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Integration of BIM and GIS: The development of the CityGML GeoBIM extension

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Abstract: There is a growing interest in the integration of BIM and GIS. However, most of the research is focused on importing BIM data in GIS applications and vice versa. Real integration of BIM and GIS is using the strong parts of the GIS technology in BIM, and of course the strong parts from BIM technology in GIS. In this paper a mix of strong parts from both worlds is integrated in a single project. The paper describes the development of a CityGML extension called GeoBIM to get semantic IFC data into a GIS context. The conversion of IFC to CityGML (including the GeoBIM extension) is implemented in the open source Building Information Modelserver.

Introduction

There is an increasing interest in the integration of Building Information Modeling (BIM) and Geospatial Information Systems (GIS) [1, 4, 12, 18, 21, 23, 25, 35]. A number of publications and projects showed promising results [12, 18, 23, 30, 35].

However, the 'BIM people' and the 'GIS people' still seem to live in different worlds. They use different technology, standards and syntax descriptions. Previous attempts to integrate BIM and GIS [18,21,26] seem to focus on either BIM or GIS. The two options seen so far are (1) integrating BIM data in the GIS world by using GIS technology, GIS standards and is done by 'GIS people' that look at buildings as information in a geospatial context [4, 23, 25]. The other work we see (2) is done by 'BIM people' who are modelling advanced detailed 3D buildings with high semantics. They model more buildings including streets; terrain and maybe some underground piping and call this integration of GIS into BIM.

Until today the two worlds do not really integrate. BIM is seen as an essential data source for built environments by GIS users [33]. GIS is seen as a crucial data source for design and integration of new BIM models in a spatial context [35]. However, while these two worlds are interested in each other's data, they do not seem to intent to switch in technology or work processes.

The authors of this paper see two different worlds that both try to import the other world into their own. There is a need to develop technology to integrate both worlds and create a synergy between the strong (technology) parts of both worlds.

Where BIM and GIS can learn from each other

The BIM world and GIS world are quite different. Both worlds have strengths, but both worlds also make progress and first steps in new technologies. A small comparison:

The AEC/BIM sector makes intense use of 3D geometry modelled using Industry Foundation Classes (IFC). The ISO standard IFC has a strong focus on constructive solid geometry, boundary representation, Boolean operations, et cetera. The IFC modelled data are mostly file based and exchanged as files (as snapshots of a BIM) by project partners. IFC and BIM usually model buildings and structures above the ground. It is typically used for new buildings and structures. Important concepts in BIM models are the decomposition and specialisation of objects in the model. The relation between objects is of strong importance [29].

On the other hand, the GIS world has a server-focused approach. GIS data obviously have a strong focus on the geolocation (using real world coordinates). The relation between geospatial objects is based on the coordinates. The GIS modeller typically models existing data or policies. GIS is strong on 2D geometry and is just starting to experiment with 3D [11, 27, 34].

We think the BIM and GIS world can create strong synergy. The server approach is getting more and more attention in the BIM world and BIM developers can learn a lot from the experience of the GIS developers. The 3D questions and issues discussed in the GIS world have well known solutions in the BIM world.

The BIM and GIS users meet in several complex projects. Both worlds however try to solve the planning questions by using their own technology and way of working. The development and growing use of both CityGML and BIM servers may create a breakthrough in the integration of the two worlds.

Integrating BIM and GIS

The authors of this paper believe that integrating the two world should be done by using the strengths from both the BIM and GIS world in the context of the other. This means we intent to use a central modelserver for BIM and intense semantics (specialisation, decomposition and relations) and 3D in GIS.

To do this, IFC models have to be available online, using a central modelserver [2]. We have decided to use the open source BIMserver during this project, because it is the only available open source software for this purpose.

It also means that the IFC semantics and relations should be available in a GIS context. We have decided to use CityGML for this [26]. It is not possible to integrate IFC semantics into CityGML by default. Therefore we use the extension mechanism for CityGML. A few existing extensions are already available [10, 13]. A new CityGML extension will create the possibility to integrate IFC semantics and properties. The open source BIMsever will be able to export IFC data to CityGML, including the IFC geometry, but more important also the semantics and properties. We call the extension on CityGML for IFC data the 'GeoBIM' extension [16].

Of course the integration of BIM and GIS is depending on the assumption that there will be applications from both domains, which can deal with this GeoBIM extension. With the development we try to encourage discussion on this topic.

Previous work on IFC and CityGML transformation

There is a lot of work already done in transforming IFC to CityGML and vice versa [14, 18, 25]. This previous work has a strong focus on converting geometry. IFC geometry uses constructive solid geometry with volumetric, parametric primitives representing the structural components of buildings. 3D GIS (including CityGML) uses boundary representations; accumulation of observable surfaces of topographic features. This paradigm creates high combinatorial complexity in the transformation. Other pros and cons between IFC and CityGML are described in detail by Isikdag and Zlatanova [24].

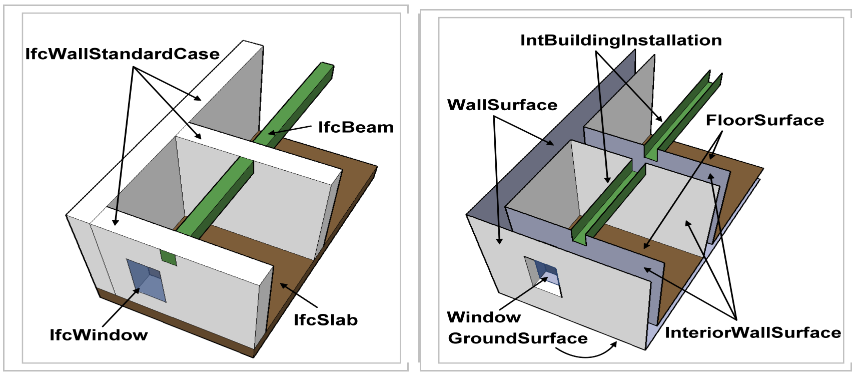

Fig. 1. Geometry modelling paradigms between IFC (left) and 3D GIS (right) [31].

Previous work on matching CityGML and IFC entities, showed the use of semantic information as a priori knowledge and the evaluation of geometric-topological relations between CityGML entities [25].

Nagel et al created software to convert IFC geometry to the different levels of detail in CityGML [19, 31].

Previous studies on the conversation of IFC to CityGML can be summarized in a few conclusions. First (1) is that previous work is primarily focused on the conversion of geometry. In the conversion of geometry the intention is to convert to different lower Levels of detail (LODs) in CityGML (2). The work so far tries to use the rich semantic IFC models to create and feed CityGML models (3) [25].

This paper will focus on the extension of CityGML with semantic IFC data. The additional IFC semantics will enrich CityGML in addition to using IFC only as a source for GIS data.

Use cases for a GeoBIM-extension

Since the OGC Web Services testbed phase 4 (OWS-4) the integration of BIM and GIS has some obvious use cases [32]. Targeted application areas explicitly include urban and landscape planning; architectural design; tourist and leisure activities; 3D cadastres; environmental simulations; mobile telecommunications; disaster management; homeland security; vehicle and pedestrian navigation; training simulators; and mobile robotics.

The most famous use cases come directly from the OWS-4 testbed. It is the 'sniper example' from homeland security. That use-case concentrates on an application where an important politician moves along a particular route. It's necessary to find all the windows and buildings which have good view on that route and where possibly a sniper can hide. Instead of virtually visiting all building models with a 3D viewer along the route, we might rather want to query the city model to create a report of all corresponding windows, rooms, and buildings in order to check these. Thus we would exploit the semantic information of a city model along the route, and especially the details that come with a highly detailed CityGML or IFC model so we can locate and identify the windows. Because CityGML does not store window width and height it would be very complex to calculate this from the geometry. The window width and height are stored semantically in IFC. These kinds of use cases create the validation for the development of a GeoBIM CityGML extension [34].

Other use-cases are: calculating the (indoor and towards the right side of a building) route to critical locations for first responders; locating key structural elements of a building during disasters (IfcStructuralElement); Integrating outdoor navigation software (PNDs) into the indoor domain (IfcStair; IfcRailing; height and width of Door; etcetera); evacuation scenario's for campuses larger than one building; LEED scores for a neighbourhood (instead of just one building); incident simulation and analyses (think of a piping leakage that effects the entrance or exit of buildings.

We are aware that some building elements like 'Stair' are already in the native CityGML (Stair for example is in the IntBuildingInstallation) but we hope to add value by storing this data more explicit.

The development of the GeoBIM-extension

The development of the GeoBIM extension for CityGML is done on several levels. First the known CityGML object types like Room, Window, Door, Building, etcetera are extended with extra properties from IFC. Ex-

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amples of these properties are the widths and heights of windows and doors. The next level of getting IFC data into CityGML is to extent the „_AbstractBuiding" with an extra property what creates a link to the base class of our (to be introduced) extra classes, called VisibleElement. The development has a focus on theoretical possibilities for the transformation of IFC data to CityGML. There is no specific use case to mirror the development.

The total IFC schema holds around 900 classes. Most of them are for geometry representation, relations and topology. Theoretical research on what IFC classes could be of use in GIS, showed that there are about 60 to 70 IFC classes that theoretically could be transformed to a GeoBIM extension [5]. These classes are listed in figure 2.

- IfcAnnotation
- IfcBeam
- IfcBuilding
- IfcBuildingElementComponent
- IfcBuildingElementPart
- IfcBuildingElementProxy
- IfcBuildingStorey
- IfcChamferEdgeFeature
- IfcColumn
- IfcCovering
- IfcCurtainWall
- IfcDiscreteAccessory
- IfcDistributionChamberElement
- IfcDistributionControlElement
- IfcDistributionElement
- IfcDistributionFlowElement
- IfcDistributionPort
- IfcElectricalElement
- IfcElectricDistributionPoint
- IfcElementAssembly
- IfcEnergyConversionDevice
- IfcEquipmentElement
- IfcFastener
- IfcFooting
- IfcGrid
- IfcMechanicalFastener
- IfcMember
- IfcOpeningElement
- IfcPile
- IfcPlate
- IfcProjectionElement
- IfcProxy
- IfcRailing
- IfcRamp
- IfcRampFlight
- IfcReinforcingBar
- IfcReinforcingMesh
- IfcRoof
- IfcRoundedEdgeFeature
- IfcSite
- IfcSlab
- IfcSpace
- IfcStair
- IfcStairFlight
- IfcStructuralCurveConnection
- IfcStructuralCurveMember
- IfcStructuralCurveMemberVarying
- IfcStructuralLinearAction
- IfcStructuralLinearActionVarying
- IfcStructuralPlanarAction
- IfcStructuralPlanarActionVarying
- IfcStructuralPointAction
- IfcStructuralPointConnection
- IfcStructuralPointReaction
- IfcStructuralSurfaceConnection
- IfcStructuralSurfaceMember
- IfcStructuralSurfaceMemberVarying
- IfcTransportElement
- IfcVirtualElement
- IfcFurnishingElement
- IfcWall
- IfcWallStandardCase
- IfcWindow

Fig. 2. List of IFC classes that could be useful in a geospatial context.

Most of the IFC classes are not of use in a practical GeoBIM use case. For example IfcStructuralPointAction is typically used for structural calculations and therefore has no use in a GeoBIM use case. Applied research has shown that 17 IFC classes are most likely to map to a GeoBIM extension of CityGML. These classes are noted in figure 3.

The properties of these classes can also be transformed to CityGML attributes. Some classes from IFC map direct to a corresponding CityGML type. For example IfcBuilding maps directly to _Building in CityGML. Other mappings are represented in figure 3.

IFC class	CityGML type	Arguments
IfcBuilding	Building	GUID -> GlobalId, Name -> Name
BuildingAddress	Address	-
IfcWall	InteriorWallSurface or Wall-Surface (Depending on boundaryType)	GUID -> GlobalId, Name -> Name
IfcWindow	Window	GUID -> GlobalId, Name -> Name, OverallWidth -> OverallWidth, OverallHeight -> OverallHeight
IfcDoor	Door	GUID -> GlobalId, Name -> Name, OverallWidth -> OverallWidth, OverallHeight -> OverallHeight
IfcSlab	RoofSurface or FloorSurface (Depending on IfcSlab-TypeEnum)	GUID -> GlobalId, Name -> Name
IfcRoof	RoofSurface	GUID -> GlobalId, Name -> Name
IfcColumn	Column	GUID -> GlobalId, Name -> Name
IfcFurnishingElement	BuildingFurniture	GUID -> GlobalId, Name -> Name
IfcFlowTerminal	FlowTerminal	GUID -> GlobalId, Name -> Name
IfcColumn	Column	GUID -> GlobalId, Name -> Name
IfcSpace	Room	GUID -> GlobalId, Name -> Name
IfcStair	Stair	GUID -> GlobalId, Name -> Name, ShapeType -> Type
IfcRailing	Railing	GUID -> GlobalId, Name -> Name, PredefinedType -> PredefinedType
IfcAnnotation	Annotation	GUID -> GlobalId, Name -> Name
IfcColumn	Column	GUID -> GlobalId, Name -> Name
IfcBeam	Beam	GUID -> GlobalId, Name -> Name

Fig. 3. Mapping of IFC classes to CityGML types; including arguments and attributes.

The result of the development of the GeoBIM extension (ADE) for CityGML is presented in an XML Schema file (XSD). The result is also represented as a UML class diagram shown in figure 4.

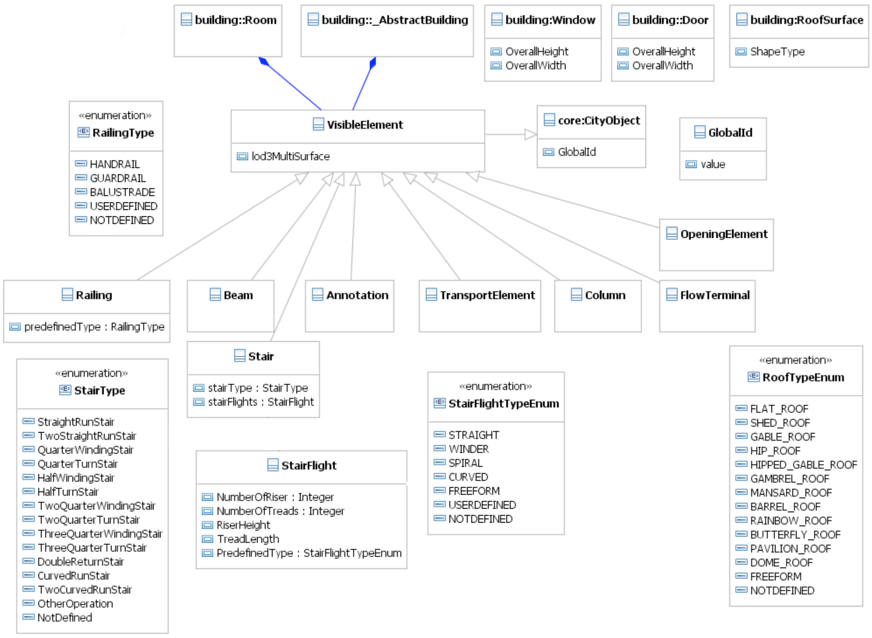

Fig. 4. The GeoBIM extension (ADE) for CityGML represented as a UML Class diagram. Note: this is not the UML schema of the complete CityGML schema including the new extension; this is the schema of only the extension XSD.

All added properties from IFC are presented in the CityGML file. The GeoBIM extension creates some new objects in CityGML. An example of such a new object type is ’Stair’. This object has some properties and also has geometry.

Prototype implementation of the GeoBIM-extension

To create a practical use, the GeoBIM extension is implemented in the open source Building Information Modelserver (BIMserver) [7]. The software implementation of the transformation from IFC to GeoBIM in the open source BIMserver creates a situation where the theoretical model will be tested by implementers. Both the theoretical model and the software implementation feed each other with experience and results. This makes the theoretical extension very robust for practical use.

The open source BIMserver architecture consists of an EMF model [15] of IFC, a BerkeleyDB database [3] and several interfaces for communication (REST, SOAP, webuserinterface). The open source BIMserver is intended to be a tool to support innovative collaboration in the AEC sector. The storage of BIM information is native IFC. Key features of the open source BIMserver are the ability to merge and query IFC models [2]. For this reason the BIMserver software does not need the ability to compose and calculate complex geometry of IFC. However, this feature is needed to transform IFC geometry to CityGML geometry. For this we connected the IFC Engine DLL library [19] to the EMF interface.

Furthermore, the CityGML4j java library [9] is used to compose CityGML files. This CityGML4j is also connected to the EMF interface of the BIMserver software.

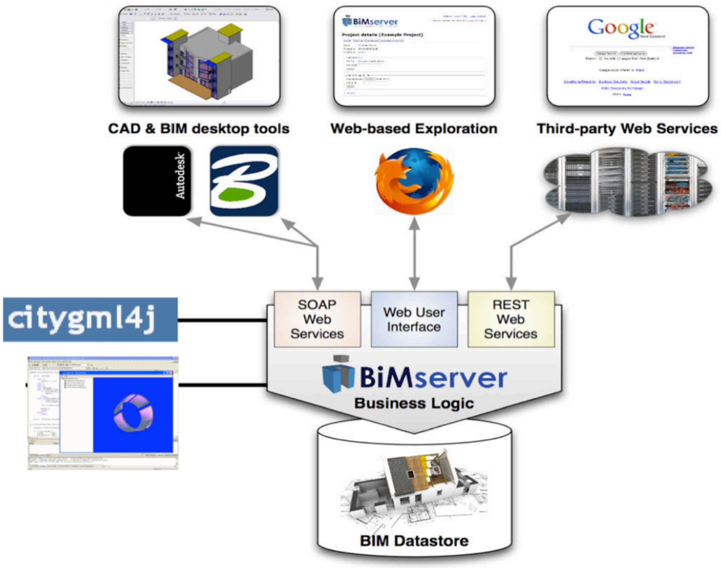

Fig. 5. The schematic representation of the open source BIMserver software architecture (inspired from [6]).

The conversion of IFC data to CityGML is done on object level of IFC data. The steps that are taken:

- Get an object from IFC (BIMserver)
- Run the object through the IFC Engine DLL (IFC Engine DLL)
- Get triangles from the object (IFC Engine DLL to BIMserver EMF interface)
- Get IFC properties belonging to the object (BIMserver EMF core)

- Get next object (BIMserver EMF core)
- Convert data from memory to CityGML file (CityGML4j)

The IFC objects with an equal object in CityGML/GeoBIM (for example IfcDoor and Door or IfcWindow and Window) will be converted to the correct CityGML objects. These objects in CityGML get the extra properties from IFC.

Prototype testing

During and after the development of the ADE and the implementation in the BIMserver, we tested the conversion. During the testing, three publicly available IFC files were used [21]. First result of this test is the notice that some viewers (like the widely used LandExplorer from Autodesk [28]) do not display geometry of objects defined in an extension. This means that no stairs (and other semantically added objects) are shown in (for example) LandExplorer. Other viewers (like the FZK viewer [16]) do not have this issue and show the result just fine.

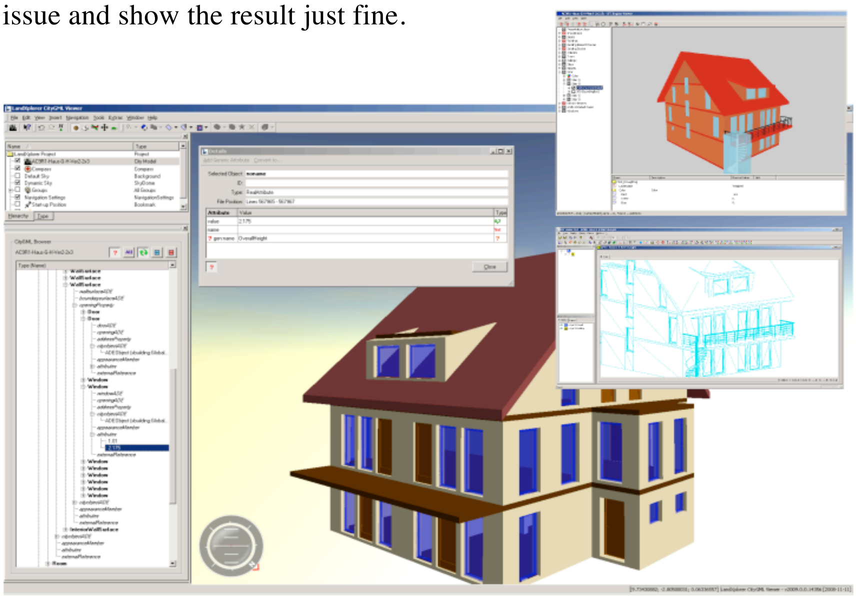

Fig. 6. Result of a conversion from IFC to CityGML including the GeoBIM extension. The added properties are to be seen in the properties view in CityGML. At the top the original IFC file. It is clear to see that the geometry of the stairs and fence is not visible in the CityGML result. Viewing the same CityGML file in the FZK viewer does show the geometry of both the stairs and the fence (small right).

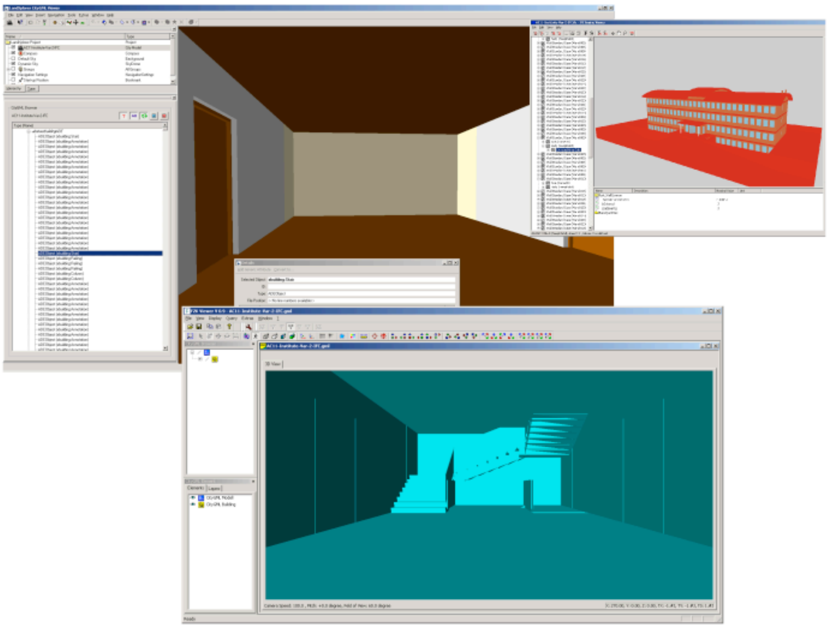

Fig. 7. Another result from the IFC to CityGML conversion including GeoBIM extension. On the top right the original IFC file. On the top left the result of the hallway in Autodesk LandExplorer. The geometry of the stairs is missing. Viewing the same CityGML file in FZK viewer does show the geometry of the stairs.

After conversion of the IFC to CityGML (including the extension data) the size of the files increased by a tenfold or more. File number 1 is 4.6 MB as STEP IFC file and 114.7 MB as CityGML file (about 25 times as big). File number 2 is 2.8 MB as STEP IFC file and 106.1 MB as CityGML file (about 38 times as big). File number 3 is 2.9 MB as STEP IFC and 31.6 MB as CityGML (about 11 times as big) [21]. We have to remark that this is with very basic geometry representation using triangles. It is a known issue that representation in XML and especially GML is data intensive. The optimization of geometry transformation between IFC and CityGML will drop the CityGML file sizes. Using Gzip or any other ZIP protocol can also solve this problem. We implemented a 'download as ZIP' option in the open source BIMserver to decrease the resulting CityGML file sizes.

During the development of the GeoBIM extension to get IFC data into CityGML the authors found no possibility to semantically create a network structure in CityGML. For ring piping for example, the final pipe cannot be (semantically) connected to the first. In the AEC sector this is a much-used method. For example heating systems and sewerage make intensive use of ring piping. Getting this semantic information into CityGML is a key issue for the link between BIM and GIS. Recent studies show that the next version of CityGML could make this possible.

The final issue we found during development and testing is the freedom IFC gives to users (e.g. software implementers) to represent data. In pure form IFC makes use of just a few base objects. All other objects are specializations of these base objects [21]. This means there is no single way to connect a specific IFC object with another. For example: An IfcWindow can be connected to an IfcOpening, which is connected to an IfcWall, which is connected to an IfcSpace, which is connected to an IfcBuilding. This route to find out which Window is connected to which Space (Room in CityGML) and Building is a chosen route in a specific data file, but not a statically defined one on IFC schema level. The link could also be IfcWindow – IfcBuildingStorey – IFC Space (for example). These kinds of links are much more statically defined in CityGML. A connection between a Window, Wall and Room in CityGML is always the same. This makes it very difficult for software implementations to transform IFC data into CityGML data. This problem is inherent to the IFC schema structure and will probably not be solved. This issue is also a reason why not all 60 to 70 semantic objects and their properties will be present in the GeoBIM extension. In theory this would be possible, but in practice no software can fully implement this transformation.

All information, object, properties and relations from IFC that are stored in the GeoBIM extension are available in the generated CityGML exports. The use of this information in CityGML is very welcome to both BIM and GIS users [4, 8].

Discussion

The results presented in this paper could help to integrate BIM and GIS. However, some elements still need some discussion and remarks.

First of all, the geometry issues known in the transformation from IFC to CityGML [31] are still not solved. This work does not contribute to a better transformation and only used basic triangles for the geometry in CityGML. This is also why the file sizes of CityGML files are between 11 to 38 times as big. The solution to this issue is needed to get practical use of this integration.

For now the implementation in the open source BIMserver only exports IFC to CityGML LOD4, including the GeoBIM extension data. To use IFC to CityGML transformation in practice, the transformation to lower LODs is necessary. This work is already done but implemented in closed source commercial software [20].

IFC data are used to exchange information in the AEC sector. It is modelled for this purpose and therefore the use of textures in IFC is rare. Almost all the transformations from IFC tot CityGML will be without textures.

The growth of semantic data in CityGML and the growing complexity of 3D geometry representations might cause a situation where the usability of the data decreases. Of course the most common and most valuable argument for this issue is that CityGML was never designed, nor intended to be used for these applications. To prevent this from happening we think of splitting 3D geometry representation and semantic information. The 3D geometry is nothing more than one of the properties of an object. It is not necessary to serve this property in all use-cases. Another possible option is to start defining 3D geometry by using binary models and standards. The use of ‚human readable' XML lowers performance and usability of 3D models on the web. The use of binary standards might help to speed up the adaptation of 3D usage on both the Geoweb and the BIMweb.

When CityGML extensions with geometry representation are not shown in (some) viewers, it is not clear how practical use-cases will develop in the future. Software developers of CityGML viewers should extend their software to view geometry representations of objects in a CityGML ADE extension.

Conclusions

This study investigates the integration of BIM and GIS. Main part of the research was the development and implementation of a GeoBIM extension on CityGML for IFC data. To fully integrate BIM and GIS it is obvious that a translation from CityGML to IFC is also necessary.

Since this paper is describing a development, which is not finished, there are no real conclusions, which can be made. However, some first findings and conclusions can be stated.

So far we concluded that it is technically possible to add semantic information from IFC into CityGML using the developed GeoBIM extension. The GeoBIM extension works in practice and is implemented in software. The conversion of IFC data to CityGML files with additional rich IFC semantics is proved to be possible.

Both IFC and CityGML have made decisions during the design and development of their native schemas that impose restrictions on the integration. Both IFC and CityGML are about to change their schema definitions. IFC to 2x4 will be a more strict definition, and CityGML 1.1 will probably have the ability to create network structures. We are aware that CityGML was not originally designed and implemented to be 100% consistent with the semantics and content available in an IFC. CityGML was originally designed for sharing 3D city models and not internal infrastructure, such as piping systems. The conclusion for now is that it will be difficult to get full IFC semantics in CityGML, and we are aware of the question if CityGML should be overloaded with additional extensions for which it was not originally designed, but in the future the technical possibilities will increase.

To fully integrate BIM and GIS the AEC sector needs to start working with central modelservers. The use of central servers in the BIM world is still to be adopted. This experiment had a strong focus on transforming IFC semantics into CityGML and showed promising results.

Future work and ambitions

In the future the GeoBIM extension should be updated given the new possibilities created by the new releases of both the IFC and CityGML schemas.

The ambition of the team is to implement the conversion of IFC to CityGML not only for the LOD 4 (including the GeoBIM extension) but for the LODs 0 to 3 as well.

Another ambition is to implement an interface to spatial query building information models [8] in the open source BIMserver, using the CityGML GeoBIM extension.

Future work should also focus on testing the use, investigate the benefits and results in practice. Since only lab testing has been done during this research, there is a need for more use-case testing on the practical implications of this technology.

To fully integrate BIM and GIS a translation from CityGML to IFC is a main issue that should be investigated and developed.

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