Appropriateness of Using CityGML Standard Version 2.0 for Developing 3D City Model in Oman

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Abstract. This paper investigates the appropriateness of using CityGML version 2.0 for developing 3D city model in Oman. Some countries have started using CityGML standard (version 1.0 and version 2.0) to establish its 3D city model. Despite the fact that the CityGML standard is an important initiative for exchanging 3D city objects, it is still not fully supportive of the 3D city model requirements. To investigate problems that might face the implementation of the upcoming 3D city model in Oman using the CityGML standard version 2.0, the state of current CityGML standard implementation has been evaluated in selected countries (Germany, the Netherlands, Turkey, Singapore), which are considered significant in CityGML standard practicing. The degree of CityGML standard implementation has been investigated using a questionnaire that was designed based on a 5-point Likert scale. Moreover, in order to investigate the data structure issues and challenges based on CityGML standard, the study has carried some experiments. The study has used geospatial tools and databases such as FME, PostgreSQL-PostGIS and 3DCityDB to generate small-scale 3D city model. The survey results reveal that the degree of CityGML implementation in the countries surveyed focused on building model applications more than other CityGML models. Furthermore, the result of the experiments at the CityGML data structure shows that there are issues and challenges that need to be addressed. We expect this paper can prompt a better vision for upcoming CityGML standards and 3D city model.

Keywords: 3D city model · CityGML

1 Introduction

Currently, the 3D city model and its related geospatial activates are considered as a good geospatial platform for standardizing, storing, representing, and sharing 3D geospatial data at the national level [1–5]. Moreover, the capability of the current 2D GIS application still has its limitations to address complex spatial data structures and solve its issues [6, 7]. Hence, the 3D geospatial data and 3D city model solution have been suggested to facilitate the management of the urban area complex infrastructure such as multi-floor buildings and underground utilities [3, 8]. Several 3D city model initiatives that employed

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CityGML version 1.0 and version 2.0 emerged in Germany, Canada, the Netherlands, Switzerland, Austria, Finland and the United States of America for surface infrastructure management [6, 9–13]. Obviously, in these countries, most 3D city models that were designed based on using CityGML standard version 2.0 focused on specific models such as buildings, roads, parking lots, water, terrain at LoD1 and LoD2 [3, 14, 15].

CityGML standard is an important initiative for the 3D city model, but it is still not fully supportive of the city's infrastructure requirements [8]. Despite improvements in CityGML standard starting from version 1.0 to version 3.0 including the creation of new thematic modules for representing the bridges and tunnels in version 2.0, developing new construction objects, revising the CityGML LoD concept and increasing interoperability with other standards in the upcoming version 3.0 [11, 16–19]. Still, there are issues that need to be solved to use CityGML for the 3D city model at the national level in an effective way [8].

In fact, developing a spatial data structure for the 3D city model is a complicated task [6, 12, 15]. Therefore, to explore the issues that can be an obstacle in integrating CityGML standard and the 3D city model, the present study has investigated the current CityGML schema(s) and LoD(s) implementation in selected countries (Germany, the Netherlands, Turkey, Singapore) and its related spatial data structure issues. Besides, to achieve the study outcomes, the study has applied the statistical approach by designing an e-questionnaire based on a five-point Likert scale, which can be analysed by the Statistical Package for the Social Sciences (SPSS). Also, the study has carried some experiments to investigate the spatial data structure issues based on CityGML standard by using FME, PostgreSQL-PostGIS and 3DCityDB. In fact, the present paper links the statistical method and experiments to have a better understanding of the current state-of-the-practice of CityGML version 2.0 in terms of the schema(s) and LoD(s). Hence, the degree of the current CityGML implementation reflects practical challenges that need to be highlighted and solved. Also, the results of the experiments explained the nature of spatial data structure challenges that may face 3D city model using CityGML version 2.0 at national coverage.

This paper is organised in seven sections, where the Sect. 2 reviews the related works. Section 3 discusses the need for 3D city model in Oman. Then, Sect. 4 reviews the CityGML standard. The methodology and the statistical approach have been explained in the Sect. 5. The Sect. 6 includes the discussion and outcomes of the study. Finally, the Sect. 7 concludes the paper.

2 Related Works

Many researchers have investigated the problems of applying CityGML from a technical and programming perspective. Studies in this field have also dealt with some practical applications to develop 3D city model for some countries based on their requirements and specifications [15]. Stoter et al. [3, 10, 15, 20] proposed a generic approach for 3D SDI in the Netherlands and discussed the challenges that faced 3D modeling based on CityGML at national coverage, while Kolbe et al. [11, 19] investigated how to establish unified 3D city models and the virtual 3D city model of Berlin, both of which helped to enhance CityGML features and make it more useable. Moreover, Soon and Khoo [5] investigated the implementation of CityGML in modeling Singapore 3D national mapping and discussing the capability of implementing CityGML for the government geospatial core business. Chaturvedi et al. [21] proposed an approach to extend CityGML for managing different versions of a 3D city model in a unified dataset based on interoperable solutions.

In this context, Al Kalbani and Abdul Rahman [1, 8] investigated the issues and challenges for implementing 3D Spatial Data Infrastructure (3D SDI) in Oman for surface and subsurface spatial objects based on the CityGML standard. Also, Agugiaro [22] discussed the process of creating a virtual model for the city of Vienna based on using CityGML and solving data structure integration issues. Preka and Doulamis [23] explored the issues for creating 3D building modeling in a relational database at LoD2 in the municipality of Kaisariani, Athens. Obviously, these studies have provided solutions to fill some of the gaps identified in the application of the 3D city model based on using CityGML. This paper contributes in showing the current state-of-the-practice of CityGML version 2.0 in terms of the schema(s) and LoD(s) in a statistical way. Besides, it presents some of the challenges that may face the 3D city model implementation at the national level based on using CityGML for the spatial data structure.

3 The Need for 3D City Model in Oman

The geospatial workflow in Oman's geospatial community is limited to 2D and 2.5D geospatial data [1, 24–26]. Until the day, there is no clear vision to integrate Oman spatial data infrastructure (SDI) with 3D geospatial initiatives [1]. On the other hand, Oman is one of the developed countries which has a complex urban infrastructure [8]. Hence, the decision-maker in Omani municipalities requires a 3D city model to manage complex problems. Furthermore, the 3D city model is considered as a significant investment for future applications such as 3D cadastral applications, e-government and 3D smart cities [8].

4 CityGML Standard

CityGML is an open XML file format for exchanging, storing and representing 3D objects [27]. Moreover, the CityGML initiatives have been developed by the Special Interest Group3D (SIG 3D), and it is organized now by Open Geospatial Consortium (OGC) [27]. CityGML (version 2.0) includes 13 models to store spatial objects and five levels of detail (LoD) [6, 20, 28]. On the other hand, the standard of CityGML mainly focuses on the spatial perspective and presents the most common spatial objects that can be found in cities such as buildings, bridges, roads and others [27, 29]. Also, CityGML standard mainly focuses on the building model-schema more than other schemas [8]. Additionally, the concept of CityGML standard allows decomposing the spatial objects to sub-objects [6, 9, 14, 20, 30–32].

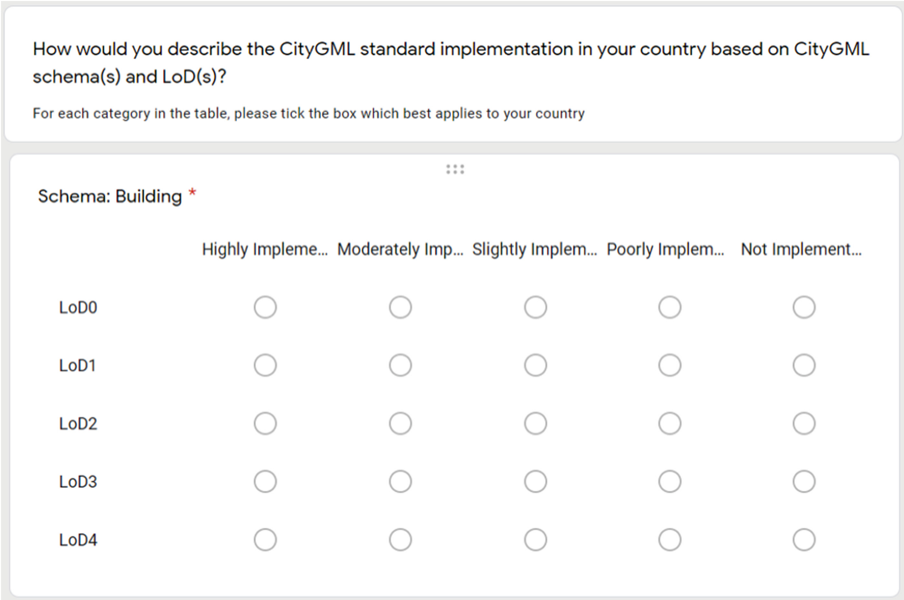
Furthermore, the structure of CityGML file format is developed based on a hierarchical structure, both for geometric and semantic information [27]. On the other hand, different geospatial solution providers have integrated their GIS products with CityGML extension for reading, writing and viewing in CityGML format [8]. What is more, CityGML has been supported with some solutions such as PostgreSQL-PostGIS, Oracle, 3D City Database (3D City DB) and Georocket for providing database structure, which is suitable for CityGML standard [8, 33]. Now, there are various spatial applications such as solar potential estimation, flood risk assessment and noise monitoring for CityGML standard [6, 20, 23, 34].

5 Methodology

The study has designed an e-questionnaire to figure out the state of the current CityGML standard and the degree of the implementation in terms of CityGML schema(s) and LoD(s). The e-questionnaire was designed based on using a matrix table question. The statistical analysis covered 9 CityGML schemas (relief, building, transportation, bridge, waterbody, city furniture, vegetation, tunnel, landuse) and related 45 LoD(s) at LoD (0–4). In order to record the responses for each LoD(s) at the level of each CityGML schema(s), the study has used a Likert scale with five responses (highly implemented, moderately implemented, slightly implemented, poorly implemented, not implemented) (see Fig. 1). The questionnaire was sent to 4 specialists in 4 selected countries such as Germany (Prof. Dr. Thomas H. Kolbe), the Netherlands (Prof. Dr. Jantien Stoterfor), Turkey (Prof. Dr. Ismail Buyuksalih) and Singapore that have a valuable background and rich history of practicing CityGML or implementing projects using CityGML standard. In the case of Singapore, as no response has been received from the competent authority, the paper analysed the study of Soon and Khoo (2017) [5] regarding CityGML modeling for Singapore 3D national mapping and converted it into numerical data that were included in the statistical analysis. The SPSS packages were applied to analyse the data and to calculate the mean (M) and the standard deviation (SD). Moreover, the study has used the interval (Mean Range) to arrange the mean (M) in descending order (from high to low values).

In order to investigate further the 3D spatial data structure issues and challenges based on using CityGML standard, the study has carried some experiments in a pilot area in Oman (Al Seeb). Besides, the study has collected the data from the related geospatial agencies in Oman (2D, 2.5D geospatial data). Geospatial tools and databases such as FME, PostgreSQL-PostGIS and 3DCityDB were used to generate a small-scale 3D city model for 3D surface spatial objects and to explore the spatial data structure challenges based on using CityGML standard (see Fig. 2).

The experiments investigated many issues and challenges related to 3D city model data structure, including the complexity of 3D spatial data structure, 3D spatial data structure standards, metadata, and others. Since CityGML version 2.0 does not fully support subsurface objects [8], the study generated its 3D objects such as pipeline networks and geological strata to study the integration challenges between the surface and subsurface spatial objects in the 3D city model data structure.



How would you describe the CityGML standard implementation in your country based on CityGML schema(s) and LoD(s)?

For each category in the table, please tick the box which best applies to your country

Schema: Building *

	Highly Impleme...	Moderately Imp...	Slightly Implem...	Poorly Implem...	Not Implement...
LoD0	○	○	○	○	○
LoD1	○	○	○	○	○
LoD2	○	○	○	○	○
LoD3	○	○	○	○	○
LoD4	○	○	○	○	○

Fig. 1. Recording the responses for each LoD(s) at the level of each CityGML schema(s) in e-questionnaire: building schema as an example

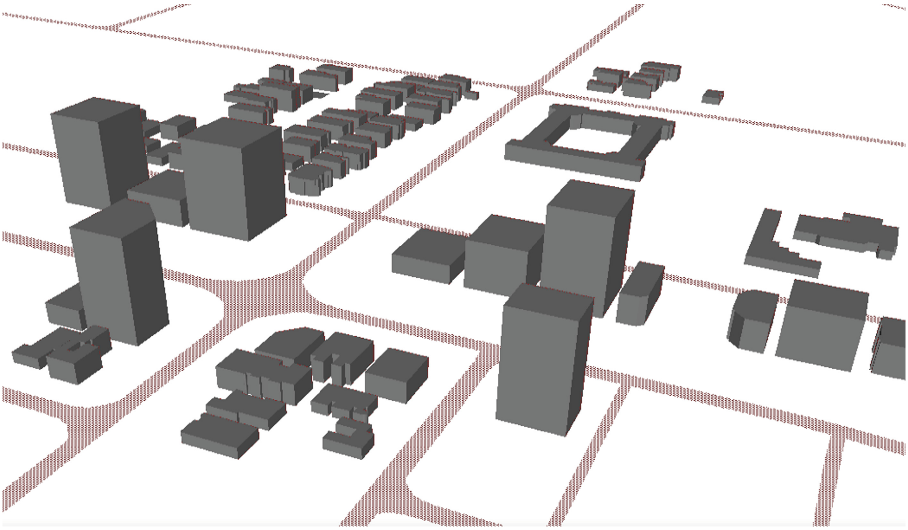


Fig. 2. Construction of a small-scale city model based on CityGML standard version 2.0

6 Discussion and Results

The implementation of CityGML version 2.0 in the countries surveyed provides a significant indication and better understanding of the current state-of-the-practice of CityGML version 2.0. The result of the e-questionnaire was designed to shows the overall mean of

Table 1. The degree of CityGML implementation in terms of the schema(s) and LoD(s) ranked from the highest LoD(s) mean to the lowest

Likert scale	Description	Mean Range
5	**Highly implemented**	**(4.21-5)**
4	**Moderately implemented**	**(3.41-4.20)**
3	**Slightly implemented**	**(2.61-3.40)**
2	**Poorly implemented**	**(1.81-2.60)**
1	**Not implemented**	**(1-1.80)**

Mean: ***(M)***
Standard Deviation: ***(SD)***
Ranking: (R)

(R)	**Schema(s)**	**LoD(s)**	**Total**	***(M)***	***(SD)***	**Interval**	**Percentage (%)**
1	Building	LoD1	4	4.75	0.500	**4.21-5**	6.7%
2	Building	LoD2	4	4.50	1.000		
3	Building	LoD0	4	4.25	1.500		
4	Relief	LoD0	4	2.75	0.500	**2.61-3.40**	11.1%
5	Transportation	LoD0	4	2.75	0.500		
6	Bridge	LoD1	4	2.75	0.957		
7	WaterBody	LoD1	4	2.75	0.957		
8	Vegetation	LoD1	4	2.75	0.957		
9	Building	LoD3	4	2.50	0.577	**1.81-2.60**	28.9%
10	Transportation	LoD1	4	2.50	0.577		
11	CityFurniture	LoD1	4	2.50	1.291		
12	Tunnel	LoD1	4	2.50	1.000		
13	Bridge	LoD0	4	2.25	0.500		
14	Tunnel	LoD2	4	2.25	1.500		
15	Landuse	LoD0	4	2.25	0.500		
16	Relief	LoD1	4	2.00	2.000		
17	Relief	LoD2	4	2.00	2.000		
18	Bridge	LoD2	4	2.00	1.414		
19	Tunnel	LoD0	4	2.00	0.000		
20	WaterBody	LoD0	4	2.00	0.816		
21	Landuse	LoD1	4	2.00	0.816		
22-45	The rest of schema(s)	The rest of LoD(s)	4			**1-1.80**	53.3%

each of the 5 LoD(s), in each of the 9 CityGML schema(s) based on the experts' point of view in the 4 selected countries.

Despite each country that was surveyed varied in the implementation of CityGML in some schema(s) and LoD(s), Table 1 shows that the overall implementation of the CityGML schema(s) and LoD(s) in these four countries mostly concentrated on building schema(s) between (LoD0) to (LoD2), which is classified as highly implementable with a percentage of 6.7% of all LoD(s) and related schema(s). Also, the result shows that the rest of the CityGML LoD(s) and related schemas are classified as slightly implemented (11.1%), poorly implemented (28.9%), and not implemented (53.3%), especially at LoD3 and LoD4. On the one hand, the reason that the CityGML models at LoD1 and LoD2 are more implemented is that they can be easily extruded by using objects' basic data (footprint) and the height value obtained from the table attribute or from the photogrammetry and the LiDAR process. On the other hand, challenges in creating 3D models at LoD3 and LoD4 are due to the need for rich data and complex processors, especially for national coverage.

On the other hand, the statistical analysis in the countries that were surveyed indicated the CityGML relief model and CityFurniture model implementation face challenges in real practice at national coverage. Thus, these two models need more investigation in terms of definition, data structure, and integration with other objects in the city model. The statistical analysis raises questions about the feasibility of defining real-world phenomena like vegetation in CityGML LoD 3 and 4 that are constantly growing, where results indicate that these models at LoD 3 and 4 are difficult to implement because of their ineffectiveness in the 3D city model.

The experiments are still ongoing, and the initial results have demonstrated that the CityGML standard and its data structure are still facing some issues in real practice. Most of these challenges are related to the complexity of 3D spatial data structure, 3D spatial data structure standards, metadata for 3D spatial data structure, 3D spatial data structures exchange, quality of 3D spatial data structure design, geometric representation, indexing 3D spatial data structure, arranging the 3D spatial data structure based on class(s), schema(s), and LoD(s), compatibility with database features, homogeneity of 3D spatial data structure, support RDBMS, handling 3D geospatial queries, a spatial reference system (SRS), support 3D spatial data structure operations, capability(s) of using the 3D spatial data structure in advanced database applications, use of the 3D spatial data structure in large-scale and 3D spatial data structure archiving. Besides, topology issues can play a role in the difficulty(s) of handling 3D queries and executing the advanced geospatial analysis.

The final remarks of the experiments and statistical analysis show that CityGML standard version 2.0 can be employed to create an Omani 3D city model for some applications at LoD0, LoD1 and LoD2. Some examples of these applications are to support smart city activities, 3D flood risk assessment (see Fig. 3), 3D registration of multi-level property rights (see Fig. 4), managing contingency plans (see Fig. 5), and integration between the surface and subsurface of 3D city objects (see Fig. 6). Nevertheless, there are still some issues and challenges in the CityGML standard that need to be tackled, as mentioned above. Also, Omani SDI needs to develop its own solutions to use the CityGML environment.

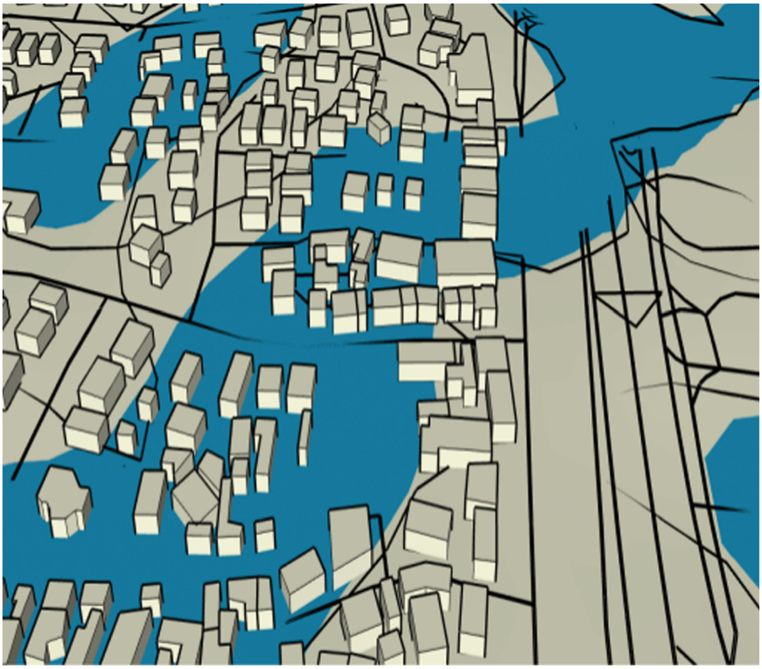


Fig. 3. Flood risk assessment in 3D (Al Seeb)

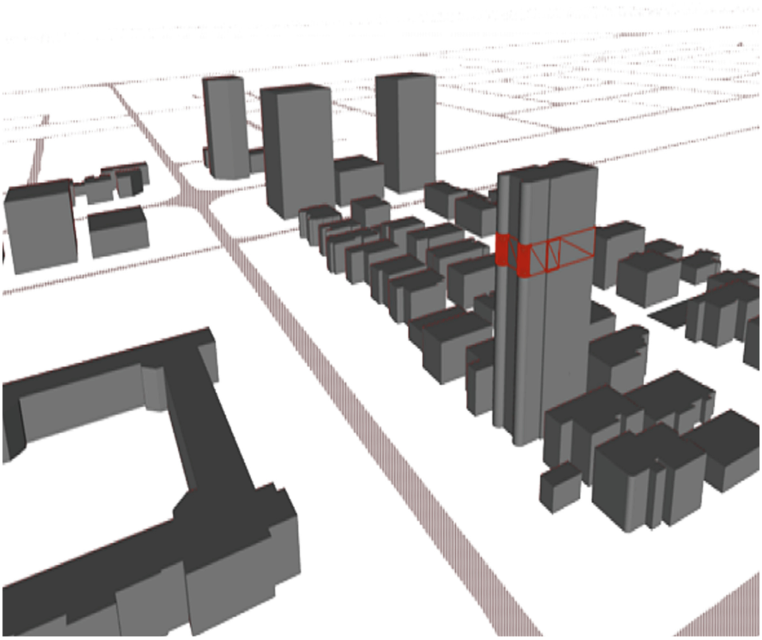


Fig. 4. Registration of multi-level property rights in 3D (Al Seeb)

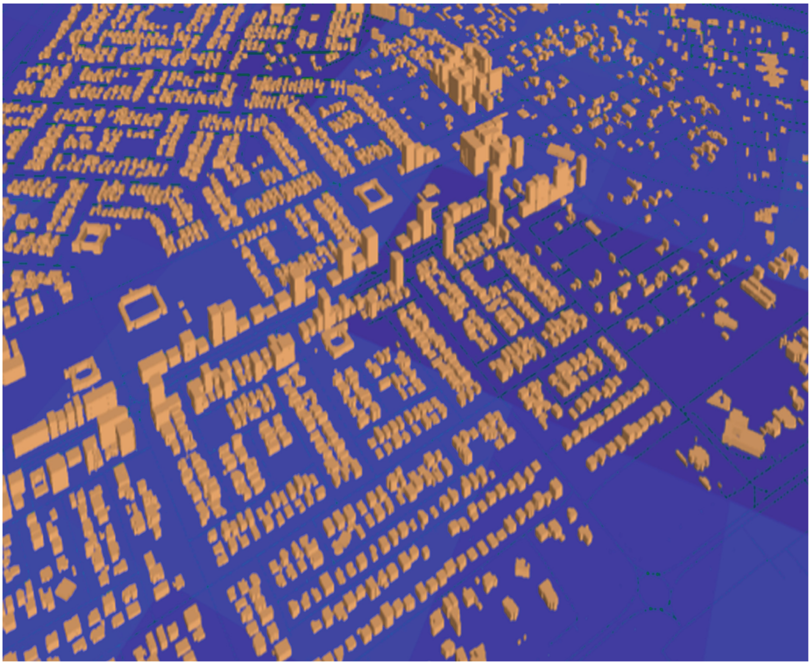


Fig. 5. Managing contingency plans (Al Seeb)

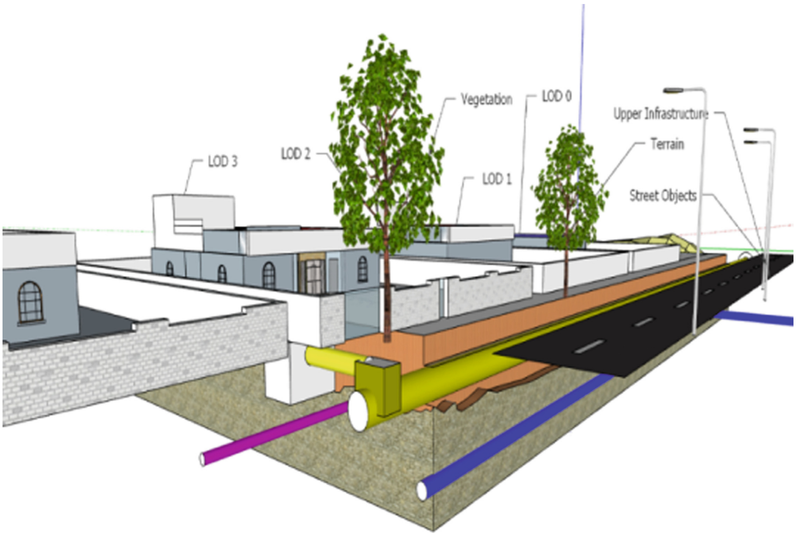


Fig. 6. Integration between the surface and subsurface 3D city object (Al Seeb)

7 Conclusion

This paper has investigated several issues related to establishing a 3D city model based on CityGML version 2.0 for Oman. The previous work shows that the current standard (version 2.0) of CityGML is still in progress and there are issues and challenges that need to be addressed. Also, this paper indicates that 3D city models inevitably are needed in a country like Oman for the next generation of geospatial and city planning and other applications. This particular piece of research work will greatly enhance the level of GIS awareness, especially in the 3D city model for Oman. Furthermore, it will help to establish a framework for the 3D SDI, which adopts 3D geospatial data issues, challenges and needs of the Oman geospatial community. In the future, based on the outcomes, we would like to investigate the appropriateness of using CityJSON solutions for developing the upcoming 3D city model and 3D SDI in Oman.

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