

Integrating BIM and GIS :

Exploring the use of IFC space objects and boundaries

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Summary

In GIS, understanding the layout of interior spaces has important applications in the analysis of energy efficiency, indoor navigation and atmospheric pollution. However, detailed models of building internals are usually held in engineering or architecture software, including Building Information Modelling (BIM) software such as Autodesk Revit, and are not easily understood by GIS in this format. Additionally, such models contain excessive detail, such as wall thickness, not required for GIS operations such as topological adjacency. This paper describes the process required to convert BIM data into GIS, addressing both conceptual modelling and data format differences.

KEYWORDS: Energy & Sustainability – Building Information Modelling – Space Boundaries – GIS and BIM Integration – 3D Topology

1. Introduction

There are two complementary geospatial systems used in the Architecture, Engineering, Construction, Owner, Operator (AECOO) community. Readers will already be aware of Geographic Information Systems (GIS) for the collation, storage, analysis and management of information. The AECOO community has also adopted Building Information Modelling (BIM) as a coordinated set of processes for the design, management and sharing of building and infrastructure information (Mott MacDonald, 2014). At the heart of the BIM process is an object-based model that is ascribed throughout with geospatial information.

The UK Government report *Construction 2025* aims to reduce greenhouse gas emissions by 50% in

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the built environment (HM Government, 2013). Implementation of BIM as standard industrial practice is key to achieving this strategic aim.

Environmental data such as ambient temperature, air and noise pollution are commonly available as GIS datasets. GIS enhances the BIM process with established toolsets for overlaying and querying data. This overlay and query of multiple-source data is a fundamental feature of GIS that permits architects and engineers to make efficient decisions (Cowen, 1988). However, fundamental differences between BIM and GIS exist that preclude successful integration.

The study of spaces is key to understanding the topological layout of buildings. The term *intramural space* is adopted in this paper to refer to the volume of a room contained within the walls, columns, floors and ceilings of the spaces. However, these building elements can overcomplicate the layout in certain situations, e.g. the determination of topological adjacency (Ellul, 2013). The term *contiguous space* is therefore used herewithin to refer to the space bound by wall centrelines that lies between the floor surface and the surface of the floor above. This paper explores the potential of using contiguous space objects and boundaries as a means of simplifying detailed BIM models so that they can then be used in conjunction with GIS methods.

2. Literature Review

2.1. BIM

The concept of 3D object-based building systems, recognisable as a Building Information Model in current parlance, has existed for 40 years (Eastman, 1975). Originally limited by computing power, the concept has since transitioned into reality. There is not one all-defining definition of BIM but great care must be taken to differentiate the BIM process and the product that is the Building Information Model (herewithin "BIM model"). The distinctive characteristics of a BIM model are listed in Table 1 (Isikdag and Zlatanova, 2009 and Lee, Sacks and Eastman, 2006).

Table 1 Distinctive characteristics of a BIM model

Object-based	Building elements and parametric relationships are object-orientated
Data-rich	All physical and functional characteristics are represented
Three-dimensional	3D as opposed to 2.5D
Spatially-related	Topology of building elements is maintained hierarchically
Semantically-rich	Semantic classification permits objects to inherit properties and behaviours
Generative views	2D and 3D visualisation with annotations
Parametric	Elements are definable from the properties of other objects

Industry Foundation Classes (IFCs) (IAI, 2000) provide the AECOO community with an interoperable format for exchanging BIM data between different software platforms (Laakso & Kiviniemi, 2012). More specifically, IFC is suitable for exporting BIM data to GIS and energy simulation software.

2.2. Three dimensional GIS

GIS has traditionally been constrained to two dimensions. Limited 3D can be implemented using a method known as 2.5D in which height is stored not as a dimension but as an attribute. Advances in computing now permit 3D GIS, opening up analytical methods that were previously impracticable. 3D GIS has many applications in the built environment that include energy performance simulation (Bazjanac, 2008), indoor navigation (Worboys, 2011), urban planning (Stoter et al., 2011), cadastral registration (Stoter et al., 2011), noise propagation (Gröger et al., 2012) and renewable energy modelling (Resch et al., 2014).

Two data structures for storing 3D GIS data are Oracle Spatial and CityCML. Oracle Spatial provides schema and functions for storing and querying spatial features in Oracle relational databases (RDBMS) (Murray, 2013). This SDO_GEOMETRY format exceeds the functionality of the OpenGIS Implementation Schema (Herring, 2010). CityGML has been developed as the OGC standard information model for describing 3D urban objects as an application schema of the Geographic Mark-up Language (Gröger et al., 2012). Although the model is formatted in XML, it is geometrically compatible with the OpenGIS and Oracle Spatial implementation schema for RDBMSs. CityGML provides the framework for semantic-geometric relationships and has the functionality of representing differing levels of detail (LoDs).

2.3. Integration of BIM and GIS

Research continues into GIS and BIM integration. Isikdag and Zlatanova (2009) concluded that manipulating data from one system to the other requires a two-part transformation of both the geometric and semantic datasets. Because the two systems are conceptually misaligned, one dataset cannot be transformed without the transformation of the other. Research has focussed on the unidirectional conversion from IFC to CityGML (Isikdag and Zlatanova, 2009) and this functionality is implemented in software such as FME Workbench (Safe Software, 2012). Unidirectional conversion is inherently wasteful and solutions have been proposed to develop a CityGML Application Domain Extension (van Berlo and de Laat, 2011) and an intermediary Unified Building Model (El-Mekawy, Östman and Hijazi, 2012). Ultimately, any meaningful attempt to integrate BIM and GIS requires a systematic mapping of conflicting semantic data structures (Bittner, Donnelly and Winter, 2006).

2.4. Space Objects and Space Boundaries

The geometry of spaces is described as two different entities in IFC, firstly as a space object (*IfcSpace*) and secondly as a space boundary (*IfcRelSpaceBoundary*). *IfcSpace* is geometrically defined as a closed solid. Depending on the complexity of the shape, the space will be represented using profile sweep or boundary representation. The space object contains attributes related to the room such as name, volume and net floor area (buildingSMART, 2014a).

IfcRelSpaceBoundary is geometrically described as a collection of planar polygon faces. Each face relates to a particular building element that is stored as a boundary attribute (buildingSMART, 2014b). Revit provides the option to export IFC space boundaries as either 1st or 2nd level space boundaries (Autodesk, 2014). 1st level space boundaries are simple polygon faces representing each building element not including openings for windows or doors (Weise et al., 2011). 2nd level space boundaries describe not just building element geometry but also the geometry of any object on the other side (Weise et al., 2011). Figure 1 shows a screenshot from Solibri Model Checker showing one *ifcSpace* object above another with the adjoining 2nd level space boundaries.

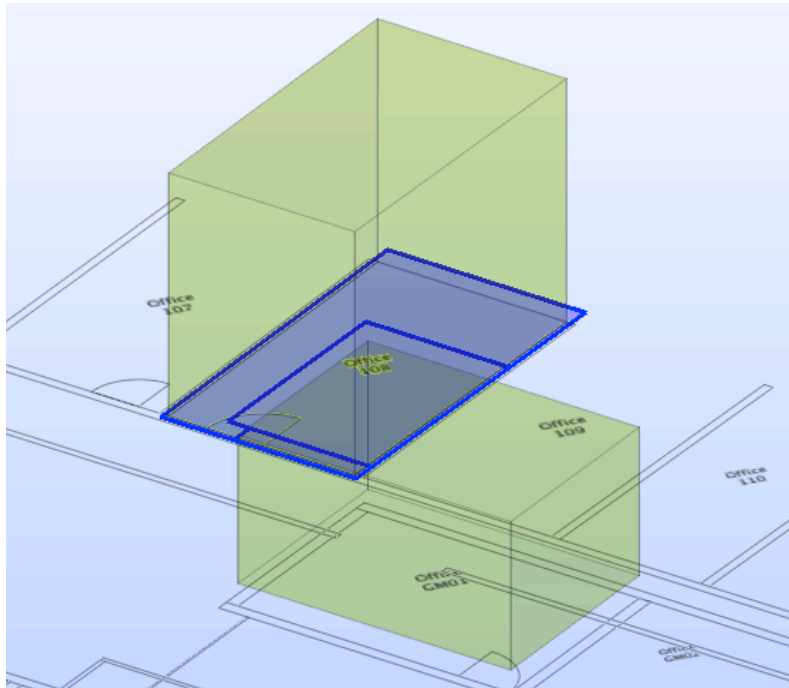


Figure 1 Space objects and 2nd level space boundaries in Solibri Model Checker

3. Data

This investigation tested the methods developed on a BIM model of a building on the University College London campus. This model had been developed in Autodesk Revit from point cloud data captured using laser-scanning equipment (Backes et al., 2014). The model uses a coordinate system aligned to the British National Grid with an applied offset.

4. Method and Results

Basic building models were created in Autodesk Revit 2015 and exported to FZK Viewer and Solibri Model Checker to test the functionality of exporting space objects and boundaries as IFC files from Revit. The suitability of FME Workbench for transforming the geometry of space objects and boundaries into Oracle Spatial SDO_GEOMETRY objects was also investigated and found to be incapable of interpreting *IfcRelSpaceBoundary* geometry. Python script was developed from code published on a web-based repository (Mvaerle, 2010) to interpret the *IfcRelSpaceBoundary* geometry as *SDO_GEOMETRY* objects. IFC class bindings and suitable geometry classes do not exist in Python and script was written to overcome this hurdle.

Building models were exported from Revit with various combinations of the *At Wall Finish / At Wall Centre* and the 1st/2nd Level Boundary settings. To create 3D spaces bounded by room ceilings, it is necessary to change the *Volume Computations* setting in the *Room & Area* drop-down menu to *Areas*

and Volumes. Figure 2 shows contiguous space boundary faces exported from Revit into Oracle Spatial and then visualised as a 3D PDF in Adobe Acrobat superimposed on an OS Mastermap of the surrounding area.

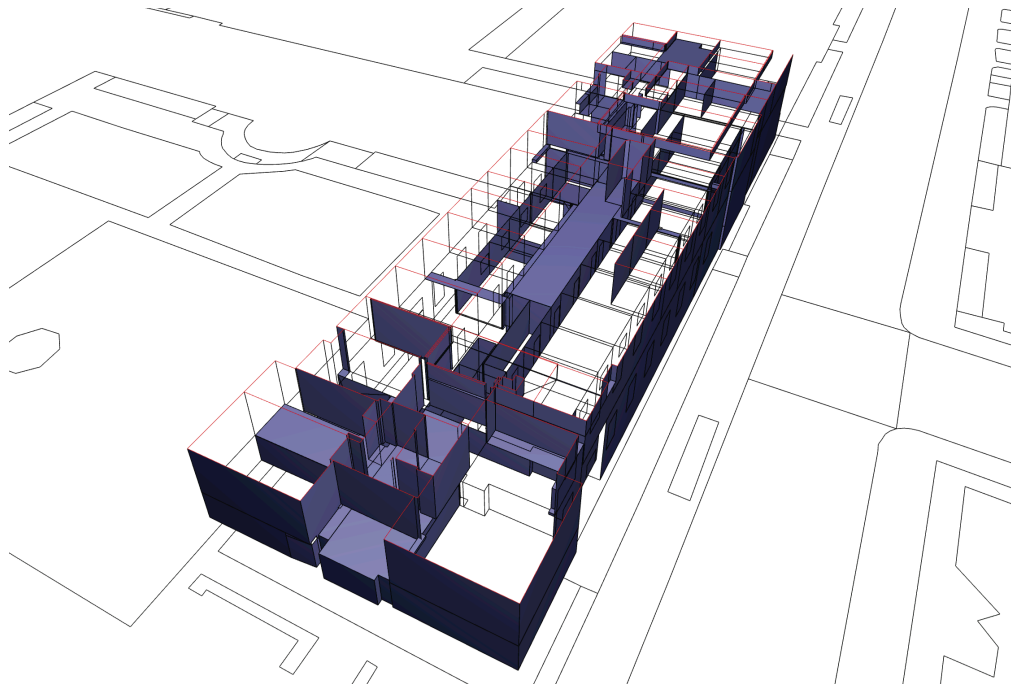


Figure 2 Space boundary faces of Chadwick Building

5. Discussion

The most efficient way to convert intramural spaces is to use FME Workbench to break up the faces of *IfcSpace* objects using a *GeometryCoercer*. Conversely, contiguous space boundaries are best exported from Revit as 2nd Level *IfcRelSpaceBoundary* objects (having selected the *At Wall Centre* setting) and then use the Python script described in the previous section to interpret the geometry and insert into Oracle Spatial.

The key to creating space objects efficiently in Revit is to start with a well-constructed model. Wherever possible, floors should be continuous throughout a particular building level. Splits in floor heights, e.g. mezzanine levels, and stairwells must be contained by a wall or virtual boundary. These methods should stand as good practice for any modellers intent on using BIM data sourced from architectural designs or captured from laser scans of a building.

The outputted 3D model has a number of shortcomings. Firstly, the polygon faces do not contain internal holes corresponding to windows and doors and further script development is in progress to

overcome this issue. Secondly, issues relating to face orientation require further investigation.

6. Conclusion

This investigation has shown that it is possible to extract simplified BIM data from Revit in a format suitable for analysis in 3D GIS. Until FME Workbench is capable of transforming the geometry of *IfcRelSpaceBoundary* objects, Python script is suitable for inserting the boundary faces into Oracle Spatial. Further work will focus on extending the functionality of the Python script to include polygon holes and resolve issues relating to face orientation.

References

- Autodesk 2014. Revit Help - Exporting a project to IFC. [online] Available at: <<http://help.autodesk.com/view/RVT/2014/ENU/?guid=GUID-14037C31-EBAD-41A8-9099-E6DD65BB626E>> [Accessed 5 August 2014].
- Backes, D., Thomson, C., Malki-Ephshtein, L. and Boehm, J. 2014. Chadwick GreenBIM: Advancing operational understanding of historical buildings with BIM to support sustainable use. In: L. Malki-Ephshtein, C. Spataru, L.M. Halburd and D. Mumovic, eds. *Proceedings of the 2014 Building Simulation and Optimization Conference*, 23-24 June 2014. London, UK.
- Bazjanac, V. 2008. IFC BIM-based methodology for semi-automated building energy performance simulation. *Lawrence Berkeley National Laboratory*.
- Bittner, T., Donnelly, M. and Winter, S. 2006. Ontology and semantic interoperability. In: *Large-scale 3D data integration: challenges and opportunities*. Large-scale 3D data integration: challenges and opportunities, pp.139–160.
- buildingSMART 2014a. IFC 2x3 documentation - IfcSpace. [online] Available at: <<http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/ifcproductextension/lexical/ifcspace.htm#definition>> [Accessed 31 July 2014].
- buildingSMART 2014b. IFC 2x3 Documentation - IfcRelSpaceBoundary. [online] Available at: <<http://www.buildingsmart-tech.org/ifc/IFC2x3/TC1/html/ifcproductextension/lexical/ifcrelspaceboundary.htm#definition>> [Accessed 31 July 2014].
- Cowen, D. 1988. GIS versus CAD versus DBMS: What are the differences? *Photogrammetric Engineering and Remote Sensing*, 54(11), pp.1511–1555.
- Eastman, C.M. 1975. The use of computers instead of drawings in building design. *AIA Journal*, [online] 63(3), pp.46–50. Available at: <codebim.com/wp-content/uploads/2013/06/Eastman_1975.pdf>.
- El-Mekawy, M., Östman, A., and Hijazi, I. 2012. A unified building model for 3D urban GIS. *ISPRS International Journal of Geo-Information*

- Ellul, C. 2013. Can topological pre-culling of faces improve rendering performance of city models in Google Earth? In: *Progress and New Trends in 3D Geoinformation Sciences*, Lecture Notes in Geoinformation and Cartography. Berlin, Heidelberg: Springer Berlin Heidelberg, pp.133–154.
- Gröger, G., Kolbe, T.H., Nagel, C. and Hafele, K.-H. 2012. *Open Geospatial Consortium OGC City Geography Markup Language (CityGML) Encoding Standard*. 2nd ed.
- Herring, J.R. 2010. *OpenGIS® Implementation Specification for Geographic information-Simple feature access-Part 2: SQL option*. 1st ed. Open Geospatial Consortium.
- HM Government 2013. *Construction 2025. Industrial Strategy - government and industry in partnership*. HM Government.
- International Alliance for Interoperability (IAI) 2000. *IFC Technical Guide, Industry Foundation Classes–Release 2x.*, T. Liebich & J. Wix, eds., International Alliance for Interoperability.
- Isikdag, U. and Zlatanova, S. 2009. Towards defining a framework for automatic generation of buildings in CityGML using Building Information Models. In: *3D Geo-Information Sciences*, Lecture Notes in Geoinformation and Cartography. Berlin, Heidelberg: Springer Berlin Heidelberg, pp.79–96.
- Laakso, M., Kiviniemi, A., 2012. The IFC standard - a review of history, development, and standardization. *Journal of Information Technology in Construction*, 17, pp.134–161.
- Lee, G., Sacks, R. and Eastman, C.M. 2006. Specifying parametric building object behavior (BOB) for a building information modeling system. *Automation in Construction*, 15(6), pp.758–776.
- Mott MacDonald 2014. Building Information Modelling. [online] mottmac.com. Available at: <<https://www.mottmac.com/article/2385/building-information-modelling-bim>> [Accessed 11 Dec. 2014].
- Murray, C. 2013. Oracle Spatial Developer's Guide 11g Release 2.[online] Available at: <docs.oracle.com/cd/E11882_01/appdev.112/e11830.pdf>[Accessed 7 July 2014]
- Mvaerle 2010. GitHub : Python-ifc. [online] Available at: <<https://github.com/mvaerle/python-ifc>> [Accessed 11 Dec. 2014].
- Resch, B., Sagl, G., Törnros, T., Bachmaier, A., Eggers, J.-B., Herkel, S., Narmsara, S. and Gündra, H. 2014. GIS-based planning and modeling for renewable energy: challenges and future research avenues. *ISPRS International Journal of Geo-Information*, 3(2), pp.662–692.
- Safe Software 2012. FMEpedia - Converting BIM IFC data to CityGML. [online] Available at: <http://fmepedia.safe.com/articles/Samples_and_Demos/Converting-BIM-IFC-data-to-CityGML> [Accessed 8 Jan. 2015].
- Stoter, J., van den Brink, L., Vosselman, G., Goos, J., Zlatanova, S., Verbee, E., Klooster, R., van Berlo, L., Vestjens, G., Reuvers, M. and Thorn, S. 2011. A generic approach for 3D SDI in the Netherlands. Proceedings of the Joint ISPRS Workshop on 3D City Modelling Applications and the th D GeoInfo Conference Wuhan, China.
- van Berlo, L. and de Laat, R. 2011. Integration of BIM and GIS: The development of the CityGML

GeoBIM extension. In: *Advances in 3D Geoinformation Systems*, Lecture Notes in Geoinformation and Cartography. Berlin, Heidelberg: Springer Berlin Heidelberg, pp.211–225.

Weise, M., Liebich, T., See, R., Bazjanac, V., Laine, T. and Welle, B. 2011. *Implementation guide: Space boundaries for energy analysis*.

Worboys, M. 2011. Modeling indoor space. The 3rd ACM SIGSPATIAL International Workshop. New York, New York, USA: ACM Press, pp.1–6.

Biographies

Gareth Boyes is an experienced engineer and non-practising solicitor. In 2013 he turned his attention to geospatial research and started an MSc in GIS at UCL, London and submitted his dissertation on the “Integration of BIM and GIS”. He is now continuing his research on a PhD studentship at UCL.

Charles Thomson is a PhD student at University College London whose research investigates the automation and validation of parametric geometry reconstruction for BIM from point cloud data. He also has interests in the point cloud data collection process, especially in relation to indoor mobile mapping systems.

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