Reports on Geodesy and Geoinformatics, 2024, Vol. 118, pp. 136–141

DOI: 10.2478/rgg-2024-0022
Received: 5 September 2024 / Accepted: 26 November 2024
Published online: 20 December 2024

ORIGINAL ARTICLE

On a unique identification of 3D features between BIM and GIS for 3D Cadastre

Karel Janečka [1]* and Martin Vaněk [1]

[1]Department of Geomatics, Faculty of Applied Sciences, University of West Bohemia, Technicka 8, 301 00, Pilsen, Czechia

*kjanecka@kgm.zcu.cz

Abstract

The recent research has demonstrated both the potential of building information management (BIM) for the 3D cadastre, especially for legal spaces of building units and the advantage of the combination of physical and legal boundaries for their visualization. During the lifetime cycle of the building and the units within, the geometry of units can change. Then, it is necessary to promote the transition from the updated BIM model to connected systems. Considering this, the paper focuses on a unique identification of building units between BIM and GIS. The main idea is that each feature (in our case, the building unit) receives a unique identifier when it is created, which is then used in every system during its life cycle. Each of these domains has its own specific technical requirements for the unique identification. The aim is to have just one identifier of the building unit regardless of the selected information system to make an effective update. The paper further aims to model the 3D legal spaces of building units using BIM and their storage inside the external spatial database based on the CityGML standard data model. The proposed solution facilitates the storage of the 3D legal spaces of building units together with their physical counterparts in one environment based on the widely recognized OGC standard. Furthermore, as many countries still use 2D parcel-based cadastre, the proposed solution also allows for the connection of the existing cadastral information systems with these externally stored 3D legal spaces without the necessity of changing the systems.

Key words: BIM, 3D cadastre, CityGML, building units, spatial database

1 Introduction

Other fields could also further benefit from the extension of building information management (BIM), primarily in the domain of the construction industry. Reusing existing models is cost-effective and in line with the Spatial Development Life Cycle (Kalogianni et al., 2020). In Czechia, there will be an obligation to use BIM for above-limit public contracts for construction works (as defined in the Public Procurement Act) financed from public budgets, including making their preparatory and project documentation, taking into account the conclusions from the evaluations of pilot projects and the specific nature of individual types of buildings (Czech Government, 2023). Furthermore, the usage of BIM is widely supported by the document "The Concept of Introducing the BIM Method into Public Administration" (Ministry of Industry and Trade, 2017), which was approved by a resolution of the government of Czechia. This conceptual document consists of a set of measures to be implemented. One of them considers the usage of BIM for 3D cadastres. The term 3D cadastre is explicitly mentioned in the document, although the current cadastral system is based on the 2D parcels paradigm. An example of how BIM could be used for a 3D cadastre is the 3D legal spaces of building units.

As the (3D) cadastre could be seen as an application of geographic information system (GIS), there arises a question over how to interconnect these two worlds, which differ in so many aspects (spatial reference systems, 3D geometric representation, data format, and data storage). The integration between BIM and GIS is also a step

toward solving problems in such different domains as Architecture, Engineering and Construction (AEC), Facility Management (FM) or Disaster Management (DM) sectors (Basir et al., 2020; Fosu et al., 2015; Ma and Ren, 2017; Pedó et al., 2023; Sani and Abdul Rahman, 2018; Zhang et al., 2021; Zhu and Wu, 2022). The integration of these two worlds supports the implementation of the Smart City concept as well (Janečka, 2019a; Zhu and Wu, 2021).

The existing BIM models are usually encoded in the Industry Foundation Classes (IFC) format (ISO 16739-1, 2018). It is an open, vendor-neutral international standard enabling the sharing of information about the building throughout its life cycle. Atazadeh (2017) argues that in the future, BIM/IFC files produced by architects will be used by land surveyors to subdivide ownership of properties. Broekhuizen et al. (2021) state that using BIM/IFC models in practice requires addressing various technical issues to make them usable for 3D land administration systems. The usage of BIM/IFC for 3D cadastral/land administration purposes has been widely explored in recent years (Atazadeh et al., 2016a,b, 2017, 2019, 2021; Barzegar et al., 2019; Gotlib and Karabin, 2017; Guler and Yomralioglu, 2021; Kalogianni et al., 2020; Oldfield et al., 2017).

In reality, to store the 3D geometries of legal objects directly in a cadastral database and their integration with other data would mean, in most countries, a paradigm shift from traditional 2D parcel-based data models into 3D. This covers all legislative, organizational, and technical aspects. Therefore, the transition from a traditional 2D cadastre to a 3D cadastre could be made incrementally in the sense of demonstrating the advantages of the 3D approach. One such step could be an integration of 3D legal objects with their physical counterparts. Aien et al. (2013) proposed the integration of physical counterparts of legal objects in the cadastral system. The reason is that the visualization of 3D properties (legal spaces) without integrating with their physical counterparts will not remove ambiguities that affect the interpretation of the rights, restrictions, and responsibilities.

However, none of the mentioned research solves the unique identification of 3D legal spaces in different worlds (BIM x GIS) and standards (IFC x CityGML x LADM). Therefore, the paper elaborates on the approach that each feature (in this case, the building unit) receives a unique identifier when the feature is created, which is used in every system during the life cycle of the feature.

Typically, the life cycle of the building and the units within is divided into four different stages: production stage, construction stage, use stage, and end-of-life stage. It is essential that when the ID of a building unit changes during its life cycle in BIM, one can identify the respective unit in all related information systems.

The paper demonstrates the principle of unique identification in the case of the 3D legal spaces of building units using BIM and their storage inside an external spatial database based on the CityGML standard data model. Storing the 3D legal spaces inside the spatial database enables the connection with other (e.g. cadastral) information systems. Also, the proposed solution enables one to store the 3D legal spaces of building units together with their physical counterparts in one environment and connect the existing cadastral information system with these 3D legal spaces without the necessity of changing this system, which is still based on the 2D parcel paradigm. The paper demonstrates this connection at the conceptual level in the example of the Czech cadastre, whose data model was described by the conceptual language of the international standard ISO 19152:2012 Land Administration Domain Model (ISO 19152, 2012) by Janečka and Souček (2017). This international standard supports the referencing of external classes, like CityGML ones. A Room object was selected to model the 3D legal space within CityGML. This is a semantic object for modelling the free space inside a building and should be uniquely related to exactly one building or building part object. It should be closed, and the geometry normally is described by a solid (lod4Solid) (Gröger et al., 2012). The Room object can also describe a logical closed 3D space, which is exactly the case of the 3D legal space of the building unit.

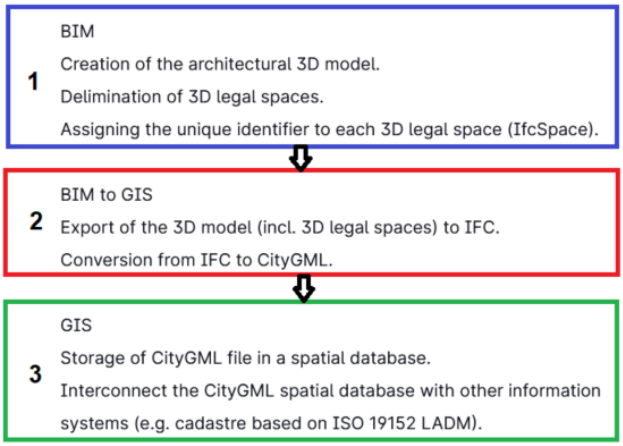

Figure 1. The research methodology

2 Methodology

The research methodology (Figure 1) includes three main steps:

1. The creation of the architectural 3D model of an apartment building in BIM-ready software. The model consists of building units, which are physically delineated by walls, ceilings, and floors. Based on the Czech legislation, the 3D legal spaces of building units were determined, and a unique identifier was assigned to each of them.
2. The export of the apartment building, including 3D legal spaces of building units, into IFC and the conversion of the IFC file into the CityGML 2.0 data model. The selected version was chosen based on its compatibility with the 3DCityDB spatial database. As the 3D legal spaces are modelled as Room semantic objects within CityGML, Level of Detail (LOD) 4 was used.
3. Storage and visualiation of 3D legal spaces in a CityGML-compliant spatial database (3DCityDB) and their connection with the cadastral data model based on ISO 19152:2012 Land Administration Domain Model (LADM) (ISO 19152, 2012).

An important aspect of the proposed solution is the unique identification of 3D legal spaces of building units from the architectural 3D model, following conversion between BIM/IFC and CityGML, culminating with their storage in the spatial database. The particular 3D legal space must be uniquely identifiable throughout this cycle using the same identifier.

3 Modelling the apartment building and 3D legal spaces of building units

An apartment building was chosen, and it is located in the city of Pilsen in Czechia. The virtual 3D model (Figure 2) was created using Autodesk Revit 2020 software according to analogue plans, which is the official documentation of construction execution confirmed by an officially certified surveying engineer. The result is a BIM-ready model of this apartment building.

The subsequent delimitation of the property spaces was carried out based on Czech legislation. Building units registered in the cadastre may be defined based on two different laws in the Czech Republic. This is either an older regulation using the Act on Ownership of Apartments (Law Number 72/1994 Coll.) or a newer regulation using the new Civil Code (CC) (Act No. 89/2012 Coll.), or Government Regulation No. 366/2013 Coll. to which the CC refers. The first unit's transfer date determines which adjustment (law) is used to define the property spaces. The CC entered into force on January 1, 2014; therefore, buildings in which the first unit was transferred after that date are subject to this regulation. The adjustment, according to the Act on Apartment Ownership, will apply to

Figure 2. 3D model of the apartment building

buildings where the first unit transfer occurred before January 1, 2014.

Since the transfer of the first unit of the selected apartment building took place before January 1, 2014, the ownership areas are defined by using the Act on Ownership of Apartments. The property spaces of individual owners are determined by the internal area of the floors, ceilings, and perimeter walls of the apartment. The internal area is used for delineation, as the main vertical and horizontal structures are considered common property. This indicates that the perimeter walls of the apartments, floors, and ceilings are already part of the common property. In addition, common areas also include corridors, staircases, load-bearing structures, insulation, various technical equipment, etc. On the other hand, private property includes apartments, garages, and cellars. The difference between the CC and the Apartment Ownership Act is particularly evident when it comes to balcony spaces. Under the Act on Ownership of Apartments, even balconies, including the outer "balcony" wall, are considered the private property of the apartment owner. This modification is also used within the modelled apartment building. On the other hand, in newer buildings that are governed by the CC-based regulation, balconies are classified as common areas, even if they are only accessible from a privately owned apartment and are for the exclusive use of the owner of the unit.

The creation of property spaces in the Autodesk Revit 2020 software was carried out in such a way that it was first necessary to cover the inner surfaces of the perimeter walls of the apartments using the "Space Separator" function. This was because, according to the current legislation, the outer wall of the apartment is considered common property. Figure 3 depicts the creation of the space separator.

Subsequently, the property spaces were created by inserting them into the model using the "Space" function. After creating the individual spaces, it was necessary to label them with identification data indicating the specific owner of the given space. Spaces created in this way are saved in the IfcSpace class when exported to IFC. In Figure 4 one can see the resulting ownership space of one apartment unit defined in the Revit software according to the applicable Czech legislation.

4 Unique identification of building units in BIM/IFC, CityGML, and LADM

For the unique identification of the 3D legal space of the building unit in Revit, a new IFC_SPACE_ID property is added to the Space object. Subsequently, a new property sheet named Identification is created for objects of Space type, and IFC_SPACE_ID is added to it.

The IFC_SPACE_ID identifier should serve for the identification of the 3D legal space in BIM/IFC, CityGML, and LADM. Therefore, one must consider the conditions of the identification of objects in CityGML using the gml:id attribute. This attribute is mandatory for all GML objects and is of xsd:ID type, which is derived from xsd:NCName (non-colonised name). This implies, that the gml:id

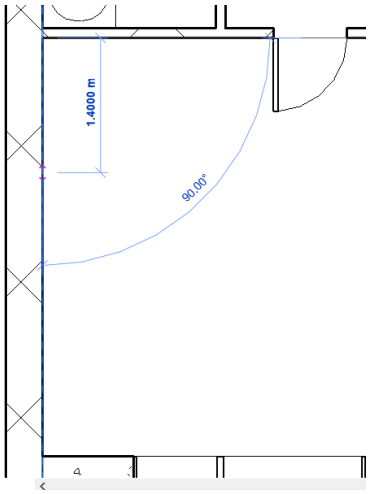

Figure 3. Creating a space separator (blue line) (Vaněk, 2021)

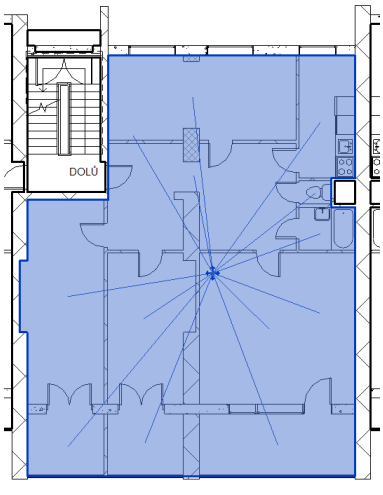

Figure 4. Resulting property space in Autodesk Revit 2020 software (Vaněk, 2021)

identifier must start either with a letter or underscore and may contain only letters, digits, underscores, hyphens, and periods.

To connect the 3D legal spaces also with the LADM-based cadastral database, the IFC_SPACE_ID identifier should meet the requirements of the LADM class LA_SpatialUnit and its attribute suID (the spatial unit identifier). The suID is of generic data type Oid, which has two attributes: localID (local identifier assigned by the data provider) and namespace, identifying the data source of the spatial object. Both attributes are of CharacterString type.

Considering the conditions for the identification of objects in CityGML and LADM, the attribute IFC_SPACE_ID is modelled as text and the value starts with the underscore (_), and then the unique sequence of digits follows (e.g. "_879487793245263"). In this form, the IFC_SPACE_ID can be used for the identification of the 3D legal space of the building unit in CityGML/3DCityDB (using gml:id attribute) and also in LADM-based cadastral data model (using suID attribute).

When exporting from Revit to IFC, the property sheet Identification is exported as IfcPropertySet. An IFC_SPACE_ID is thus available for each building unit in the output IFC file, which is further processed.

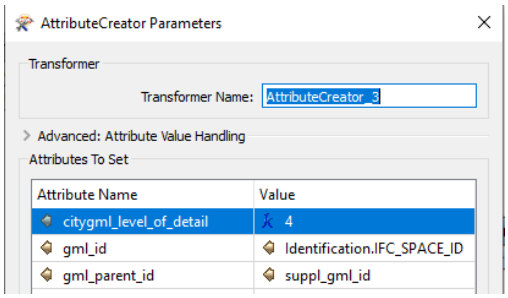

Figure 5. Setting gml_id. The IFC_SPACE_ID from the input IFC file is used

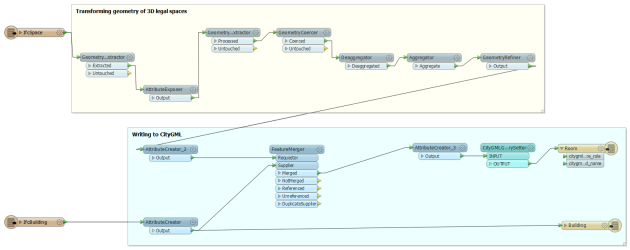

Figure 6. Transformation of 3D legal spaces from IFC into CityGML

5 Transformation from IFC into CityGML

The transformation was realised in FME Workbench, which is a visual workflow editor for developing spatial extraction-transformation-load (ETL) tools. As the first step, the IFC readers for the apartment building (IfcBuilding) and 3D legal spaces (IfcSpaces) were added.

One of the most important steps of the whole transformation consists of the extraction of the IFC_SPACE_ID attribute (transformers GeometryPropertyExtractor and AttributeExposer) and changing the IFC volume geometry of IfcSpaces into CityGML solid geometry of Rooms. To change the geometry, the transformers GeometryPartExtractor and GeometryCoerces were used.

The extracted value IFC_SPACE_ID was used as the identifier (gml:id) of the corresponding 3D legal space within the CityGML file (see Figure 5).

The whole transformation scheme is depicted in Figure 6. During the writing of the final CityGML, the 3D legal spaces are transformed into the appropriate coordinate system. To be compatible with the cadastre, the data are transformed into S-JTSK / Krovak East North (EPSG:5514), which is a legally binding coordinate system used in Czechia. Figure 7 shows a snippet of the generated CityGML file.

Extending CityGML with legal information enables representation of the legal boundaries within the context of a 3D city model (Biljecki et al., 2018).

```
<bldg:interiorRoom>
<bldg:Room gml:id="_759871323545768">
<bldg:lod4Solid>
<gml:Solid srsName="EPSG:5514" srsDimension="3">
<gml:exterior>
<gml:CompositeSurface>
<gml:surfaceMember>
<gml:Polygon>
<gml:exterior>
<gml:LinearRing>
<gml:posList>-822859.680834027 -1067434.21877104 415.52
</gml:LinearRing>
</gml:exterior>
</gml:Polygon>
</gml:surfaceMember>
<gml:surfaceMember>
<gml:Polygon>
```

Figure 7. The 3D legal spaces are modelled as interior Rooms in CityGML

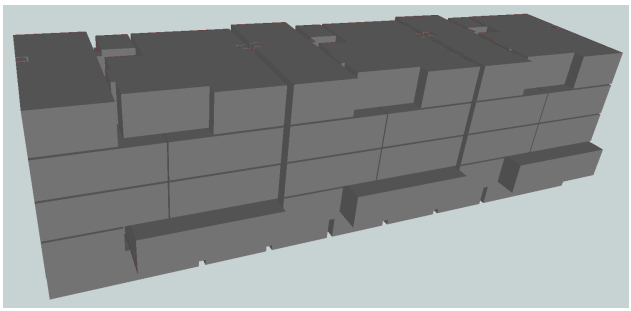

Figure 8. 3D legal spaces of building units

6 Storage in 3DCityDB

The 3D City Database (3DCityDB) (Yao et al., 2018) is a free and open-source package consisting of a database schema and a set of software tools to import, manage, analyze, visualize, and export virtual 3D city models on top of a spatial database system. The 3DCityDB implements the CityGML 2.0 standard, which is a widely spread standard for the interoperable exchange of 3D city models (Gröger and Plümer, 2012; Gröger et al., 2012; Janečka, 2019b). For testing purposes, an instance of the 3DCityDB was set up in the PostgreSQL database with the PostGIS extension.

Before the import of data into 3DCityDB, data were validated using the 3DCityDB Importer/Exporter tool against the official CityGML XML schema. The validation results were printed to the console window - data were valid. After data insertion into 3DCityDB, these were stored in the *citydb* scheme. Figure 8 captures 3D legal spaces of building units stored in a 3DCityDB-based spatial database.

7 Connection with cadastral data model and querying the 3D legal spaces

The LADM-based country profile of Czechia (Figure 9) was proposed by Janečka and Souček (2017). The proposed profile comprises legal and spatial components and reflects the current cadastral registration and the corresponding legal requirements. The class *CZ_LegalSpaceBuildingUnit* is there for modelling legal spaces in building units.

The class *CZ_LegalSpaceBuildingUnit* from the Czechia LADM-based profile contains the attribute *suID*, which is the spatial unit identifier. The *suID* value is equal to the value of *gml:id* identifier of corresponding 3D legal space (modelled as *bldg:InteriorRoom*) inside the 3DCityDB database. This class also contains the attribute *extAddressID*, which contains the address of the external 3DCityDB database with the stored geometry of 3D legal space.

Having the suID, one can then request the geometry of the corresponding 3D legal space from the external 3DCityDB database (see Figure 10).

8 Conclusions

The paper aimed at the 3D modelling of legal spaces in building units and their unambiguous identification throughout their life cycle in different information systems. The proposed solution is based on the widely recognized international standards in the scientific literature. Other relevant standards (e.g. LandXML) can be further considered.

The IfcSpace class is used to model the 3D legal space of the building unit. The delineation of the 3D legal space described in the paper is based on Czech legislation. The situation may vary in different countries. As the legal spaces can be connected (via ownership at a conceptual level), further research should explore

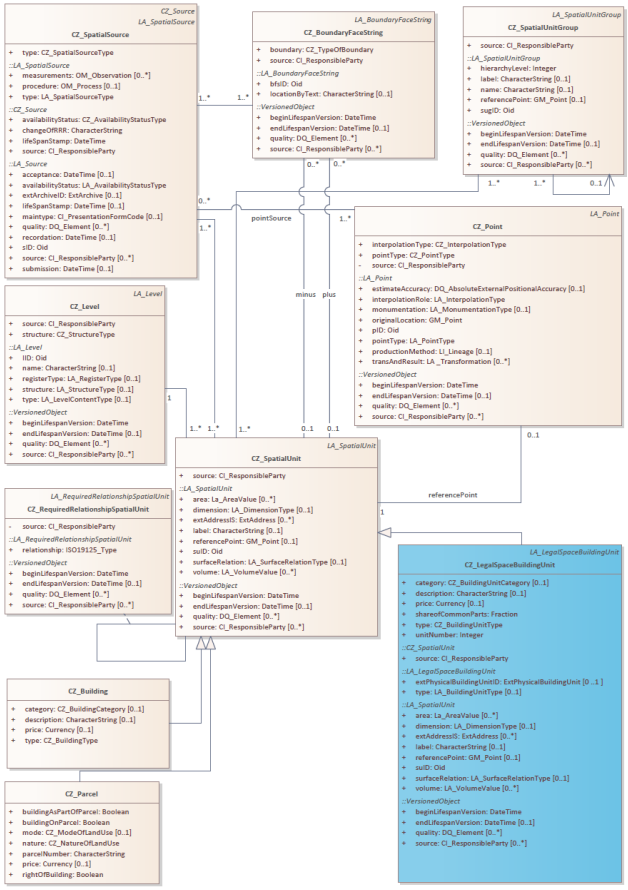

Figure 9. The spatial part of the LADM-based Czechia country profile (Janečka and Souček, 2017). The class for 3D modelling legal spaces in building units is highlighted in blue.

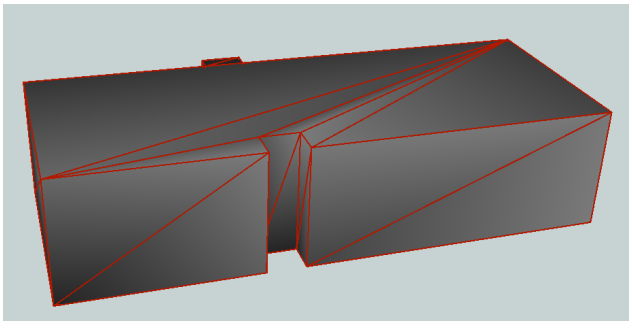

Figure 10. The 3D legal space of the selected building unit loaded from the 3DCityDB PostgreSQL/PostGIS database

the usage and the unique identification of IfcZone. To do so, it would be necessary to identify the appropriate concept in corresponding standards.

To ensure unique identification, the technical requirements of different domains must be considered. The focus was also on storing 3D geometries in the external spatial database according to the CityGML data model. This enables the integration of 3D legal and physical boundaries of real objects (building units) in one common environment. The proposed solution was tested using a CityGML-compliant spatial database. The database scheme is proposed according to version 2 of the CityGML standard. Nowadays, the newer version 3 already exists, bringing some novelty to 3D geometry, especially the support for volume geometry. As the BIM geometry is often based on volumes, the conversion from BIM to GIS can be more straightforward. Thus, future research should consider the usage of this new version.

The storage of 3D legal spaces in the CityGML-compliant spatial database enables the connection of this data to other information systems, e.g. cadastre. This approach is entirely in line with the international standard ISO 19152 LADM, which supports the connection of the cadastre with external information systems. Several countries, including the Czech Republic, still have a cadastre based on 2D parcels. The approach described in the article will allow these countries to connect 3D legal spaces to existing databases without changing the current paradigm.

Another crucial issue must be considered to make all the processes fully operational. The important aspect of the proposed solution of unambiguous identification is the organizational one. At the central level, the authority that will be in charge of assigning unique identifiers must be clearly declared.

The presented principles and solutions can serve, for example, to implement the so-called Register of Building Units. Such a register could help with the unambiguous identification of apartments, for example, during the population census.

Acknowledgements

This work was supported by the Grant Use of Mathematics and Informatics in Geomatics [number SGS-2022-027].

References

Aien, A., Kalantari, M., Rajabifard, A., Williamson, I., and Wallace, J. (2013). Towards integration of 3D legal and physical objects in cadastral data models. *Land Use Policy*, 35:140–154, doi:10.1016/j.landusepol.2013.05.014.

Atazadeh, B. (2017). *Building information modelling for urban land administration*. PhD thesis, University of Melbourne, Australia.

Atazadeh, B., Kalantari, M., and Rajabifard, A. (2016a). Comparing three types of BIM-based models for managing 3D ownership interests in multi-level buildings. In *Proceedings of the 5th 3D Cadastre Workshop, Athens, Greece*, pages 183–198.

Atazadeh, B., Kalantari, M., Rajabifard, A., Ho, S., and Champion, T. (2016b). Extending a BIM-based data model to support 3D digital management of complex ownership spaces. *International Journal of Geographical Information Science*, 31(3):499–522, doi:10.1080/13658816.2016.1207775.

Atazadeh, B., Kalantari, M., Rajabifard, A., Ho, S., and Ngo, T. (2017). Building information modelling for high-rise land administration. *Transactions in GIS*, 21(1):91–113, doi:10.1111/tgis.12199.

Atazadeh, B., Olfat, H., Rajabifard, A., Kalantari, M., Shojaei, D., and Marjani, A. M. (2021). Linking Land Administration Domain Model and BIM environment for 3D digital cadastre in multi-storey buildings. *Land Use Policy*, 104:105367, doi:10.1016/j.landusepol.2021.105367.

Atazadeh, B., Rajabifard, A., Zhang, Y., and Barzegar, M. (2019). Querying 3d cadastral information from bim models. *ISPRS International Journal of Geo-Information*, 8(8):329, doi:10.3390/ijgi8080329.

Barzegar, M., Rajabifard, A., Kalantari, M., and Atazadeh, B. (2019). 3D BIM-enabled spatial query for retrieving property boundaries: a case study in Victoria, Australia. *International Journal of Geographical Information Science*, 34(2):251–271, doi:10.1080/13658816.2019.1658877.

Basir, W. N. F. W. A., Ujang, U., Majid, Z., Azri, S., and Choon, T. L. (2020). The integration of BIM and GIS in construction project – a data consistency review. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLIV-4/W3-2020:107–116, doi:10.5194/isprs-archives-xliv-4-w3-2020-107-2020.

Biljecki, F., Kumar, K., and Nagel, C. (2018). CityGML Applica-

tion Domain Extension (ADE): overview of developments. *Open Geospatial Data, Software and Standards*, 3(1), doi:10.1186/s40965-018-0055-6.

Broekhuizen, M., Kalogianni, E., and van Oosterom, P. (2021). BIM models as input for 3D land administration systems for apartment registration. doi:10.4233/UUID:5E240A06-5FDF-4354-9E6D-09C675F1CD8B.

Czech Government (2023). The substantive intent of the Act on Construction Information Management and the Information Model of Construction and the Built Environment (BIM Act). Resolution no. 298., Czech government.

Fosu, R., Suprabhas, K., Rathore, Z., and Cory, C. (2015). Integration of Building Information Modeling (BIM) and Geographic Information Systems (GIS) – a literature review and future needs. In *Proceedings of the 32nd CIB W78 Conference, Eindhoven, The Netherlands*, pages 27–29.

Gotlib, D. and Karabin, M. (2017). Integration of models of building interiors with cadastral data. *Reports on Geodesy and Geoinformatics*, 104(1):91–102, doi:10.1515/rgg-2017-0018.

Gröger, G., Kolbe, T. H., Nagel, C., and Häfele, K.-H. (2012). OGC city geography markup language (CityGML) encoding standard. Open Geospatial Consort. Wayland, MA, USA.

Gröger, G. and Plümer, L. (2012). CityGML – interoperable semantic 3D city models. *ISPRS Journal of Photogrammetry and Remote Sensing*, 71:12–33, doi:10.1016/j.isprsjprs.2012.04.004.

Guler, D. and Yomralioglu, T. (2021). A conceptual model for IFC-based delineation of condominium rights in Turkey: Initial experiments. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, VIII-4/W2-2021:5–12, doi:10.5194/isprs-annals-viii-4-w2-2021-5-2021.

ISO 16739-1 (2018). Industry foundation classes (IFC) for data sharing in the construction and facility management industries. National Organisation for Standardisation: Geneva, Switzerland.

ISO 19152 (2012). Geographic Information – Land Administration Domain Model (LADM). International Organisation for Standardisation: Geneva, Switzerland.

Janečka, K. (2019a). Standardization supporting future smart cities – a case of BIM/GIS and 3D cadastre. *GeoScape*, 13(2):106–113, doi:10.2478/geosc-2019-0010.

Janečka, K. (2019b). Transformation of 3D geospatial data into CityGML – a case of Prague. *Reports on Geodesy and Geoinformatics*, 107(1):41–48, doi:10.2478/rgg-2019-0005.

Janečka, K. and Souček, P. (2017). A country profile of the Czech Republic based on an LADM for the development of a 3D cadastre. *ISPRS International Journal of Geo-Information*, 6(5):143, doi:10.3390/ijgi6050143.

Kalogianni, E., Dimopoulou, E., Lemmen, C., and van Oosterom, P. (2020). BIM/IFC files for 3D real property registration: an initial analysis. In *Proceedings of the FIG Working Week 2020: Smart Surveyors for Land and Water Management. Amsterdam, the Netherlands*. International Federation of Surveyors, FIG.

Ma, Z. and Ren, Y. (2017). Integrated application of BIM and GIS: An overview. *Procedia Engineering*, 196:1072–1079, doi:10.1016/j.proeng.2017.08.064.

Ministry of Industry and Trade (2017). The concept of introducing the BIM method in the Czech Republic. https://www.koncepcebim.cz/wp-content/uploads/2023/04/Koncepce-zavadeni-metody-BIM-v-CR.pdf.

Oldfield, J., Van Oosterom, P., Beetz, J., and Krijnen, T. (2017). Working with open BIM standards to source legal spaces for a 3D cadastre. *ISPRS International Journal of Geo-Information*, 6(11):351, doi:10.3390/ijgi6110351.

Pedó, B., Tezel, A., Goethals, D., Koskela, L., Leaver, M., Victory, A., Vrabie, E., and Bocian, E. (2023). BIM and GIS integration: Lessons learned from multiple case studies. In *40th International CIB W78 Conference, Heraklion, Greece*, volume 4. European Council on Computing in Construction.

Sani, M. J. and Abdul Rahman, 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, doi:10.5194/isprs-archives-xlii-4-w9-299-2018.

Vaněk, M. (2021). Principy tvorby 3D BIM modelu na příkladu vybrané stavby a jeho využití ve 3D GIS (Principles of creating a 3D BIM model on the example of a selected building and its use in 3D GIS). Bachelor's thesis, University of West Bohemia in Pilsen, Czech Republic.

Yao, Z., Nagel, C., Kunde, F., Hudra, G., Willkomm, P., Donaubauer, A., Adolphi, T., and Kolbe, T. H. (2018). 3DCityDB - a 3D geodatabase solution for the management, analysis, and visualization of semantic 3D city models based on CityGML. *Open Geospatial Data, Software and Standards*, 3(1), doi:10.1186/s40965-018-0046-7.

Zhang, H., Yuan, X., Yang, X., Han, Q., and Wen, Y. (2021). The integration and application of BIM and GIS in modeling. *Journal of Physics: Conference Series*, 1903(1):012074, doi:10.1088/1742-6596/1903/1/012074.

Zhu, J. and Wu, P. (2021). Towards effective BIM/GIS data integration for Smart City by Integrating Computer Graphics technique. *Remote Sensing*, 13(10):1889, doi:10.3390/rs13101889.

Zhu, J. and Wu, P. (2022). BIM/GIS data integration from the perspective of information flow. *Automation in Construction*, 136:104166, doi:10.1016/j.autcon.2022.104166.