International Conference on Innovative Production and Construction (IPC 2017)
30 November - 1 December 2017, Perth, Australia

AN ECONOMICAL APPROACH TO GEO-REFERENCING 3D MODEL FOR INTEGRATION OF BIM AND GIS

Junxiang Zhu [1*], Yi Tan [2], Jun Wang [1], and Xiangyu Wang [1]

[1] Australasian Joint Research Centre for Building Information Modelling, Curtin University Perth, Australia
[2] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong
[*] Corresponding author (junxiang.zhu@postgrad.curtin.edu.au)

ABSTRACT

The integration of Building Information Modelling (BIM) and Geographic Information System (GIS) has been studied for a long period of time by researchers from both domains. The foundation of the integration is the interoperability of the data, that means the BIM data has to have a right reference system, allowing it to be read correctly by GIS software applications. 3D models from the BIM world may not be correctly geo-referenced, which impairs the data interoperability. Instead of rebuilding models from scratch, which is time- and labour-consuming, this paper proposes a more efficient, economical, two-step alternative mainly based on Affine transformation. In the first step, the modification is made against the x- and y-coordinates. A number of control points would be selected to form displacement links. Based on them, the transformation parameters would be calculated, and the 2D footprint of the model would be rectified by Affine transformation. Then, the z-value (height information) of each vertex in the model would be adjusted using the scaling factor f. This method could get a 3D model without a geographical coordinate system correctly geo-referenced, and thus, it could be further read by GIS applications and consume the vast spatial analysis tools supported by the GIS world and achieve more than just visualization. The key to the success of this study is creating an accurate right footprint of the model, and selecting appropriate control points to guarantee the accuracy of transformation. By far, this approach has only been tested with a bridge model, its performance on other building models needs to be further studied.

Keywords: *GIS, BIM, 3D Geo-referencing*

1. INTRODUCTION

Research on integration of Building Information Modelling (BIM) and Geographic Information System (GIS) has emerged those years, because of its significant benefits to both worlds(Ebrahim et al., 2016; Li et al., 2017). The GIS world could use the detailed 3D models created by BIM to overcome its drawback in the building of 3D models, while the BIM world might use the vast spatial analysis tools provided by GIS to expand its capacity(Chong et al., 2017, Shou et al., 2015).

Approaches to combining BIM and GIS could be categorized into three levels, i.e. application level, process level and data level (Amirebrahimi et al., 2015). Among them, the data level is the most fundamental, as the other two levels are more or less depending on it. In the data level, the data format is transformed from one to another. For example, the most common way is to transform from Industrial Foundation Class (IFC) to City Geography Markup Language (CityGML) (Deng et al., 2016). IFC is an open file format for facilitating interoperability in the architecture, engineering and construction (AEC) industry, while CityGML is an open standardised data model and exchange format to store 3D models of cities and landscapes based on Geography Markup Language (GML) defined by Open Geospatial Consortium (OGC) in Extensible Markup Language (XML) format (Kang and Hong, 2017). Both of them are designed to store and exchange data in their own domain. Another alternative is to translate IFC file into shapefile, a data format developed by Environmental Systems Research Institute, Inc. (ESRI) and widely-accepted open format in the geospatial domain for data storage and analysis(Amirebrahimi et al., 2016). The difference between the two approaches is that CityGML is more often used for data exchange, while the shapefile is for spatial analysis.

The barrier that cannot be neglected during the data transformation is the incompatibility of spatial reference systems adopted by the two domains. GIS uses global reference system such as geographic coordinate system in the form of latitude, longitude and altitude, whereas BIM uses a local coordinate system in the form of X, Y and Z in a 3D Cartesian Coordinate System(Karan and Irizarry, 2015, Wang et al., 2015). Without a geographic coordinate system, the BIM model would introduce errors when imported into a GIS platform, such as incorrect size or location. All models need to be geo-referenced before they can be properly processed by GIS applications. To achieve the integration of BIM and GIS, the BIM world introduced geographic coordinate system, and the GIS world starts to support local coordinate system defined in CityGML (Gröger et al., 2014).

Nevertheless, obstacles still exist. The geographic coordinate system may still not be defined at the beginning of a BIM project, due to designer's preference to local coordinate system, or some old BIM models may also not include a proper geographic coordinate system. In this situation, if those models are to be used in GIS, they have to be either rebuilt or geo-referenced. Compared with the first option, the second is much more economical.

The GIS world has a mature experience in geo-referencing 2D data, such as remote sensing imagery, contour map, and other data with 2D geometry(Turner et al., 2014). However, as a beginner in 3D domain, it doesn't have a well-accepted approach to geo-reference 3D data from BIM, considering its complexity.

This paper proposes a two-step approach to geo-reference 3D models from the BIM world without a geographical coordinate system. No new complex mathematical algorithm is going to be developed, instead, the traditional 2D geo-referencing algorithm will be utilized and extended. To demonstrate the feasibility of the proposed method, a bridge model is selected, processed by the approach, and the final geo-referenced model is displayed.

2. METHODOLOGY

2.1 Data

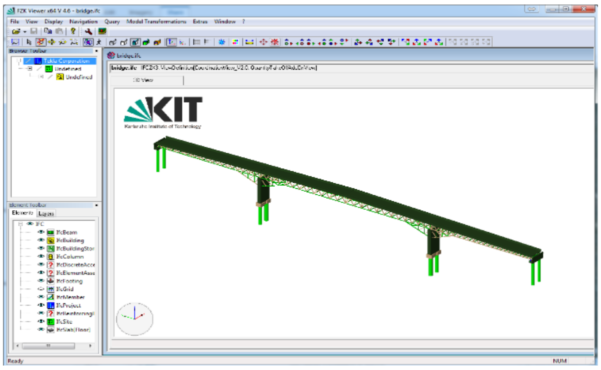

Fig. 1. Bridge model in IFC format

Fig. 2. The planned location of the bridge in real world

A 3D model of a bridge with a width of 8.5 meters and a length of 223 meters, from a project in design stage in Guangdong Province, China, is used, as shown in Fig. 1. This model is built with Tekla in a local coordinate system, and exported in IFC format, making it able to be exchanged to other applications. A footprint of the model was also created in ArcGIS with a WGS 1984 World Mercator coordinate system, indicating the real location of the bridge, as presented in Fig. 2.

2.2 Geo-referencing

The purpose of geo-referencing is to assign geographic coordinates to an image or misplaced vector data, to display them correctly.

The available algorithms for geo-referencing include Affine transformation, similarity transformation and projective transformation(Inc., 2017a). In this study, Affine is adopted, because only a simple linear translation as well as a shift is required, and it's the mostly used method in 2D coordinate system transformation.

An affine transformation can differentially scale the data, skew it, rotate it and translate it. It could be represented by

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} A & B \\ D & E \end{pmatrix} \begin{pmatrix} \hat{x} \\ \hat{y} \end{pmatrix} + \begin{pmatrix} C \\ F \end{pmatrix}, \tag{1}$$

where x and y are the adjusted coordinates (or target coordinates), and $\hat{x}$ and $\hat{y}$ indicate the original coordinates (or source coordinates) (Song et al., 2014). A, B, C, D, E, and F are transformation parameters, which could be calculated from control points.

2.3 Workflow

The workflow in Fig. 3 shows the steps from the beginning until it is finished. It spans two areas, BIM and GIS, and connects many platforms (Tekla, ArcMap, ArcScene and ArcGIS Pro) to geo-reference the data.

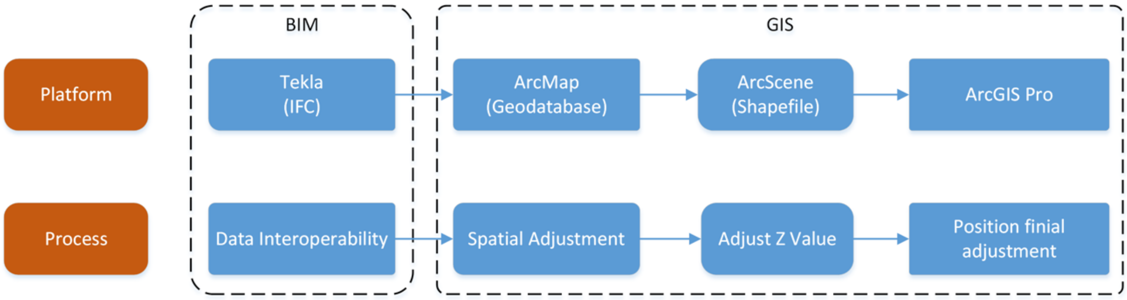

Fig. 3. Workflow

The data is first transformed from IFC to geodatabase by ArcGIS Data Interoperability tool, supported by Feature Manipulation Engine (FME) (Inc., 2017b). After that, a two-step process is conducted to geo-reference the model. The first step, completed by ArcMap, is to rectify its x- and y-coordinates (2D footprint). The second is to adjust the z-value of each point in the model, and this part is finished by ArcScene.

2.3.1 X- and Y-coordinates rectification

In this section, the x- and y- coordinates would be rectified. A "right" footprint (RF) has to be created first using the right size and location information of the bridge. Meanwhile, the original footprint of the model is referred as "wrong" footprint (WF).

Then, control points are selected from both RF and WF, and the mathematic relationship between them is established. A pair of control points, one from RF and another from WF, constitute a displacement link. In a 2D case, at least 3 displacement links are required. With those control points, the transformation parameters in Equation 1 could be derived and the transformation could be completed.

2.3.2 Height information adjustment

After x- and y-coordinates being rectified, the model is distorted, as it is not scaled proportionally. The height information or z-value must also be adjusted to maintain its structure correctness. The z-value could be adjusted by

$$Z_a = f \times Z_b, \tag{2}$$

where Z_a is the adjusted value, Z_b is the original value, and f stands for a scaling factor, indicating whether the value is increasing (f>1) or decreasing (f<1), and it could be calculated by

$$f = L_r / L_w, \tag{3}$$

where L_r is the length of the RF, whereas L_w stands for the length of the WF, both of them could be acquired by measuring using internal applications provided by ArcMap. Note that the f could also be calculated using the width of the bridge in this case, but length is preferred, as it could reduce the measuring error. The f is the key to guarantee the model's structure correctness.

3. RESULTS

3.1 WF and RF

Fig. 4 shows the WF of the model as well as the RF, with a background of a satellite image covering part of Guangdong Province. The WF is represented as a red box, because of its wrong referencing system, its size presented in the map is not real and considerably larger than the RF, which is too small to be displayed in the map, and an exaggeration has been made, as shown in the green box. It could be learnt that if a 3D model imported into GIS platform is not correctly geo-referenced, it could not be displayed and analyzed appropriately. As the project is still in design stage, the bridge has not been built yet, nevertheless, its location has been required by consulting the designer.

Fig. 4. The WF (red box) and the RF in the green box

3.2 Footprint Rectification

In order to perform the transformation, the parameters, namely A, B, C, D, E, and F in **Equation 1**, are required. They could be derived by choosing a number of control points. A point in WF and its corresponding point in RF make up a displacement link. All the displacement links are shown in Fig. 5, each arrow stands for a displacement link.

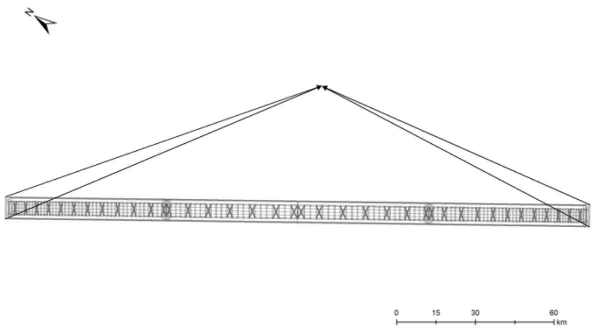

Fig. 5. Displacement link

Fig. 6. Rectified footprint

Table 1 presents the control points selected. *X Source* and *Y Source* are coordinates from the WF, while the *X Destination* and *Y Destination* are from the RF. Each row of the table denotes a displacement link. The residual error is a measure of the fit between the true locations and the transformed locations of the output control points and is generated for each displacement link. It is calculated by

$$RE = \sqrt{(x_a - x_d)^2 + (y_a - y_d)^2}, \tag{4}$$

where RE is residual error, x_a and y_a are adjusted coordinates of *X Source* and *Y Source* calculated using the affine transformation, while x_d and y_d are values of *X Destination* and *Y Destination* respectively. All the residual errors here are zero, indicating a high transformation accuracy. *Fig. 6* illustrates the rectified footprint of the bridge.

Table 1. Control points

ID	X Source	Y Source	X Destination	Y Destination	Residual Error
1	12446488.628050	2709125.359343	12550256.642045	2634645.825519	0.000000
2	12439460.110040	2704345.198607	12550248.151620	2634646.084748	0.000000
3	12571785.074786	2524895.501584	12550250.684949	2634424.219664	0.000000
4	12564756.556776	2520115.340848	12550242.194525	2634424.478929	0.000000

3.3 Z-value adjustment

The Z-value is adjusted by the scaling factor *f*, which is the ratio of the true footprint's size to the wrong footprint's size. In this study, the width of the true footprint is 8.5 meters (map units), while that of the wrong footprint is 8500 meters (map units), calculated by measuring tool in ArcMap, thus the value of scaling factor *f* is 0.001.

The fully rectified model was shown in **Fig.** 7, which is just the same as the original one shown in **Fig.** 1. The advantage of combining BIM and GIS is to utilize the excellent 3D visualization of BIM model and the vast spatial analysis functions provided by GIS to make the most of the model. **Fig.** 8 puts the bridge model in the "real" scene created by GIS. The GIS links the isolated bridge model to its surroundings, which introduces richer environmental information to it.

Fig. 7. Rectified bridge model

Fig. 8. The rectified model in a real scene

4. DISCUSSION

4.1 Semantic information loss

As a well-recognized issue in the integration of BIM and GIS, the semantic information loss was also noted in this study. During the transformation of data format from IFC to shapefile, the file was separated into six thematic files. This process created a file for each type of element, namely, slab, member, footing, discrete accessory, column and beam defined in BIM. As a result, the hierarchy structure of those elements was destroyed, causing semantic information loss. However, by checking each file's attribution table, we found they contain a field, ifc_parent, pointing to each component's parent, which means the hierarchy structure was not totally lost, and could be restored in some way.

4.2 Selection of control points

The accuracy of the geo-referencing process could be affected by many aspects, one of the most significant aspects roots in the 2D footprint rectification, introduced by the selection of control points. The effect that control points have on the adjustment depends on the number and location of those points. In this study, the selection of control points was relatively simple, as the outline of the bridge footprint is a rectangle. Four vertices from the four corners of the footprint were selected, and high transformation accuracy was achieved. However, in other similar applications, if the footprint of an object was not rectangular or square, the authors would suggest select those points at the corner, as they are easier to identify than those in the middle of a line.

4.3 Enrichment of model property

Apart from the default information, such as global ID, name, description, tag and parent, imported from the IFC file, other customized attributes could also be created and added to the model later on the GIS side to enrich the property of the model for various purposes. For example, the material, manufacturer, manufacture date and installation date information could be incorporated for the maintenance of the bridge. With the assistance of an additional sensor network, a bridge health monitoring system could be established. Once a component is found to be a risk to the bridge, replacement and manufacturer information could be quickly obtained, and even the order process could be made automated, as all the needed information are within the model, thus improve the efficiency of bridge maintenance.

5. CONCLUSION

This paper presents an easy-to-conduct but efficient approach to geo-referencing 3D models without a geographical coordinate system. A 3D bridge model was used to demonstrate the performance of the proposed approached, and good result was achieved. This approach is economical, as the non-georeferenced 3D model does not have to be rebuilt from scratch. If the bridge used in this study is to be rebut, it will take about 20 hours estimated by the builder himself, while using this method, it will take only about 2 hours. The correctly geo-referenced bridge model could utilize the vast functions provided by spatial analysis, and can provide more than just 3D visualization.

However, since manual intervention is required, this method only suits situations where merely a small number of models are to be geo-referenced. In a scenario where there are a large number of models, authors would suggest developing an automated way. By far, this method has only been applied to a bridge model. Theoretically, any model with a wrong referencing system could adopt this approach to rectify the model, however, its real performance on those models needs to be further validated.

ACKNOWLEDGMENT

This research was undertaken with the benefit of a grant from Australian Research Council Linkage Program (Grant No. LP130100451).

REFERENCES

AMIREBRAHIMI, S., RAJABIFARD, A., MENDIS, P. & NGO, T. 2015. A framework for a microscale flood damage assessment and visualization for a building using BIM–GIS integration. International Journal of Digital Earth, 1-24.

AMIREBRAHIMI, S., RAJABIFARD, A., SABRI, S. & MENDIS, P. 2016. Spatial Information in Support of 3D Flood Damage Assessment of Buildings at Micro Level: A Review. ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences, 4.

CHONG, H.-Y., LEE, C.-Y. & WANG, X. 2017. A mixed review of the adoption of Building Information Modelling (BIM) for sustainability. Journal of Cleaner Production, 142, 4114-4126.

DENG, Y., CHENG, J. C. & ANUMBA, C. 2016. Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison. Automation in Construction, 67, 1-21.

EBRAHIM, M. A.-B., MOSLY, I. & ABED-ELHAFEZ, I. Y. 2016. Building construction information system using GIS. Arabian Journal for Science and Engineering, 41, 3827-3840.

GRÖGER, G., KOLBE, T., NAGEL, C. & HAFELE, K. 2014. OpenGIS City Geography Markup Language (CityGML) Encoding Standard (OGC 12-019). Version 2.0. 0. OGC 12-019. Open Geospatial Consortium.

INC., E. 2017a. About spatial adjustment transformations [Online]. Available: http://desktop.arcgis.com/en/arcmap/latest/manage-data/editing-existing-features/about-spatial-adjustment-transformations.htm [Accessed 2017].

INC., S. S. 2017b. Integrate Esri ArcGIS Shapefile (SHP) Using FME [Online]. Available: https://www.safe.com/integrate/arcgis-shp/ [Accessed 2017].

KANG, T. W. & HONG, C. H. 2017. IFC-CityGML LOD mapping automation using multiprocessing-based screen-buffer scanning including mapping rule. KSCE Journal of Civil Engineering, 1-11.

KARAN, E. P. & IRIZARRY, J. 2015. Extending BIM interoperability to preconstruction operations using geospatial analyses and semantic web services. Automation in Construction, 53, 1-12.

Li, X., Wu, P., Shen, G.Q., Wang, X. and Teng Y. 2017. Mapping the knowledge domains of Building Information Modelling: a bibliometric approach. Automation in Construction, 84, 195-206.

SHOU, W., WANG, J., WANG, X. & CHONG, H. Y. 2015. A comparative review of building information modelling implementation in building and infrastructure industries. Archives of computational methods in engineering, 22, 291-308.

SONG, Z., ZHOU, S. & GUAN, J. 2014. A novel image registration algorithm for remote sensing under affine transformation. IEEE Transactions on Geoscience and Remote Sensing, 52, 4895-4912.

TURNER, D., LUCIEER, A. & WALLACE, L. 2014. Direct georeferencing of ultrahigh-resolution UAV imagery. IEEE Transactions on Geoscience and Remote Sensing, 52, 2738-2745.

WANG, J., ZHANG, X., SHOU, W., WANG, X., XU, B., KIM, M. J. & WU, P. 2015. A BIM-based approach for automated tower crane layout planning. Automation in Construction, 59, 168-178.