THE INTEGRATION OF BIM AND GIS IN CONSTRUCTION PROJECT – A DATA CONSISTENCY REVIEW

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ABSTRACT:

From days to days, management of construction project has been improved during life-cycle project, starting from planning until maintenance. This happen cause of the advantages in implementation technology of Building Information Modeling (BIM) and Geographic Information System (GIS) in supporting construction project. Few years ago, enhancement in term of BIM and GIS that provides an additional extension for the purpose of information management is very interesting. With the advantages that been provided by BIM and GIS, information of construction project can be adapted into real situation of the construction site which be helpful during the life-cycle of building construction. BIM and GIS is a different platform which contains their own advantages that support construction project. In order to bring the most effectiveness in management of construction project, integration between BIM and GIS becomes an important task to support the design phase until operational phase which include the facility management and maintenance. Although this integration can support the building information management, the software that used in integration process is still having limitations and differences in fulfilling the needs of users. For that reasons, data consistency needs to be studied in order to develop the best practices of integration application. The purpose of this paper is to investigate the data consistency during the integration process. From the investigation, it showed that there are some data inconsistency occurs in IFC platform after conversion process. Through this paper, the comparison of the geometric and semantic data before and after translation process will be examined.

1. INTRODUCTION

In the concept of construction project, Building Information Modeling (BIM) can provide a database that can link to any model. Usually this database contains the building information for the life-cycle of construction process until maintenance parts (Eastman et al., 2011; Arayici and Aouad, 2010). Along with the models, BIM also offer the advance of three-dimensional (3D) viewing that can make the process of data interpretation become easier and accessible (Ahzar, 2011). Meanwhile, Geographic Information System (GIS) model focuses on acquisition, editing, manipulation, analysis, modelling, visualization, and storage (Goodchild, 2009). These data can be represented into 2D thematic map or 3D map. More works in GIS can be seen working in 3D (see Shichao et al., 2020; Keling et al., 2017; Azri et al., 2014). For the better practice in construction project, integration between BIM and GIS should be considered. Although these two platforms can support various type of data, it still difficult to transform the data from one platform to another platform.

In 1995, The International Alliance for Interoperability (IAI) was established to develop first version of vendor naturel standard, called Industry Foundation Classes (IFCs). IFCs are a collection of entities (classes), that form an information model and it was released in 1997 (Isikdag et al, 2004). According to Arayici and Aouad (2010), IFC standards have been implemented in software application to create a common data exchange platform. An IFC standard is a primary standard that used for information transfer in BIM and GIS domains (Lim et al., 2019). Practically, the end user of the application used IFC as a feature to save and retrieve data in a form that is understandable to other software applications.

Nowadays, the process of conversion data between BIM and GIS is still a problem because of the mismatch data among them (Basir, 2018; Sani, 2018; Andrew, 2020). This happen because of the limitation associated with these two platforms which involve the data exchange and knowledge. In general, dissimilarities and mismatches between BIM and GIS happen because of different users' requirements, different application, different developmental stages, different spatial scales, different coordinate system, different semantic and geometric representations, different levels of granularity, and different information storage and access methods (Liu et al, 2017).

In order to bridging the gap between BIM and GIS model, providing interoperability in semantics at the data level (Juan et al., 2006; Vanlande, 2008; Wu et al., 2010; De Laat, 2011; El-Mekawy, 2012 (a); El-Mekawy, 2012(b); Donkers, 2013; Mignard and Nicolle, 2014; Kand and Hong, 2015;) and as well as web services (Berners-Lee, 2006; Groger, 2007; Lapierre and Cote, 2008; Niu et al., 2015; Karan, 2015; Beetz, 2014; Deng, 2016(b); Pauwels et al., 2017) is the best solution. While data interoperability can bridge the gap between BIM and GIS, data consistency needs to be defined throughout transformation in order to evaluate the process's effectiveness.

2. DATA CONSISTENCY

Data consistency is one of the components in data quality for geospatial database. There is multiples interpretation of data consistency. Table 1 show the interpretation of data consistency based on different purposes.

Authors Name	Years	Interpretation of Data Consistency
Veregin, H.	1999	Data Consistency refers to the absence of apparent contradictions in a database.
Srivastava, R.N.	2008	Data consistency can be termed as the absence of conflicts in a particular database.
Wang, F.	2008	Spatial data consistency refers to the logical rules of structure and attributes for spatial data and describes the compatibility between dataset items.
ISO/TC 211 standard 19113	2002	Logical consistency as " degree of adherence to logical rules of data structure, attribution and relationships (data structure can be conceptual, logical or physical)"
Plumer, L and Groger, G.	1997	Data consistency refers to the lack of any logical contradiction within a model of reality.
Abadi, D.	2019	Data consistency refers to the ability of a system to ensure that it complies (without fail) to a predefined set of rules, but this rules changes based on context.
Shi et al.	2019	Data consistency is a data characteristic that contradictory conclusions cannot be derived from the given data.

Table 1. Interpretation of data consistency.

There are many aspects of data consistency problems in spatial databases, such as the inconsistency between attribute and geometry data; the inconsistency of topological relations after geometry objects is modified (Xinyan et al., 2000(a); Xinyan et al., 2000(b)).

In this paper, we bring for you a review of data consistency during the data integration between BIM and GIS. Besides, the comparison based on the tools used during conversion process also was observed.

3. REVIEW ON DATA CONSISTENCY IN DATA INTEGRATION BETWEEN BIM AND GIS

In construction process, there are several phases that involved during the life-cycle which started from the planning and design (P&D), construction, operation and maintenance (O&M) and demolition (Ma and Ren, 2017). In order to organize all these phases, BIM was used to manage the data during entire life-cycle of construction process.

GIS can be defined as the information that related to the geography which provides the detail spatial data on specific location by using coordinates. By integrating these two platforms, BIM data can be representing in the real world.

Integrating BIM and GIS can be done by using three options which are (Ma and Ren, 2017):

i. Extract data from BIM system into GIS system
ii. Extract data from GIS system into BIM system
iii. Extract data from both systems (BIM and GIS) into another system.

For this paper, reviews on the part of data consistency from BIM system into GIS system will be discussed.

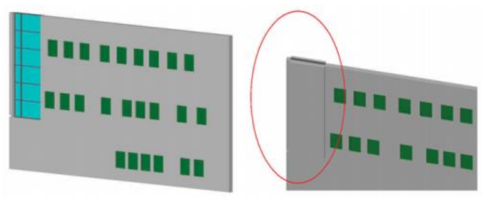
Zhu et al. (2020) proposed an approach for automatically converting IFC clipping representation onto shapefile format for the use in GIS. The proposed method successfully automated the conversion of IFC clipping into shapefile and the type of half space, and increasing the boundary size will not increase the size of corresponding B-Reps for half space, but will slightly increase the producing time of half spaces and processing time of building components. The conversion of geometry data becomes easier, more efficient and more reliable way.

Zhu et al. (2019) studied on an Open-Source Approach (OSA) that can retrieved the geometric information in IFC through the spatial structure IFC and converted into shapefile by developing an automatic mutipatch generation algorithm (AMG). By using this AMG, the multipatch can be generated regardless of the initial ring order and extrusion direction. With any ring (clockwise or anti-clockwise), patches can always be generated. However, the results of multipatch may not be closed and thus have limited usage. This study focus on geometry information, therefore semantic information need to be enhanced because only few attribute were extracted during the process. The comparison has been done between OSA, Data Interoperability Extension for ArcGIS (DIA) and Feature Manipulation Engine (FME). Table 2 show the comparison conversion process between OSA, DIA and FME.

	Time (s)	Shapefiles Output	Model Scale
OSA	2.5	One model for entire bridge	Output model with correct scale.
DIA	32.3	Cut the bridge model into three individual parts (beam, slab, and column)	Output model may have error if length unit other than 'meter'.
FME	0.8	One model for entire bridge	Output model may have error if length unit other than 'meter'.

Table 2. Comparison conversion approach using OSA, DIA and FME.

Adouane et al. (2019) developed a method to solve geometric and semantic problem during the process data conversion from BIM-IFC into CityGML. The main advantage of that method is to control data flow, especially for geometric processing, which is advantageous to prevent from potential artefacts. In order to reinforce the mapping performances, maximising the use of schemas that available in CityGML is one of the important elements when BIM-IFC datasets are involved. During this process, there is some inconsistency on geometric data which is results of geometrically errors. Figure 1 shows the data inconsistency on geometric data after conversion process.



(a) Expected facade conversion (b) Unexpected facade obstruction.

Figure 1. Data inconsistency after conversation process.

Figure 2 below shows the validation for each element in the model. The consolidated Δ result found zero, encourages and validates the results. From this figure, the result of data consistencies can be seen which refer to each element in BIM were correctly mapped in CityGML.

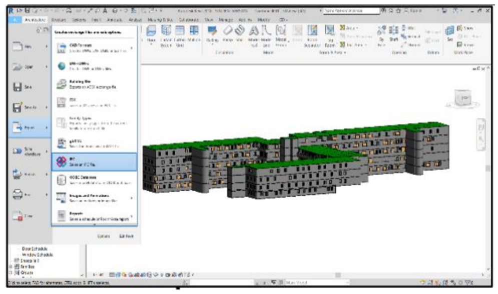
	IFC			total	Δ	total	CityGML
	ifcBuilding						bldg:Building
	1			1	0	1	1
	ifcSpace						bldg:Room
	91			91	0	91	91
	ifcDoor						bldg:Door
	100			100	0	100	100
	ifcWindow						bldg:Window
	24			24	0	24	24
ifcSlab	ifcCovering	ifcMember					bldg:FloorSurface
29	65	3308		3402	0	3402	3402
	ifcRoof						bldg:RoofSurface
	1			1	0	1	1
ifcWallStandardCase	ifcWall						bldg:WallSurface
166	6			172	0	172	172
ifcStairFlight	ifcPlate	ifcBuildingElementProxy	ifcBuildingStorey				bldg:BuildingPart
20	1349	50	5	1424	0	1424	1424

Figure 2. Validation elements from IFC into CityGML.

The other limitation is the way of geometry is explicitly stored in the model, which consequence to artificially increase the size of the generated CityGML target instance.

Wang and Raja (2019) utilizes the standard open-sourced indoorGML data structure as the medium model to develop indoor ontology at semantic level. The proposed method can facilitate the semantic interoperability between BIM/IFC and GIS/IndoorGML. This method can enhance the seamless data exchange between BIM and GIS applications which lead to the improvement of indoor routing for the project operation stage. In information of IFC elements consists of ID, GUID, and property name and reference IFC instance IDs. For entity IfcDoor and IfcWindow, additional attributes such as OverallHeight and OverallWidth was included. Geometric information was completely translated during the translation process although only few detailed semantic information was carried forward during the translation.

Mustorpha and Mohd (2019) studied on the 3D indoor GIS requirements for space management which is data level integration, data management, 3D indoor GIS analysis and 3D space management. During this study, geometric information exported from Revit through IFC into multipatch feature using ESRI Data Interoperability Extension. There are four IFC data components; geometry, semantics, relationship classes and properties of building elements are converted into 3D indoor GIS. The IFC geometry been converted into boundary representation (b-rep), Sweep Solid (SS) and Constrictive Solid Geometry (CSG) while semantics of building elements between IFC classes could be transformed into semantics in GIS environment. Figure 3 show the geometric information exported from Autodesk Revit software through IFC into multipatch features by using ESRI Data Interoperability Extension for developing ESRI geodatabase.



(a) Export BIM model from Revit into IFC format

(b) Import BIM IFC model to GIS format

Figure 3. Example of BIM to GIS data conversion for 3D indoor GIS

Table 3 shows several BIM elements in IFC format that can be transformed into the 3D indoor GIS. Therefore, the information from IFC data needs to be properly organized in 3D space management to keep their source correctly.

BIM elements	GIS elements
IfcWall	Wall
IfcWindow	Window
IfcDoor	Door
IfcCovering	CeilingSurface
IfcSpace	Room

Table 3. Semantic data in IFC organized in GIS environment

Floros et al. (2018) investigated interoperability options between the aforementioned standards, by converting IFC models to CityGML LoD 4 Models. During the converting process, an important attribute has been missing which is texture of the surface. During modelling the model, Autodesk Revit can assign and visualized the material but during export to IFC, the texture of surface is lost. This happen because IFC is designed for Architecture, Engineering and Construction (AEC) purposes and does not support the texture visualization (De Laat and v. Berlo, 2011). However, it is possible to maintain this type of information as semantic information. Figure 3 show the IFC material of walls transferred to CityGML.

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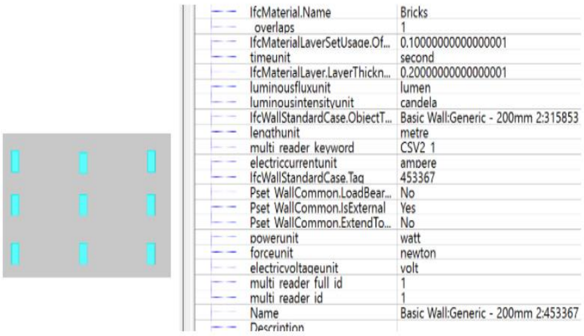

Figure 3. IFC material of walls transferred to CityGML LoD 4 model.

Besides that, the separation and manipulation of the entities in order to generate a LoD 4 model is more challenging compare to LoD 3 model since the interior of the building encloses more geometric and semantic information than the exterior. Moreover, the different software environments during the conversion process can benefit the generated CityGML model by fixing errors that affect the representation and implementation of the generated model such as a door that misses multiple surfaces due to the fact that the IFC properties and elements are either damaged or missing elements in the first place. Another example is the fact that IFC solids can overlap which can be a common mistake since in BIM all components are placed based on the set elevation views and an unintentional error is possible.

Deng et al. (2016(a)) investigated 3D traffic noise mapping using data from BIM and GIS integration. In this paper, BIM and 3D GIS integration is used to assess the traffic noise for indoor and outdoor environment in one platform. The built platform contains 3D GIS models at high levels detail of data from BIM. With this integration, the 3D GIS model can access detailed indoor features for noise evaluation. Important parameters such as absorption coefficient and transmission loss can be extracted directly from BIM for noise calculation. The data conversion engine is developed to allow seamless data integration between BIM and GIS which mean all data in BIM model can be translated into GIS model without missing geometry data and information that needed for noise mapping.

Teo and Cho (2016) proposed an indoor network model from BIM for various indoor-outdoor routes planning application (e.g., emergency response and pedestrian route planning). The advantage from this study is reuses the existing BIM data and extend it to GIS analysis. An algorithm to automatically generate 3D indoor network model from BIM call multi-purpose geometric network model (MGNM) using IFC-to-MGNM strategy. MGNM refines geometry and attribute information which contains various elements such as room, door, windows, landing from BIM into GIS platform.

Tashakkori et al. (2015) proposed the new 3D Indoor or Emergency Spatial Model (IESM) to assist rescuers in the planning emergency response in improving destination travel times. This IESM was developed based on the IFC representation of BIM which is contained geometric and semantic of building elements and space inside the buildings. This IESM can provide the detailed semantic and geometrical information of building, and emergency information which enables spatial queries and information retrieval about indoor environment. Figure 4 shows the example of the translation result's IFC into GIS which cover the semantic and geometric information in GIS platform.

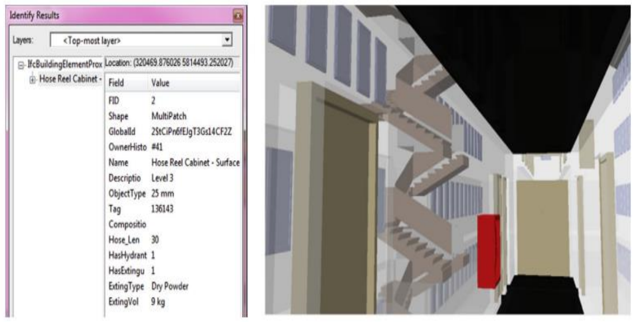

Figure 4. Location of indoor emergency utilities and their semantic information.

Through the new IESM, it can be used to identify which area of the building can be accessed by using a fire hose with a certain length and in particular identifying the originating point. Figure 5 show IESM can useful in identify all points that can be reached within 10 m walking distance from the originating point even considering the stairs level distances.

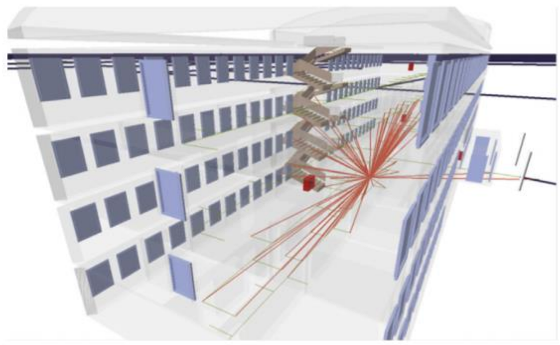

Figure 5. Identifying reachable areas using certain length fire hose (Tashakkori et al., 20015).

Amirebrahimi et al. (2016) presented a method for BIM-GIS integration to support the requirements of detailed assessment and 3D visualization of flood damage to buildings. Through this paper, a data model that was proposed allows information storage to be unified and consistent from building information along with flood parameters and other information (e.g. Height model) to support the micro-level Flood Damage Assessment (FDA) in the building. The integration of BIM-GIS can facilitate the detailed assessment and 3D visualization of the cost of building damage that are currently not supported by the input type used in current method for FDA. Besides that, the designed data model allows for a unified and consistent storage of the detailed representation of the building information alongside the flood parameters and other information (e.g. elevation model) in support of the micro-level FDA on buildings. Table 4 illustrates the mapping between the building components of the proposed data model and the IFC4 classes.

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Building element	Class in data model	Class in IFC4
Property, parcel	*Site*	*IfcSite*
Building	*Building*	*IfcBuilding, Pset_BuildingCommon*
Buliding storey	*BuildingStorey*	*IfcBuildingStorey*
Space	*Space*	*IfcSpace*
Building assembly	*_BuildingElement*	*IfcBuildingElement*
Roof	*Roof*	*IfcRoof*
Beam	*Beam*	*IfcBeam*
Column	*Column*	*IfcColumn*
Slab/floor	*Slab*	*IfcSlab*
Stairs	*Stair, StairFlight, Railing*	*IfcStair, IfcRailing, IfcStairFlight*
Wall	*Wall*	*IfcWall, IfcWallStandard*
Building element part	*_BuildingElement, BuildingElementPart*	*IfcBuildingElementPart*
Framing members	*FramingMember*	*IfcMember*
Windows	*Window, WindowPanel, WindowLining*	*IfcWindow, IfcWindowPanelProperties,IfcWindowLiningProperties*
Doors	*Door, DoorPanel, DoorLining*	*IfcDoor,IfcDoorPanelProperties,IfcDoorLiningProperties*
Glass layers	*GlassLayers*	*Pset_DoorWindowGlazingType*
Weep holes/other void openings	*Weephole, voidOpening*	*IfcOpeningElement, IfcVoidingElement*
Proxy elements	*BuildingElementProxy*	*IfcBuildingElementProxy*
Mouldings	*Skirting, Cornice*	*IfcCovering*
Eve linings (soffit)	*Soffit*	*IfcCovering*
Ceiling	*Ceiling*	*IfcCovering*
Flooring	*Flooring*	*IfcCovering*
Connections(e.g. wall tie)	*Connection, MechanicalConnection,*	*IfcRelConnectsElements, IfcFastener, IfcMechanicalFastener*
Spatial structures	*SpatialStructure*	*IfcSpatialStructureElement*
Materials	*Material, MaterialLayer, MaterialConstituent*	*IfcMaterial, IfcMaterialLayer, IfcMaterialConstituent*
Utilities	*_UtilityObject, FlowSegment _FlowController, _FlowTerminal,*	*IfcFlowTerminal, IfcFlowController, IfcDistributionFlowElement, IfcFlowSegment*
Classification	*Classification, ClassificationDefinition*	*IfcClassification, IfcClassificationReference*
Costs/values	*AssemblyCostObject, BuildingValue*	*IfcCostValue, IfcCurrencyRelationship*

Table 4. Mapping between the proposed data model's building relevant classes and the IFC 4 classes.

Isikdag et al. (2008) examined the applicability of BIM (IFC in particular) in a geospatial environment to facilitate the data management in location selection and fire response management processes through the use of multi-model geospatial information. Through this study, it show that it possible to transfer (high level of geometric and semantic) information acquired from BIM into GIS environment.

Figure 6 shows visual representations of two different BIMs in two different environments. The screenshots on the left show the BIMs in a CAD environment, while those on the right show the (same) models that are transformed into the geospatial environment and represented (visualized) in a GIS.

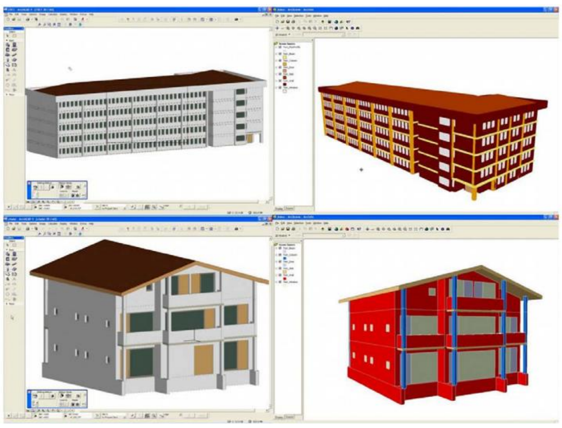


Figure 6. Different representations of two BIMs shown in both a CAD and a GIS.

There are two outcomes from this study that limit the implementation and representation of BIM in the geospatial context, as well as the section describing the design and physical implementation. This study also found that during the process of model transformation, two forms of data mismatches occur between BIM and the geospatial context. It corresponds to the geometric and semantic inconsistency.

Biljecki and Tauscher (2019) identified the common errors in the CityGML output that occur during the development of conversion method from BIM into GIS. The errors can be categorized as wrong spatio-semantic paradigms (Biljecki et al., 2016), semantic misclassification (El-Mekawy et al., 2012(b)), omission of features (Geiger et al., 2015; Donkers et al., 2016; Deng et al., 2016(b)), invalid 3D geometric primities, overlapping and inconsistent spaces (Lilis et al., 2018), lack of non-geometric information, dislocated geometry, high numeric values and mismatch of units (Donkers et al., 2016), attribute misconversion, lack of geographic references (Arroyo Ohari et al., 2017), schema errors, and redundancy of geometry.

4. MODELING THE BUILDING

Through this study, Autodesk Revit® 2017 was used to created 3D building model. This Autodesk Revit® is developed for the purposes of building information modeling (BIM) application. In Revit® BIM software, there are few design features that can be use such as architectural design, MEP and structural engineering and also construction. Each template of the design features is difference based on their requirement. Basically, Revit® can support multidiscipline, collaborative design process that provides a complete architectural design and documentation solution, started from the planning process until the finishing project (Revit®, 2017). Figure 7 show the BIM model in Autodesk Revit®. This BIM model contains all the information that needed in the construction project.

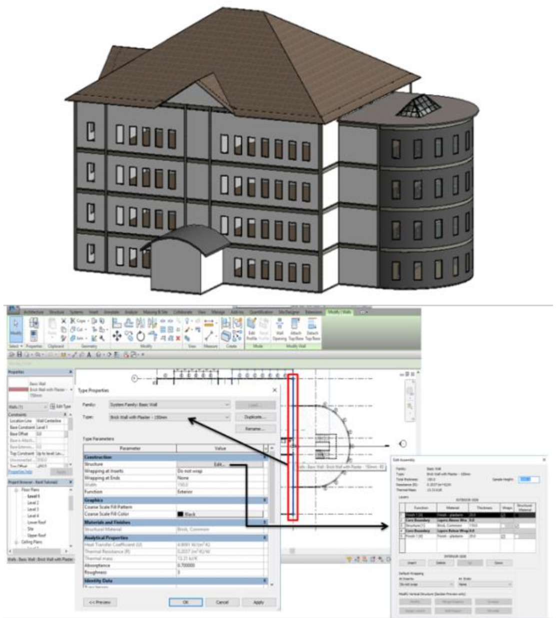


Figure 7. BIM Model in Autodesk Revit®.

5. BIM DATA CONVERSION

Besides of Revit® can supports multidiscipline design process, the other reason for choosing this software is Revit® also provide various type of exporting format such as CAD's format (dwg, wxf and dgn), gbXML, IFC, SHP and etc.. The focusing for this paper is exporting data using CAD format (.dwg) and IFC format. IFC was created by IAI for data interoperability purposes between different parties in Architectural, Construction and Engineering (AEC) (Eastman et al., 2011; Laakso, 2012). The objective of these tests is to investigate the result of BIM-GIS integrations.

5.1 Importing Data to ArcGIS

ArcGIS is a platform for organization to create, manage, share and analyse the spatial data (ArcGIS, 2017). One of the ArcGIS an advantage is this platform can read and analyse the CAD formats that have been exported from Revit®. Also, by using FME software, we can perform BIM format data into ArcGIS.

5.1.1 CAD Format (DWG) to ArcGIS 10

By using ArcGIS interoperability tool, CAD format (.dwg) can be read and manage as layers in ArcGIS software. Through this tool, CAD format will be categories in several layers such as annotation, multipatch, point, polygon and polyline. But, this data conversation still not offers the solution for the data integration because it only represents the geometric data, not including the semantic data.

5.1.2 IFC to ArcGIS

For IFC format, FME software was used to convert the data into ArcGIS. Figure 8 shows the data in IFC format. This 3D data is originally from Revit® software.

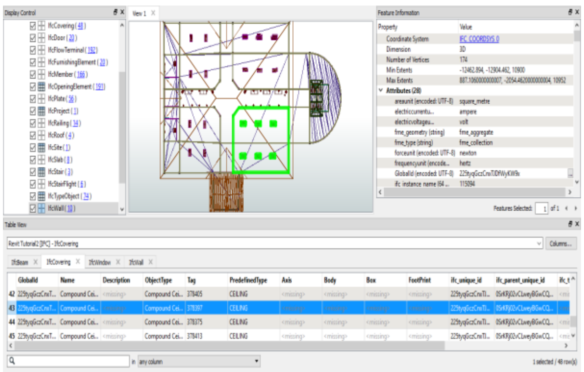
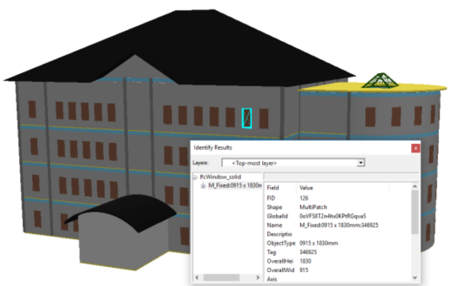


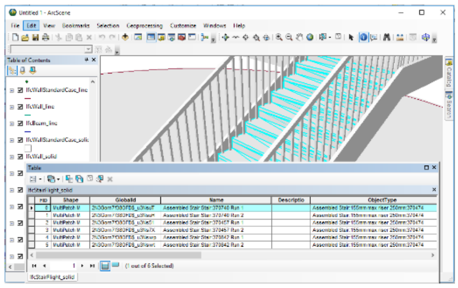
Figure 8. BIM model in FME (IFC format).

By using FME, the 3D building data will be imported as group of layers which identify each entity in the building. Each entity contains the geometric and also sematic data.

Figure 9 show the results of the conversion process from BIM into GIS. ArcScene software was used to visualize the model. In this model, querying process can be performed.



(a)



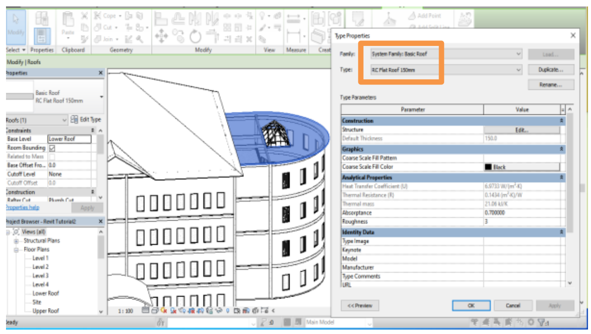
(b)

Figure 9. BIM model in ArcGIS platform ((a) 3D model in ArcScene which show the misallocated element flat roof into slab element, (b) the querying process of the StairFlight elements).

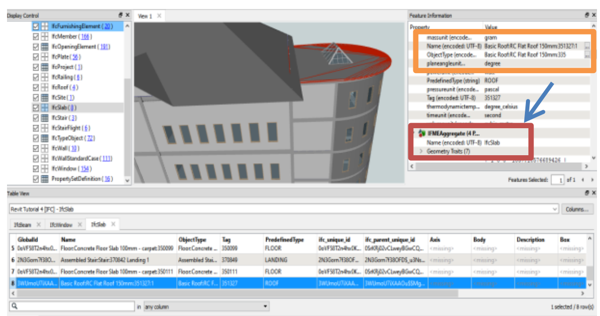
6. ANALYZING DATA CONVERSION BETWEEN BIM, IFC AND GIS.

After completed the process of conversion data between BIM (AutoDesk Revit®), IFC and GIS data, the next step is the validation of the model in term of data consistency (geometric and semantic data). This validation was focus on comparison of geometric and semantic data in each platform.

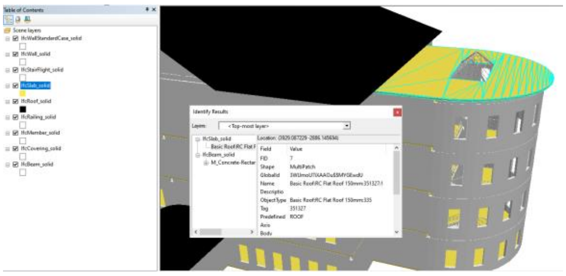
First validation is focusing on geometric data. During the process of conversion between BIM into IFC, there are some errors occur such as the “Flat Roof” in BIM (AutoDesk Revi®t) represents “Slab” in IFC (FME) and GIS (ArcGIS). Figure 10 show the validation of data inconsistency of geometric data after conversion process. In IFC platform, “Flat Roof” becomes one of entity in “Slab” elements.



(a) Flat Roof element was developing in AutoDesk Revit®.



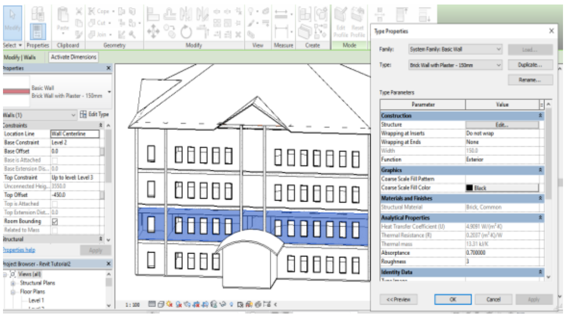
(b) Flat roof in roof elements in BIM becomes Slab elements after conversion BIM to IFC.



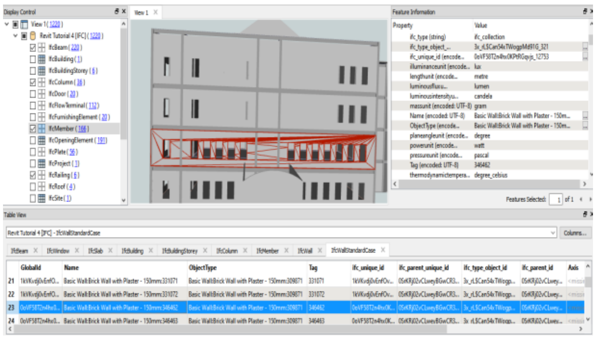
(c) Flat roof elements become Slab because of the process conversion from IFC into GIS.

Figure 10. Comparison of data inconsistency on geometric data after conversion process from BIM into IFC.

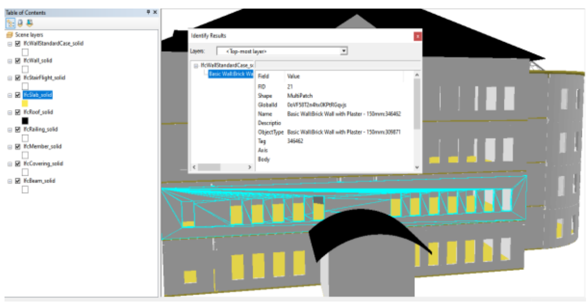
Second validation is on semantic data. There are some semantic data missing during converting BIM into IFC and GIS. In Figure 11 show the validation on semantic data after conversion process.



(a) Wall attribute in BIM platform.



(b) Wall attribute in IFC platform.



(c) Wall attribute in GIS platform.

Figure 11. Validation on part of data semantic missing during conversion process from BIM into IFC.

Through Figure 11, data inconsistency on part of data semantic can be seen. For example, in BIM platform, there is information about the level of the wall but during the translation process; the information is missing in IFC platform. In IFC platform, there are only several information that been carry forward from BIM such as the name of the element, object type, and ID. The rest information is missing. From Figure 11, we can see that wall attribute in GIS platform is same with wall attribute in IFC platform. Table 5 below show the possible reasons for occurrence of the data inconsistency during the test was conducted.

	Data inconsistency	**Reason for data inconsistency**
Geometric Data	Mismatch of data element (flat roof in BIM become slab in GIS platform)	It happen because of the characteristic of flat roof and slab is quite similar in GIS platform.
Semantic Data	Missing of data semantic during data exchange process.	During process of exporting data in Revit into IFC, it's did not bring along the BIM information because of criteria selection.

Table 5. The possible causes of the inconsistency during exporting process.

For part of visualization, BIM model in AutoDesk Revit® can view their material of the elements but in IFC, the material cannot be shown because IFC is designed for AEC purposes and does not support the texture visualization. In the term of storage, for the same model; the storage for IFC platform is biggest than BIM and GIS. Although IFC did not carry all semantic information from BIM (AutoDesk Revit®), the storage is still bigger; IFC is 8378 kb while BIM is 8060 kb.

7. SUMMARY

The paper provides an initial understanding of data accuracy of incorporating BIM data into GIS framework. Since BIM applications are still an ongoing research, many aspects would need to be investigated and assessed to explore for functionality possibilities of BIM data to be incorporated in GIS framework (including spatial and semantic data). Through this paper, a few issues on part of data consistency have been found especially on part of semantic data. In order to solve this issue, a few aspects such as the data format and the criteria selection for the semantic data need to be verified back. For future research, more advanced data analysis such as topological analysis (Salleh and Ujang, 2018), 3D spatial urban data management (Azri et al., 2016) and multi-criteria site selection analysis (Kaya et al., 2020; Mohd et al., 2016) can be carried out based on the BIM-GIS integration.

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REFERENCES

Abadi, D., 2019. Overview of Consistency Levels in Database Systems. http://dbmsmusings.blogspot.com/2019/07/overview-of-consistency-levels-in.html. (Accessed on Jun 2020).

Adouane, K., Stouffs, R., Janssen, P., Domer, B., 2019. A model-based approach to convert a building BIM-IFC data set model into CityGML. *Journal of Spatial Science*. doi: 10.1080/14498596.2019.1658650

Ahzar, S., 2011. Building Information Modeling (BIM): Trends, Benefits, Risks and Challenges for the AEC Industry. *Leadership Management Engineering,* 11(3): 241-252.

Amirebrahimi, S., Rajabifard, A., Mendis, P., Ngo, T., 2016. A BIM-GIS integration method in support of the assessment and 3D Visualization of flood damage to a building. *Journal of Spatial Science*, Pp. 1-12.

Andrew, C., 2020. Common Patterns for BIM and GIS Integration. https://www.esri.com/arcgis-blog/products/arcgis-pro/transportation/common-patterns-for-bim-and-gis-integration/ (January 2020).

Arayici, Y., Aouad, G., 2010. Building Information Modeling (BIM) for Construction Lifecycle Management. *Construction and Building: Design, Materials, and Techniques*, Pp. 99-118.

ArcGIS, 2017, ArcGIS 10.1 for Desktop, ESRI, http://www.esri.com/ products/ (December 2017).

Arroyo Ohari, K., Diakite, A., Krijnen, T., Ledoux, H., Stoter, J., 2018. Processing BIM and GIS Models in Practice: Experiences and Recommendations from GeoBIM Project in The Netherlands. *ISPRS International Journal of Geo-Information*, 7(8), 311.

Azri, S., Ujang, U., Castro, F.A., Abdul Rahman, A., Mioc, D., 2016. Classified and clustered data constellation: An efficient approach of 3D urban data management. ISPRS Journal of Photogrammetry and Remote Sensing 113, 30-42.

Azri, S., Ujang, U., Anton, F., Mioc, D., Rahman, A.A., 2014. Spatial Access Method for Urban Geospatial Database Management: An Efficient Approach of 3D Vector Data Clustering Technique, 9th International Conference on Digital Information Management (ICDIM). IEEE, Bangkok, Thailand.

Basir, W.N.F.W.A., Majid, Z., Ujang, U., Chong, A., 2018. Integration of GIS and BIM Techniques in Construction Project Management – A Review. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-4/W9, 307-316.

Beetz, J., 2014. A scalable network of concept libraries using distributed graph databases. *In Proceedings of the Joint ICCCBE 2014 and the 2014 CIB W078 Conference*, Orlando, FL, USA, 23–25 June 2014.

Benner, J., Geiger, A., Haefele, K.-H., Isele, J., 2010. Interoperability of geothermal data models. *In Proceedings of the World Geothermal Congress*, Bali, Indonesia, 25–29 April 2010.

Biljecki, F., Ledoux, H., Du, X., Stoter, J., Soon, K., Khoo, V., 2016. The most common geometric and semantic errors in CityGML datasets. *ISPRS Annal Photogrammetry, Remote Sensing, Spatial Information Science*, IV-2/W1, 13-22.

Biljecki, F., Tauscher, H., 2019. Quality of BIM-GIS conversion. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-4/W8, 35-42.

De Laat, R., van Berlo, L., 2011. Integration of BIM and GIS: The development of the citygml GeoBIM extension. *In Advances in 3D Geo-Information Sciences; Springer*: New York, NY, USA, 2011; pp. 211–225.

Deng, Y.C., Cheng, J.C.P., Anumba, C., 2016(a). A framework for 3D traffic noise mapping using data from BIM and GIS Integration. *Journal of Structure & Infrastructure Engineering*, 12(10), 1267-1280.

Deng, Y., Cheng, J.C., Anumba, C., 2016(b). Mapping between BIM and 3D GIS in different levels of detail using schema mediation and instance comparison. *Automation Construction*, 67, 1–21.

Donkers, S., Ledoux, H., Zhoa, J., Stoter, J., 2016. Automatic conversion of IFC datasets to geometrically and semantically correct CityGML LOD 3 buildings. *Transactions in GIS*, 20(4), 547-569.

Donkers, S., 2013. Automatic Generation of Citygml lod3 Building Models from IFC Models; TU Delft, Delft University of Technology: Delft, The Netherlands.

Eastman, C., Techoiz, P., Sack, R., Liston, K., 2011. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors.* John Wiley & Sons, Inc., New Jersey.

El-Mekawy, M., Östman, A., Hijazi, I., 2012(a). A unified building model for 3D urban GIS. *ISPRS International Journal Geo-Information,* 1, 120–145.

El-Mekawy, M., Östman, A., Hijazi, I., 2012(b). An evaluation of IFC-CityGML unidirectional conversion. *International Journal Advance Computation Science Application*, 3, 159–171.

Floros, G., Ellul, C., Dimopoulou, E., 2018. Investigating Interoperability Capabilities between IFC and CityGML LoD 4 – Retaining Semantic Information. *International Society for Photogrammetry, Remote Sensing Spatial Information Sciences,* XLII-4-W10, 33-40.

Geiger, A., benner, J., Haefele, K.H., 2015. Generalization of 3D IFC buildings model. *3D Geoinformation Science*, Springer International Publishing, Dubai, UAE, 19-35.

Göçer, Ö., Hua, Y., Göçer, K., 2015. Completing the missing link inbuilding design process: Enhancing post-occupancy evaluation method for effective feedback for building performance. *Journal of Building and Environment,* 89, 14-27.

Goodchild, M.F., 2009. GIScience and Systems. *International Encyclopedia of Human Geography*, Pp. 526-538.

Groger, G., Kolbe, T., Czerwinski, A., 2007. Candidate OpenGIS®Citygml Implementation Specification (City Geography Markup Language); *Open Geospatial Consortium Inc* (OGC): Wayland, MA, USA.

Isikdag, U., Aouad, G., Underwood, J., Trodd, N., 2004. Integrating Building Information Models with Geographic Information Systems: Technology Review. *International Research Week 2004 Salford*, Manchester, Uk.

Isikdag, U., Underwood, J., Aouad, G., 2008. An investigation into the applicability of building information models in geospatial environment in support of site selection and fire response management processes, *Journal of Advanced Engineering Informatics*, 22(4), 504-519.

ISO, 2002. Geographic information -- Quality principles, ISO 19113:2002, pp. TC 211; ISO Standards.

Jaun, L., Khoon, T.R, Qing, Z., 2006. Research and Implement of 3D Data Integration between 3D GIS and 3D CAD. *Innovation on 3D Geo Information Systems, First International Workshop on 3D Geoinformation.* doi:10.1007/978-3-540-36998-1_19.

Kang, T.W., Hong, C.H., 2015. A Study on Software Architecture for Effective BIM/GIS-based Facility Management Data Integration. *Automation in Construction*, 54, 25-38.

Karan, E.P., Irizarry, J., Haymaker, J., 2015. BIM and GIS integration and interoperability based on semantic web technology. *Journal Computing Civil Engineering*, 30(3), 04015043(1)-04015043(11).

Kaya, Ö., Tortum, A., Alemdar, K.D., Çodur, M.Y., 2020. Site selection for EVCS in Istanbul by GIS and multi-criteria decision-making. Transportation Research Part D: Transport and Environment 80, 102271.

Keling, N., Mohamad Yusoff, I., Lateh, H., Ujang, U., 2017. Highly Efficient Computer Oriented Octree Data Structure and Neighbours Search in 3D GIS, in: Abdul-Rahman, A. (Ed.), Advances in 3D Geoinformation. Springer International Publishing, Cham, pp. 285-303.

Laakso M., 2012. The IFC Standard. A review of history, development and standardization, *ITcon.*, 17, 134-161. http://www.itcon.org. 2012. 9.

Lapierre, A., Cote, P., 2008. Using Open Web Services for Urban Data Management: A Testbed Resulting from an OGC Initiative Offering Standard CAD/GIS/BIM Services. *In Urban and Regional Data Management;* Rumor, M., Coors, V., Fendel, E.M., Zlatanova, S., Eds.; Taylor and Francis Group: London, UK, pp. 381–393.

Lilis, G.N., Giannakis, G.I., Katsigarakis, K., Costa, G., Sicilia, A., Garcia-Fuentes, M., Rovas, D.V., 2016. Simulation model generation combining IFC and CityGML data. *Proceedings of the 11th European Conference on Product and Process Modeling (ECOOM2016)*, Limassol, Cyprus, 215-222.

Lim, J., Tauscher, H., Biljecki, F., 2019. Grapg transformation rules for IFC-to-CityGML attribute conversion. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* IV-4/W8, 83-90.

Liu, X., Wang, X., Wright, G., Cheng, J. C. P., Li, X., Liu, R., 2017. A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *In: ISPRS International Journal of GeoInformation*, 6(53). doi:10.3390/ijgi6020053.

Ma, Z., Ren, Y., 2017. Integrated Application of BIM and GIS: An Overview. *Procedia Engineering,* 196, 1072-1079.

Mignard, C., Nicolle, C., 2014. Merging BIM and GIS using ontologies application to urban facility management in ACTIVe3D. *Journal Computers in Industry*, 65(9), 1276-1290.

Mohd, Z.H., Ujang, U., 2016. Integrating Multiple Criteria Evaluation and GIS In Ecotourism: A Review. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLII-4/W1, 351-354.

Mustorpha, S.N.A.S., Mohd, W.M.N.W., 2019. A BIM Oriented Model to a 3D Indoor GIS for Space Management – A Requirement Analysis. *IOP Conference Series: Earth and Environment Science*, 385, 012046, 1-11. doi:10.1088/1755-1315/385/1/012046.

Niu, S., Pan, W., Zhao, Y., 2015. A BIM—GIS Integrated Web-based Visualization System for Low Energy Building Design. *Procedia Engineering,* 121, 2184-2192.

Pauwels, P., Zhang, S., Lee, Y.C., 2017. Semantic Web Technologies in AEC Industry: A Literature Overview. *Journal of Automation in Construction*, 73, 145-165.

Plumer, L., Groger, G., 1997. Achieving integrity constrains in geographic information systems. *GeoInformatica*, 1(4), 345-367.

Revit, 2017. Autodesk Revit software for building design and construction, http://www.autodesk.com/products/autodesk-revitfamily/overview. (October 2017).

Salleh, S., Ujang, U., 2018. Topological information extraction from buildings in CityGML. IOP Conference Series: Earth and Environmental Science 169, 012088.

Sani, M.J., Rahman, A.A., 2018. GIS and BIM Integration at Data Level: A Review. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-4/W9, 299-306.

Shi, P., Cui, Y., Xu, K., Zhang, M., Ding, L., 2019. Data Consistency Theory and Case Study for Scientific Big Data. *Information*, 10(137), 1-15.

Shichao, G., Dandan, G., Qiongyu, Z., Nankai, W., Jiaxin, D., 2020. Research on Electromagnetic Environment Situation Display of Digital Map Radar based on 3D GIS. Journal of Physics: Conference Series 1550, 042071.

Srivastana, R.N., 2008. Spatial Data Quality: An Introduction. *GIS Lounge*, https://www.gislounge.com/spatial-data-quality-an-introduction/. (Jun 2020).

Tashakkori, H., Rajabifard, A., Kalantari, M., 2015. A New 3D Indoor/Outdoor Spatial Model for Indoor Emergency Response Facilitation. *Building and Environment*, 89, 170-182.

Teo, T.A., Cho, K.H., 2016. BIM-oriented indoor network for indoor and outdoor combined route planning. *Journal of Advanced Engineering Informatics*, 30, 268-282.

Vanlande, R., Nicolle, C., Cruz, C., 2008. IFC and building lifecycle management. *Journal of Automation Construction*, 18, 70–7.

Veregin, H., 1999. Data Quality Parameters. In: Longley, P.A., Goodchild, M.F., Rhind D. and Maguire, D. (eds.), *Geographical Information Systems, Principles and Applications – Volume 1, Principles and Technical Issues*, 2nd edition. New York: John Wiley & Sons, pp. 177-189.

Wang, N., Raja, R.A., 2019. Ontology-based integration of BIM and GIS for indoor routing. *Construction Research Congress 2020*, 1-10.

Wu, H., He, Z., Gong, J., 2010. A Virtual Globe-Based 3D Visualization and Interactive Framework for Public Particicipication in Urban Planning Process. *Computers, Environment and Urban Systems*, 34, 291-298.

Xinyan, Z., Deren, L., Jianya, G., 2000(a). An Study on Data Consistency in Spatial Database System. *International Archives of Photogrammetry and Remote Sensing,* XXXIII-Part B4, 1252-1256.

Xinyan, Z., Yi, W., Deren, L., Jianya, G., 2000(b). Research on Data Consistency in Spatial Database System. *Geo-spatial Information Science*, 3(4), 24-29. doi: 10.1007/BF02829392.

Zhu, J., Wang, X., Wang, P., Wu, Z., Kim, M.J., 2019. Integrating of BIM and GIS: Geometry from IFC to Shapefile using Open-Source Technology. *Automation in Construction*, 102, 105-119.

Zhu, J., Wu, P., Chen, M., Kim, M.J., Wang, X, Fang, T., 2020. Representation for BIM and GIS Integration at the Process Level. *Applied Sciences*, 10(2009), 1-19. doi:10.3390/app10062009.