A framework for assessing cadastral data as a source for 3D indoor modelling

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Key words: IndoorGML, 3D cadastre, real property, floor plan, 3D modelling

SUMMARY

This article focuses on 3D indoor modelling of buildings using cadastral data as an alternative way of indoor spatial data acquisition. Despite the rapid development of indoor spatial data acquisition technology, there are no existing solutions that would enable mass acquisition of indoor data. The main motivation for our research was the general difficulty of indoor spatial data acquisition and consequently modelling, which is needed in particular for the purpose of indoor location-based services, while there is a large amount of cadastral data available that can be used for 3D indoor modelling. For the case study, we chose the Slovenian Building Cadastre, which provides a technical basis for condominium establishment and is the only centrally maintained and accessible database that contains data about building interior structure in Slovenia. We designed a framework for 3D indoor modelling based on cadastral data, comprised of a chain of processes, starting from initial cadastral data and ending with the IndoorGML document. The OGC IndoorGML standard is used for final outputs, as it provides a standardized data model for the representation and exchange of indoor spatial information designed for indoor navigation and location-based services. The process chain consists of three main parts, which are described in detail and summed up in a flowchart diagram. Our aim has been to design each process in the most generic way as possible, while also considering the particularities of Slovenian cadastral data. The proposed approach is software independent and can be implemented using various spatially enabled software packages. The study provides a good example of the cadastral data usefulness for 3D indoor modelling for Slovenia and can be used in many countries having a similar condominium registration system, i. e. land administration.

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1. INTRODUCTION

In everyday life, we are often faced with locating points of interest (POI) and finding optimal paths to them, which can be effectively solved by using navigation principles. An effective navigation process requires two key components, positioning and spatial data, which provide the spatial context to position information. Recent developments in the field of remote sensing have enabled efficient large-scale acquisition of quality spatial data. Sufficiently accurate positioning based on global navigation satellite systems (GNSS) is nowadays highly affordable and widely available on smartphones and other electronic devices, where it can be combined with spatial data to perform navigation. Unfortunately, this is only true for the outdoor environment, as both remote sensing and GNSS technologies have a very limited usability in the indoor environment, where nowadays we spend a great part of our time, whether working, resting, exercising, shopping, etc.

Compared to outdoor navigation, which is used daily by everyone who possess a smartphone or other GNSS-enabled electronic device with some storage and computational power available, indoor navigation has not yet evolved to a degree of mass use. However, this does not mean that the fields of indoor data acquisition and indoor positioning are not developing. In fact, several technologies are being developed to enable efficient indoor spatial data acquisition using various combinations of passive image sensors and active ranging sensors (Gunduz, Isikdag and Basaraner 2016; Jiao et al. 2017; Liang et al. 2016; Lee et al. 2017; Kang and Lee 2016; Lenac et al. 2017). Indoor positioning is also a rapidly evolving field with several technologies already available (Vanclooster, Van de Weghe and De Maeyer 2016; Correa et al. 2017; Brena et al. 2017). The common problem of both data acquisition and positioning technologies related to the indoor environment, which sets them apart from technologies for outdoors, is that they are both spatially very limited and cannot be performed on a large scale. This means that each building must be equipped with an indoor positioning system, and a detailed 3D model of the building indoor structure should be available.

The complexity and consequently high costs of indoor spatial data acquisition noted above justifies research on the usability of already acquired and stored data. Construction plans contain very detailed data about building interior structure, but their availability and consequentially usability is very limited, as their storage in many countries, including Slovenia, is not centralized. Recent developments in the field of BIM (ISO, 2013) are very promising (Deng, Cheng and Anumba 2016; Li and He 2008; Chen et al. 2014; Hong et al. 2015) as the models contain very detailed and semantically rich 3D indoor data. Currently, BIM is not yet widely operationally introduced into the process of building design, construction and maintenance, but in the future, it will be a valuable source of indoor data. Another source of normally not so detailed data about buildings are land administration databases. Although their content, structure, degree of detail and entry regulations depend on each country's legislation, this data is generally centralized and easier to access compared to construction plans.

This article focuses on 3D indoor modelling of buildings using cadastral data as an alternative way of indoor spatial data acquisition. In this way the article also aims to contribute to the idea of a multipurpose 3D cadastre, offering data for indoor location-based services. The indoor navigation applications are of particular interest with regard to public buildings (hospitals, schools, universities, bus and railway stations, etc.) and shopping centres to facilitate POI searching for visitors. Apart from that, several public services are potential users of indoor spatial data if available (police, emergency medical aid, firefighters, etc.). These services would benefit from indoor spatial data of every type of building, not just the aforementioned ones.

The case study for our research is based on the Slovenian Building Cadastre, which served as input data for 3D indoor modelling following the IndoorGML data model. Our aim was to develop a universal framework which could be applied to data from several countries having a similar condominium registration system, i. e. land administration.

2. LITERATURE REVIEW

The field of indoor location-based services has been experiencing strong research intensification in recent years as the services and available technologies lag behind compared to the ones developed for the outdoor environment (Jensen, Lu and Yang 2010; Gunduz, Isikdag and Basaraner 2016). Important factors that facilitate the research and development and ensure their consistency are international standards. The OGC standard IndoorGML was introduced in 2014, aiming to foster the development in the field of indoor location-based services. Several studies related to this standard and indoor data modelling have been made since then. Ryoo, Kim and Li (2015) compared OGC standards IndoorGML and CityGML (OGC, 2012), which both deal with 3D modelling of indoor space. Although they are similar in the 3D modelling aspect, the authors showed their differences, especially in their scope and applications. As is typical for rapidly developing fields, there are a large number of remaining unresolved issues related to indoor mapping and modelling. These issues are systematically analysed and categorized into existing and future ones in Zlatanova et al. (2013). Recently Kang and Li (2017) emphasized the potential of the IndoorGML standard and encouraged the research community to include it in their research, either to propose new features, develop new extensions or to study it in use cases. Some research has also been conducted in relation to the data sources and modelling processes for obtaining IndoorGML compliant models (Khan, Donaubauer and Kolbe 2014; Mirvahabi and Abbaspour 2015; Kim and Lee 2015; Diakité and Zlatanova 2016; Teo and Yu 2017).

The studies that combine the land administration system and indoor data modelling (Alattas et al. 2017; Zlatanova et al. 2016) deal with linking IndoorGML with LADM (ISO, 2012) on a conceptual level. Their main aim is to analyse how legal information from LADM can improve semantic properties of IndoorGML models and thus improve the process of indoor navigation. The cadastral extension is also mentioned as a candidate for semantic extension of

IndoorGML in Kang and Li (2017). The link between land administration and IndoorGML has therefore already been established, but until now only semantic enrichment of the core model has been considered.

2.1 IndoorGML standard

The rapid development of indoor location-based services in recent years has increased the demand for standardization. The OGC's answer to this demand was the introduction of the IndoorGML standard in 2014. Its data model is designed to support indoor navigation applications. To achieve that, it must cover geometric, topological and semantic aspects of indoor space. The standard follows the cellular space concept, where indoor space is modelled as a collection of non-overlapping cells. This sets it apart from the other standards (CityGML, IFC etc.) as they do not model the indoor space itself, but the building features (walls, windows etc.), which, on the other hand, can also define indoor space. The overlap with other standards in the geometric part is solved with possible external references to geometry. However, 3D geometry can also be included in an IndoorGML document.

The key component of the IndoorGML standard is a topology in the form of a Node-Relation Graph (NRG), as topology information is vital for navigation applications (Lee 2004). The theoretical basis for derivation of NRG from the indoor space geometry is the Poincaré duality, where a k-dimensional object in N-dimensional primal space is transformed to an (N-k) dimensional object in dual space (Munkres 1984). The topological relationships in IndoorGML are explicitly described using the *XLinks* concept of XML provided by GML. The referencing is realized using *href* attributes (*xlink:href* is used in the paper).

Another important concept defining the IndoorGML standard is a Multi-Layered Representation, which originates in Becker, Nagel and Kolbe (2009). It allows the same indoor space to be modelled in several layers according to the cellular space concept and therefore enables WIFI and RFID sensor coverage space modelling.

According to Kang and Li (2017) there is a need to support the implementation of IndoorGML standard with research activities in several topics, including subspacing of the cells, development of new semantic extensions and case studies.

3. METHODOLOGY

In our research, we designed a conceptual framework for 3D indoor modelling based on cadastral data, comprised of a chain of processes, starting from initial cadastral data and ending with the IndoorGML document. The OGC IndoorGML standard is used for final outputs. The process chain consists of three main parts that are described in detail and summed up in a flowchart diagram.

The empirical part of our research was carried out on a simulated representative case for a residential house. The data was prepared based on professional experience from practice and has the same structure and content as the data, which can be acquired from the Building Cadastre in Slovenia. The digitization process in GIS software was used in the first part for conversion from raster images (scanned documents) into vector features. At this stage the missing attributes needed in later processes were added. The digitized and supplemented data was the input for an automatic transformation and structuration process, which results in a final document that is compliant with the IndoorGML standard. The design of the digitization and transformation process was carried out cyclically, as the design of the transformation determined which missing attributes should be added in the digitization phase. In the structuration phase, the transformed features were hierarchically arranged and composed according to the IndoorGML XML schema.

3.1 The case study – Slovenian Building Cadastre

The Slovenian Building Cadastre, a separate database from the Land Cadastre, was introduced in 2000, as a technical basis for condominium registration in the Land Registry. In the following years up to 2006, the photogrammetric acquisition of building data was conducted for the whole country. In addition to 2D building outlines, additional attributes were collected, including ground height and maximum height. In 2006, the Building Cadastre was legally and operationally introduced.

In the Building Cadastre, data on buildings and parts of buildings (legal subdivision of a building) is stored and maintained. According to Slovenian legislation, a building that can be registered in the Building Cadastre is a construction which cannot be moved without damage to its substance and where a person can enter and is designed for permanent or temporary residence, business activities or any other activity. A building, i.e. real property, unit is an apartment, office or other separated part of a building which can be an independent subject on the real estate market. The Slovenian land administration system is currently undergoing a major reform. The now separately maintained but interlinked databases, the Land Cadastre and the Building Cadastre, will be integrated in one real property database with central maintenance. Some changes will also affect the building registration process.

In this study, we focused on floor plans, which are a part of the documentation for registration of the building in the Building Cadastre. All documentation is scanned and thus available in digital form. The mandatory content of floor plans are outlines of building parts for each floor. In many cases, the documentation contains more detailed floor plans, where each room is drawn. These floor plans were used for the study presented in this paper.

4. PROCESS CHAIN

In this section, the entire process chain from preparation of cadastral data to 3D indoor modelling of a building is presented.

4.1 Digitization phase

Firstly, the input data that contains useful information on the indoor environment has to be selected and acquired. For our study, we took detailed raster floor plans of a residential house (with outlines of all rooms), which can be acquired from the Slovenian Building Cadastre. The geometry and topology of indoor spaces were obtained through digitization of raster floor plans. For each floor plan, three layers were created; a polygon layer for room geometry, a line layer for connections (graph edges), and a point layer for graph nodes. Each room outline was digitized using the polygon feature and checked for overlap with other polygons. To enable the construction of 3D cell spaces with the extrusion, the floor and ceiling heights have to be added. It is worth mentioning that this method could produce overlapping of 3D cells in cases where the floor and ceiling are not straight and horizontal. The documentation of the Building Cadastre does not contain any information about room connectivity, which is essential for obtaining a connectivity graph. When using floor plans, the possible connections are narrowed down to common boundaries (faces in 3D) between rooms, but actual connections still have to be added manually.

Once the room polygons are created, points representing graph nodes can be created automatically as centroids, while lines representing graph edges have to be added manually, as they represent room connections, which are not extractable from existing data. Due to the duality concept, the points receive the same identifier as room polygons. Each line is snapped to the start and end point with the start and end point identifiers added as attributes. The lines representing connections between rooms in different floors (stairs and elevators) were snapped to points on different layers with added both point identifiers as attributes to enable integration of the connectivity graphs for each floor into one connectivity graph. While the positional alignment of floors has little effect on topology, it is important to properly align the floor plans one above the other, to enable proper 3D visualization of geometry. This also has to be done manually.

Additional attribute data available in the Building Cadastre database are the area and usage code for each room and usage code for the part of the building. Annex D in the IndoorGML standard contains the code lists for space class types, space function types and space usage types, defined using the OmniClass Construction Classification System created and used by the North American architectural, engineering and construction (AEC) industry. We tried to make a semantic link between those code lists and the code list that provides classification of rooms in the Slovenian Building Cadastre. We discovered that a proper semantic link between them cannot be established. The code lists originate from different domains, as the Building Cadastre code list is primarily designed to support real property registration and valuation. In the event that we decide to include the room and building part usage code as additional attributes, we would need to use the Indoor Navigation Module besides the Core Module and also provide the Building Cadastre code list.

Very similar digitization could be performed using construction plans. The main added value of using floor plans stored in land administration databases is their availability and the possibility to establish a direct link to information about rights, restrictions and responsibilities (RRR). It is also possible to establish a link to a registry of house numbers and addresses, which can serve as a key attribute to integrate outdoor and indoor navigation (Vanclooster, Van de Weghe and De Maeyer 2016).

4.2 Transformation phase

Properly digitized data in 2D vector format with additional attributes need to go through a series of transformations. All layers of the same type are first combined together, followed by three different sets of transformations, one set for each type (polygon, line, point).

The polygons representing the rooms' outlines with additional height attributes can be transformed into 3D cells with an extrusion process. After extrusion, the orientation of faces has to be checked and then assembled into a solid geometry. The final phase of a polygon transformation is creating the IndoorGML specific attributes (Table 1) that provide unique id, the hierarchy in the IndoorGML document (parent property and parent id) and the link to a node according to the Poincaré duality (duality *xlink:href*).

Table 1. IndoorGML specific attributes for each feature type

CELL	NODE	EDGE
id	*id*	*id*
parent property	parent property	parent property
parent *id*	parent *id*	parent *id*
duality *xlink:href*	duality *xlink:href*	
	connects *xlink:href*	connects *xlink:href*
		weight

The nodes first need the height attribute, which is derived from the polygon attributes, to position them inside the linked cell. Then, we assigned the same attributes to each node as to cells, with an additional attribute (connects *xlink:href*) that contains a list of all edges that are connected with a given node. This list was not included in the digitization phase, as the node can have any number of connected edges. The list was instead created by joining the edge attributes containing start and end node id. For each node, the joining produces a list of edges that either start or end with it.

For 3D visualization the edges need the height attributes (Figure 1). The start and end height are derived from node heights, while any additional line breaks get the same height as the start node. This can produce incorrect geometry of connection between two cells, but we decided to use it to simplify the transformation process and reduce manual input. In the attribute assignment, we left out the duality *xlink:href* attribute used to link the edges and faces, and added the weight attribute, which provides weights for navigation.

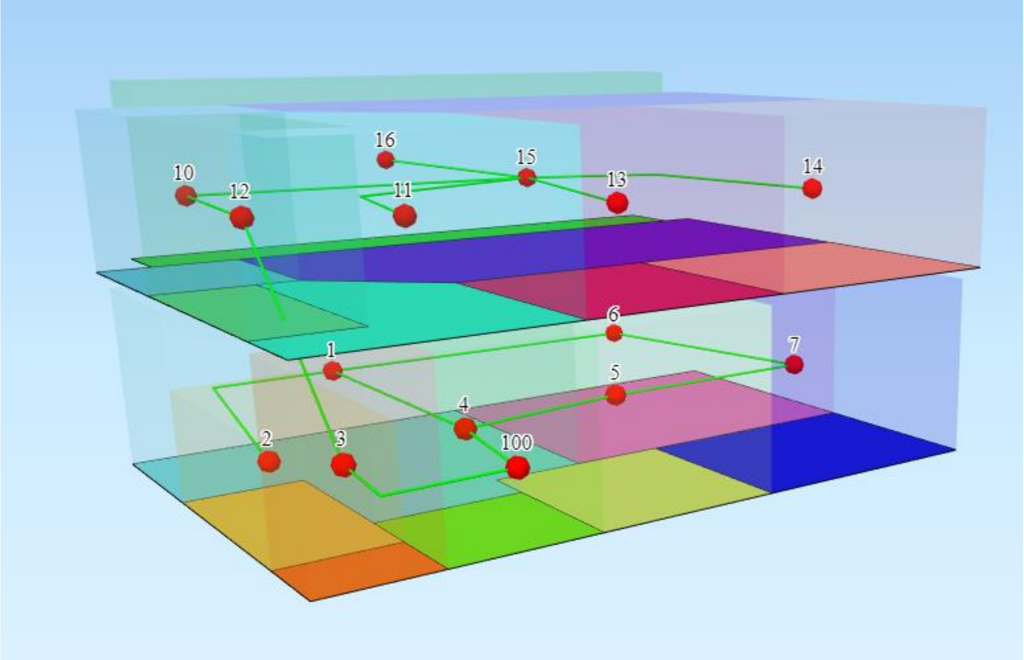

Figure 1. 3D visualization of transformed data

4.3 Structuration phase

In the final step, the transformed data is structured according to the IndoorGML structure and written into the IndoorGML document. The 3D cell solid geometry encoded in GML (ISO, 2007) is assigned to a CellSpace element, node geometry to a State element and edge geometry to a Transition element. The parent *id* and parent property attributes make possible the creation of *cellSpaceMember*, *stateMember* in *transitionMember* elements and place them properly in the document. With duality *xlink:href* attributes for cells and nodes, the duality elements are created for the CellSpace and State elements that establish links between Cellspace and State elements. The connected elements for State and Transition elements were created with connects *xlink:href* attributes for nodes and edges, containing attribute lists of connected feature identifiers. The Transition also received the weight element with weight attribute assigned. All other IndoorGML elements and their attributes were created to comply to IndoorGML standard. Below, those elements are coloured black, while the elements that came from transformation of points, lines and polygons are coloured blue. The red text indicates the place of GML geometry elements that are omitted.

```
<indoor:IndoorFeatures
     <indoor:primalSpaceFeatures>
          <indoor:PrimalSpaceFeatures gml:id="PS1">
               <indoor:cellSpaceMember>
                    <indoor:CellSpace gml:id="C1">
                         <indoor:Geometry3D>
                              GML Solid Geometry
                         </indoor:Geometry3D>
                         <indoor:duality xlink:href="#R1"/>
                    </indoor:CellSpace>
               </indoor:cellSpaceMember>
               …
          </indoor:PrimalSpaceFeatures>
     </indoor:primalSpaceFeatures>
     <indoor:MultiLayeredGraph gml:id="MG1">
          <indoor:spaceLayers gml:id="SL1">
               <indoor:spaceLayerMember>
                    <indoor:SpaceLayer gml:id="IS1">
                         <indoor:nodes gml:id="N1">
                              <indoor:stateMember>
                                   <indoor:State gml:id="R1">
                                        <indoor:duality xlink:href="#C1"/>
                                        <indoor:connects xlink:href="#T1"/>
                                        <indoor:geometry>
                                             GML LineString Geometry
                                        </indoor:geometry>
                                   </indoor:State>
                              </indoor:stateMember>
                              …
                         </indoor:nodes>
                         <indoor:edges gml:id="E1">
                              <indoor:transitionMember>
                                   <indoor:Transition gml:id="T1">
                                        <indoor:weight>1</indoor:weight>
                                        <indoor:connects xlink:href="#R1"/>
                                        <indoor:connects xlink:href="#R2"/>
                                        <indoor:geometry>
                                             GML Point Geometry
                                        </indoor:geometry>
                                   </indoor:Transition>
                              </indoor:transitionMember>
                              …
                         </indoor:edges>
                    </indoor:SpaceLayer>
               </indoor:spaceLayerMember>
          </indoor:spaceLayers>
     </indoor:MultiLayeredGraph>
</indoor:IndoorFeatures>
```

All three groups of processes presented above can be summarized with a flowchart diagram (Figure 2), which represents the core of our framework with all important steps from cadastral data as input to the IndoorGML document as output. Its purpose is also to clarify the textual description of the processes.

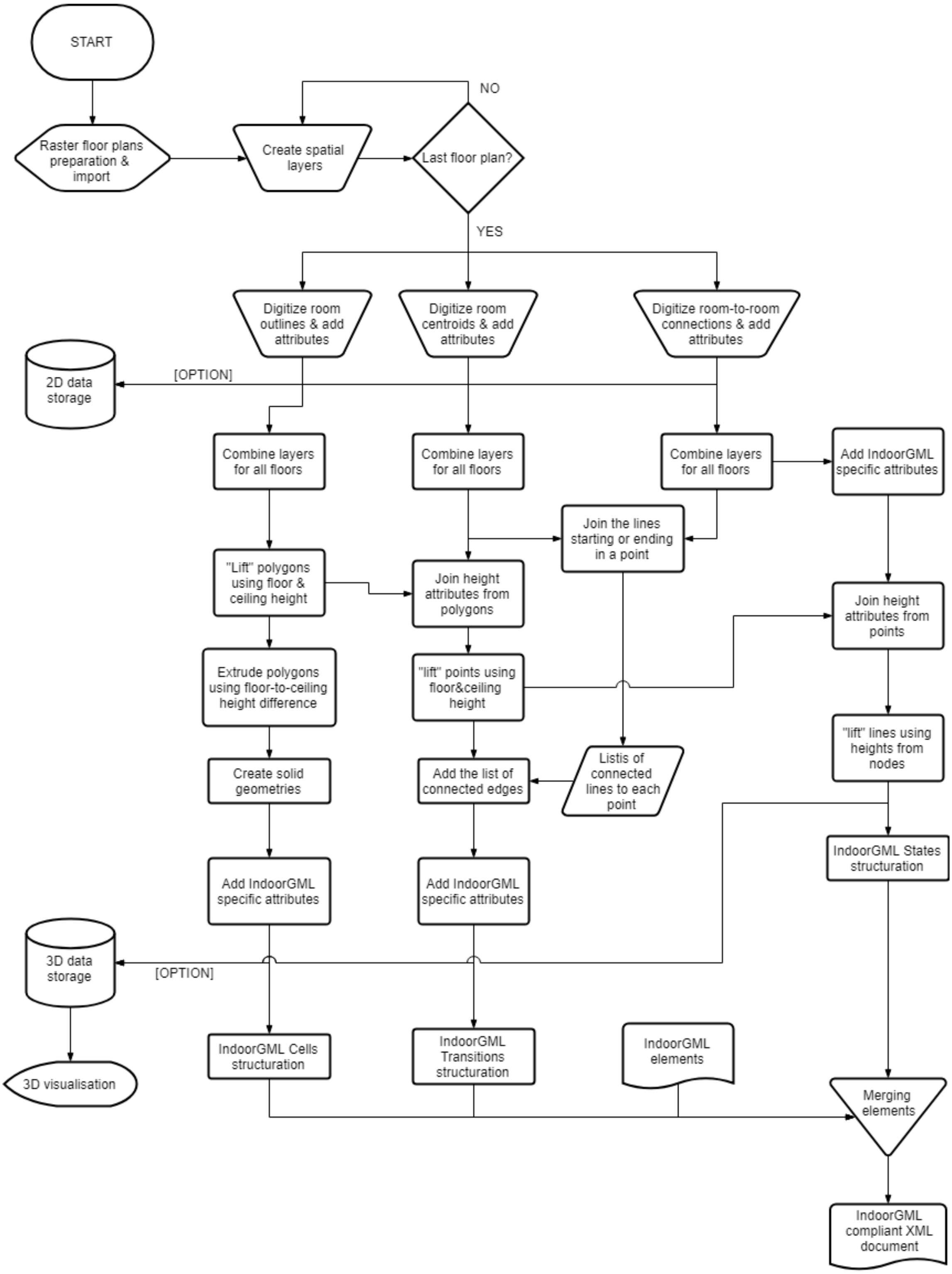

Figure 2. Process chain flowchart for creating IndoorGML document from raster floor plan

5. DISCUSSION

The detailed description of processes needed to develop a 3D indoor model of a building based on cadastral data with the final result in the form of an IndoorGML document opens up several topics for discussion. In the first part of the process chain, the missing cadastral attributes that need to be added are emphasized. Additional data input is generally not cheap, and its acquisition is time-consuming, especially for the indoor environment. The key missing attributes in the current Slovenian cadastre are heights of the floors and heights of the ceiling. These two attributes do not demand much additional effort in the data acquisition for preparation of the documents for the building registration. The need to digitize the geometry of rooms can easily be avoided with provision and storage of the floor plans in vector format, which are initially already made in vector format.

The inclusion of room connectivity information into the cadastral documentation would be a greater challenge, as it is far beyond the scope of the "classical" land administration. On the other hand, not much additional information would need to be collected. A basic connectivity graph without detailed edge geometry could already be generated from room connections in table form. The nodes can be created automatically as centroids and then also edges, using geometry of nodes and connectivity information from the table. The algorithms for automatic generation of centroids can create the centroid outside the polygon feature, but that can be automatically checked and manually corrected. Therefore, a generated graph would have little geometric properties, but its topology would be correct. Figure 3 shows the comparison of a graph generated with digitization of nodes and edges, and a graph with automatically created nodes and edges from polygons and room connectivity information. With increased building complexity, the difference between the two graphs would also increase.

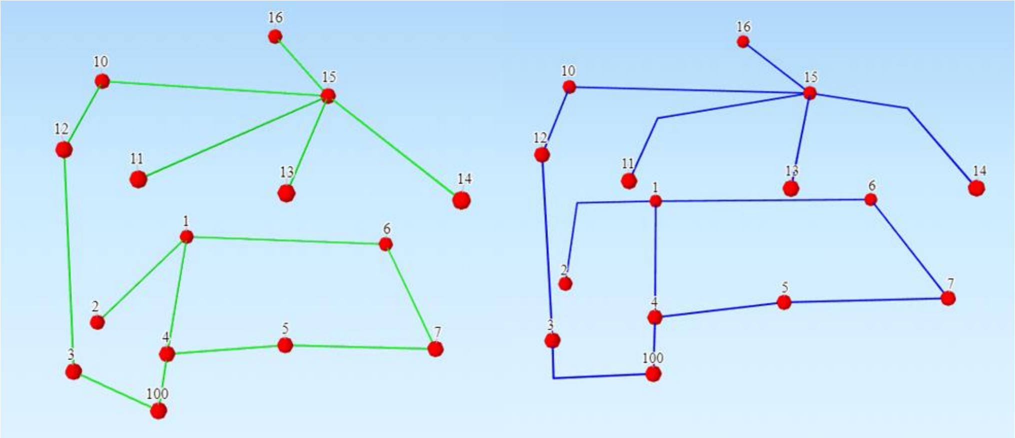

Figure 3. Automatically derived graph from room polygons and room connection information (left) and graph containing digitized nodes and edges (right)

The IndoorGML standard provides two different approaches for cell modelling, a "thin wall" model and a "thick wall" model. We chose the "thin wall" model, as it is closely aligned with floor plans in the Slovenian Building Cadastre, which do not account for the thickness of walls. If construction plans are used instead, it would be better to use the "thick wall" model. One of the drawbacks of the "thin wall" model is that it does not allow creating the cells with correct geometry while maintaining correct outer shape of the building. These two concepts also represent open questions regarding modelling rules for 3D geometries in a 3D real property cadastre. If the 3D geometry provides only reference to physical structures of the building, which define the real extent of RRR in space, the correct geometry is not as important as in the case when 3D geometry defines the real extent of RRR. The second option allows the reconstruction of the property unit geometry without the building structure (not yet built or demolished). The open (legal) question is also how the border between two property units is defined, the middle of the wall or on each side of the wall (Atazadeh, Kalantari and Rajabifard 2016).

Our framework has several features in common with JInedit software, which is an open source program that enables the creation of IndoorGML documents based on raster floor plans. While it uses the same input and provides practically the same output, there are several differences between our process chain and Jlnedit software that are listed below:

- The JInedit is a standalone software, while our process is a set of software independent operations, a framework that can be implemented using various spatially enabled software.
- Our process enables more flexible height provision (each room can have its own floor and ceiling height) and hence better representation of a real world situation.
- Only limited data can be acquired in Jlnedit, while our process allows additional data currently not supported by the IndoorGML standard to be captured and stored in the spatial database.
- Our process enables exporting 3D cell geometry in various 3D formats.
- Our process allows direct storage of geometry and attributes from the transformation phase into the database where routing capabilities can later be used.
- JInedit enables the execution of the whole process without the need for any additional software, while our process requires various software packages and users who are more skilled in geospatial data processing.

Our framework was implemented using QGIS open source GIS software in the digitization phase and ETL software FME from SAFE software in the ensuing phases.

6. CONCLUSIONS

The study aimed to create a process chain for 3D indoor modelling of buildings from input raster floor plans stored in the Slovenian Building Cadastre database to an IndoorGML compliant XML document. We identified key missing data in the current Building Cadastre that is needed for 3D indoor modelling. To produce proper results at the end, the need for digitizing raster floor plans in particular has been identified, and additionally floor height information and room-to-room connectivity are currently missing in the cadastral database. Although the paper does not focus on semantic enrichment of the 3D model, it should be stressed that additional data can be provided by linking the source data to land administration databases, which has great potential for semantic enrichment of IndoorGML models. The analysis of the compatibility between the current Slovenian and Omni Class classification of spaces shows that we would need to introduce a code list, adjusted to Slovenian classification, if we wanted to include this information in an IndoorGML document.

The process chain is developed based on Slovenian cadastral data, but it can be used for any similar data with some adjustments, especially in the attributes that require manual input. Detailed description of all processes and the process diagram, together with the following remarks and considerations, can serve as a starting point to assess the data in national land administration systems worldwide. Our future research will be focused on the analysis of other data which is available by linking the source data to connected databases and their usability in the context of indoor navigation applications.

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BIOGRAPHICAL NOTES

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