

CELL COMPLEXES TOPOLOGICAL LINKS FOR BUILDINGS IN CITYGML

Syahiirah Salleh^{1,*}, Uznir Ujang², Suhaibah Azri³, Tan Liat Choon⁴

^{1,2,3,4} Department of Geoinformation, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia – syahiirahsalleh78@gmail.com, (mduznir, suhaibah, tlchoon)@utm.my

Commission VI, WG VI/4

KEY WORDS: CityGML, 3D Topology, 3D City Model

ABSTRACT:

Topology has served as the foundation for analysis in modelling cities and buildings. CityGML as an international standard for 3D city modelling utilises a simple ‘topology-incidence’ which links connected geometries by reference without the presence of a complete topological model to explicitly preserve the topological properties. This paper explains the use of cell complexes topological links for buildings in CityGML. Two datasets were used in this study which consisted of two connected buildings and two disjointed buildings. The geometries which make up the buildings were extracted as 0D nodes, 1D lines, 2D surfaces and 3D buildings. The resulting topological links generated are from a-0 links to a-3 links where a-0 links are lines that connect nodes (1D), a-1 links are connected lines that form surfaces (2D), a-2 links are connected surfaces that makes up a building (3D) and a-3 links represents connections between 3D buildings. The connected buildings started with a generated total of 57 a-0 links which decreased to 2 a-2 links where each building is represented by 1 a-2 link. A similar result was obtained for the disjointed buildings where ultimately the buildings were individually represented by an a-2 link. Besides that, a-3 links could be generated for the connected buildings which described that building 0 was connected to building 1 and vice versa. This shows that the cell complexes topological links is a simple yet compact way of preserving topological properties and facilitating navigation through the connected objects.

1. INTRODUCTION

Topological information is one of the basic properties in representing buildings as a 3D model and describing connectivity information (Krämer and Huhnt, 2009). CityGML as the international standard for 3D city models utilises a simple topology-incidence where XLinks mechanism or XML links is used to reference objects that share a common surface (Li et al., 2016). Generally, the XLinks mechanism is sufficient for linking related objects which share surfaces. This is due to the nature of topological relations that can be indirectly represented via the attached references between the objects (Thomsen et al., 2008). Furthermore, the main purpose of 3D city modelling which is the visualisation of buildings does not necessitate a comprehensive topology (Arroyo Otori et al., 2015a). However, elaborate analyses that require connectivity throughout the entire object requires an explicit and comprehensive preservation of the topological properties. As mentioned before, XLinks can reference objects which share common surfaces yet neighbouring buildings are often modelled using separate surfaces (“invisible” surfaces) to facilitate efficient and consistent visualisation (Gröger et al., 2005). This hinders the objects from being referenced to each other using the XLinks mechanism which results in no preservation of topological information between the buildings.

In order to preserve the topological properties of objects, a topological data structure is used to define how the topological properties are stored. There are various data structures that can cater the needs of preserving topological properties such as the cell complexes data structure. The idea behind the 3D cell complex is the ability to navigate through surfaces that are connected via a line or edge (Arroyo Otori, 2014). Consequently, a 3D volume can be decomposed into lower dimension primitives that describe how the surfaces are connected to form the 3D volume (Arroyo Otori et al., 2015b).

Another similar data structure is the Generalised Map or G-Map. In general, this data structure maps a specific combination of points, line and surface within the 3D volume which is linked to darts (Thomsen et al., 2008). The navigation through the G-Map implements transitions that are able to traverse through the darts (Thomsen et al., 2008).

In this paper, we attempt to preserve topological properties of buildings in CityGML using cell complexes topological links. In Section 2, the methodology used in this paper to extract geometrical properties and generate the topological links is explained. This includes the extraction of geometrical properties from CityGML files and generation of topological links. Section 3 presents the results (generated topological links) and discussion. Finally, the conclusion and outlook of future research is put forth in Section 4.

2. METHODOLOGY

The cell complexes topological links implemented in this research is similar to cell complexes and G-Map data structure. The data structures are based on a common idea which is to traverse via decomposed lower dimension primitives such as 0D points, 1D lines and 2D surfaces to make up a 3D object while preserving connectivity information.

2.1 Extracting Geometrical Properties from CityGML File

Two datasets were used for this paper which was acquired from the CityGML open data initiatives. Dataset A consists of two connected buildings while Dataset B consists of two disjointed buildings. Datasets A and B are both displayed using FZK Viewer as shown in Figure 1 and Figure 2 respectively.

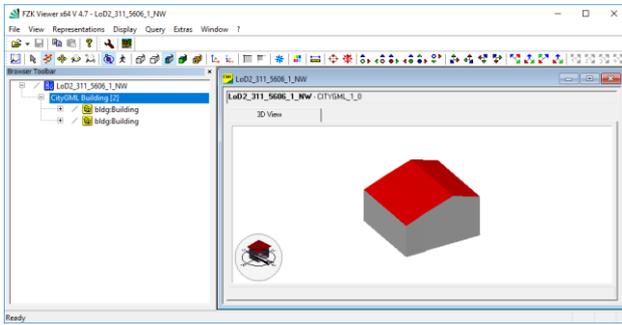


Figure 1. Two connected buildings (Dataset A)

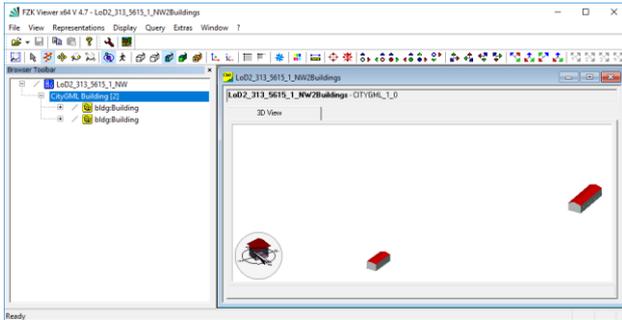


Figure 2. Two disjoint buildings (Dataset B)

The buildings consisted of ground surfaces, wall surfaces, and roof surfaces. Each of these 2D surfaces are made up of 1D lines and 0D nodes that each have x, y, and z-coordinates. An example of the extracted geometrical properties from Dataset A and B are shown in Figure 3 and 4 respectively.

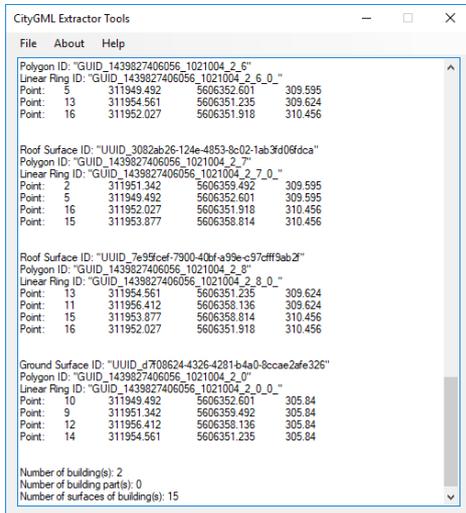


Figure 3. Extracted geometrical properties of Dataset A

The connected buildings in Dataset A consisted of a total of 15 surfaces and 16 nodes. Meanwhile, the disjoint buildings in Dataset B is made up of 18 surfaces and 20 nodes.

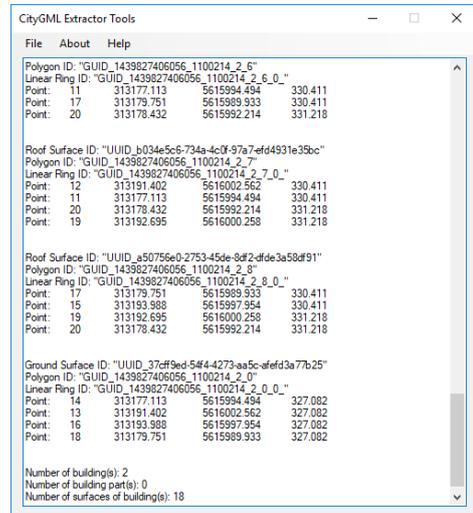


Figure 4. Extracted geometrical properties of Dataset B

The geometrical properties of the building in 0D, 1D, and 2D are used to generate the topological links which in turn can traverse through the building and topologically represent the building. A program was developed using Visual Studio 2010 to generate the topological links for the buildings. The program interface is shown in Figure 5.

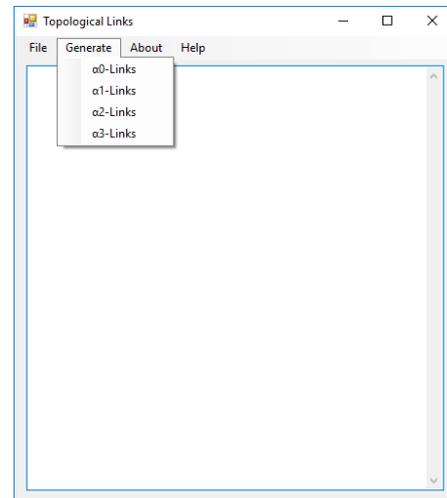


Figure 5. Topological links generator program

2.2 Generating a-0 Links

The first topological link generated is the a-0 links which links 0D nodes to form 1D lines. The geometrical properties from the CityGML file which consisted of the surfaces and the points that make up the surfaces are used as the input to generate the a-0 links. In order to generate the a-0 links, the extracted geometrical properties are used as the input. The flowchart for generating the a-0 links is shown in Figure 6.

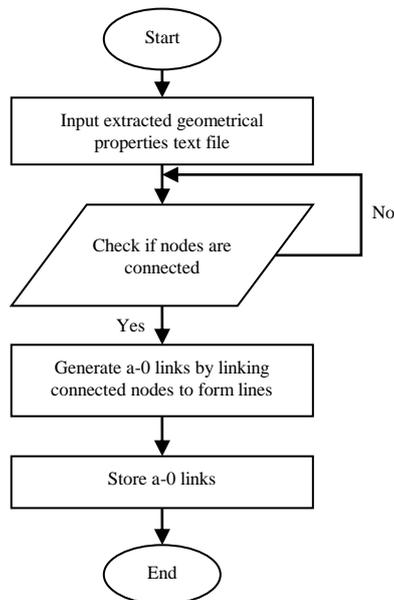


Figure 6. Flowchart for generating a-0 links

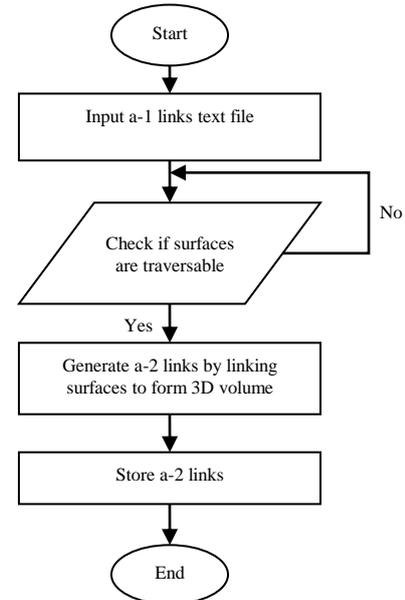


Figure 8. Flowchart for generating a-2 links

2.3 Generating a-1 Links

The a-1 links are the second topological link that is generated which links 1D lines to form 2D surfaces. The previously generated a-0 links is used as input for the generation of the a-1 links. The generation of a-1 links is illustrated in the flowchart in Figure 7.

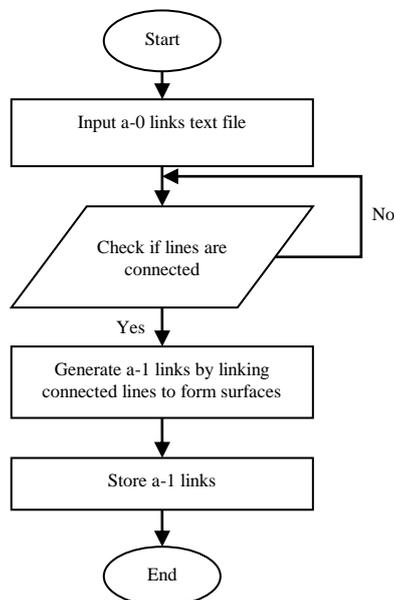


Figure 7. Flowchart for generating a-1 links

2.4 Generating a-2 Links

The a-2 links are generated from the a-1 links where the 2D surfaces are topologically linked to form 3D volumes or buildings. The surfaces are found to be topologically linked if the surfaces are traversable through a shared line. The flowchart in Figure 8 illustrates the generation of the a-2 links.

2.5 Generating a-3 Links

The a-3 links are generated from the a-2 links where a topological link is represents the connections between the 3D buildings. The flowchart in Figure 9 displays the generation of the a-3 links.

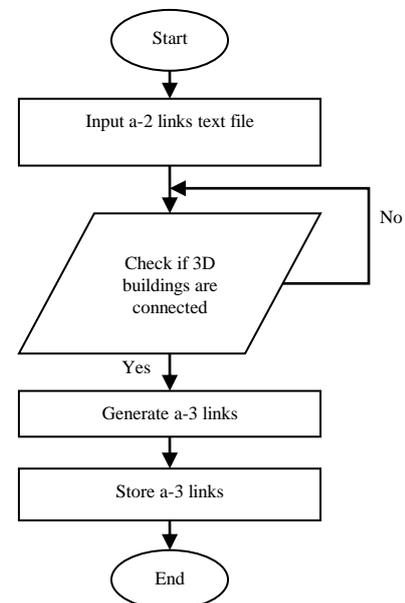


Figure 9. Flowchart for generating a-3 links

3. RESULTS & DISCUSSIONS

As mentioned in the previous section, the first topological link or a-0 link was generated using the extracted geometrical properties of the CityGML file as input. The resulting a-0 links for Dataset A and B are shown in Figure 10 and Figure 11 respectively.

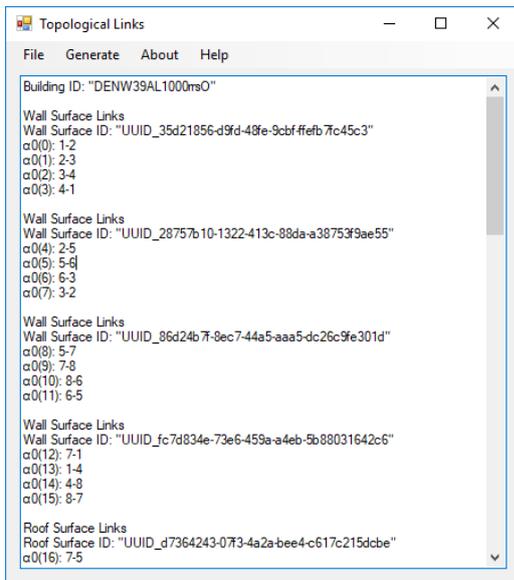


Figure 10. a-0 links for Dataset A

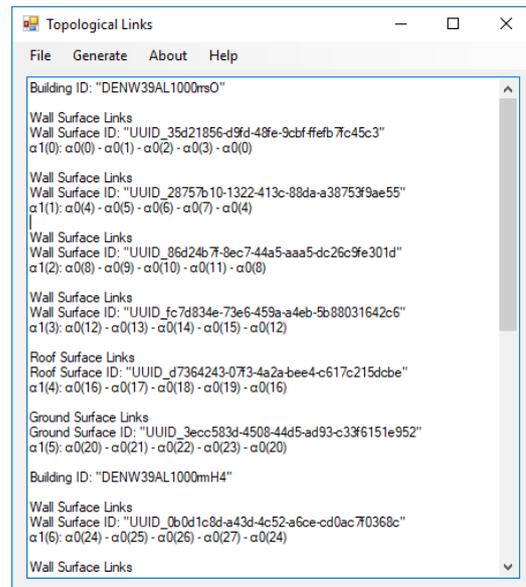


Figure 12. a-1 links for Dataset A

The extracted geometrical properties of Dataset A consisted of 16 nodes. The resulting a-0 links made up a total of 57 links of connected 0D nodes that form 1D lines.

The total a-1 links generated for Dataset A is 15 links which is also the total surfaces of the two connected buildings. The resulting a-1 links for Dataset B amounted to a total of 18 links which is also the total surfaces of the two disjointed buildings.

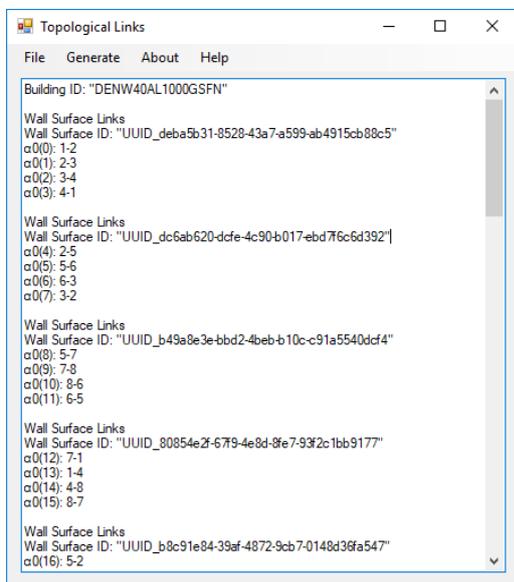


Figure 11. a-0 links for Dataset B

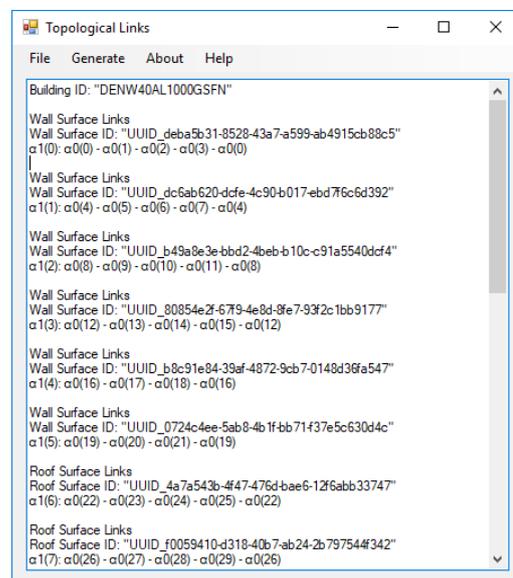


Figure 13. a-1 links for Dataset B

The extracted geometrical properties of Dataset B consisted of 20 nodes. The resulting a-0 links made up a total of 67 links of connected 0D nodes that form 1D lines.

The third topological link or a-2 link is generated from the previous a-1 links as input. The a-2 links generated for Dataset A and B are shown in Figure 14 and Figure 15 respectively. A total of 2 a-2 links were generated for Dataset A as a result where each building is represented by one a-2 link. Dataset B also obtained the same amount of a-2 links which is 2 topological links.

The second topological link or a-1 link uses the previously generated a-0 links as input. The a-1 links generated for Dataset A and B are shown in Figure 12 and 13 respectively.

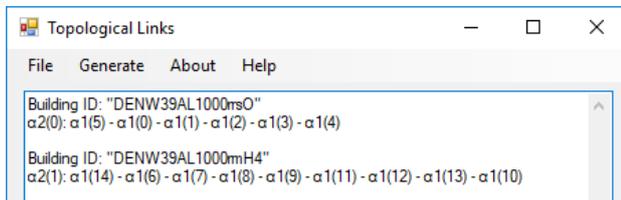


Figure 14. a-2 links for Dataset A

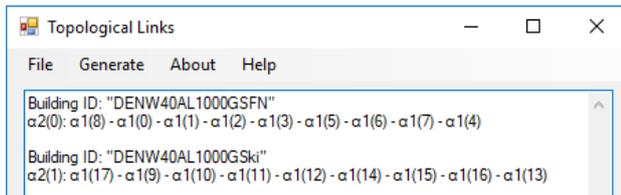


Figure 15. a-2 links for Dataset B

The fourth and final topological link is the a-3 link which is generated only if the 3D buildings are connected. The previously generated a-2 links are used as input to generate the a-3 links. The resulting a-3 links for Dataset A and B are shown in Figure 16 and Figure 17 respectively. Only the connected buildings of Dataset A are able to generate a-3 links whereas the disjointed buildings of Dataset B do not generate any a-3 links. The a-3 links for Dataset A describes that Building 0 (a-2(0)) is connected to Building 1 (a-2(1)) and vice versa.

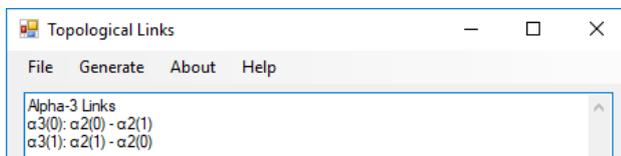


Figure 16. a-3 links for Dataset A

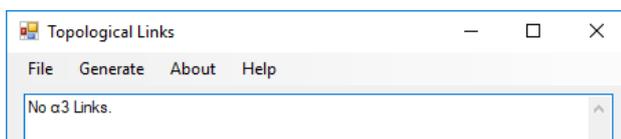


Figure 17. a-3 links result for Dataset B

Originally, the two connected buildings of Dataset A consisted of 15 surfaces and 16 nodes. Each building was represented by 1 a-2 topological link which consisted of the nodes, lines and surfaces that make up the building. The buildings in Dataset B which consisted of 18 surfaces and 20 nodes were also represented by 1 a-2 link per building. Apart from that, the a-3 links were also able to describe the connection between the buildings of Dataset A which could not be referenced in CityGML due to being connected via an “invisible” face. Therefore, the topological links are a simple yet compact way of preserving the topological information and is able to describe how surfaces are connected in the building.

4. CONCLUSION

Topological information for buildings in CityGML are preserved using XLinks mechanism which references surfaces that share a common surface. This is a simple yet sound foundation for maintaining topological integrity within a 3D model. However, analyses that require connectivity information

necessitates a comprehensive preservation of topological properties. This paper demonstrated the use of cell complexes topological links to preserve topological properties of buildings in CityGML. Two datasets were used which consisted of two connected buildings and two disjointed buildings. Four links which are a-0 (connects points to form 1D line), a-1 (connects lines to form 2D surface), a-2 (connects surfaces to form 3D volume) and a-3 (represents connections between 3D volumes) were generated. The decrease in number of links from a-0 (57 links) to a-2 (2 links) for Dataset A and a similar decrease for Dataset B shows that the cell complexes topological links is a simple and compact way of preserving topological properties. Additionally, the topological links also describe how the geometries are connected which allows navigation through the connections. Future studies can be carried out regarding the implementation or integration of topological data structures within CityGML and explore other methods of preserving topological information for buildings in CityGML.

ACKNOWLEDGEMENTS

This work is supported by the UTM Research University Grant, Vot Q.J.130000.2527.15H49 and Vot Q.J.130000.2527.11H78. The CityGML datasets used in this study were obtained freely from Nordrhein-Westfalen Open Data. The CityGML viewer used in this study is the FZK Viewer developed by Karlsruhe Institute of Technology.

REFERENCES

- Arroyo Otori, K., 2014. *Higher-dimensional Modelling of Geographic Information*. PhD Thesis, Delft University of Technology, Netherlands.
- Arroyo Otori, K., Ledoux, H., & Stoter, J., 2015a. An Evaluation and Classification of nD Topological Data Structures for the Representation of Objects in a Higher-dimensional GIS. *International Journal of Geographical Information Science*, 29(5), 825-849.
- Arroyo Otori, K., Ledoux, H., Biljecki, F., & Stoter, J., 2015b. Modeling a 3D City Model and Its Levels of Detail as a True 4D Model. *ISPRS International Journal of Geo-Information*, 4(3), 1055-1075.
- Gröger, G., & Plümer, L., 2005. How to Get 3-D for the Price of 2-D—Topology and Consistency of 3-D Urban GIS. *GeoInformatica*, 9(2), 139-158.
- Krämer, T., & Huhnt, W., 2009. Topological Information in Geometrical Models of Buildings. *Computing in Civil Engineering*, 572-581.
- Li, L., Luo, F., Zhu, H., Ying, S., & Zhao, Z., 2016. A Two-level Topological Model for 3D Features in CityGML. *Computers, Environment and Urban Systems*, Vol. 59, pg. 11-24.
- Thomsen, A., Breunig, M., Butwilowski, E., & Broscheit, B., 2008. Modelling and Managing Topology in 3D Geoinformation Systems. In: *Advances in 3D Geoinformation Systems*, pg. 229-246. Berlin, Heidelberg: Springer Berlin Heidelberg.

Revised May 2018