An investigation into the possibilities of BIM and GIS cooperation and utilization of GIS in the BIM process

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Abstract

In the coming years we will most probably watch a significant increase of the BIM (building information model) utilization in the AEC (Architecture/Engineering/-Construction) sector even in the Czech Republic. Therefore, it would be reasonable to consider possible utilization of the well-established geographic information systems within the building information modelling process. This paper is based on the currently existing literature and is focused on the interrelationship between BIM and GIS. The main goal is to reveal potential fields of cooperation and to find possible utilization of GIS in BIM. To provide a theoretical framework, this article briefly introduces and defines the term of BIM and deals with the most important semantic models in AEC and 3D GIS – IFC and CityGML. The paper also contains examples of specific efforts recently dealing with the BIM and GIS collaboration.

Keywords: BIM, Building Information Modelling, IFC, GIS, CityGML

1. Introduction

In recent years we can hear more and more about building information modelling. However, the employment of a shared information model during the whole building lifecycle is still not very common, especially if we speak about the Czech Republic. On the other hand there already exist several scientific papers which are focused on the interrelationship between this relatively new field and the well-established field of geographic information systems (GIS). Martin Černý's dissertation thesis "GIS analysis in building information models" [6] can be a very good example and one of the first academic theses in our country which deal with BIM.

The main goal of this paper is to reveal main areas where BIM and GIS can benefit from their cooperation. This could not be achieved without a theoretical framework. Therefore, the paper first explains the term of BIM and introduces the most important AEC and GIS standards, mainly the IFC and CityGML semantic models. The most important part of the paper is focused on the BIM and GIS relationship and describes main fields of cooperation, the most serious obstacles and above all introduces particular efforts to integrate BIM and GIS.

2. The basics of building information modelling

The term BIM was used in AEC for the first time in 2002 [5]. There are more ways how to interpret this acronym: it can mean building information model, building information modelling or even building information management. In the Czech Republic all these terms are translated into Czech and explained in the BIM reference book by the Czech BIM Council (czBIM) [5] which can be considered as a fundamental source for the Czech environment. Nevertheless, because this paper is written in English, it would not be appropriate to translate all definitions back in English. Therefore, original English definitions found are listed hereafter.

According to Isikdag et al. [17] building information modelling can be described as "a new way of creating, sharing, exchanging and managing the information throughout the entire building lifecycle."

> BIM is a computable representation of all the physical and functional characteristics of a building and its related project/life-cycle information, which is intended to be a repository of information for the building owner/operator to use and maintain throughout the life-cycle of a building.

NBIMS (The National BIM Standard—United States)

> BIM is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and improve the process of delivering the facility.

AGC (Associated General Contractors of America)

> BIM is a three dimensional database designed specifically for built facilities. BIM integrates a digital description of a building with all the elements that contribute to its on-going function such as air conditioning, maintenance, cleaning or refurbishment along with describing the relationship between each element.

CRC (Cooperative Research Centre for Construction Innovation)

It is apparent from the mentioned definitions that building information model is an information database which comprises all information about a building throughout its whole lifecycle (design, construction, operation and maintenance, demolition/renovation). Building information modelling/management[1] is then the comprehensive process of sharing and exchanging information about the building.

The word "building" in the acronyms can be understood as the specific type of structure above ground surrounded by walls, roof, etc. but also as the general construction process of arbitrary structures. It is important to realize that BIMs can also be used for different structures than buildings (e.g. road or railway structures – roads, bridges, tunnels. . .).

In BIM, shapes and dimensions of buildings are always described three-dimensionally. However, it is of utmost importance that the 3D model alone (i.e. only 3D geometry) cannot still be called building information model. The geometrical model is only one of more ways of

[1] There is another term with this meaning used in the USA: VDC – virtual design and construction [25].

representation of stored information. "The 3D geometry is only one of the properties, at the same level as the name of the vendor, cost, etc." [27].

Considering the mentioned, BIM can be understood as an object-oriented parametric modelling of a building. Parameters (i.e. non-graphic and additional information about particular elements) express structural and material properties of elements, positions in the construction schedule, inspection and exchange schedules or investment and operating costs. A comprehensive model of a real building can be created using parameters and this model can be used for the construction preparation, the construction itself and further for the facility management and analyses.

BIM should also enable the N-dimensional modelling. Time is considered as the fourth dimension whereas cost information, energy consumption or facility management information can create another dimensions of BIM [5].

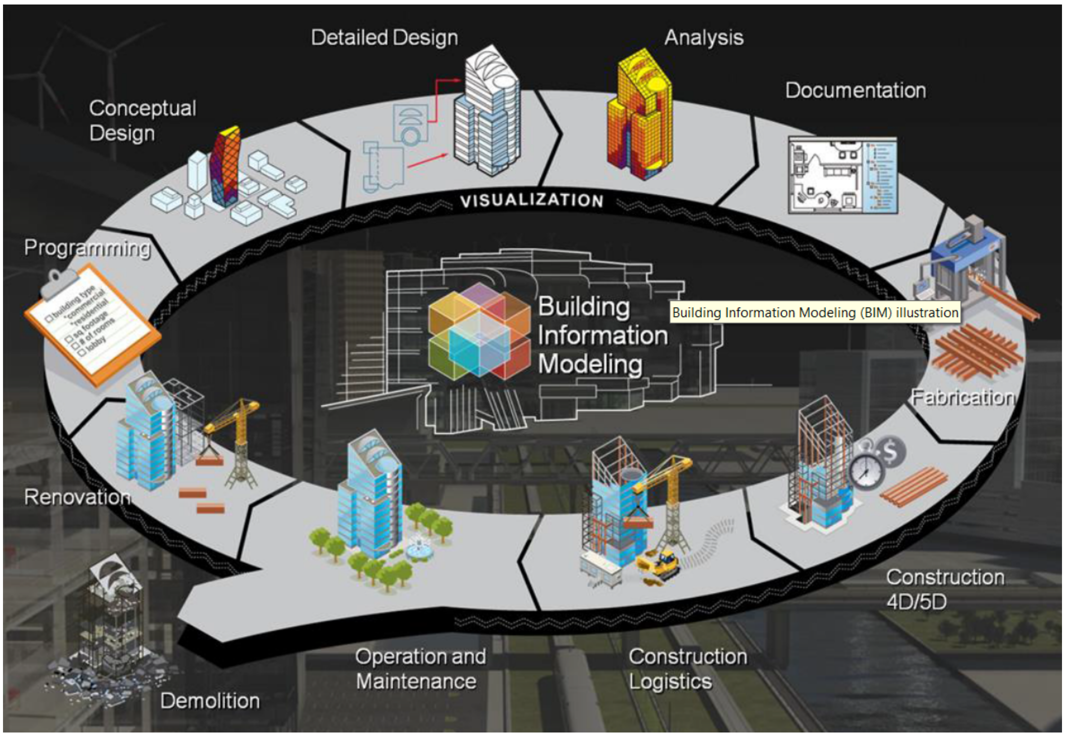

Figure 1: The life cycle of a building [25]

3. Existing standards

Today's BIM standards are the successors of older exchange formats such as DXF. The most mentioned standards are currently Industry Foundation Classes (IFC) and CIMSteel Integration Standards (CIS/2). These semantic models describe buildings using the EXPRESS language which is a part of STEP (STandard for the Exchange of Product model data, ISO 10303) [17, 8]. Standards are not only being developed to describe the geometric model. United States Army Corps of Engineers file format COBie (Construction Operations Building Information Exchange) is mainly focused on non-geometric data and can be used for the facility management [25].

The up to date 3D GIS file formats are often based on XML. An example is the COLLADA format which is used together with the OGC[2] standard KML for the geometry representation in Google Earth (within KMZ files) and Trimble SketchUp. Another important OGC standards are GML (Geography Markup Language, ISO 19136) and its application schema CityGML (see below). The CityGML standard is widely used as an interface within the process of transformation from BIM (IFC) into the geospatial environment. On the other hand, ESRI shapefile may be called de-facto standard "due to its wide acceptance by users and software vendors" [27]. This format is quite important because in most cases it is the target destination of BIM to GIS transformations although the conversions often employ CityGML as an intermediate format. This is no surprise considering the worldwide spread of the ESRI products. The ESRI Multipatch geometry type is used to model the three-dimensional shell of objects within shapefile or ESRI geodatabase [10].

3.1. The Industry Foundation Classes data model

IFC (Industry Foundation Classes) is an open data model and file format developed and managed by buildingSMART International (formerly the International Alliance for Interoperability). The data model was introduced in 1997 as the first standard by this alliance. In 2005 IFC became an ISO standard (ISO 16739). The most up to date version is currently IFC4 which is still not widely supported by software vendors. Therefore, IFC 2x3 TC1 is now the most widespread version [6, 5, 27, 18].

It was already mentioned afore that the most common model description method in IFC is the EXPRESS language. However, there also exist an XML implementation – ifcXML. Both EXPRESS and XML model descriptions are stored as a text file and are human-readable. The ifcZIP file format can be used for the data compression.

There are two basic types of objects in IFC: spatial structure elements (site, building, building storey, space) and building elements (walls, columns, doors, windows. . .). Important thing is that neither spatial structure elements, nor building elements have to have geometry defined and a model can be purely semantic (which is consistent with the BIM focus on all kinds of information, not only on geometry). On the other hand, IFC supports many ways of geometry representation: Compound Solid Geometry (CSG), swept geometry (sweep volume, sweeping) as well as Boundary Representation (B-Rep) which is common in 3D GIS [6, 8].

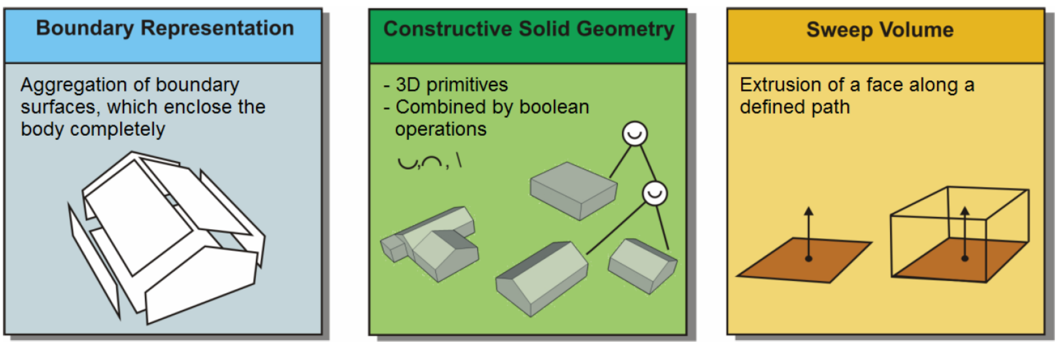

Figure 2: The ways of geometry representation in IFC [8]

[2] Open Geospatial Consortium: http://www.opengeospatial.org/

3.2. CityGML - between the worlds of BIM and GIS

CityGML is an open data model and file format based on XML which can be used for storing and sharing virtual 3D city models. It is an application schema of GML 3.1.1. CityGML was originally developed by SIG3D (Special Interest Group 3D GDI-DE[3]) and first successful implementation was performed in 2005 within the Pilot 3D project. In 2008 CityGML became an adopted OGC standard. At present the most up to date version is 2.0.0. CityGML is currently used as a standard for 3D models of cities in many countries in Europe (Germany, France, the Netherlands, Monaco, Switzerland or Denmark) and worldwide (Turkey, Qatar, Japan, Malaysia) [7].

The standard defines the way of description of geometry, semantics, topology and appearance for the most important objects in cities. Its focus on semantics is very similar to the BIM (IFC) approach. The geometric-topological model is adopted from GML3, employs the ISO standard 19107 Geographic information – Spatial schema and represents geometry using the Boundary Representation method. The semantics is described by the thematic model which contains classes for the most important objects in modern cities. Currently there are fourteen modules in the CityGML thematic model – CityGML core and thirteen thematic extension modules: Appearance, Bridge, Building, CityFurniture, CityObjectGroup, Generics, LandUse, Relief, Transportation, Tunnel, Vegetation, WaterBody, TexturedSurface [7].

Different applications of CityGML require various detail of three-dimensional city models. Therefore, different levels of detail (LOD, 0 – 4) can be used. Every city object can have more geometric representations in one CityGML dataset (one for each LOD). In addition, explicit generalisation associations between city objects can be defined. This enables aggregation of objects in a lower LOD.

Considering that building information models attempt to depict structures in the greatest detail possible, the most detailed CityGML LOD4 is closest to BIM. In LOD4 buildings are portrayed as architectural models with their surfaces categorised as walls, roofs or openings and with details such as balconies, chimneys, dormers or antennas. Interiors are also modelled and buildings are divided into rooms with interior installation (stairs, railings, radiators or pipes) and furniture (tables, chairs). Other structures than buildings (tunnels, bridges) are modelled in LOD4 in a similar way. However, even in LOD4 CityGML data model is not sufficient and has to be extended to be better compatible with BIM (IFC) models (see 5.2) [7].

4. BIM and GIS cooperation

4.1. Fields of cooperation

Isikdag states in his article [14] that an implementation of BIM in the geospatial context can be useful for site selection analyses, simulations to determine energy consumption and lighting requirements in buildings, fire response management operations and N-dimensional analyses at the urban level.

Donkers [8] indicates possible utilization of building models for cadastral applications (3D cadastre), environmental analyses, determination of solar potential, architectural applications (count and distribution of windows according to the location of a building, assessment of

[3] GeoDaten Infrastruktur Deutschland

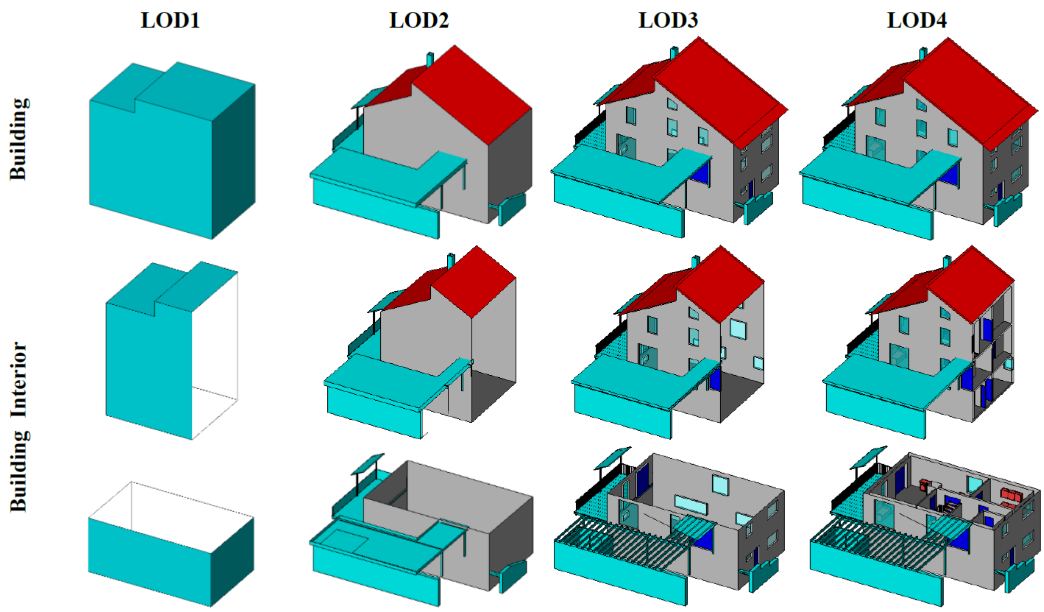

Figure 3: A building model in CityGML LOD1 – LOD4 [7]

interaction between neighbouring buildings and their surroundings – noise and heat transfer) or for real estate agents (searching houses with specific features).

Laat and Berlo [23] describe the mutual benefits of BIM and GIS cooperation when BIM can be an important data source for models of urban areas in GIS and conversely, GIS can serve as a data source for the design and integration of new buildings in the geospatial context. According to Hijazi et al. [12] the ability to integrate 3D models of buildings into the geospatial context is the crucial issue for facilitating interaction with 3D models of cities. These models can then be employed, for example, for navigation purposes. Also BIM and GIS cooperation for facility management (administration of a university campus) is mentioned in this article.

Another similar description of the BIM usability can be found in the work by Kolbe [22] which is focused on the CityGML standard. Kolbe states that BIMs in the IFC file format can be a very important data source for the LOD 4 CityGML city models. Such models can be utilized for disaster management (damage extent estimates, flood simulations, rescue teams navigation...), combined (indoor/outdoor) navigation and for 3D visualizations. If we speak about CityGML LOD4 and indoor navigation, the article by Isikdag et al. [16] is also very important. In this article the creation of graphs from primal geometric models for navigation purposes is analysed. Zlatanova [27] expands the 3D city model area of use in disaster management on training simulators based on real city models.

Benner et al. [2] also describe the utilization of high detailed city models. The QUASY data model described in his contribution should further extend the usability of such models in the areas of town planning and urban management, emergency and catastrophe planning or for traffic simulations. The BIM and GIS interconnection for traffic infrastructure planning in the surroundings of a high-rise building is described in [26]. Moreover, Bansal [1] employs the BIM and GIS cooperation in the construction safety planning.

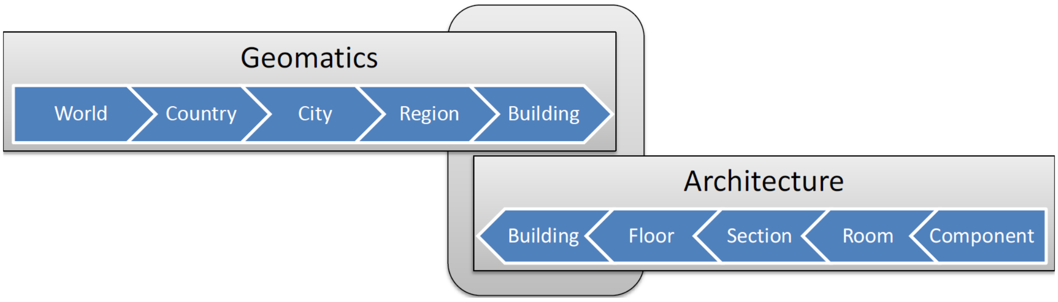

Figure 4: Overlap between the fields of Geomatics and Architecture [8]

4.2. Main obstacles

Building information models and geographic information systems were originally developed for different purposes and therefore significant differences can be found between them. Building information models and also their predecessors CAD systems are especially developed for the building design. That is for modelling of yet non-existent buildings. This models are to be maximally detailed in both geometry and semantics. Relationships between particular objects in a building are of utmost importance but absolute coordinates are not so relevant.

On the other hand geographic information systems mostly model the reality – already existing objects and phenomena around us. A great degree of abstraction is used in most cases and much emphasis is put on georeferencing (i.e. absolute coordinates of modelled elements) [15, 14].

With the use of the available literature the main obstacles of BIM and GIS integration were found as follows:

1. BIM (e.g. the IFC file format) uses more ways of geometry representation (CSG and sweeping in addition to B-Rep used in GIS)
2. BIM and GIS use different semantics
3. BIM and GIS use different coordinate systems

The first issue may be the most significant obstacle in the conversion from BIM (IFC) to GIS file formats such as CityGML. Whereas BIM models can use CSG or swept geometry, in GIS the geometry representation is limited to B-Rep and usually only straight lines and planar faces are used as the boundaries. In contrast to volumetric IFC models CityGML objects are only represented by visible surfaces. Therefore, the exterior shell of objects has to be extracted within the IFC to CityGML conversion. The exterior shell computation is not a trivial problem and a lot of existing conversion tools do not provide a fully valid results [8, 2].

Whereas BIM is focused on modelling detailed building models, in GIS whole cities and landscapes should be portrayed. Thus, it is logical that in BIM (e.g. IFC) and GIS (e.g. CityGML) objects do not correspond to each other completely. Semantic mapping which should eliminate the problems with different semantics during transformation is described in [15].

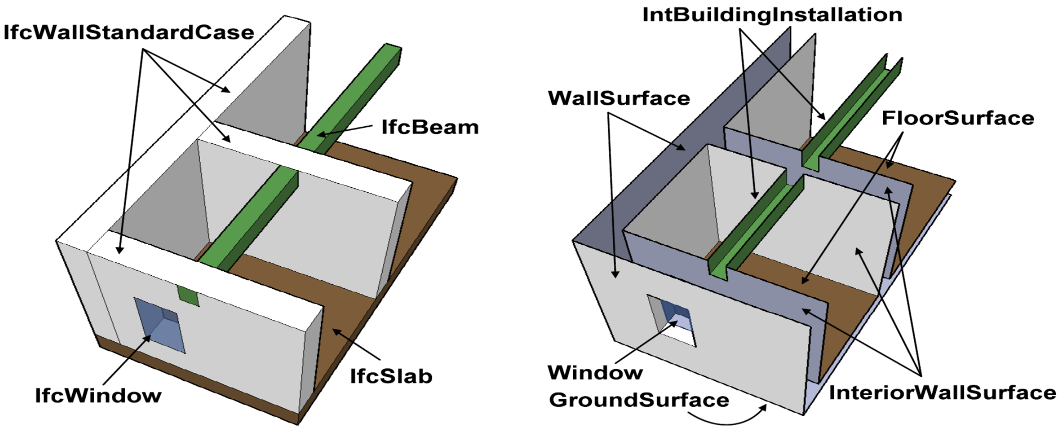

Figure 5: Differences between geometry representations in BIM and 3D GIS [23]

The difference between coordinate systems describes, for example, Černý [6]. In BIM the World Coordinate System (WCS) is used. WCS is a local rectangular coordinate system of a drawing. The origin and the orientation of its axes have to be defined to enable transformation into a global spatial reference system of GIS. These parameters should be listed in IFC (in WGS84) but they are not mandatory and they may only have an approximate precision. This problem is solved in IFC4 but, as said afore, this specification is still not widely supported.

5. Recent cooperation efforts

The most interesting found efforts dealing with the BIM and GIS collaboration are described in this chapter. At present it is clear that due to their differences the full integration (at the system level) is not reachable [6, 8, 13]. On the other hand Hijazi [12] states that it is possible to achieve integration at the data level, semantic level or within a web service. Academic debate aside some institutions are already using GIS tools for BIM tasks (see e.g. facility management of the University Campus Bohunice of the Masaryk University performed in ArcGIS).

5.1. IFC to CityGML transformation

According to Isikdag and Zlatanova [15] the transformation from IFC to CityGML has two parts: the conversion of semantics and the transformation of geometry. These parts cannot be realized separately due to the significant difference between both data models. One object might be mapped into a group of objects and vice versa. The paper contains theoretical framework to facilitate the transformation and describes specific objects and attributes of IFC which can be used to generate building models in CityGML LOD1 - 4.

Donkers deals in his thesis [8] mainly with the transformation of geometry. He states that a lot of today's IFC to CityGML conversion tools (Safe Software FME[4], BIMserver tools[5]) do not produce fully valid geometry. Therefore, his conversion is focused on the valid CityGML output. The already mentioned exterior shell computation is described as the most impor-

[4] http://www.safe.com/
[5] http://bimserver.org/

tant operation due to the differences in geometry representations. After semantic mapping and geometry transformation Donkers performs geometric and semantic refinement to ensure validity. The thesis contains a proposed framework and its testing implementation for LOD3 and experimentally for the most detailed LOD4 CityGML models.

5.2. CityGML extensions

The CityGML standard supports application specific extensions of its data model. These extensions can be created using the ADE (Application Domain Extension) mechanism. Every ADE can specify new properties of existing CityGML classes (e.g. the number of habitants of a building) or entirely new object types [7]. Most of the existing CityGML extensions can be found on the CityGML wiki.

Laat and Berlo [23] use the ADE mechanism to develop the GeoBIM extension. This ADE should increase the compatibility of the CityGML semantics with building models in the IFC file format. The extension adds new IFC compatible properties to CityGML classes (Room, Window, Door, Building…). Examples of these properties are the widths and heights of windows and doors. Furthermore, new classes are added, e.g. the Stair class. The GeoBIM ADE is implemented in the open source BIMserver.

5.3. BIM in the geospatial context

Isikdag et al. deal in [18] and [14] with the utilisation of the transformed IFC model in the geospatial context to facilitate site selection analysis and fire response management. The fire response application is the pivotal part of this effort. It is supposed that the information about the affected building should be acquired from the BIM model. This model ought to be transformed from BIM to GIS directly during the rescue operation. The conversion steps are very similar to the IFC to CityGML transformation described in [15] (5.1). However, the target destination is here the ESRI shapefile or the ESRI geodatabase.

The IFC to shapefile conversion performs also Černý as a part of his dissertation thesis [6] (see also 5.5).

5.4. Historic building modelling

In most cases, the information model is created for newly built buildings. Such model is produced and continuously updated during the whole process of the building design and construction. If all stakeholders take part in the model creation, the model is developed naturally. On the other hand, production of BIM of an already existing building can be highly time consuming. In this case existing documentation have to be revised and reprocessed or even geodetic survey of the actual state have to be performed. However, general consensus seems to be that the creation of BIMs of existing buildings can also pay off because the 3D BIM documentation is not much more time consuming than the 2D building passport (according to Černý [6] and the "BIM in Facility Management" panel discussion within the BIM DAY 2014).

The creation of models of historic heritage buildings is an even more special example of the BIM employment. Fai et al. [11] describe the N-dimensional modelling of a heritage building in a BIM software where the building is modelled in multiple versions corresponding to different time periods. The contribution by Dore and Murphy [9] names such process Historic Building Information Modelling (HBIM). Within HBIM, historic buildings are modelled based on laser scanning and photogrammetry using BIM software (e.g. ArchiCAD). The resulting model is then integrated into the 3D GIS environment for storing and further analysis.

An approach similar to HBIM can also be found in the Czech Republic. The papers by Jedlička et al. [19] and Jedlička and Hájek [20] deal with the creation of a semantic 3D model of a heritage building. Although they do not use any BIM software for modelling, the process of the model integration into GIS and the focus on information-rich models is analogous with HBIM. Buildings are modelled using the SketchUp application, exported to CityGML and then imported into the ESRI geodatabase.

Speaking about the Czech Republic there exist a method of heritage building documentation whose origins date back to the 1940s or even further - the structural - historical investigation. The goal of this method is to gather maximum information about a heritage object. Objects are examined from different point of views by historians, architects, architectural historians, civil engineers or structural engineers. The results of the investigation are presented both textually and graphically. The textual part comprises outcomes of historical research, architectural analysis of the building and description of its structural development. Graphic part consists of historic maps, plans, photographs and paintings and is newly supplemented with plans and photographs of the current state. Finally, the very important graphical evaluation is provided which evaluates the development of the building structures and their historical value and uses floor plans as base layers [24]. It is obvious that this thorough investigation can be a very valuable data source for BIMs of heritage buildings and conversely BIM can be a suitable tool for the storage, presentation and analyses of these results.

5.5. GIS analyses in the BIM environment

Borrman [3] and Borrmann and Rank [4] deal with the development of a 3D spatial query language. 3D spatial queries can be useful for BIM (IFC) models and also in 3D GIS. The mentioned work contains description of metric, directional and topological spatial operators. To verify the concept, a prototype software was implemented to process models defined in the VRML language.

Černý in his thesis [6] analyses this topic in detail and focus on the implementation of spatial queries originating in GIS in the 3D BIM environment. His work first identifies several drawbacks of the GIS software (ArcGIS) utilisation (necessary degradation of geometry during the conversion to GIS, inability of ArcGIS to analyse geometrically complex objects and difficult promotion of results back to the original BIM model). Therefore, Černý chose another approach and developed his own tool which enables to analyse directly BIM models in IFC. This approach eliminates the mentioned issues but on the other hand works only with one IFC model with no geospatial context.

5.6. Server solution

The BIM4GeoA (BIM for Geo-Analysis) concept which is described in the article by Hijazi et al. [12] combines existing open source software to ensure efficient data management and analyses of building models in the broader geospatial context. The PostGIS spatial database, the BIMserver model server, the Google Earth 3D viewer and IFC, CityGML and KML file formats are the key components of this effort. The system architecture is used to develop applications for management of a university campus (i.e. for facility management and indoor routing). This effort is another example of GIS utilization for the task of facility management.

6. Discussion

After the examination of the currently existing literature dealing with the BIM and GIS relationship it can be said that a lot of effort was spent to convert BIM models in IFC into the GIS file formats (i.e. CityGML or ESRI shapefile). The possible utilization is always presented but the description of the actual work with the model in the GIS environment is usually missing. This may be related to the fact that the BIM and GIS interrelationship as well as the BIM itself are relatively new fields of study and respective workflows are still in development. Therefore, up to date literature should be further sought and also development in the industry should be carefully monitored.

The very important thing is that BIM cannot be considered as one particular software but rather as a way of communication between programs of the building process stakeholders (e.g. with the use of exchange formats). From this point of view a GIS programs might serve as one of BIM tools and enable to consider the designed building in the broader geospatial context. According to the literature possible use cases can be found as follows: site selection analysis, visibility analysis, assessment of interaction between neighbouring buildings and their surroundings, construction safety planning and traffic planning. To facilitate this tasks, the aforementioned matter of conversions will have to be solved. We are talking here not only about the widely discussed topic of BIM to GIS transformation but also about the backward conversion. The difficult promotion of results back to BIM has been described [6] and only few papers mention this issue (minor reference about the derivation of IFC objects from CityGML found in [21]).

On the other hand, BIMs of finished buildings can be used to populate 3D models of cities. These models can be further employed for the tasks of disaster management, training simulators, indoor navigation, and last but not least for visualisation purposes. Moreover, speaking about finished buildings, GIS can also be used for the facility management. The database management of the building information and georeferencing are here the main advantages of GIS. Especially in the case of large building complexes (university campuses, factories), GIS might actually become a very powerful BIM tool. It is clear that GIS will have to compete with purely facility management software (e.g. Archibus). On the other hand, existing solutions – the aforementioned FM of Masaryk University, for instance, show that the utilization of GIS for facility management purposes can be advantageous.

A special field of study is the creation of models of already existing buildings. These models can be further used in the same way as the models which were developed during the design and construction process. Such information-rich models of existing (or even historic) buildings are worthy of attention because their creation involves geodetic survey, photogrammetry, laser scanning, measured data processing, model creation, database storage, administration of the resulting spatial model, its analyses and presentation all this being known to the field of geomatics. Moreover, in the Czech Republic, results of the mentioned structural-historical investigations would be probably used as a data source for models of historic buildings. It is up to the experts of geomatics to emphasize their experience (and, where appropriate, the advantages of GIS) in this field of study.

A very important is also the question of safety of such BIMs. It is clear that especially heritage institutions will very carefully consider acquiring an information model which describe in detail a heritage building with very valuable movables inside. However, even so closely guarded objects such as banks are today provided with building information models[6] and, of course, not all information should be given available to the wide audience.

7. Conclusion

The main goal of this article was to search the fields where BIM and GIS could benefit from their cooperation and to introduce the most interesting examples of BIM and GIS collaboration efforts. The most promising fields of study were found as follows: the facility management of large building complexes and the creation of models of existing (or even historic) buildings. Nevertheless, the whole field of BIM should be carefully monitored by experts of GIS and geomatics in general to keep abreast of future developments.

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