

# Integrating BIM and GIS :

## Exploring the use of IFC space objects and boundaries

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January 9, 2015

### 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).

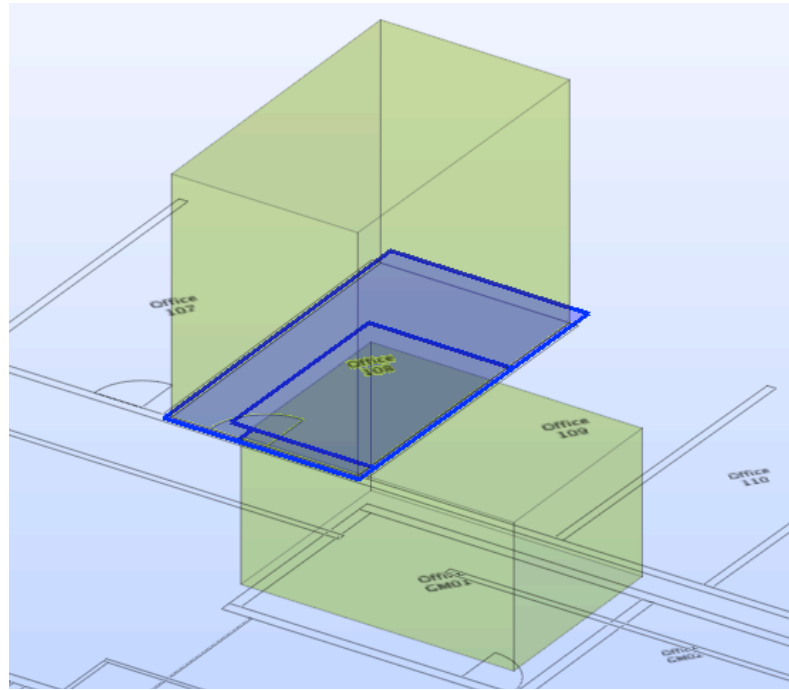
### 2.3. Integration of BIM and GIS

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

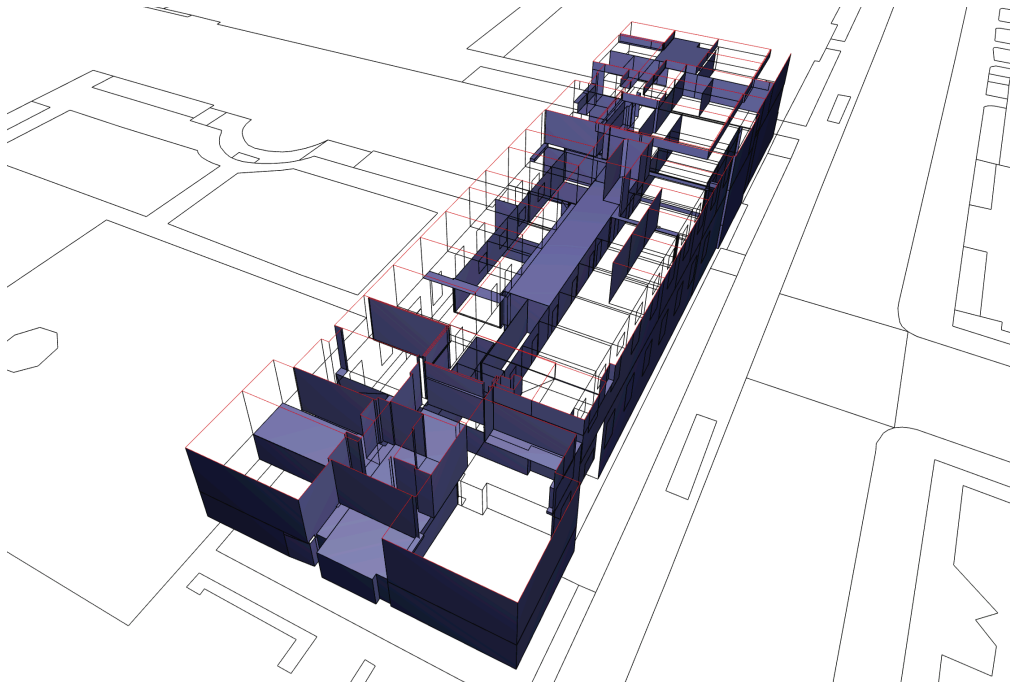
This investigation tested the methods developed on a BIM model of a building on the University College London campus. This model had been developed in Autodesk Revit from point cloud data captured using laser-scanning equipment (Backes et al., 2014). The model uses a coordinate system aligned to the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

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## **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.

Claire Ellul is a Lecturer in Geographical Information Science at University College London. Prior to starting her PhD, she spent 10 years as a GIS consultant in the UK and overseas, and now carried out research into the usability of 3D GIS and 3D GIS/BIM integration. She is the founder and current chair of the Association of Geographical Information's 3D Specialist Interest Group.