Conceptual Framework Towards Unified 3D Topological Modelling and Visualization Based on CityGML

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Key words: 2D and 3D spatial data, topological data structure, CityGML and multiple LoDs.

SUMMARY

Different applications or users need different model (level of details; geometry and information) especially in computer application such GIS modelling. Representing single 3D objects (e.g. buildings) with multiple representations produce data redundancy and visualization limitations (e.g. only one LoD per viewer). Designing a unified data model requires reliable data interoperability (module) for sharing 2D or 3D data across multiple scale models, applications and users (e.g. CityGML). This paper discusses a conceptual view of a new simplified topological structure where the connection of multiple LoDs (geometry, attribute and semantic) could be possible to embed into a single viewer. We truly believed that an integrated or unified model should be made available for sharing information and make use of each LoDs or future spatial applications. Inevitably, this piece of research work could trigger better 3D geoinformation software and new data schema/standard development (e.g. new version of CityGML) for sharing purposes.

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1. INTRODUCTION

Traditionally, 2D and 2.5D objects are stored and structured separately in different databases and viewers. This situation creates some drawbacks especially in finding and getting information of the objects such as lack of relationships and limited queries. Thus, it produces limited information from the designed or developed applications. There are several existing tools or solutions for the 2D situations as reported in the literature based on multipoint and polyline approaches (ESRI, 2017; Kennedy, 2013). However, currently, there are hardly available literature or reports to address more advanced 3D situations.

For 3D cases, most of the available applications need to have different abstractions of the real world or in other words they were perceived with different needs, requirements, views and applications. Each application requires its own set of level of details (LoDs) to be embedded into the model. Most of these models focus on the accuracy elements of geometry, attribute and some in semantic information; however, less focuses on topological element (and mostly for navigation purposes). These applications or user oriented customized models resulting difficulties for sharing with other stakeholders. Due to this situation, Open Geospatial Consortium (OGC) introduced CityGML v1.0 in 2008 and v2.0 in 2011 as a standardised data model and exchanged format for 3D models of city and landscape features (Kolbe, 2015; Biljecky, 2017a).

CityGML solves only some of those sharing problems. There are many focus elements need to be addressed and standardized as more users begin to realize the importance of spatial data and wider applications domain. Thus, OGC is now working towards establishing a new version of CityGML (version 3.0) with sixteen (16) LoDs as compared to only five (5) in the previous versions (Biljecky, 2017b). However, representing the same 3D object (e.g. a building) with multiple representations as proposed by Löwner et. al (2016) may produce some major drawbacks; redundancy of other less focused element (e.g. attribute and semantic) and visualization (accessing only one model or LoD in a single viewer).

We strongly believe that a unified (seamless 2D and 3D) geometry and topological data structure could integrate information on multiple LoDs (CityGML) into a single viewer. Based on the above situations, the proposed data structure (in Section 5) could be utilized for future applications (3D mapping and analysis) including underground utility, 3D building management, 3D cadastre, and other 3D applications for urban city planning.

Section 2 describes the current 3D modelling approach and application, Section 3 discusses on research motivation, Section 4 and 5 describe on current work and proposed framework solution. Finally, the conclusion of the paper in Section 6.

2. 3D MODELLING AND CURRENT APPLICATION

2.1 Type and Category of Spatial Modelling

There are two types of spatial models: geometrical and topological. Geometrical models are easier to develop than topological models (Zlatanova et al., 2004; and Jamali et al., 2016) (see Figure 1). 3D topological models with explicit representation of objects, object-oriented models, and 3D structures with explicit representations of relationships were discussed by Zlatanova et al. (2004), including topological relationship as in Figure 2.

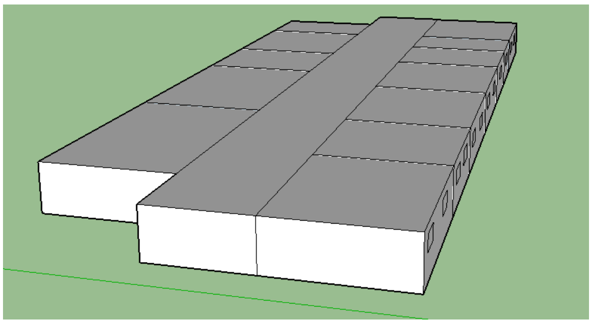


Figure 1: A 3D geometrical building model

Urban Data Model (UDM) is based on full partition of space and represents the geometry of a surface by planar convex faces (Coors, 2003). In object-oriented models, Formal Data Structure (FDS), Tetrahedron Network (TEN), Structural Semantic Model (SSM) and UDM are stored in a Relational Data Base Management System (RDBMS). There are several researches based on 3D structures with explicit representations of relationships; e.g. Brisson (1990) and Pigot (1995).

There are many different 2D/3D spatial data models used in 3D building modelling including constructive solid geometry (CSG), boundary representation (B-Rep), regular decomposition, irregular decomposition and non-manifold structures (Ledoux and Gold, 2007). B-Rep represents a solid such as polyhedron as a union of faces defined by their boundaries: edges and vertices. B-Rep models are widely used in CAD systems capable to be adapted in GIS (de Cambray, 1993).

Half-edge (Mäntylä, 1988), winged-edge (Baumgart, 1975) and quad-edge (Guibas and Stolfi, 1985) are examples of B-REP representation. These data structures can be used for a single 2-manifold solid representation but cannot be used for complex models where, for example, two or more adjacent solids have linked into one complex (see Figure 3).

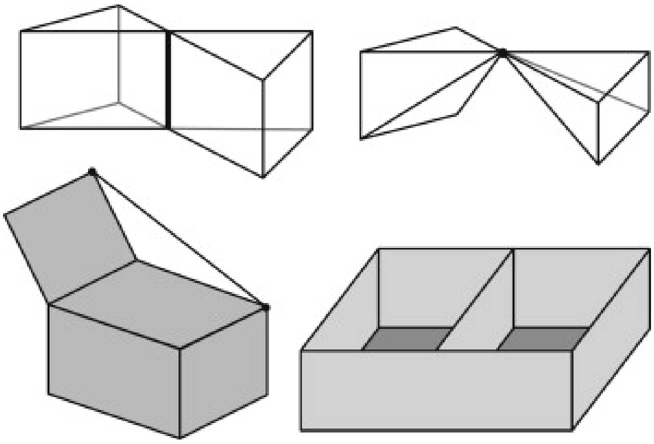


Figure 3: Examples of non-manifold models (Lee, 2001)

A cell complex is an irregular decomposition of space or an object into non-overlapping cells of any shape. G-maps (Lienhardt, 1991) and facet-edges (Dobkin and Laszlo, 1987) are examples of data structures which can be used for the construction of irregular decomposition models such as constructing a 3D Delaunay tetrahedralization – an initial step for topological graph/relationship for 3D topological model.

3D topological models with explicit representation of objects include Formal Data Structure (FDS), Tetrahedral Network (TEN), Simplified Spatial Model (SSM) and Urban Data Model (UDM). FDS is based on a single-valued map (Molenaar, 1998) which partitions a space into non-overlapping objects. TEN was used by Pilouk (1996) to solve some issues encountered by FDS. SSM focused on the visualization of spatial queries (Zlatanova, 2000). The SSM model does not require the partitioning of space and all objects are embedded in 3D.

Boguslawski et al. (2011) developed a data structure called Dual Half-Edge (DHE) which was based on the Poincaré Duality (Spivak, 1967), Figure 2. This structure resolves some of the modelling issues in 3D GIS and expresses the geometric structures as a cell complex, in preserving adjacency relationships between cells, and including semantic information using attributes.

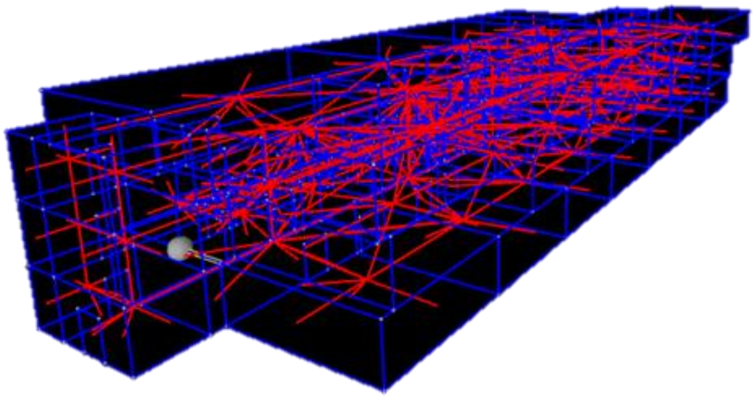


Figure 2: A 3D topological building model in DHE data structure; red and blue indicate the topology and geometry of the 3D model respectively in DHE structure (Jamali et al., 2016)

2.2 Level of Details (LoDs) of the Model

Different applications/users need different abstractions of the real world phenomenon (Karim and et al., 2016); or in other words, different models of 3D object. Each application requires its own set level of details (LoD) to be embedded into the model. Most of the models focus on the geometry accuracy, attribute and some semantic information (visualization and measurement purposes). However, less emphasis were given on topological aspect such as for navigation purposes, even CityGML model.

This application/user oriented customized models resulting difficulties in sharing the model to other stakeholders or receiving from others. Realizing these problems, Open Geospatial Consortium (OGC) has introduced CityGML v1.0.0 in 2008 and v2.0.0 in 2011 as described in the previous section. CityGML is an international standard for the representation and exchange of semantic 3D city and landscape models, which not only represents the shape and graphical appearance of city models but specifically addresses the object semantics and the representation of the thematic properties, taxonomies and aggregations (Groger and Plumer, 2011).

CityGML is an open data model using XML-based format for the storage and exchange of virtual city models and a common information model for the representation of 3D urban objects. However, more and more applications trigger for the needs of conceptual meanings beyond geometry since the pure appearance representation mainly focus on the photorealistic visualization while ignoring a full comprehension of the data. Applications like urban planning and facility supervision, disaster management and personal navigation require additional information, i.e. classification and relationship of components about the city objects given in a standardized representation (Kwan and Lee, 2005). Therefore, 3D city models should incorporate the geometry and the semantics.

Existing datasets are often produced by photogrammetric approach or CAD tools but lack of semantics. An efficient way should be proposed to complement the thematic meanings of the geometry and at the same time, fundamental issues such as geometry consistency, semantics and topology were comprehensively studied (Kolbe et al., 2008; Kwan and Lee, 2005). Thus, the basis of CityGML and semantic modeling. Recently, several extensions of CityGML are also proposed, such as the integration of both above and underground features as well as temporal semantics of objects properties (Emgard and Zlatanova, 2008).

CityGML supports different Levels-of-Detail (LoD), which may occur from independent data collection processes and are used for well-organized visualization and efficient data analysis. In one CityGML data set, the same object may be presented in different LoD simultaneously, enabling the analysis and visualization of the same object with regards to various degrees of resolution/details. CityGML provides five different LoDs, as illustrated in Figure 4.

LoD0 is essentially a two and a half dimensional Digital Terrain Model, over which an aerial image or a map may be draped. LoD1 is the well-known blocks model, without any roof structures or textures. Comparing LoD1 with LoD2, the latter has differentiated roof structures and textures and vegetation objects may also be represented. LoD3 denotes architectural models with detailed wall and roof structures, balconies, bays and projections. High-resolution textures can be mapped onto these structures. In addition, detailed vegetation and transportation objects are components of a LoD3 model. LoD4 completes a LoD3 model by adding interior structures like rooms, interior doors, stairs, and furniture.

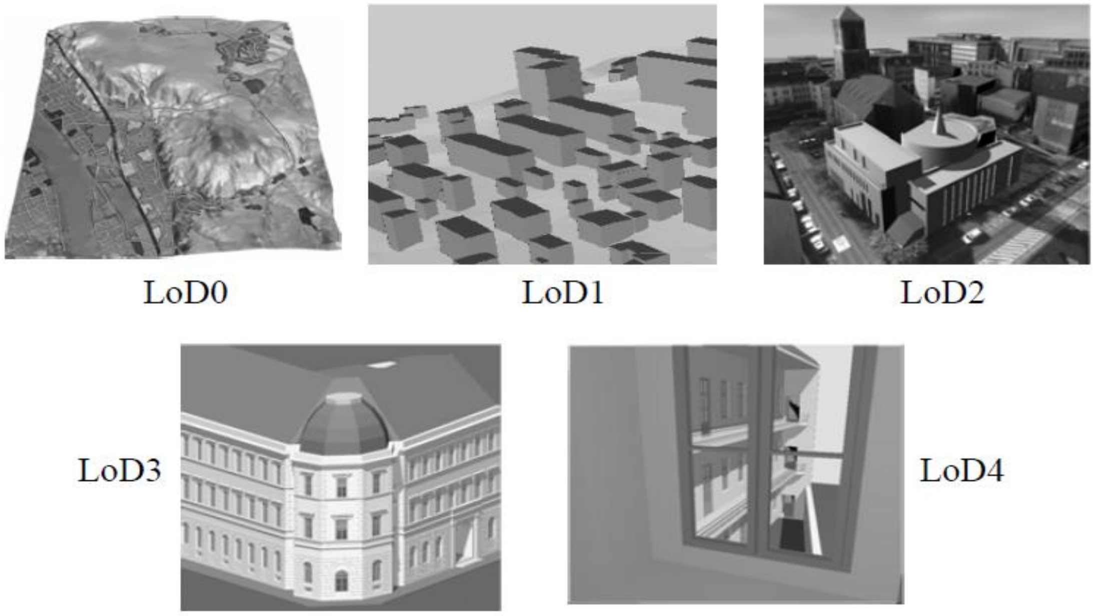


Figure 4. The five level of details (LoD) defined by CityGML (Kolbe et al., 2010)

CityGML is indeed solving some problems, but not entirely. There are many left-over focus elements need to be covered and standardized as more people started to realize the importance of spatial data and applications side is getting expended (more new applications). Currently, OGC is working towards establishing a new version of CityGML, version 3.0 as proposed by Biljecki et. al. (2016) and Löwner et. al. (2016). This new version attempts to include sixteen (16) LoDs as compared to only five (5) in the previous versions.

Representing the same 3D object (e.g. a building) with multiple representations produce some major drawbacks; redundancy of other less focused element (e.g. attribute and semantic, if focuses on geometry) and visualization (accessing only one model/LoD in a single viewer).

3. THE MOTIVATION

3.1 Existing 2D and 3D Data Model

There are many works on 2D and 3D data structures and the related data models. Most of them focus towards a specific application, only involve with a level of detail, and for specific user. As for example, Dual Half Edge (DHE) data structure specifically designed for indoor navigation application while utilizing internal and external topology (see Figure 4).

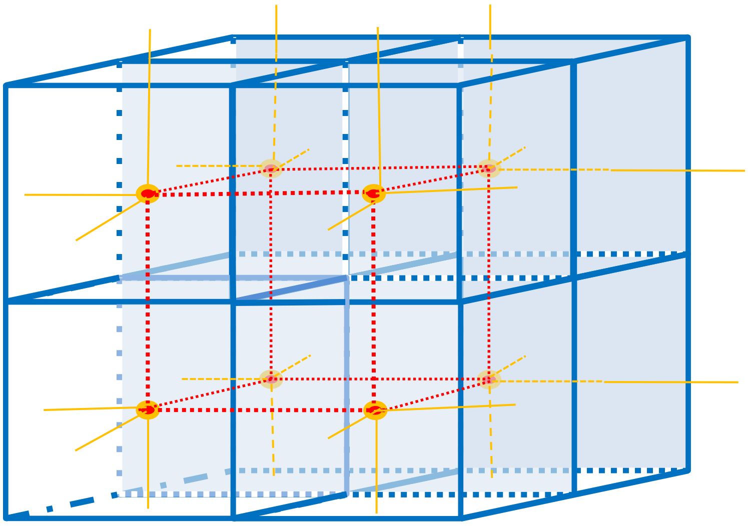


Figure 4: Primal and the dual spaces in a complex cell such as a building

3.2 Navigation Network Modelling

A 3D topological model is necessary in network analysis. Network analysis is one of the most significant aspects of GIS (Curtin, 2007). Network analysis is used in disciplines such as medicine (Finnvold, 2006), psychology (Walker et al., 2006), urban planning (Toccolini et al., 2006), and computer science (Bera and Claramunt, 2005). There are two data structures in network analysis: non-topological and topological networks. A non-topological structure (i.e. the "spaghetti" data model) does not contain any topological information related to edges.

Non-topological network models are simple to understand and they are sufficient for digital cartographic maps. The spaghetti data model is widely used in Computer Aided Design (CAD) community due to its simplicity. Duplication of storage for same vertices is one of the disadvantages of the spaghetti data model. Non-topological network models are useless for network analysis. One of the major issues with topological network data structures is the definition of bridges or tunnels (Cooke, 1998).

The Geometric Network Model (GNM) has been widely accepted as a suitable navigable network. A GNM is a graph consisting of nodes and edges in which nodes represent the position or location of an object such as a room while edges represent connection between nodes.

3.3 Existing Data Model Limitations and Challenges

Different focus aspects or applications or users oriented customized models resulting difficulties in sharing the model within stakeholders. The current version of CityGML (v2.0) and next version (v3.0) are indeed useful for sharing the model and information to others with the same LoD. However, representing 3D objects (e.g. buildings) with multiple representations (LoDs) inevitably produce significant drawbacks - data redundancy, expensive storage and visualization limitations (e.g. only one LoD per viewer) and disabling query from other LoD of the same object. Available GIS software solution either open source, commercial or customized applications normally use single viewer to view each LoD. A new viewer (display) needs to be on if user wants to compare the model or to know the information (attribute) stored in other LoD.

Current research works indicate that there is a need for a unified data model capable of supporting all aspects of geometry, attribute, semantic and topology. Designing a unified data model requires reliable data interoperability (module) for sharing 2D or 3D data across multiple scale models, applications and users (e.g. CityGML).

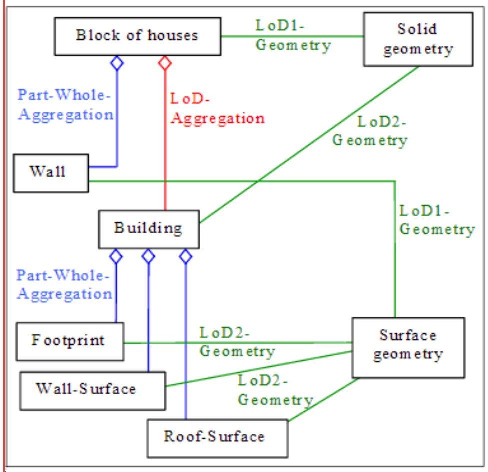
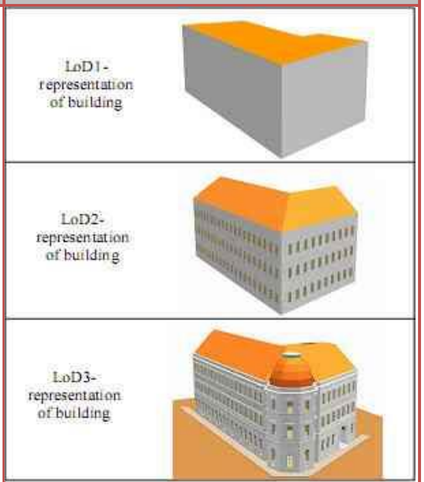
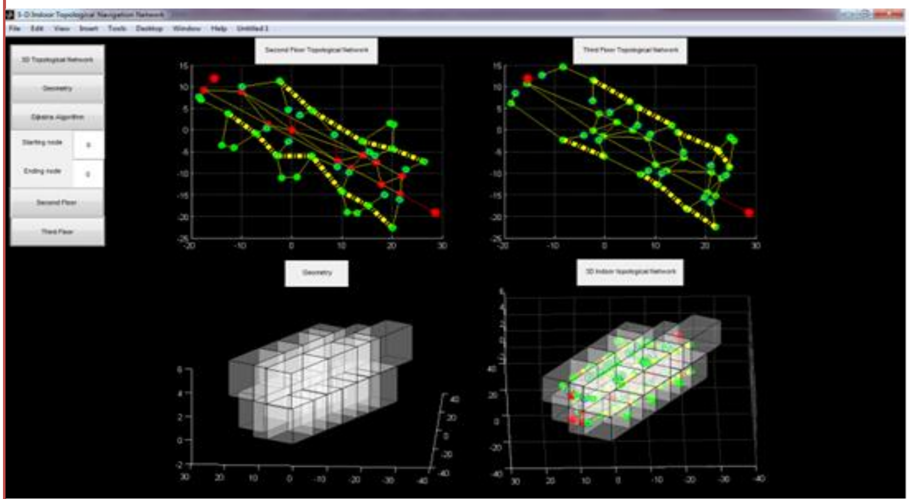
Thus, in this paper, a simplified topological model framework will be proposed to integrate information on multiple LoDs (CityGML) into a single viewer/selected model where topological concepts and database design form part of discussions.

4. INITIAL DEVELOPMENT

4.1 Related Works on Unifying Model

There are several works in this domain where Kolbe and Groger (2004) and Jamali at. el. (2017) attempted as illustrated in Table 1.

Table 1: Previous research works towards unifying geometry, semantic and topological graph across LoDs

Researcher / Project Description		System Architecture	Model
1	Towards Unified 3D City Models. (Kolbe T. H., Groger G, 2004 and 2009) A strategy for the smooth integration of subsurface structures is proposed as the outcome of the research.		
2	Data Structure and Navigational network. Jamali et al. (2017). Based on rapid indoor navigational network using DHE data structure, a proposed simplified structure was developed which create navigable network in topology element.		

Simplified data model developed by Jamali et al. (2017) includes geometrical, semantic and topological model. Topological model is a graph which is used for spatial queries such as shortest path finding between geometrical elements (e.g. rooms) (see Figure 5). Indoor building elements are represented by geometrical model which are topologically connected in topological space and properties of each building element is stored as semantic information.

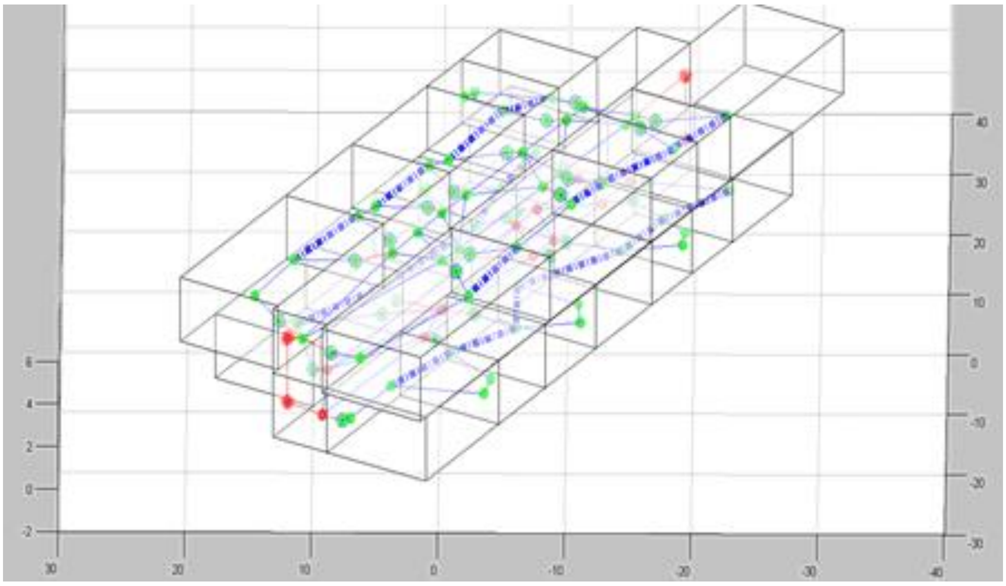


Figure 5: Simplified data model developed by Jamali et al. (2017)

4.2 Potential Implementation

4.2.1 Underground utility mapping

This is an ongoing work where visualization of 3D buildings and data modelling (orthophoto-terrain surface and underground utility - pipes or cables) are in progress as shown in Figure 6, 7 and 8 respectively. The visualization uses 3D Unity game engine to provide fast navigation and 3D rendering as discussed in Buyuksalih et. al. (2017).

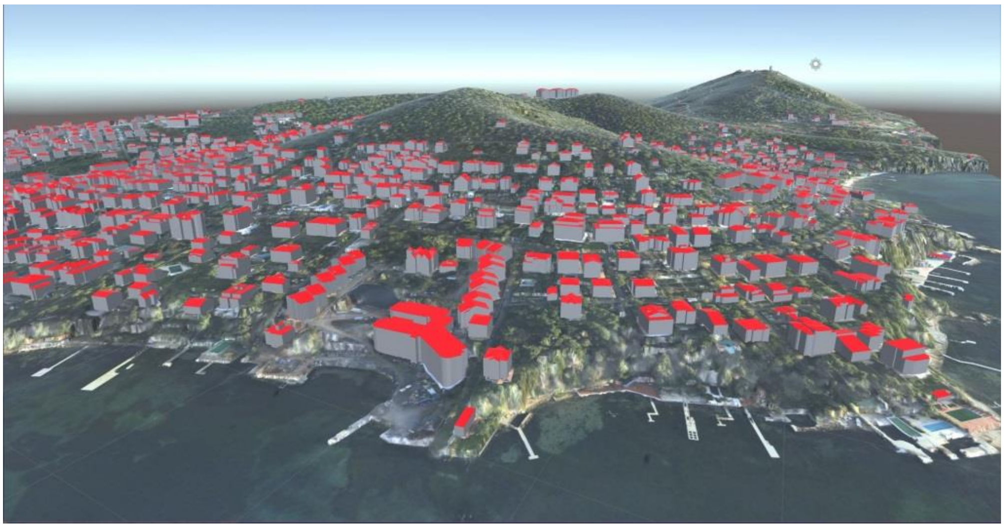


Figure 6. 3D visualization of the buildings (bird-eye view)

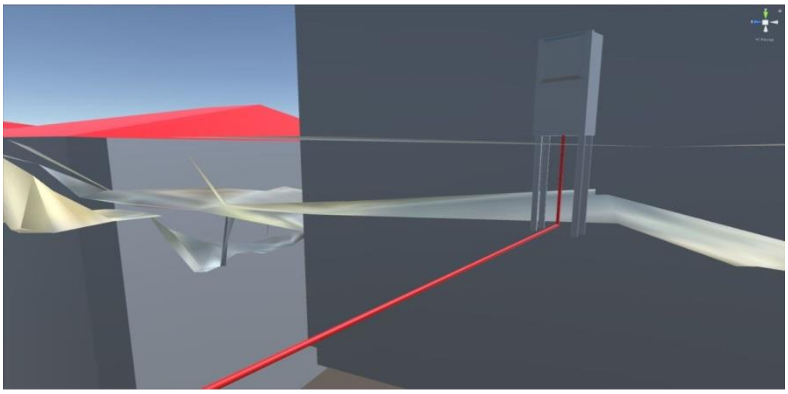


Figure 7. 3D visualization of underground utility (gas).

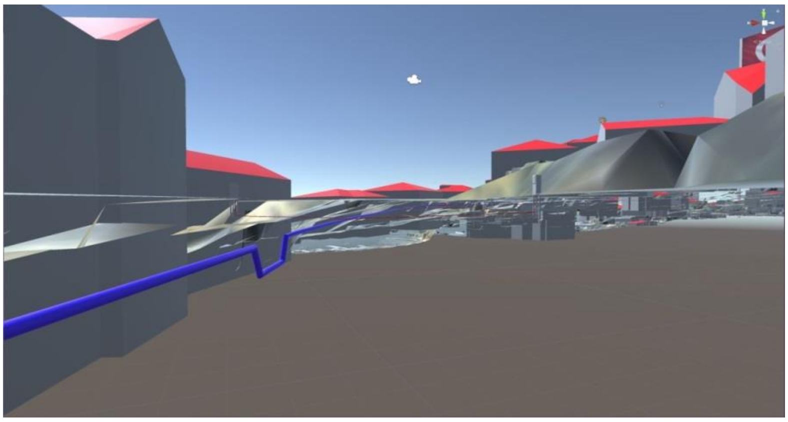


Figure 8. 3D visualization of underground utility (gas)

4.2.2 Estimating Solar Panel

The outcomes of estimation of potential solar energy received for the whole area - daily, weekly, monthly and yearly basis (Figure 9, 10 and 11), thus providing and assisting decision for solar panel installation. Estimated energy will be calculated for rooftops or façades of the selected building.

Figure 9. Selection of a building to be calculated

Figure 10. Solar estimation for the selected building rooftop

Figure 11. Solar estimation for the selected building rooftop and façade (potential solar panel)

5. THE PROPOSED FRAMEWORK

The proposed framework on unifying topological, semantic and geometry of the object covers the following aspects:

- 2D and 3D model integration.
- Multiple LoDs (e.g. CityGML standard – LoD0 to LoD4).
- Topology that connects with geometry and semantic information.
- Navigation procedure either via geometry, topology or attribute query.
- Non-generalization technique.
- Database connection (faster query).
- Single viewer (either LoD1, 2 or 3).

A general concept of multi-level retrieval of attributes and semantics from other LoDs as illustrated in Figure 12.

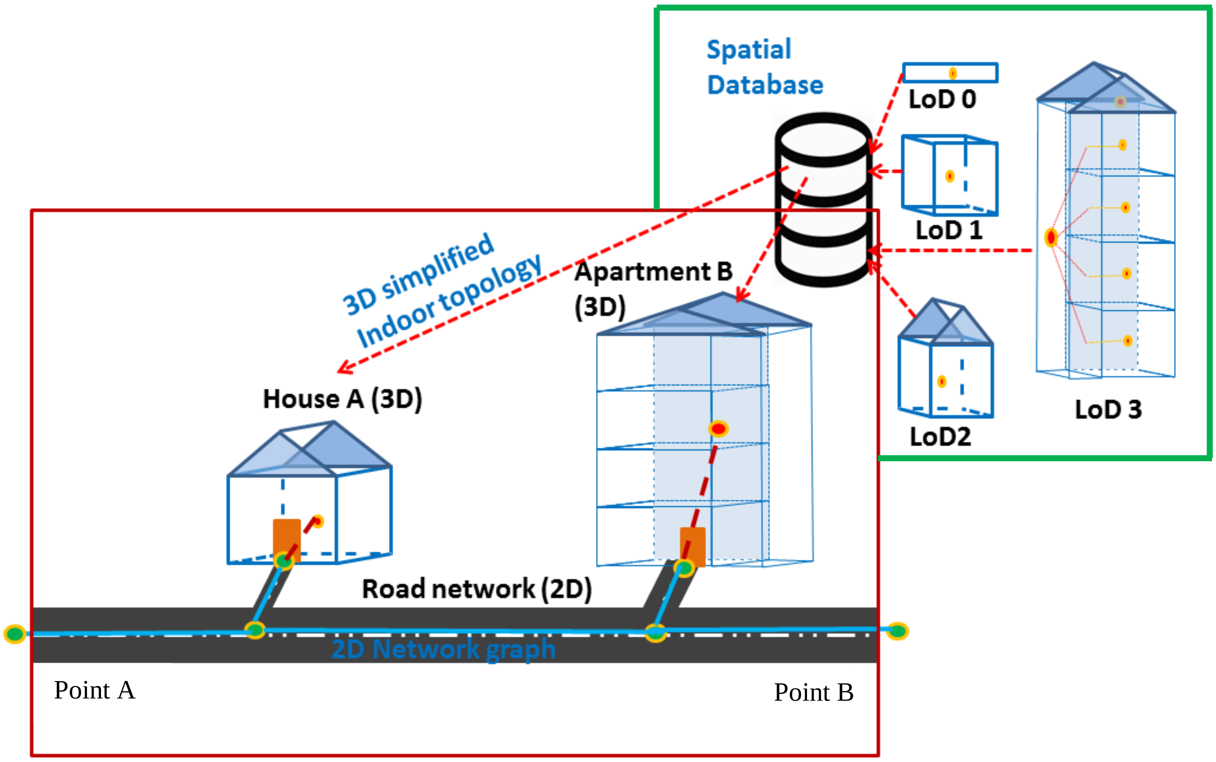


Figure 12: Example of GUI (2D + 3D) with primal and dual spaces.

Figure 12. General framework on unifying topological structure with geometry and semantic information across multiple LoDs

The proposed concept (Figure 12) is derived based on the Poincare duality rule (Figure 13) where connections between topology and geometry of objects' edges and nodes are established for data structures (Boguslawski and Gold, 2015; Boguslawski et al. 2011; Jamali, 2017). However, it could be re-modified and simplified for the implementation such as 3D modelling for strata and stratum (underground) as illustrated in Figure 14. 2D and 3D objects of above ground and underground are linked via a combined 2D and 3D topological data structure i.e. unified topological graph.

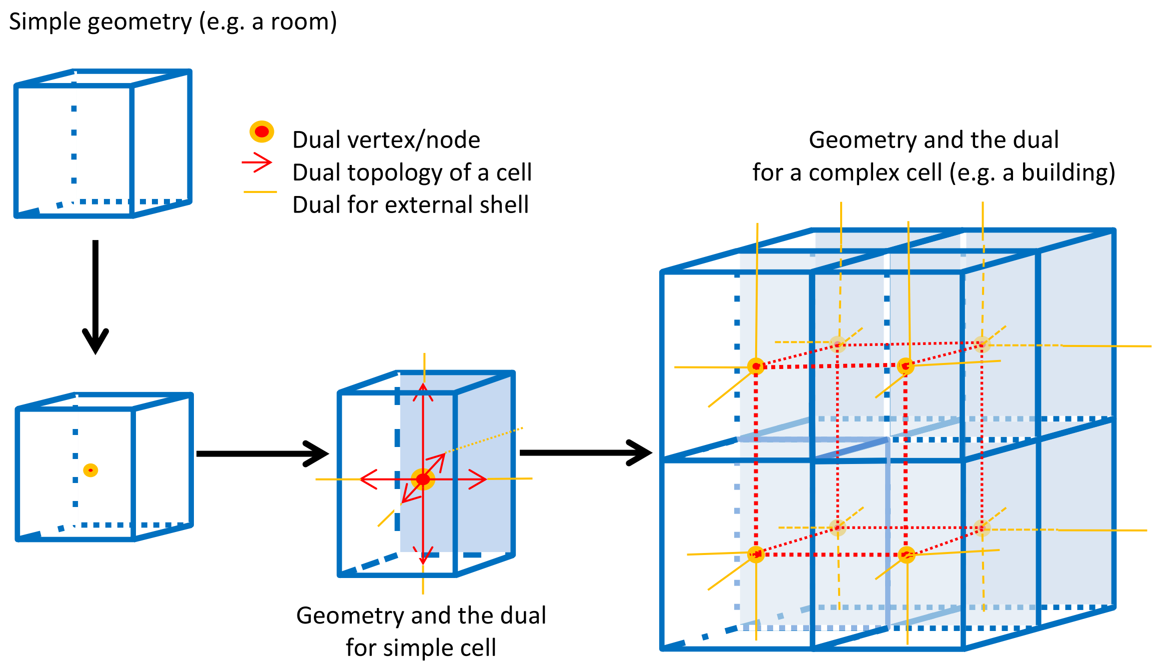


Figure 13: Poincare duality rule in DHE data structure

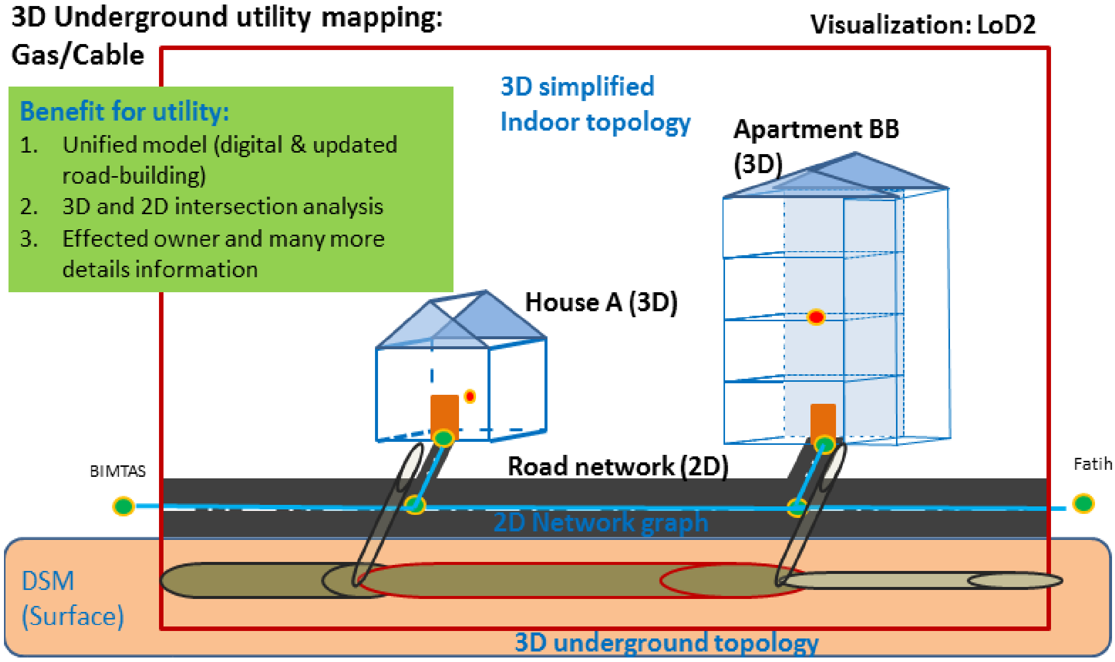
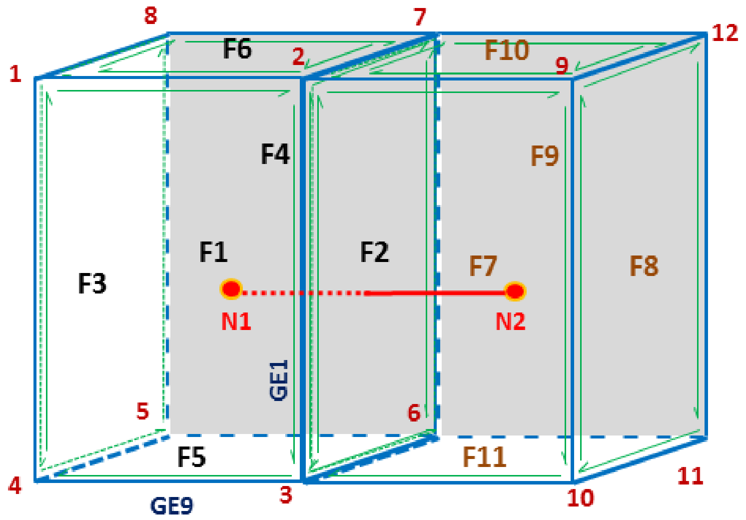


Figure 14. Illustration of underground utility by using the unified topological graph

5.1 Table Structure

According to the proposed general concept (Figure 12), an efficient flow of storing the data (topology and semantic) within a spatial database should be created. The table structure for navigation graph (geometry and topology) between 2D and 3D objects (neighbours) could be implemented as in Figure 15 and Figure 16.



Face	FaceOrder	Structure	Accessibility
F1	1,2,3,4	Wall	Yes, door
F2	3,2,7,6	Wall	Yes, door
F3	1,8,5,4	Wall	No
F4	5,6,7,8	Wall	No
F5	3,6,5,4	Floor	No
F6	2,1,8,7	Roof	No
F7	2,9,10,3	Wall	Yes, door
F8	10		
F9	7,6		
F10	2,7		
F11	10		

Edge	NodeA	NodeB	Face
GE1	2	3	F1
GE1	3	2	F1
GE3	2	3	F2
GE4	3	3	F2
...	1...	...	

Figure 15. Simple illustration of graph and dual node

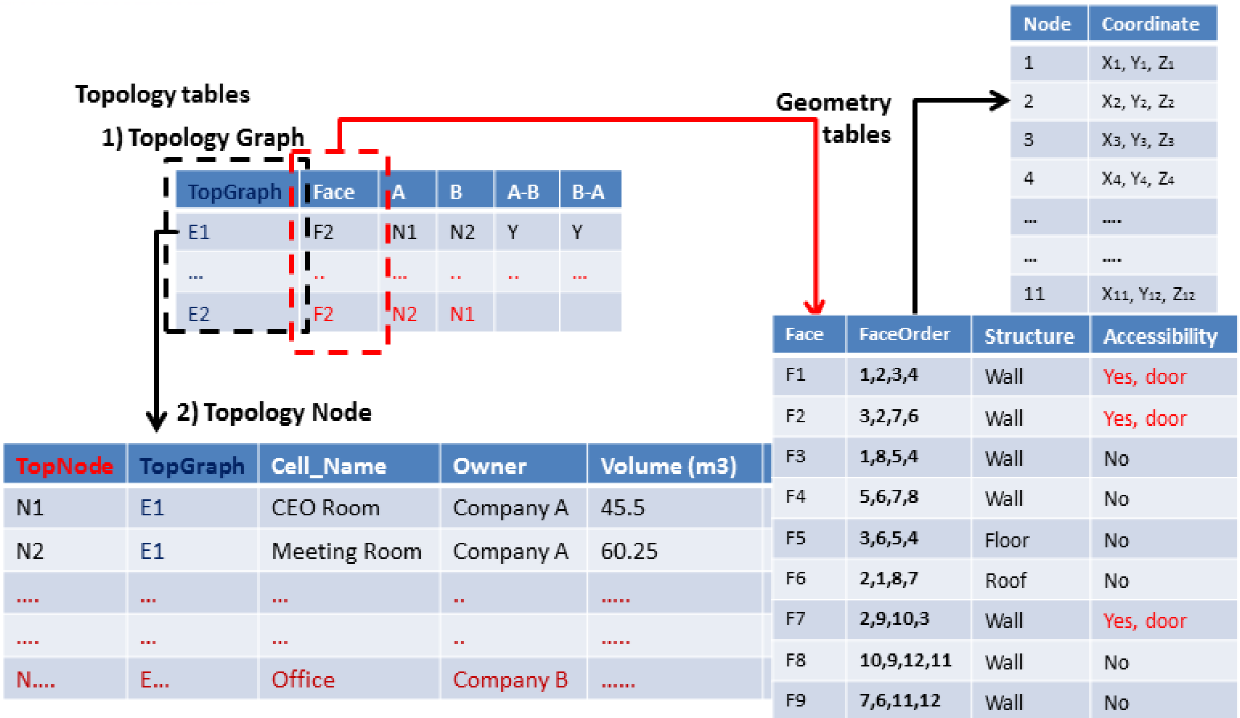


Figure 16. Relationship between geometry, graph (topology) and attribute table

The topological graph table as in Figure 15 will be simplified into a single dual-node as for representing unique ID/spatial for the object (2D or 3D as a block) at any LoD. All LoDs (of the same object) will be stored in a 3D spatial database (e.g. 3D Oracle Spatial) to be visualized in a single selected LoD as illustrated in Figure 17.

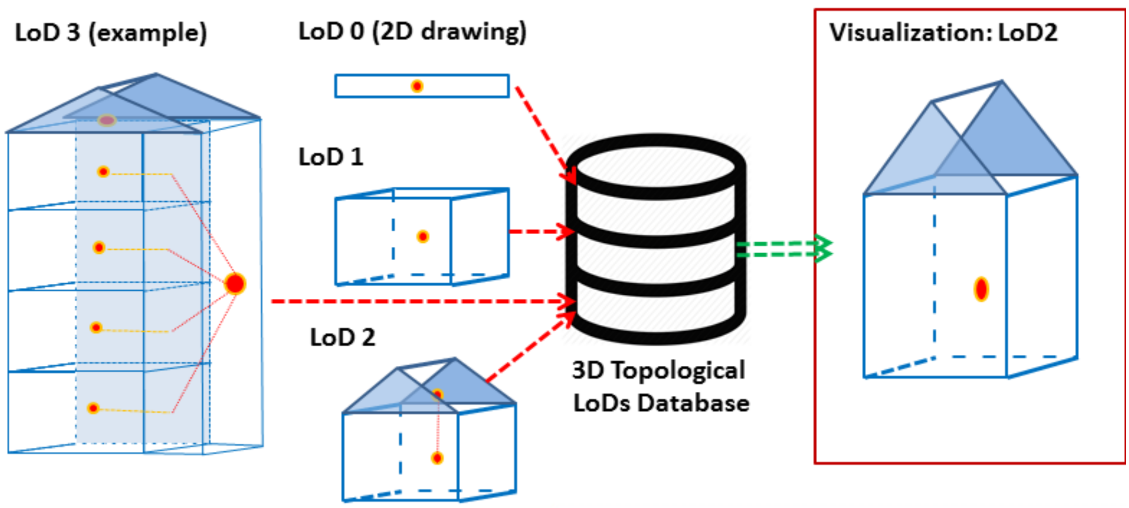


Figure 17: Simple illustration of overall topological graph

Any queries related toward information from other LoDs attributes will activate the spatial ID of a particular LoD and get access to the topological/geometrical graph in the same level. Information/attribute stored in topological or geometrical nodes, edges, faces or 3D cells can be accessed via the table connector in Figure 15 and 16.

6. CONCLUSION

In this paper, we presented a brief literature on 3D modelling, level of details of each model and describe some limitations of the current multi-representation model especially on visualization and attribute retrieval from other different LoDs. We proposed a conceptual framework towards unified 3D topological modelling and visualization information retrieval and current-future analysis and applications. The proposed concept able to access semantic, attribute and geometry information via topological graph across LoDs. This method provides less storage consumption, graphic and time for rendering the model. It offers a flexible and simple to integrate with other 2D and 3D data structures. The model also capable of integrating multiple LoDs (geometry) for semantic and information extraction. For future work, the relevant application and implementation of the framework could be developed for relevant applications such as 3D cadastre and underground utility system.

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