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Topological information extraction from buildings in CityGML

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Abstract. The demand for 3D city modelling for various applications continue to grow with the capabilities of 3D city modelling. One of the uses of 3D city models is to facilitate 3D analysis which usually requires information regarding the topology of the objects within the city model. CityGML as the international standard for 3D city modelling maintains topological information with the use of a ‘topology-incidence’ where objects are referenced to each other with the condition that the objects share a common surface. This paper explains the extraction of topological information based on the data structure of the geometries in CityGML files and discusses the usability of the existing topology mechanism of CityGML. The topological information was extracted from the CityGML files using the hierarchical geometric structure of CityGML as a stand-in model to describe the topological properties of the object. The extracted information consisted of building surfaces which have been decomposed to 0D points with their respective identification and coordinates. Based on the extracted topological information and related literature, it was found that the topological information extracted from the geometric structure of CityGML was limited to the locality of the object in question and could not extend beyond the dimension of the primitive.

1. Introduction
In the past decade, the modelling of cities has continued to flourish moving from 2D drawings to complex 3D models and even venturing towards n-dimensions. The unique intricacies of a city represented by a 3D model can facilitate a better understanding of the city as a whole and also the various interrelations of the objects within it [1]. As an effort to further consolidate the usability and interoperability of 3D models in city modelling, an international standard and open data model was established by the Open Geospatial Consortium (OGC) known as City Geographic Markup Language or CityGML. The development of CityGML was targeted to be a shared definition of entities, attributes and relationships within a 3D city model [2,3]. The key elements that constitutes CityGML as the standard for 3D city modelling is as shown in Figure 1.

In order to provide a standard for a complete 3D city model, CityGML focuses on five main aspects as shown in Figure 1 which are 3D geometry, semantics, scale or level-of-detail (LoD), appearance and topology. The first aspect which is 3D geometry refers to the geometric properties of the features which is based on the Geographic Markup Language (GML) standard. The geometries are represented by classes for 0D to 3D geometric primitives which are provided by the GML geometry model (GML3) [2]. Next, the semantics aspect deals with the semantic information or attributes of the
features. The support for semantics in CityGML is provided in the form of class definitions, rules and descriptions which expresses the non-spatial aspects of the features according to themes such as transportation, water body, vegetation and others [2]. The third aspect allows multiresolution modelling which represents the scale as LoDs where the coarsest LoD is LoD0 and the finest LoD is LoD4. The fourth aspect which is appearance handles how CityGML displays the 3D city model in terms of textures which differentiates between surfaces or facades. The final aspect is topology which refers to the mechanism used within CityGML to store topological properties of the 3D city model.

As mentioned before, interactions between objects in a city or how they are connected to each other is significant in order to gain a comprehensive interpretation of the city. Topology can be defined as properties which define the relative relationships between objects within the space [5]. In terms of city modelling, the topological properties of a city can be expressed as the relationships between objects or buildings within the city. Similarly, if viewed at a smaller scale, the connectivity and interactions between different parts of the building can describe the basic function of the building [6,7]. Moreover, a comprehensive topology of the 3D objects is required in ensuring consistency and connectivity of objects including its individual elements [8]. Topological properties can also aid in outlining the topological structure of an object which is important in supporting exploratory analyses regarding related building elements [9,10]. However, without the support of 3D topology, the outcomes from analyses carried out will remain in 2D [11]. On top of that, analytical queries related to adjacency, intersection, connectivity, containment and disjointedness also requires information that includes topological properties [12]. These analyses also provide a foundation for more complex and application-specific uses such as indoor navigation, simulations, and others. In other words, the availability of topological properties will accommodate answers to questions such as which elements (especially if said elements are disjointed) belong to the same wall, how are objects connected, and accessibility between rooms or building interiors to the exterior.

This paper presents the extraction of topological information from test data in CityGML. In section 2, a brief explanation regarding the topological component of CityGML presented. The extraction of topological information and extraction results are put forward in section 3. This is followed by a discussion regarding the extracted topological information in section 4. Finally, the conclusion of this paper is presented in section 5.

2. Topological component of CityGML

Unlike the geometric component of CityGML, the topological model provided by Geography Markup Language Version 3 (GML3) and ISO19107 was not implemented in the topological component of CityGML [13]. The topological model by GML3 represents topology by breaking down the topological primitives of higher dimensions into primitives of one dimension less than the original primitive until it is ultimately broken down into the lowest dimension (0D) [2]. In addition, the topological model by GML3 also requires each primitive to have an individual object identification (ID) [2]. Therefore, the topological model provided by GML3 was too complex to be implemented within CityGML as it will complicate the data model and physical entities within the model [4,2]. Consequently, the topological component of CityGML remains as a simple topology-incidence where the common surface is represented once and referenced by another to avoid redundancies while
maintaining topological connections [13]. The topological component of CityGML is shown in Figure 2 where two explicitly stored geometries are known to be related using XML links or XLinks.

Also shown in Figure 2 is the semantic component of CityGML which defines the features according to different themes such as building, transportation, water body, vegetation and others. Semantics can be expressed as the conceptual meaning of features which exceeds the geometry of the features [15]. For instance, the semantics of a building can be expressed as walls, rooms, doors, windows and roof surfaces. CityGML defines the semantics of buildings by using surfaces that represent the conceptual interpretation of the features in reality using semantic classes [16]. This semantic definition not only defines the behaviour of the feature but also encompasses its parts [14]. For example, a building can have a window and door which are both openings in a wall but only doors can be used as entrances. This semantic information is crucial for various applications that require accessibility or navigational analysis.

The foundation of CityGML which is the geometric component is also shown in Figure 2. This defines how features are constructed based on the geometric model GML3 classes for geometric primitives from 0D to 3D [2]. The geometric primitives in CityGML consists of 0D point (node), 1D curve or linear ring (line), 2D surface (polygon), and 3D solid [16]. For instance, a number of 0D points forms a 1D curve, many 1D curves forms a 2D surface, and many 2D surfaces forms a 3D solid. These primitives make up the solids defined by the bounding surfaces ergo utilising the Boundary Representation (B-rep) structure in constructing the features [4,2]. Geometric primitives are then combined to create classes which are used to define a solid or building. Aggregate geometry is one of the geometric classes in CityGML which groups together geometric primitives in the same dimension and can be expressed as “Multi” without any topological restraints [16,2]. Another geometric class is composite geometries which is composed of geometries that are topologically connected and topologically equivalent [2]. An example of composite geometry is a room of four walls which can be grouped together as a “CompositeSurface”.

![Figure 2. Semantic, topological and geometric components of CityGML [13]](image)

As a solution to the complexities of maintaining topological information within CityGML, a straightforward and adaptable method based on GML was implemented in CityGML. The XLinks mechanism conforms to the XML format of CityGML where for example; shared surfaces of different objects can be related to each other by linking or referencing the surface to the common surface of another object [4,2,13]. The example in Figure 3 shows how topology is represented between two solids (s1 and s2) which share a common surface (su1) where su1 is only represented in s2 and is
referenced by s1. On the other hand, Figure 4 shows a separate example on how the XLinks mechanism is used to establish topology between two objects by referencing the common surface.

![Figure 3. Illustration of topology representation between two objects and their instances [4]](image)

![Figure 4. Example of establishing topology using XLinks mechanism [2]](image)

### 3. Extracting topological information

Hierarchically, the 3D building was represented by 2D surfaces which are wall surface, roof surface and ground surface. Each 2D surface was composed of a 1D linear line made up of several 0D nodes or points which contained the coordinates of the points. Due to the lack of topological capabilities of CityGML, the topological information was extracted from the geometrical structure of buildings. In this study, a computer application was developed to extract the geometries from two different CityGML files. The extraction of topological information was based on the hierarchical structure of the geometries from the test data CityGML files. In the absence of a topological data structure, the data structure which specifies the construction of geometries can be a stand-in model to describe the topological properties of an object [6]. The information extracted from the geometries consisted of wall surfaces, roof surfaces and ground surfaces with their respective identification and coordinates.

The CityGML files of the test data were viewed using the FZK Viewer (Karlsruhe Institute of Technology) where Figure 5 depicts a building with two building parts while Figure 6 displays two disjointed buildings.

![Figure 5. 3D model of a building with two building parts](image)

![Figure 6. 3D model of two disjointed buildings](image)
Figure 7 shows the application where a CityGML file was entered as input for the application and a text file containing all the surfaces and lower dimension geometries with coordinates was exported as the output.

The topological information extracted for both test data are shown in Figure 8 and Figure 9.
Figure 9. Results for two disjointed buildings.

4. Discussion

Based on the results, the information extracted from the geometries consists of points or nodes (with coordinates), linear rings or lines, polygons as surfaces and whole buildings as volumes. This is consistent with the fundamental Simplexes and Complexes topology where 0D node equals to a 0D topology simplex, linear rings or lines are 1D topology simplex, and 2D polygons equals to 2D topology simplexes [16]. These simplexes make up a 3D volume equivalent to a 3D topology complex which represents the buildings in a 3D model. The basic representations of objects using simplexes and complexes can be further elaborated using a graph representation to visualise the topology of the objects. The graph representation for each of the tests are shown in Figure 10 and Figure 11.

Both graph models show that the topological relationships between the objects are based on a hierarchy or tree structure where buildings are broken into sub-elements such as walls, roofs and ground. This topological information at most, allows the selection of sub-elements from the parent object; for instance, selection of a specific wall from a building. The method of establishing topology by incidence can only be done with the explicit representation of the common surface as an individual geometry [13]. This is due to the inability of CityGML to support topological primitives and effectively build 3D topology [17,13]. This disadvantage also hinders the preservation of relationships between topological primitives in different dimensions [18]. Hence, the topological information extracted from the geometric primitives are limited to the object in question and is isolated in terms of connectivity [6].
5. Conclusion

The existing topological component of CityGML consisted of a simple topology-incidence which catered to the relations between stored objects that shared a common surface. This method provided a simple yet sound foundation for maintaining topological integrity of geometries in a 3D city model. However, more application specific analysis requires a comprehensive topological model to best accommodate the analyses and turn out better results. This paper demonstrated an extraction of topological information from CityGML test data based on the existing data structure. The extraction of topological information was based on the existing geometrical structure of CityGML as a stand in model for topological properties as no explicit topological model is currently used in CityGML. The extracted topological information was represented in graph models which depicted a tree hierarchical topological structure that starts from the object or building as a 3D parent element and decomposes by one dimension until 0D topological primitive (point). Therefore, the topological information was limited to the locality of the object in question and isolated from objects of other dimensions. This also restricts the capabilities in performing analysis which requires connectivity between objects of different dimensions. A comprehensive topological model to explicitly preserve topological
information is advantageous in accommodating 3D analysis for 3D city modelling where different needs or applications arise each day. Future studies can be carried out to ascertain the different requirements of a topological model in 3D city modelling and exploring methods to explicitly preserve 3D topological information within CityGML as the current international standard.

![Graph model representation of topological information for two disjointed buildings](image)

**Figure 11.** Graph model representation of topological information for two disjointed buildings

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