D nonartificial things (Biljecki et al., 2017). The CSG (constructive solid geometry) model, which describes a three-dimensional object by merging three-dimensional parts. 3D components are commonly used shapes such as a cube, cylinder, cone, prism, and sphere. Transformations and logic operators are used to connect these entities. Combining models, also known as hybrid models are generated by combining existing models.

The choice of any of the approaches also depends on the environment of the data model. At present, the object oriented and spatial database approach of 3D spatial data model is in vogue.

2.4 3D Spatial Data Model with respect to Surface and Subsurface Objects

For the execution of city projects dealing with the third spatial dimension (elevation), such as urban and spatial planning, environmental simulations, or disaster management, 3D spatial data models are essential (Janečka, 2019).

The change in urban dynamics occurs not only horizontally and upward, but also downward. The use of the subsurface to reduce the stress on the increasingly congested urban surface is becoming more common (Zerhouny et al., 2018; von der Tann et al., 2020). In many sectors, including networks (cables, sewage, and drainage), transit (subway, tunnels, and passageways), storage (warehouses, cellars, parking spaces, and thermal energy), as well as shelter and protection locations, subterranean building has entirely taken the place of surface construction (nuclear bunkers, bank vaults, and underpasses) (Mielby et al., 2017). Compared to information obtainable above ground, the information on this environment is restricted (Chapman et al., 2020). 3D spatial data models of the surface and subsurface can be created that are more exact and accurate, and they also enable more full and detailed analyzes to be performed in much less time than two-dimensional ones (Fidosova & Antova, 2021). Some related works on surface and subsurface objects linking to 3D spatial data models as illustrated in Table 1, provided in the following order: citation, title of the work done, model type, summary of approach used, and findings. From the table, 13 research studies in 2017 to 2022, 1 in 2016, and 3 from 2010 to 2013 (due to their peculiarities in the subject matter) were considered, making a total of 16 previous studies. From Table 2, it can be deduced from the review that several approaches are not based on 3D spatial data models but rather on data sources, proposed frameworks, 3D geological modeling, and sometimes 3D spatial data model based on stand-alone 3D representation of surface or subsurface.

Citation	Title	Model Type	Approach	Findings
Fidosova & Antova (2021)	Three-Dimensional Modeling of Spatial Data in Urban Territory	3D model	CityEngine and Computer-Generated Architecture (CGA) for 3D.	No integrative model was used
Kushwaha et al.(2020)	Analysis and Integration of Surface and Subsurface Information from Different Bridges	3D Point Cloud	In essence, acquisition and processing with TLS and photogrammetric software.	Integration based on data source and not 3D spatial data model.
Tilly & Kelterbaum (2017)	Investigating the Surface and Subsurface in Karstic Regions	3D DEM	Remote sensing approach used to perform DEMs.	Basically, used remote sensing approach for 3D DEM generation
Norrman et al.(2016)	Integration of the subsurface and surface sectors for a more holistic approach for sustainable redevelopment of urban brownfields	A generic framework	A generic framework is proposed to enhance decision making.	The practical involvement of 3D spatial data model
Graciano et al. (2018)	Real-time visualization of 3D terrain and subsurface geological structures	3D geological model	Processing and Visualization of Surface and Subsurface	3D Model applicable to terrain and geological subsurface.
Fossatti et al. (2020)	Data Modeling for Operation and Maintenance of Utility Networks Implementation and Testing	O& M Domain ontology model	A CityGML compliant TIN based DEM and database. Tools include FME, 3DcityDB, and QGIS	The model was used specifically for subsurface utility.
Kouros et al. (2018)	Surface/subsurface mapping with an integrated rover-GPR system	3D Topography	Joint mapping using of rover with a sonar- based simulated GPR	A Simulation Approach
Fenais et al.(2019)	Integrating Geographic Information Systems and Augmented Reality for Mapping Underground Utility Plans	Underground Utility Mapping	AR-GIS for mapping	Does not used 3D modeling approach
Wang et al.(2019)	Integrated underground utility management and decision support based on BIM and GIS	Integrated BIM-GIS platform	Framework for underground utility management	The framework was not established on 3D spatial data model
Pan et al. (2020)	3D scene and geological modeling using integrated multi-source spatial data	Point cloud model & DEM	3D modeling scene and visualization	management and spatial analysis of geological data
Ortega et al. (2020)	Topological Data Models for Virtual Management of Hidden Facilities Through Digital Reality	Data model in memory	CRUD (Create, Read, Update, Delete) through GUI	It also has model for the exchange of information through standard format
Graciano et al.(2017)	Toward a Hybrid Framework for the Visualization and Analysis of 3D Spatial Data	A hybrid framework	3D visualization framework capable of rendering field and vector data	This is a framework that is yet to be utilized on real-world objects.
Wu et al.(2021)	Construction of a spatial information model of 3D real estate: case study of the Nanjing gulou central business district	3D Real Estate (3RE modeling)	Building modelling of 3D parcels and divided units	The model is limited to building objects.
Duncan & Rahman (2013)	A Unified 3D Spatial Data Model for Surface and Subsurface Spatial Objects	3D Spatial Data Model	Microsoft Visual C++ version 2010 and Qt and OpenGL (GUI) to generate simulations.	Implementation on real world objects is required
(Zhang et al. (2011)	GeoScope: Full 3D geospatial information system case study	3D data model (framework)	A full software architecture was designed for the model.	Implementation will be complex as the model was not expanded standard format
Shen et al.(2010)	A Hybrid 3D Spatial Data Structure for the Integration of Aboveground, Ground, and Underground Objects	3D Spatial Data Structure	A framework for hybrid spatial objects integration	The model has not been used for any pilot project in real world.

Table 1. 3D Representation of Surface and Subsurface Spatial Objects

2.5 Integration of Surface and Subsurface Spatial Objects

To give subsurface information a crucial presence in urban planning and administration, spatial information needs to be delivered in the correct format at the right time. It is crucial to incorporate surface items into the model as well as underground infrastructure. (Schokker et al., 2017). There is still a need for integration into a broader model that combines all data on the surface including road structure and terrain, to which the subsurface infrastructure is highly linked (Chapman et al., 2020). Regarding surface and subsurface integration, (Kouros et al., 2018) carried out surface and subsurface mapping with an integrated rover, Ground Penetrating Radar, to achieve multiple integration of several perspectives in the simulation environment.

The authors foresee future work to evaluate the influence of various object shapes, sizes, and interactions, particularly in 3D spatial data models. Similarly, (Tilly & Kelterbaum, 2017) investigated a karst depression in southern Germany by evaluating the efficacy of terrestrial laser scanning (TLS) and low-altitude airborne photography from an unmanned aerial vehicle (UAV) in capturing the surface, developing a viable method of merging these 3D surface data with subsurface information produced from geophysical prospecting. Though not at 3D spatial data model integration, (Kushwaha et al., 2020) reiterated that surface and subsurface information may indeed be combined with each other. The authors used TLS and close-range photogrammetry (CRP) to generate a thorough 3D point cloud representation of real-world objects to perform surface and subsurface analysis. This allowed the author to comprehend the relationship between the positions of surface and subsurface objects.

Furthermore, (Pan et al., 2020) offered a way of integrating deep underground mines into a 3D modelling scenario, as well as a geological construction model for open-pit mines and surface objects. A framework for the integration of surface and subsurface spatial by Al Kalbani & Abdul Rahman, (2019), to create the 3D model, geospatial technologies and databases such as FME, PostgreSQL-PostGIS, and 3D City Database were used. Although several attempts and proposals have been made regarding surface and subsurface spatial objects integration in the 3D spatial data model context, there are issues and challenges.

3. ISSUES AND CHALLENGES WITH 3D SPATIAL DATA MODELS

Surface and subsurface representation can benefit greatly from the use of 3D spatial data models. However, there exist several issues and challenges with the three-dimensional representation of spatial objects. Although in order for 3D spatial data models to be used and yield the maximum result, the following constraints must be addressed.

3.1 Data Quality

Another problem that prevents the exchange of 3D city models among various software platforms and applications the quality, or the lack of data thereof. Most publicly accessible 3D geographic data models include several geometric and topological inaccuracies for instance, duplication of vertices, surfaces missing, self-intersecting volumes, etc., as noted by (Ohori et al., 2017; Ledoux, 2018; Ledoux et al., 2019). Practitioners can sometimes be oblivious to the problem. The datasets cannot, however, be utilized in other programmes or for sophisticated applications, which is necessary to support 3D data as a platform. Depending on the accuracy and reliability of the acquired 3D data for 3D spatial data modeling, the end result may affect the quality of the data.

3.2 Consistency between Models

Another problem is the mismatch between 3D city models covering the same area. At the moment, different base (sensor) data, reconstruction methods, and software are routinely used to produce 3D city models individually. Consequently, the geometry of the produced models usually varies significantly (e.g., a collection of surfaces versus a volumetric representation). Furthermore, these models' underlying data models regularly change as a result of the different file types (XML, picture, or binary) in which they are kept. Even identical models that are handled differently, whether through incompatible upgrades or format conversions, may produce noticeable changes. In 3D modelling, the uniformity or regularity of models is an essential consideration. Thompson et al. (2016) relates to how modern spatial planning and governance may effectively harness and incorporate so much information. Data accessibility and availability, data correctness and consistency, data management, and data integration are key aspects of 3D models (Thompson et al., 2016). Further attempt to providing consistency between models was suggested by (Višnjevac et al., 2019), that prototype should include a user interface and techniques for displaying 3D spatial objects, as well as data integrity and consistency by storing the data in a database management system. Inconsistency between models sometimes may occur as a result of different standards and formats.

3.3 Different Standards and Formats

The data model used to represent 3D objects for a certain application determines techniques for storing, accessing, managing, displaying, and constraining data (Nguyen-Gia et al., 2017). In order to attain uniformity in geometry and semantics, standardization is required. CityGML, an OGC standard, is the main format for storing and sharing 3D models. Its objective is to identify the basic classes that may be used to represent the most common classes of objects observed in a 3D spatial data model, as well as those classes' constituent parts, attributes, and interactions.

There are more methods that make use of CityGML data model to circumvent these problems. One is 3DCityDB, an open-source database based on Oracle Spatial or PostGIS that stores the CityGML data model in a relational database. Another choice for CityGML encoding is CityJSON, which represents a piece of the CityGML data model using JavaScript Object Notation (JSON). CityJSON was developed with programmers in mind to assist the quick creation of tools and APIs that support it(Ledoux et al., 2019). It is meant to be smaller than XML-based CityGML files, with a compression factor of roughly six, making it practical for online and mobile development (i.e., it supports the use of 3D data beyond exchanging data).

3.4 Use Cases in the Real World

Improvements involving the use of 3D spatial data models that appear promising in concepts and trials may meet issues in reality. Real-world production setups frequently involve larger spaces and greater automation, which can make planning and controlling data quality more difficult. Furthermore, when applied to bigger places like the surface and subsurface of a whole city, technologies that are effective for surface items are pushed to their limits (both in terms of outcomes and the instances they must represent). (Stoter et al., 2017; Breunig et al., 2020). There are several research in different domains that utilized 3D spatial data models. For instance, studies that used 3D spatial data model in geology / geosciences areas were conducted by (Graciano et al., 2018; Hao et al., 2019; Pan et al., 2020; Guo et al., 2021). Other studies that utilized 3D spatial data models include the development of a spatial information model (SIM-3RE) for 3D real estate that was done by (Wu et al.,2021) while a virtual globe-based integration and visualization framework for above-ground and subsurface 3D spatial objects was carried out by Chen et al. in 2018 among others.

It will require more work to create workable 3D spatial data models that might form the basis of a 3D data platform serving a variety of urban applications on the surface and subsurface. Regarding 3D spatial data, there are also organizational and institutional issues to take into account. For example, what 3D spatial data model should be available, where and how it should be available, who is willing to bear responsibility for upgrades and repairs, and how to integrate 3D spatial data models with detailed surface and subsurface spatial objects are issues that need to be taken into consideration. To overcome the numerous challenges specified, a unified 3D spatial data model has to be utilized for 3D model-based digital representation and spatial analysis of surface and subsurface objects.

4 CONCLUSIONS

From the review of 3D spatial data models for surface and subsurface spatial objects from journals, articles, and conference papers published in recent, we describe introduction and development of 3D spatial data models, the current status of 3D spatial data models with respect to surface and subsurface spatial objects, the integration of surface and subsurface spatial objects then issues and challenges. The authors realized that the 3D spatial data models available are mostly on stand-alone representation. The difficulties that now prevent the use of 3D spatial data models for the integration of surface and subsurface have been mentioned in this paper. A unified spatial data model to handle the full integration of spatial objects of the surface and subsurface is crucial.

Furthermore, the unified 3D spatial data model will be explored in the CityJSON environment to realize the simplicity of data storage, visualization, manipulation, and data update compared to CityGML. By supporting the development of (open-source) tools by programmers and researchers as well as by making it simpler for practitioners to exchange and analyze their datasets. The authors suggest that CityJSON will be advantageous for the whole community. The authors intend to continue developing a unified 3D spatial data model to make it as practical as possible in reality using a standard exchange format such as CityJSON.

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