Extending OpenStreetMap to Indoor Environments: Bringing Volunteered Geographic Information to the Next Level

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ABSTRACT: Extensive and high-quality geographic data sources are important for any kind of spatial analysis or application, especially in the field of urban data management. In the last couple of years, Volunteered Geographic Information (VGI) has increasingly gained attractiveness not only to amateur users, but also to professionals in the geoinformation industry. Different VGI communities evolved and especially the OpenStreetMap (OSM) community became very strong. OSM provides very detailed information about the landscape, the street network and also more and more buildings are mapped. However, until now, this building mapping is mainly related to the outer shape of the ground space of the building and there is hardly any information about the inner structure available. This paper presents an approach of extending the OSM tagging schema to indoor environments. A 3D Building Ontology targeted to VGI communities is presented for describing different information aspects about buildings and their inner structure. Based on this ontology, the OSM extension is developed and explained. A proof of concept is given by applying the developed extension in mapping a use case building.

1 INTRODUCTION

When dealing with spatial and geographic phenomena in urban regions and performing analysis and computations about them, it is always important to have enough high-quality data. In the past, urban data management used to be performed by professional cartographers, public authorities or commercial data providers. Nevertheless, in the last couple of years a new and different trend for data collection has evolved, describing the collaborative and volunteered collection of geographic data. According to Elwood (2009) there are many different terms for this trend, but one of the most popular terms is Volunteered Geographic Information (VGI). VGI comprises the effect that an ever-expanding range of users creates, assembles and disseminates geographic and spatial data in a collaborative and volunteered manner (Goodchild 2007a). That is, individual persons or groups collect and create geographic data based on their personal measurements (via GPS etc.) and their knowledge about their surroundings and furthermore share that information with others through open web platforms. VGI is a combination of elements of the Web 2.0 and a collective intelligence, and there is an enormous potential arising from six billion humans acting as remote sensors (Goodchild 2007b). That is, VGI can also be considered as a new opportunity of systems and sensors for monitoring urban and regional environments. Particularly in urban environments the coverage is very good, because many humans results in many potential sensors and therefore the usage of VGI in urban management increases (Song & Sun 2010). Furthermore, public participation in urban planning and data management gets increasingly important (Cf. (Hansen 2004), (Bugs et. al. 2010)).

Diverse online mapping platforms such as OpenStreetMap (OSM) or Wikimapia have been initiated, allowing users to contribute and collaboratively edit spatial data. The increasing number of participants leads to a variety of different spatial data and information about geographic phenomena such as the street network, cities, POIs, buildings, landuse etc. At UDMS 2009, VGI has also been shown to be useful for urban data management by providing new sources of information that even can be integrated into a 3D platform (Schilling et. al. 2009).

However, most of current mapping activities are related to the outdoor environments (e.g. rough building structures, information about type of businesses, playgrounds, footpaths etc.) and there is hardly any information about indoor environments available. Since there is an increasing need for mature indoor navigation solutions and other indoor location based services (Goetz & Zipf 2010) and data providers are hardly able to commercially capture indoor data for large areas, there is an enormous potential within VGI communities for capturing and providing information about indoor environments which are open to the public (e.g. airports or shopping malls). For that purpose, it is essential to provide clear and understandable methodologies for mapping data about indoor environments. Therefore the main contribution of this paper is an extension to indoor environments for bringing VGI to the next level.

The remainder of this paper is organized as follows: First, there is an introduction to OpenStreetMap, especially focusing on its data model and data acquisition methods. Afterwards, there is a brief overview about related research. Thereafter, an extensive ontology for 3D building models with detailed information about indoor environments is presented. Subsequently, there is a description of how to extend the existing OSM tagging schema to indoor environments according to this ontology. The presented methodology is demonstrated on a use-case building and the last chapter summarizes the presented research and discusses future work.

2 THE OPENSTREETMAP COMMUNITY

One very popular (or even the most popular) VGI community is the so called OpenStreetMap project. OSM follows the peer production model (Haklay & Weber 2008) that created Wikipedia and aims for the provision of free to use and editable map data. Since 2004, the project grew rapidly and by November 2010 there were more than 320.000 registered users and more than 2.000 millions tracked points in the database (OSM 2010a). The data in OSM is created in different ways. The most important way is the acquisition of original data, manually captured by users via GPS devices. However, people can also contribute data based on aerial images (e.g. by Bing or Yahoo) or by contributing their local knowledge about the region they live in.

Basically, OSM consist of differently tagged nodes, i.e. a point with distinct coordinates. For defining lines or simple polygons (i.e. a polygon without holes), users can create so called ways which consist of several nodes. For defining a polygon, this way needs to be closed, i.e. the start point equals the end point. For mapping complex polygons or describing existing relationships between different elements, there are furthermore so called relations. These contain ways, nodes and also other relations.

In conjunction with user-generated content and collaboratively collected data, there is always a question about the accuracy and quality of the provided data. By comparing OSM data with data provided by commercial vendors like Teleatlas, it became evident that VGI is able to compete against commercial providers (Cf. (Zielstra & Zipf 2010), (Haklay 2010), (Ludwig et. al. 2010)). That is, data from OSM can be considered as a real alternative data source for spatial and geographic data in urban environments.

The data of OSM mainly focuses on outdoor environments and objects (e.g. streets, landuse etc.). When considering buildings, some information can be available within OSM, but these do only refer to very basic things like the location, outer shape or the height of the building. The latter mentioned information can be applied in the 3D visualization of city models as within the OSM-3D project (Over et. al. 2010). There are also some discussions about indoor mapping (Cf. next chapter), but until now they cannot be regarded as mature.

3 RELATED WORK

When investigating new models for the built environment provided by volunteers in a crowdsourcing approach, it first needs to be assessed, what the state of art of existing and professional building models looks like. There are some basic topological data structures and models such as Molenaar (1990), Zlatanova & Tempfli (1998), Coors (2003), Billen & Zlatanova (2003), Holweg et. al. (2004) or Zlatanova et. al. (2004), but they do not focus on semantic aspects, thus they are not applicable for the intended purpose.

The term Building Information Modeling (BIM) describes the process of generating and managing building data (Ashcraft 2007), whereby typically 3D modeling approaches are utilized. A commonly used format for BIM is the Industry Foundation Classes (IFC), describing a neutral and open specification which is also registered as ISO 16739 (IFC 2010). IFC defines an entity-relationship model (i.e. an abstract and conceptual representation of data) which consists of several entities (often hundreds or thousands) organized into an object-oriented hierarchy. Examples for such an entity are *ifcWall* or *ifcWindowType*, describing on the one hand a particular part of the building and on the other hand adding additional information about the type of the window. The entities in IFC can be divided into many different groups or concepts (for a detailed description refer to IFC (2010)), which on the one hand makes the whole framework very extensive and powerful, but on the other hand very complicated and confusing. The latter mentioned fact is also the reason why IFC is good for professional purposes, however for involving the broad public and average hobbyists, IFC is way too detailed and complex.

A closely related initiative to IFC is the City Geographic Markup Language (CityGML) which is an Open Geospatial Consortium (OGC) standard based on GML3. It is usable for describing geometric, topologic and semantic aspects of urban spaces and city models in a three-dimensional way (Kolbe et. al. 2005). Thereby it does not only focus on buildings, but also on other objects (e.g. vegetation). Furthermore, semantic and spatial aspects are structured into five different Levels of Details (LoD), where LoD0 describes a coarse model of the city and LoD4 (i.e. the most detailed one) even contains information about indoor environments. That is, CityGML can be utilized for a detailed and fine-grained description of buildings and their interiors. Nevertheless, CityGML is rather considered as a storage and exchange format for 3D city models and is mainly used by professionals. It is likely that CityGML is too complex for an application within VGI. But when new models for community based urban modeling tasks are proposed, these existing standards will provide some useful hints that shall ease the future combination of models from both worlds.

When trying to model 3D buildings, it is essential to share a common understanding of what kind of information is relevant and important. Therefore, different ontologies for buildings and indoor environments have been developed in past research efforts. Anagnostopoulos et. al. (2005) developed an extensive indoor navigation ontology, which is usable for path searching as well as for the presentation tasks of the navigation system. However, despite the many details about the indoor space, the presented ontology does not provide any information about the building itself. For modeling, visualization and other purposes, such information is nevertheless very important and therefore should be considered in a 3D building ontology.

A different approach is presented by Yuan & Zizhang (2008). Based on BIM, the authors propose an indoor navigation ontology which captures different parts inside the building such as corridors, elevators, stairways, doors etc. However, this ontology does also not provide information about the overall building (e.g. façade color, roof type etc.) and furthermore details about concrete measures and positions of the rooms etc. are also not covered by this ontology.

Dudas et. al. (2009) present ONALIN, an ontology which considers the special needs and requirements of different groups and individuals, whereby a strong focus lies on the limitations of different users (e.g. visually impaired, wheelchair driver etc.). ONALIN is a "*comprehensive ontology that considers the needs of all potential people traversing in buildings based on the ADA (Americans with Disabilities Act) standards*" (Dudas et. al. 2009).

Other ontologies are furthermore presented by Andersen & Vasilakis (2007) and Lee et. al. (2008). However, these are either not detailed enough for both outer appearance and inner structure, or on the other hand they are too detailed, so it is likely that the average OSM user won't be able to capture all required data.

Besides scientific work on 3D building modeling frameworks and ontologies, there is also some related work within the OSM community. In (OSM 2010b) it is described how to map buildings. By utilizing the key-value *building* = *yes*, users are able to describe the ground shape of a building with a set of individual nodes. Furthermore the keys *height* and *building:height* can be utilized for adding information about the (estimated) height of the building. Currently there are more than 26 million buildings available and about 645.000 of them contain height information. Furthermore there are some discussions about how to map indoor environments (OSM 2010c). Thereby the key-value *indoor* = *yes* has been proposed, indicating that the corresponding OSM object is inside a room or building. Furthermore the key *level* shall be used for describing in which building level the corresponding OSM object is located. Currently there are about 500 indoor objects available, so compared to the whole dataset, the coverage of the *indoor* key is negligible. Nevertheless, there is a strong trend towards building and indoor mapping activities. In Germany currently over 100.000 new building outlines are added to OSM every week. The development of the usage of the keys *building* and *indoor* is depicted in Figure 1 (a) and Figure 1 (b). There is an accelerating increase of the usage and it is likely that this development will increase even further in the near future as it has been the case with other object types in OSM before. Especially when more and more outdoor spaces are completely captured, it is likely that the community will commence with buildings and indoor spaces.

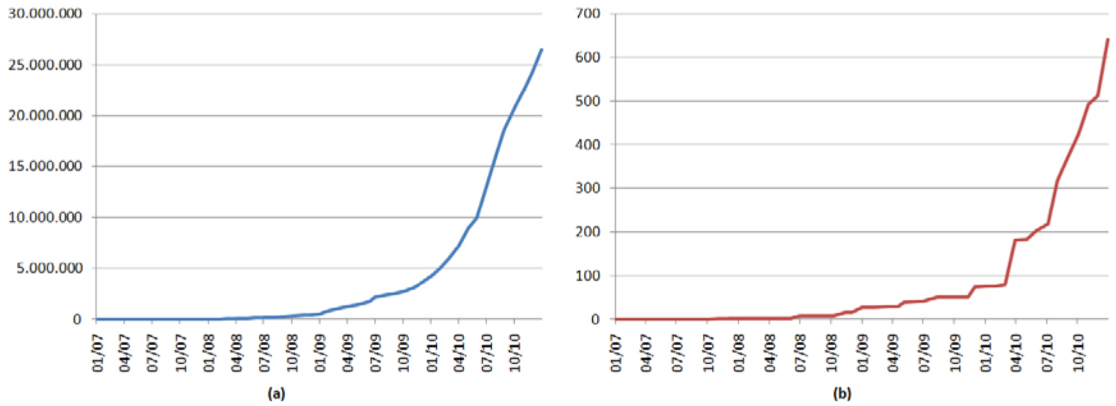

Figure 1. Usage of the *building* key (a) and the *indoor* key (b) between 2007 and 2010

4 3D BUILDING ONTOLOGY

Indoor spatial information and data allows transferring and extending popular existing outdoor applications and services (e.g. routing, navigation or mapping) to indoor environments. In doing so, diverse indoor services (e.g. navigation in a shopping mall or train station) can be provided to the public, thus assist the users in difficult situations and therefore increase their quality of life. As mentioned above, a commercial data collection for broad indoor areas is not likely and therefore it is a good opportunity to include and involve voluntarily acting hobbyists in the data acquisition process. This however leads to kind of a cleavage, because on the one hand a scientific correctness and completeness is required for proper applications, but on the other hand the OSM community is likely to not accept and utilize too complex methodologies. That is, there is a trade-off between the comprehensiveness and the usability of the invented methodology.

Trying to be able to share a common understanding of building information and fulfilling a scientific correctness and completeness, a 3D Building Ontology (3DBO) has been developed. Thereby, the ontology is designed as simple as possible, having in mind that not only professional users will use the extension but mainly normal users without professional skills. The ontology is suitable for describing the outer appearance and characteristics of the building as well as the inner building structure and it is likely that all relevant data can be captured by the community. So on the one hand, the ontology is kept as simple as possible, but on the other hand it contains enough information for different purposes such as a quite realistic visualization of the building or the provision of different indoor applications and services.

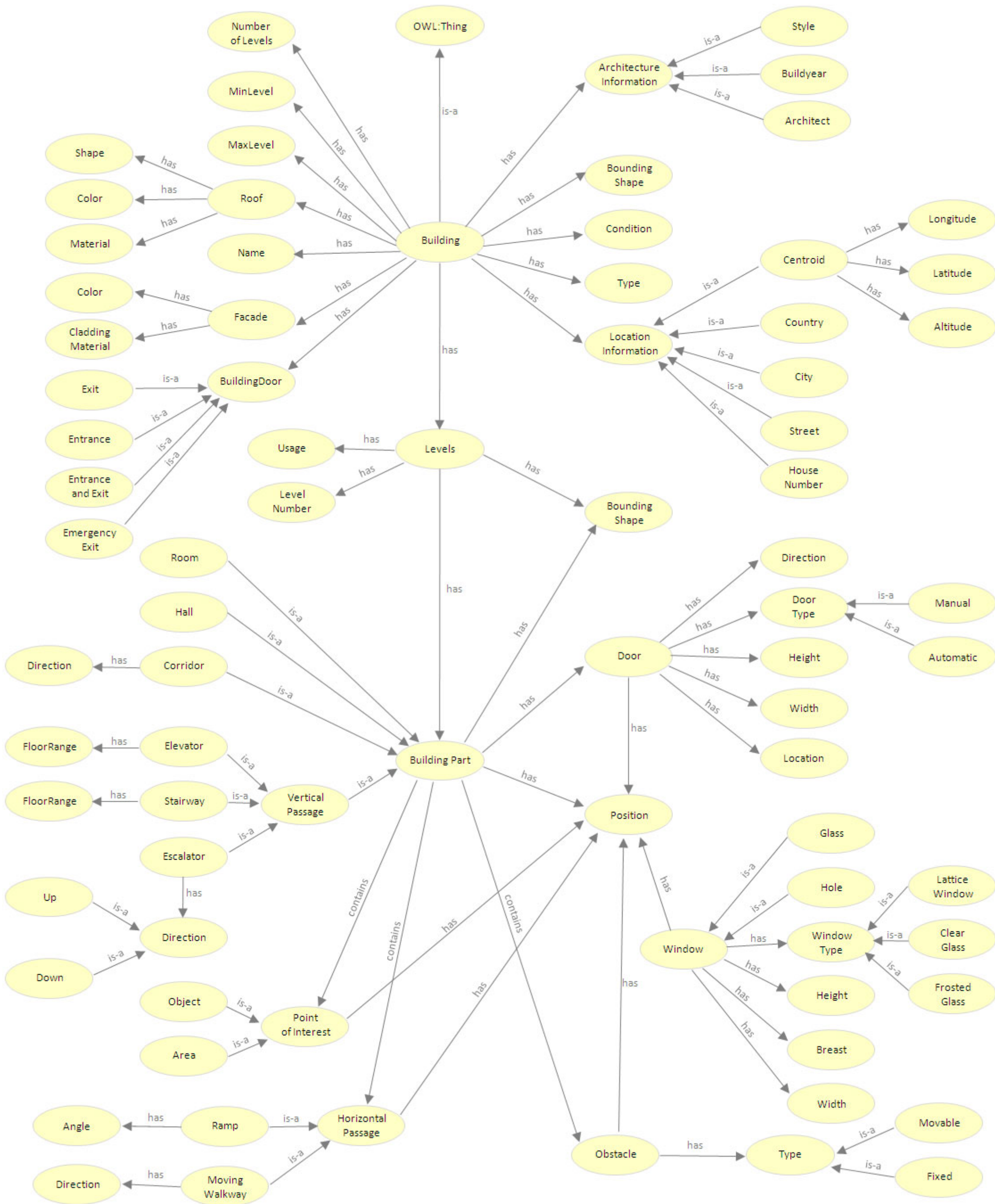

Figure 2. 3D Building Ontology for describing the inside and outside of a building

The ontology has been developed in OWL/RDF using Protégé. It is visualized in Figure 2 and a human-readable documentation is given below:

Building: The concept of a building is the main part of the developed ontology. A building has diverse characteristics which describe the outer appearance of the building. One example is the roof of the building which can be described according to its shape (e.g. flat, gabled etc.), color (e.g. black, red etc.) or material (e.g. aluminum, wood etc.). A building also has distinct shape, considering the ground area. The façade of the building can be described by a color and the cladding material (e.g. glass, concrete etc.). There are also additional semantic characteristics describing the building such as its condition (e.g. new, renovated etc.), its type (e.g. public, academic etc.), its name (e.g. “BST 48”) or its total number of levels. Architectural information such as style or buildyear can also serve as additional information. Furthermore the location of the building can be described by an address and/or the exact coordinates.

BuildingDoor: A building has one or more building doors, describing a direct connection through a door from the inside of the ground floor to the outside and vice versa.

Levels: A building contains a distinct amount of levels (one or more), whereby each of them has a level number (e.g. -1, 2). A level has a bounding shape which can vary from the building area and it can have a particular usage (e.g. commercial, residential, etc.).

BuildingPart: A buildingpart describes any spatial element that is part of a distinct level. Those can be generally categorized as rooms, halls, vertical passages or corridors, whereby corridors can have a distinct direction. Such buildingparts can be described according to their bounding shape and they furthermore have a concrete position on the floor. They can have windows, whereby these are described by their width, height, breast (i.e. height from the ground to the bottom of the window), position and type (e.g. lattice window, clear glass etc.). Similar to the concept of windows, buildingparts also have doors, whereby these are described by their width, height and position. Doors have a distinct type and can be mainly categorized into automatic doors and manual doors. Additionally, doors can have a direction, describing that the door is only usable in one direction (e.g. security gates at the airport).

Point of Interest: A Point of Interest (POI) describes a distinct area (e.g. smoking area) or object, which might be of interest or usefulness for a user (e.g. a landmark for navigation).

Obstacle: A floor element can contain an obstacle, whereby the obstacle has a distinct position. These obstacles can either be a movable (e.g. an office desk) or fixed (e.g. a raised stage). These groups of obstacles have in common that they are characterizing features of a floor element and furthermore it is important to be aware of them for different applications (e.g. indoor navigation of the blind).

Horizontal Passages: Horizontal passages are areas or elements inside floor elements. They can be divided into ramps with a distinct angle and into moving walkways with a distinct direction. Such passages furthermore have a position inside the floor element.

Vertical Passages: The main types of vertical passages are elevators, stairways and escalators. The two former ones both have a floor range (e.g. a stairway from the first floor to the sixth floor). In contrast, the escalator does not have a floor range, but a distinct direction describing that it is either going up to the next floor or down to the previous floor.

Table 1. Proposed relation tags for general building information.

Key	Description	Exemplary Value(s)	Tag Count*
building	it's a building	yes	26.495.911
building:levels	number of levels	4	211.939
building:min_level	minimum level	-1	641
building:max_level	maximum level	6	
building:roof	roof shape	flat, pitch, hip	6.112
building:roof:color	roof color	black	781
building:roof:material	roof material	cardboard	3
name	building name	Federal hospital	368.235
building:cladding	façade material	glass	3.007
building:facade:color	façade color	yellow	56
building:facade:image	URL to façade image	http://url.de/image.gif	
building:architecture	architecture style	modern	238
building:buildyear	buildyear	1987	15
building:architect	architect	Neumann	2
building:height	building height	25m	20.623
height	building height	25m	625.370
building:condition	building condition	renovated	56
addr:country	country	Germany	581.588
addr:city	city	Munich	789.228
addr:street	street	Luisenstraße	1.183.888
addr:housenumber	house number	5	1.300.440

* if this key is already available in OSM, the number in the column indicates the total usage amount (based on personal analysis)

The presented ontology is a generic spatial ontology for describing generic buildings with indoor spatial environments. It is of course not complete in terms of containing all information about a building (e.g. information about power cables etc). However it represents a suitable selection of relevant building information for the described application areas (Cf. above).

5 EXTENDING THE OSM TAGGING SCHEMA TO INDOOR ENVIRONMENTS

The fundamental basis of the OSM schema extension is the above presented 3DBO. In most cases, buildings in OSM are mapped as a closed way or, in the case of a complex building shape, as a relation. The principle of the developed extension is to map the building as a relation. For every level inside the building there is one relation member (which also will be a relation) and an one additional relation-member per building door. These doors are mapped as single nodes on the bounding shape with key *building:entrance* and values *yes, entrance, exit, emergency, both*. The relation itself has diverse key-value pairs for adding (semantic) information about the building (Cf. 3DBO). The proposed keys with exemplary values are described in Table 1.

As mentioned before, each level is also defined as a relation respectively. The members of these relations are other relations, ways or single nodes, representing the different elements (rooms, halls, corridors, passages etc.) in this level. An additional relation-member (way or relation) is introduced for mapping the bounding shape of this distinct level. The relation itself again has diverse key-value pairs for adding additional information. The proposed keys for the OSM extension are depicted in Table 2.

Table 2. Proposed relation tags for general level information.

Key	Description	Exemplary Value(s)	Tag Count
indoor	it's inside the building	yes	642
name	Name of the level	Ground floor	
level:usage	Usage of the level	academic *	
level:height	Height of the level	4m	
building:level	Actual level number	1	1.416

* some values of the OSM key *amenity* are also reasonable for *level:usage*

Table 3. Proposed tags for buildingparts (nodes, ways or relations).

Key	Description	Exemplary Value(s)
buildingpart	what type of buildingpart	room, hall, corridor
name	name of the buildingpart	Room 101
buildingpart:corridor:direction	corridor direction	one-way
buildingpart:height	height	3m
buildingpart:window	it's a window	yes, glass, hole
buildingpart:window:type	window type	lattice window, frosted glass
buildingpart:window:height	window height	1.2m
buildingpart:window:width	window width	1m
buildingpart:window:breast	breast of the window	1.3m
buildingpart:poi	point of interest	object, area
buildingpart:door	it's a door	yes, manual, automatic
buildingpart:door:height	door height	2m
buildingpart:door:width	door width	1m
buildingpart:door:direction	door direction	one-way
buildingpart:horizontalpassage	it's a horizontal passage	ramp, moving walkway
buildingpart:horizontalpassage:angle	horizontal passage angle	5 degree
buildingpart:horizontalpassage:direction	horizontal passage direction	one-way
buildingpart:verticalpassage	it's a vertical passage	elevator, stairway, escalator
buildingpart:verticalpassage:floorrange	vertical passage floor range	1-5
buildingpart:verticalpassage:direction	escalator direction	up, down

The different elements of a distinct level are modeled as relations, ways or single nodes (depending on their requirements and complexity). For example, windows or doors are mapped as single nodes which are part of the corresponding element shape. That is, the bounding shape is mapped with a closed way and at every position where a window is located, there is a node with the tag *buildingpart:window*. Furthermore, there is additional information attached to them (e.g. height or width). In a similar way, rooms, halls or corridors are mapped as (closed) ways and tagged with *indoor=yes*. The before described procedure is valid for any kind of level element (Cf. 3DBO). The possible and reasonable keys for additional information are listed and described in Table 3. The position of the different elements is implicitly provided by their nodes.

For mapping obstacles inside buildingparts (e.g. a strut in a hall) there are two possibilities. If the obstacle belongs to the building and is not movable, it is the best to map it as a hole in a polygon (considering the hall shape as a polygon and the strut as a hole). In contrast, if the obstacle is not part of a building (e.g. an office desk), it is possible to map it as a closed way or single node with the keys *obstacle=yes* and *obstacle:type* with value *movable* or *fixed*.

6 EXAMPLARY USAGE OF THE PROPOSED SCHEMA

For demonstrating the OSM indoor extension, the building of the Chair of GIScience of the University of Heidelberg (Cf. Figure 3) has been mapped. It has four different levels (one basement and three above the ground) and one main entrance. It mainly contains offices and three bigger rooms for lectures. The levels are connected with two different staircases. The location of the building was gathered via GPS. Information about the specific dimensions and the inner structure of the building were gathered by CAD floor plans, kindly provided by building authorities.

Figure 3. Use case building

The whole building was mapped as a relation and several keys (e.g. *building = yes*, *building:cladding = concrete*, *height = 14.5m*, *building:roof = flat* etc.) were attached to it. There are a total of five relation-members, whereby one is a single node (indicating the building entrance) and the other four members are again relations for describing the different levels of the building. For every single level there were different keys (e.g. *level=yes*, *building:level=1* etc.) attached to the corresponding relation. Several closed ways (as relation-members) were utilized for mapping the bounding shape and the buildingparts of the respective level. Every buildingpart was tagged with the key *indoor=yes* and additional semantic information was added by several key-value-pairs (Cf. chapter 5). Windows were mapped by adding additional nodes to the bounding-shape ways and adding different keys e.g. *buildingpart:window=glass* or *buildingpart:window:breast=1.2m* to them. Doors were mapped in a similar way by adding additional nodes to the corresponding buildingpart ways. The two stairways inside the building were mapped as a closed ways, whereby it has been decided to model the stairs on every level (it is also possible to simply map the stairway on one level and to leave it blank for the other levels). The key *buildingpart:verticalpassage:floorrange=-1 to 2* was utilized for describing the floor-range of the respective stairways.

The size and shape of the different buildingparts were gained from the CAD files and manually mapped in the OSM editor JOSM. Thereby, all levels have been mapped individually and afterwards manually combined by editing the OSM-XML file. This manual code-editing is required, because JOSM (and other OSM editors) lack visualization possibilities for multi-storage buildings with indoor environments and it is hard to distinguish between several overlapping ways. Another problem has been encountered when uploading the mapped building into the OSM database. For some reasons, the OSM renderer does not recognize buildings mapped as relations, whereby the main-relation is tagged with *building=yes*. Instead, it is required that a member of the relation (a closed way) is tagged with *building=yes* key. So at first, the use-case building was not displayed in the OSM map. For overcoming this problem, it has been decided to additionally tag the bounding-shape of the ground floor with the key *building=yes*. Utilizing the bound-shape of the ground floor was obvious, because it describes the building shape on the ground but in general also the other bounding-shapes could have been utilized. Nevertheless it must be said that these problems occur in current editors and renderers because they are not intended for this purpose, but the presented methodology shall be considered as an impulse for improvements.

7 CONCLUSIONS AND FUTURE WORK

In this paper, an extension of the existing OSM tagging schema for mapping indoor environments has been proposed. An extensive 3D building ontology has been presented, whereby the ontology suits both the description of the outer appearance and characteristics of the building as well as the detailed description of the inner building structure. Based on this ontology, the existing OSM tagging schema has been extended and methodologies for mapping indoor spaces have been developed. By applying these extensions, members of the OSM community are now able to map indoor spaces, thus provide more detailed information about buildings and their inner structures. Both the ontology and the tagging schema extension have been kept as simple as possible, so it is realistic that the OSM community will understand and accept them.

As described above, existing OSM editors are currently not able to provide an easy-to-use functionality for the presented extensions. Therefore it is important to develop an OSM editor which provides such functionality, so it is possible to map inner building structures in an easy-to-use manner. The use-case demonstrated that existing OSM renderers need refinements, so that relations tagged with *building=yes* are also recognized in the map. Furthermore it will be interesting to see, how relevant data can be captured. Different information such as façade color or roof type can be extracted from images or visual experience, but for measuring distances or positions inside buildings, different methodologies (such as Lidar or pedometers) must be applied. Also future cell phones are likely to contain more sensors for different measurements. Moreover, importing existing standards like CAD or IFC into OSM is wishful but a challenging idea for future research. This would allow an integration of existing floor plans into OSM. From a different point of view, privacy aspects for indoor spaces are also an important factor. Not every kind of information is appointed to be of interest for the public and providing those bears some kind of security risk, so this field also needs to be further investigated and explored.

ACKNOWLEDGEMENTS

The authors would like to thank the anonymous reviewers for providing valuable comments towards the improvement of this paper. We would also like to thank the building authorities of the University of Heidelberg for providing the floor plans of our use case building. Furthermore we would like to thank all members of the Chair of GIScience for their proofreading and helpful hints.

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