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Converting BIM Data to CityGML for 3D Cadastre Purposes

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Key words: BIM, CityGML, Strata XML, 3D Cadastre

SUMMARY

Currently, stratified property rights are registered and managed using two-dimensional subdivision plans. These plans do not accurately depict property spaces in complex structures such as high-rise buildings, tunnels and utilities, underground infrastructures, etc. 3D rich data like building information modelling (BIM) could be utilized as a source of 3D data for 3D urban data management especially 3D Cadastre. However, not all available data are useful and straight forward when it comes to 3D Cadastre due to the existing strata regulations. This paper describes how the BIM data could be transformed, modelled, and utilized for 3D Cadastre. Here, the conversion involves BIM data and Strata XML to CityGML format. This paper also demonstrates the procedure of the conversion of a building data. Several issues and challenges are highlighted at the recommendation section of this paper.

Converting BIM Data to CityGML for 3D Cadastre Purposes

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1. INTRODUCTION

Currently, stratified property rights are registered and managed using two-dimensional (2D) subdivision plans. These plans do not accurately depict property spaces in complex situations (high-rise buildings, tunnels and utilities, underground infrastructures, etc.). Additionally, the spatial complexity of three-dimensional (3D) property spaces associated with irregular physical structures within buildings may not be adequately represented by their projection into horizontal and vertical planes. Therefore, the cadastre should be extended to 3D space to accurately represent stratified properties and rights above or below a particular parcel (Gulliver et al., 2017).

The advancements in 3D Geographic Information Systems (GIS) and Building Information Modeling (BIM) propose novel methods for modelling urban space in 3D geometrically and semantically. Both systems propose appropriate methods capable of representing the geometry and semantics of 3D objects. 3D GIS can be used to capture the geometry and topological relationships of three-dimensional cadastral objects. Additionally, it enables the structuring of semantic data about these cadastral objects in a relational 3D spatial database. By contrast, BIM is a process that is object-oriented and describes buildings in terms of their geometric and semantic properties. As a result, it enables the creation and management of spatial models of the physical and functional characteristics of building spaces and their surroundings (Isikdag and Zlatanova, 2009).

3D cadastre enables the representation and management of legal information concerning RRRs (Rights, Restrictions, and Responsibilities) and their physical models in 3D. Numerous scholars have explored the use of BIM and 3D GIS in the development of cadastral approaches. Extensions to the IFC (Industry Foundation Class) standard to represent cadastral concepts were therefore proposed in the context of BIM (Atazadeh et al., 2016), while 3D GIS-based approaches have adopted the CityGML standard to provide an environment for 3D spatial analysis (Ying et al., 2012). The integration of BIM and 3D GIS is largely based on the exchange of data between the two systems. Among the proposed approaches, the transformation between IFC and CityGML is adopted as a solution for semantic mapping between the two schemas. The conversion of BIM data to 3D GIS has shown a growing interest in several applications such as urban planning, 3D cadastre (Ohori et al., 2018).

Based on the current situation of BIM to 3D cadastre, there outmost need to consider the use of Strata XML which is currently implemented by the Malaysian mapping authority. Due to limitation on the Strata XML for 3D physical geometry storage, thus, there is a need to adopt CityGML for the 3D data storage. The authority uses Strata XML to store strata objects information such as *Building, Parcel Unit, Accessory Unit, Land Parcel, Common Property Unit, Limited Common Property Unit, etc.* for the management and registration. The Strata XML is currently a custom format for defining properties and attributes related to strata unit (title) and was developed based on XML syntax. Unfortunately, it is not able to be visualized in 3D views (the physical 3D strata objects) due to the lack of geometry information stored in the Strata XML. Therefore, this study aims to take advantage of the 3D data from the BIM model to support the legal ownership boundaries, cadastral attributes, and 3D visualization of the Strata XML objects. The remainder of the paper is structured as follows: Section 2 describes the related works on BIM and 3D cadastre, whereas Section 3 on the methodology, and finally, Section 4 highlights discussion and conclusion.

2. THE RELATED WORKS ON BIM AND 3D CADASTRE

BIM is an acronym for building information model and building information modelling. The later involves the creation, administration, derivation, and sharing of information across many specialists in the fields of architecture, engineering, and construction (AEC) industry, making communication and cooperation easier (Eastman et al. 2011). Where it’s resulted to 3D model comprises of the following: semantic information, functional elements, geometry also, created mutual relationship between structural components like the architectural and structural components within the structures (Atazadeh et al., 2018). BIM has tremendously solved the issue surrounding 2D and 3D, therefore suggested numerous resourceful benefits in the AEC industry (Arayici and Tah 2008), that leads researchers developed interest in this domain in order to find a solution related to interoperability and information integration (Isikdag et al., 2013). The problem of interoperability within the industry was solve by introducing an open data model that serves as a link for interoperability and information sharing among numerous BIM software packages and thus “industry foundation classes” IFC developed by buildingSMART in 1994 (buildingSMART). As aforementioned, it is an open BIM standard that uses a common information model to manage physical building components and increase interoperability across various BIM applications.

The application of BIM world based on IFC standard in 3D cadastre has been explored in various countries across the world as shown in Table 1.

Table1: Summary of related work on BIM (IFC) in 3D cadastre based on country.

Country	Author(s)	Deliverables
Australia	Rajabifard et al., 2019; Atazadeh et al. 2019; Atazadeh et al. 2021; Atazadeh et al. 2018	Developed an approach enriching BIM with cadastral information, where the IFC standard is broadened with various data requirements in urban cadastre such as boundaries, attributes, administrative plan information, legal ownership space etc. Extending IFC data by harnessing LADM data elements to support the integration of legal and physical view. Create a relationship between BIM and LADM environment which would subsequently provide a better understanding of legal spaces

Country	Author(s)	Deliverables
Netherlands	Storter et al., 2017; Oldfield et al., 2016.	BIM is considered as a primary source of 3D digital data 3D cadastre. Enactment of BIM for 3D cadastre based on a new workflow to facilitate cadastral registration using 3D PDF.
China	Ying et al., 2019	The study focused on the developed easement modelling approach (EMA) by utilising BIM environment. It's determined that IFC standard is an effective data model for easement specialization. BIM environment enhances the representation of 3D cadastral objects. Developed and analysed a conceptual model based on IFC standard. Finally, it was presented that the integration of legal and spatial information in BIM was named as a successful approach for handling and functioning buildings as well as planning and developing a compressed city in China.
Sweden	Andree et al., 2018; El-Makawy et al., 2014; Sun et al., 2019	A smart built environment was created to serve as a strategic program to identify potential methods for effective utilization of BIM data during the building development process including planning, building permit, property formation and management. The following were taken into consideration, legal problem, financial aspect, and technical matters. More recently research has proposed a generic framework for 3D cadastre by integrating IFC and CityGML data the integrated model was later link to LADM data in order to provide a comprehensive legal and spatial view of indoor and outdoor ownership spaces in a complex built environment.

Based on the literature, it has been spelled out that IFC as a BIM standard provides data for 3D cadastre such as a comprehensive legal and spatial data of ownership spaces in complex structures. The integration of IFC and LADM environment create a mutual relationship that would provide a better understanding of legal spaces in future. It is noted that in many countries current registration and modelling of buildings is not sufficient to give unambiguous and faithful spatial representation in the cadastre. Therefore, the mentioned situation motivates this particular work in Malaysian 3D cadastre scenario.

2.1 IFC XML

In this paper we used IFC an open data model for our conversion to 3D cadastre. The default IFC file format is based on the international standard organisation (ISO) a standard for the exchange of product data (STEP) physical format (SPF) standard. IFC SPF is the most widely used format of IFC, it is a text format defined by ISO 10303-21 (STEP file), where each line typically consists of a simple file extension “ifc”. It has the advantage of compact size set readable text. The file can also be opened with Notepad in Windows, or any other text editor. However, this can only be done in order to see the text data that make up the file, the 3D design cannot be visualized in any of these programs. In contrast, ifcXML files are XML-based, is a substitute to the plain text. The IFC format, utilises XML formatting so that the building model data can be exchanged and parsed more easily also, use XML viewer and editor in order to understand the text in those types of files. Converting IFC file to ifcXML and others like OBJ etc. IfcOpenShell can be used to save IFC file to several other file formats.

2.2 CityGML

Gózdz et al. (2014) presented an investigation confirmed that CityGML offers a flexible conceptual model which can be tailored to land administration domain, specifically for supporting the spatial concepts needed for cadastral systems. The CityGML is an XML-based open data standard for storing and exchanging virtual 3D city models. It's an application schema for GML 3.1.1 (GML3), an open international standard enabling geographic data sharing. The goal of CityGML development is to arrive at a standard description of a 3D city model's core entities, characteristics, and relationships. A geometric model and a theme model are included in the standard.

A core module and theme extension modules make up the CityGML data model. The expansion modules address particular theme aspects of the virtual 3D city model, such as Appearance, Bridge, Building, City Furniture, City Object Group, Generics, LandUse, Relief, Transportation, Tunnel, Vegetation, Water Body, and Textured Surface. Moreover, Application Domain Extensions (ADEs) can contribute to the CityGML data model. The CityGML distinguishes five successive Levels of Detail (LOD), with each LOD increasing object detail in terms of both geometry and thematic elements (CityGML, 2012).

3. THE METHODOLOGY

The methodology involves three phases which are BIM data filtering, 3D objects extraction and conversion, and integration with Strata XML. Figure 1 illustrates the overall of data integration from IFC model and Strata XML into 3D Strata Units. The use of geometric data from IFC model is to build a 3D cadastre in the context of buildings (by conversion into CityGML format).

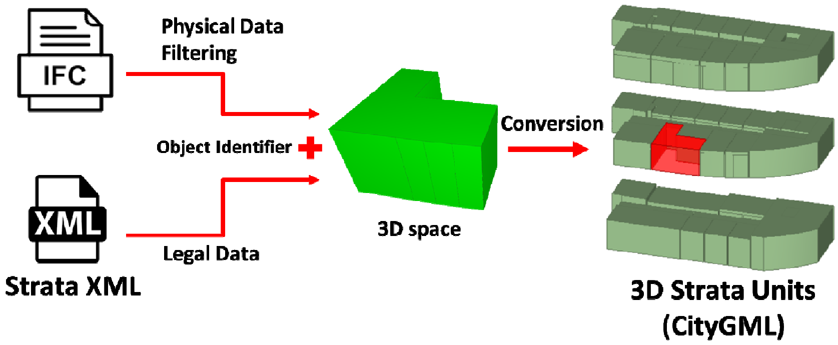

Figure 1: The overall of data integration from IFC model and Strata XML into 3D Strata Unit.

3.1 BIM data filtering

BIM data filtering phase was carried by identifying the important elements (e.g., *IfcSpace* and *IfcZone*) in the IFC model. The IfcSpace refers to an entity that is used to represent volumetric functional spaces within a building. Figure 2 shows the use of IFC model dataset that contains rich IFC structural entities such as *IfcWindow*, *IfcSpace*, *IfcDoor*, *IfcRailling*, *IfcSite*, *IfcWall*, *IfcSlab*, etc.

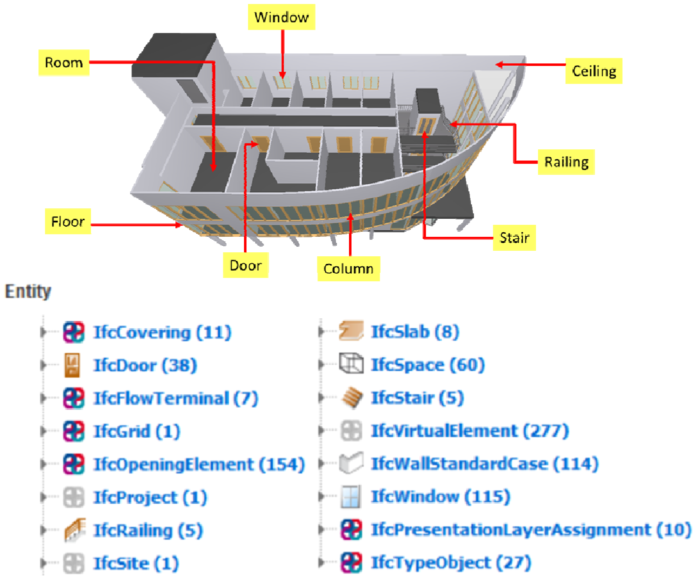

Figure 2: The IFC model for 3D cadastral purpose.

The physical BIM data which is *IfcSpace* filtered to create 3D cadastral objects based on the legal data contain in the Strata XML. The space data from the BIM can be used to provide legal boundaries in 3D which is limited in the current 2D strata and subdivision plans.

3.2 3D objects extraction and conversion

The 3D physical object extraction phase involves the extraction of geometries and semantic data from the IFC model. The *IfcSpace* and *IfcZone* entities are filtered to match with the strata objects in the Strata XML file. Figure 3 shows the filtered IFC physical data (geometries) that have been identified belong to a strata unit.

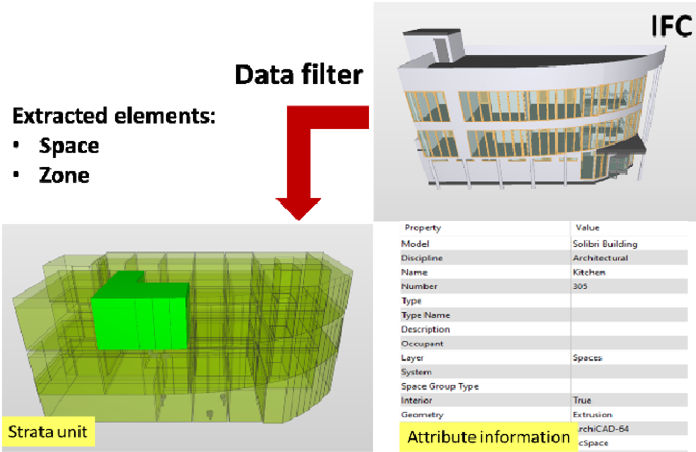

Figure 3: The extraction of 3D space from the IFC model.

The process of physical data extraction, mapping, and conversion are conducted using the data integration platform called FME (Feature Manipulation Engine). Figure 4 shows a part of the data processing workflow in FME, which is translating the IFC elements into CityGML data format. The role of CityGML is for the 3D physical data storage due the limitation of Strata XML. Legal data from the Strata XML (e.g., *Building, Parcel Unit, Accessory Unit, Land Parcel*, *Common Property Unit*, *Limited Common Property Unit, etc.*) are transferred to CityGML and stored as attributes information under the Building and Space layers.

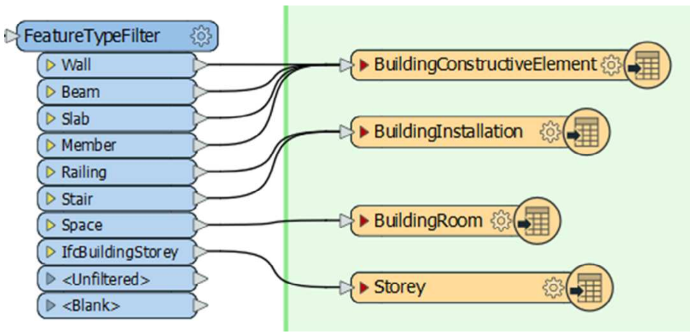

Figure 4: Data extraction and conversion from IFC to CityGML through FME.

3.3 Coordinate transformation

The converted 3D model in CityGML is georeferenced based on the coordinate system used in the Strata XML. IFC files are 3D models in a planar surface, therefore do not contain geographic information. The files are often placed using the LCS (local coordinate system), mostly used in the computer 3D design tools, in this case the origin of the file is at (0,0,0). Geographic coordinate system (GCS) is to define the location of object on the earth, considering the 3D spherical surface. The transformation of the LCS building model to a GCS model in the host CityGML, is significant to choose the right coordinate systems, so also the process for the translation of the coordinates. At this point the absolute projected coordinates system was selected (EPSG:4920) for the georeferencing purposes.

In order to extract the geometric information of a building elements, two categories of information are significant, and was considered, these include: the placement of the element (*IfcLocalPlacement*) and its representation (*IfcProductDefinitionShape*). The placement defines the location of an element, and the representation defines the shape of that element. Next, the local coordinates of the objects' vertices were computed using the following equation (1).

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = Ax \begin{bmatrix} Wx \\ Wy \\ Wz \end{bmatrix} + \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad \text{........... (1)}$$

where:

(Wx, Wy, Wz):	represents the direction Vector of sweeping
A:	represents the sweeping distance.
(x', y', z'):	represents the LCS.
(x, y, z) :	represents the GCS.

Finally, is the computation and the transformation of the LCS to GCS using a transformation matrix equation as presented by (Wu & Hsieh, 2007) in the equation (2), CityGML object model is generated.

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & cos\varphi x & sin\varphi x \\ 0 & -sin\varphi x & cos\varphi x \end{bmatrix} \begin{bmatrix} cos\varphi y & 0 & -sin\varphi y \\ 0 & 1 & 0 \\ sin\varphi y & 0 & cos\varphi y \end{bmatrix} \begin{bmatrix} cos\varphi z & sin\varphi z & 0 \\ -sin\varphi z & cos\varphi z & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} + \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} \quad \text{-- (2)}$$

where:

(x,y,z): represents the GCS.
(x',y',z'): represents the LCS.
(Δx,Δy,Δz): represents translation (change) from LCS to GCS from the origin.
(φx,φy,φz): respectively represents the angle of rotation with respect to (x-axis, y- axis and z-axis)

3.4 Integration with Strata XML

The integration phase involves the process of identifying and linking the extracted 3D physical objects with the legal data from the strata objects (Strata XML). There are two types of identifiers used related to cadastre management in Malaysia called Unique Parcel Identifier (UPI) and Unique Feature Identifier (UFI). UPI is crucial in matters related to land and strata since it is used to describe each land parcel individually. Code for each UPI is determined by the authority with 16 characters according to State, District, Town / City, Sections and Lot No. Meanwhile, UFI is a code that consists of 26 characters with additional 10 characters of UPI used to describe 3D cadastre in Malaysia. It was introduced to represent multi-level buildings such as Apartments and commercial buildings. Figure 5 illustrates the process of linking the 3D geometry with the strata objects through the utilization of UFI as the key object identifier.

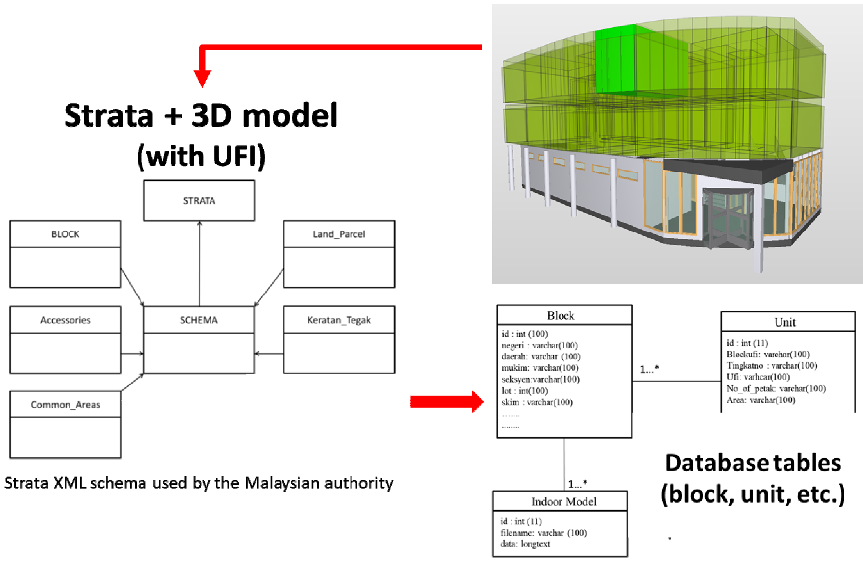

Figure 5: Process of linking the extracted 3D physical geometry with the strata objects (legal data) via the utilization of UFI.

The Malaysian Strata XML consists of *block*, *strata*, *land_parcel*, vertical section (*keratan_tegak*), *common_areas*, and *accessories*. The 3D physical space is assigned with the ID to the strata schema via UFI linkage. Then, the linked data (Strata XML and 3D model) is output into the destination format (i.e., CityGML) enriched with the physical and legal information.

4. DISCUSSION AND CONCLUSION

This paper proposed a method for converting BIM data to CityGML for 3D cadastre purposes that utilized the rich structural information in IFC model to support the legal ownership boundaries, cadastral attributes, and 3D visualization of the strata units. Figure 6 shows the strata units based on the integration of BIM model and Strata XML.

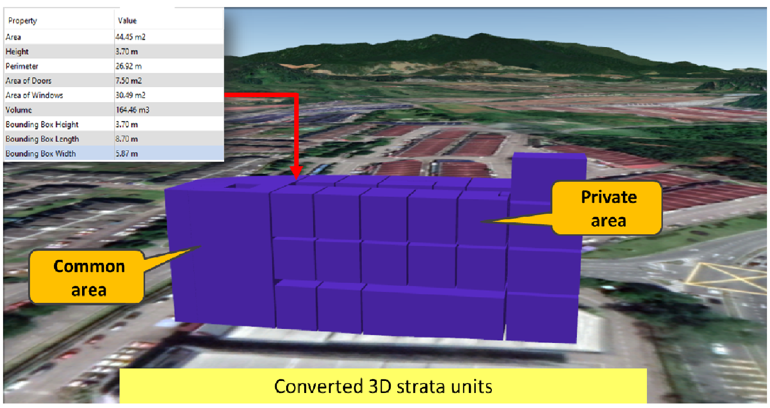

Figure 6: The strata units based on the integration of BIM model and Strata XML.

In this method, the flexibility of IFC as a standard for BIM was utilised to harness the rich data for the conversion such as *IfcSpace* and *IfcZone* as source elements suitable for 3D cadastral objects modelling due to their versatility for geometrical aspect of 3D cadastral objects, for example, walls, floors (upper and lower), doors, and window, also, *IfcLocalPlacement* and *IfcProductDefinitionShape* for the location and shape of the objects respectively. The conversion able to produce strata data into CityGML based format building with several floors and strata units. Furthermore, especially the ownership of a strata unit can be identified such as blocks, buildings, accessories, land parcels and common area information as indicated in Figure 6.

This paper strongly believes that the work obviously requires more attention in the aspect of physical geometry data filtering, and semantic data mapping (different coordinate systems). Other recommendation, such as modification of the data structures of geometry and semantic information of the two models (IFC and CityGML). Important aspects of 3D cadastral such as RRRs (Rights, Restrictions, and Responsibilities) will be investigated further in the near future. Currently, the paper focuses on the modelling and the Rights aspects. Apparently, innovative conversion from 3D cadastral to BIM could be investigated further such as for updating purposes.

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BIOGRAPHICAL NOTES

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