3D Indoor Models and their applications

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Definition

Indoor environments are often referred as to *enclosed spaces*. However the general definition of space can already indicate a space can be bounded. Wordnet (http://wordnet.priceton.edu) defines space as 'an empty areas usually bounded in some way between things'. Specialised ontologies such as OmniClass (http://www.omniclass.org, a classification for Architecture, Engineering and Construction in North America) distinguish between *spaces by form* and *spaces by function*. 'Spaces by form are basic units of the built environment delineated by physical or abstract boundaries and characterised by physical form'. 'Spaces by function are basic units of the built environment delineated by physical or abstract boundaries and characterised by their function'. The spaces can be both 2D and 3D. For example, space by form can be a 3D room or a 2D walking path. An interesting example is a wall (interior, exterior), which is considered a space by function, which implies that spaces can be filled with some material, i.e., not just air.

Indoor spaces are artificial constructs designed and developed to support human activities. 3D indoor models, being a virtual digital representations of indoor spaces, have to be able to support these activities.

Historical background

Indoor mapping and modelling has received an increased level of attention during the last decade [Worboys 2011, Zlatanova et al, 2014]. Indoor space differs from outdoor space in many aspects: the space is smaller and closed; there are many constraints such as walls, doors, stairs and furniture, the structure is multilayered frequently containing intermediate and irregular spaces, the lighting is largely artificial and so forth (Figure 1, Figure 2). To be able to represent indoor spaces in a proper manner, many data acquisition concepts, data models, and ISO/OGC standards have to be defined or redefined to meet the requirements of indoor spatial applications.

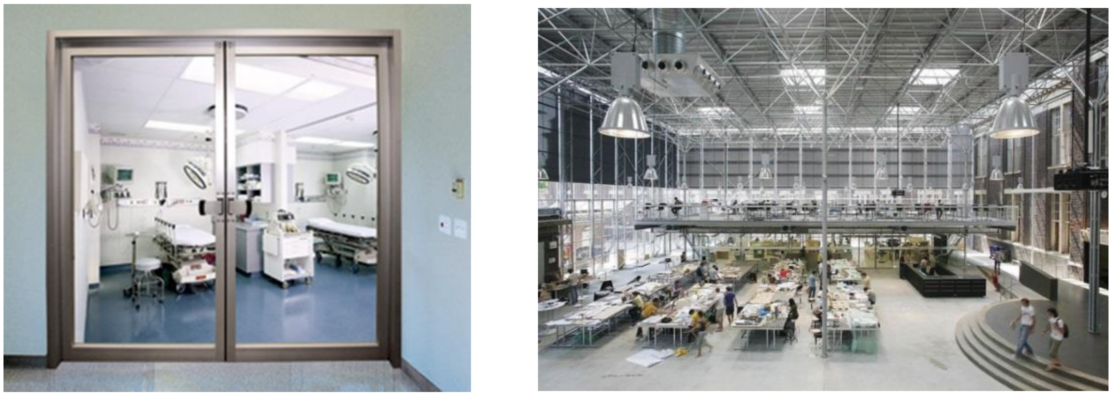

Figure 1: Example of obstacles (left) and intermediate floors (right)

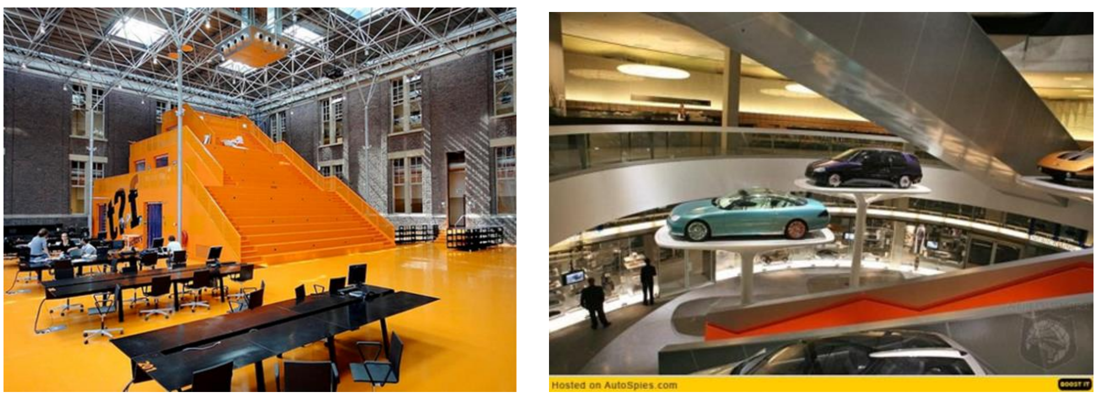

Figure 2: Examples of 'rooms inside rooms' (left) and complex layered structures (right)

Indoor models representing 3D information can be generated by using various manual, semi-automatic and automatic methods. The global research trends are focused on finding methods for automatic generation. Many of them are on model transformation such as generation of application specific indoor models from general digital indoor models such as IFC (Industry Foundation Class) or CityGML LOD4. Although this is a valuable approach, it is often insufficient. The existing models might be outdated, incomplete, or even not existing. In such cases, new measurements are required using a range of sensors and processing techniques. The processed raw data are then organized in 3D geometry representations such as 3D vector (B-reps, CSG, BIM) and 3D raster (or dense colored point clouds). Some of these representation have semantics and topology. The tendency is to identify semantics and topology at very early stage of data processing, to avoid post-processing and so called semantic enrichment of geometric models [Billen et al, 2014]. [Azri et al, 2012] have identified several possible approaches for automatic generation of 3D indoor models (Table 1).

Table 1. Approaches and Methodologies of Automatic Indoor Model Generation

Generation Approaches	Method(s) to be Utilized	Enriching semantics	Enriching geometry
Document Analysis	• Text Analysis • Speech Analysis • Video Analysis	Documents Recordings	Documents Recordings
Data Fusion	• Data processing • Model Integration	ID Tags CAD Files Documents	CAD/GIS Files Point Clouds Videos/images

Model Transformation	• Transformation	BIM City Models	BIM City Models
User-based	• SLAM	GUI / Software	GUI /Software

Computer Aided Design (CAD) and lately Architecture Engineering and Construction (AEC) is the oldest domain offering 3D tools for representation of indoors. CAD was primarily developed for engineers responsible for designing and building facilities [Azri et al, 2012]. It is easy to compute and design with CAD tools due to its friendly environment and dynamic interaction. CAD tools which were dealing with large-scale and detailed models did not focus on maintenance of attributes and lack the support of geodetic reference systems. Although CAD models offer a convenience in representing indoor information, several drawbacks of CAD models have been revealed. For instance, CAD is only a platform to design and model geometries. Thus, information such as attribute, topology can only be tagged externally during the design process. Some new extensions of CAD/AEC (Bentley Systems, Autodesk products) do allow the maintenance of topology and semantics but in a quite vendor-dependent way. Therefore the topology and semantics is lost when the model is exported to another software tool. If the information attached to the model is not transferred together with the model, the users can only interpret information from what they have seen through the model. In addition, if the building model was developed with low level of detail, there may not be much geometric and semantic information that can be extracted and used.

Building Information Model (BIM) is the next stage in the digital representation of a building interiors and facilities. BIMs can be used to model building information in 3D with the support of an intelligent database that contains information for design decision making, production of accurate construction documents, prediction of performance factors, cost-estimating, design scenario planning, and construction planning. BIM is object oriented, semantically rich model. The spatial relationships between building elements are maintained in hierarchical manner. It maintains many geometric primitives ranging from simple B-reps to free form curves and surfaces. Today, the most prominent BIM standard is the Industry Foundation Classes (IFC).

3D indoor models are investigated by researchers in GIS domain as well. Digital City models have become widely used for digital representation of major cities. With the advent of 3D City Models such as in Google Earth, CityGML, and others, indoor modelling became a priority topic of research in GIS society. Today CityGML is the best known model for 3D indoor modelling. CityGML is developed for representing 3D city geometry, (a kind of) topology, and thematic-semantic modeling. CityGML can be used to represent buildings and building parts and properties in different levels of detail (LOD) (i.e., from LOD0 up to LOD4). CityGML LOD4 provides a sematic-thematic model for representing indoors. The indoor objects are much less that the objects that can be represented in IFC. However, their simplicity seems quite sufficient for a large group of outdoor and indoor applications [Billen et al].

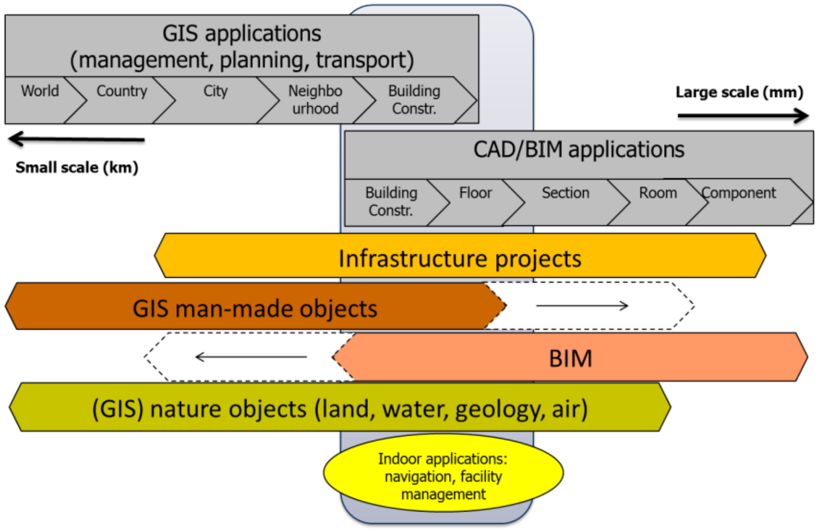

Figure 3: The overlap between GIS and CAD/BIM domains (modified after Jacob Beetz)

Which of the two most prominent standards will be used for 3Dindoor modelling depends very much on the application. CAD/BIM domain has been traditionally dealing with very large scale representations, while GIS with very small scale (up to km). In the last decade a fusion and overlap between the two domains is observed (Figure 3). However, there are fundamental difference between the two models related to the conceptual definition of the indoor objects. IFC objects are defined from the view of the constructor and the LOD LOD4 from the view of the user (**Error! Reference source not found.**). IFC is very appropriate to maintain information about construction parts of building as concrete walls, slabs and columns. CityGML is focused on the modelling of the visible environment such as surfaces of the walls part of one room or, surfaces of walls as part of the façade of a building. This poses numerous challenges to the transformations between the two models.

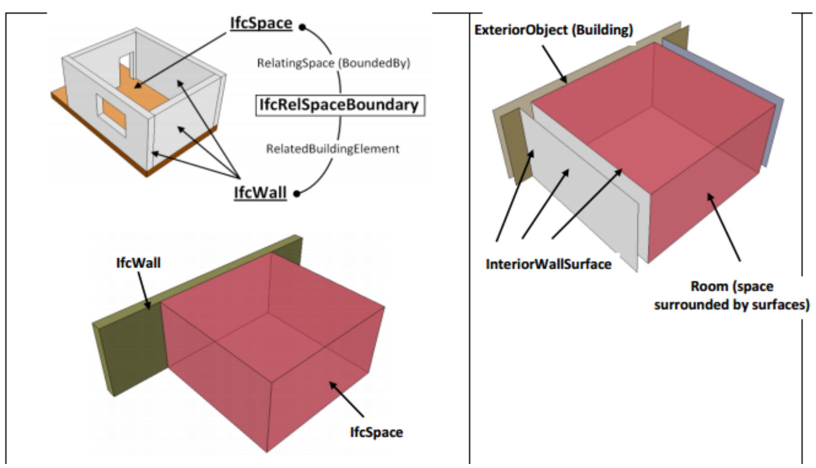

Figure 4: Conceptual difference between IFC (left) and CityGML LOD4 (right) for modelling interiors (courtesy Fillipo Mortari)

The interest, research and developments in modelling indoors resulted in the first standard dedicated on Indoor navigation, i.e., IndoorGML. Similar to all OGS standards, IndoorGML is designed to represent and allow exchange of geo-information that is intended to support indoor navigation applications. As mentioned previously, the characteristics of CityGML and IFC might be not sufficient (either too complex or lacking information) for all kinds of indoor applications. Indoor navigation require a specific semantics and a topological (connectivity) model, which would allow user-oriented path computation. IndoorGML semantics, geometry and connectivity can be derived from other 3D indoor models such as IFC and CityGML following the rule of the model. In contract to CityGML and IFC, IndoorGML requires complete subdivision of the space into cellular units. The subdivision can be done with respect to different themes: topographic theme (i.e., representing the internal structure of the building) or sensor theme (representing the coverage of WiFi access points) or security theme (representing accessible areas due to security restrictions) [Becker et al, 2008]. Therefore the semantics of quite general; it indicates whether it can be used for navigation or not (Figure 5). The topology can then be derived automatically from the semantic following the duality-graph principle.

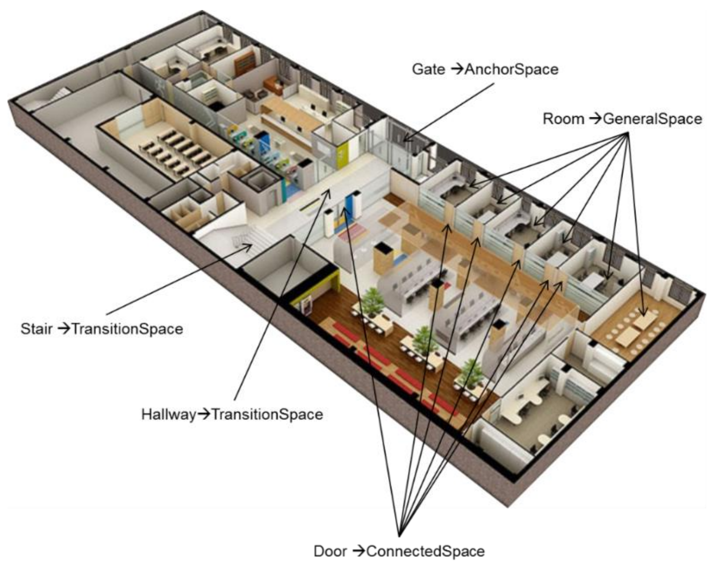

Figure 5: Semantics of IndoorGML (IndoorGML, OGC)

Key Applications

Indoor applications have been traditionally not a topic of research of GIS community. Designers, constructors, engineers have been worked and used 3D indoor representations for modelling airflow simulation, smoke modelling, interior design and facility management. However, the two prominent indoor applications are indoor navigation and facility management.

Indoor navigation

Generally speaking, a navigation system consists of the following components: positioning of a user, calculation of a best path (cheapest, fastest, safest, etc.) to some destination(s), and guidance along the path. Indoor navigation is a very prominent and active research area. It has been originated from navigation robots and it moved to human navigation in the last two decades. However, it remains challenging topic for several reasons: indoor positioning is not very accurate, users can freely move within the building, topology models (or path network) construction process may not be straightforward due to complexity of indoor space, humans need an appropriate guidance. Many papers have provided extended overview on navigation systems and models (2D and 3D) to support indoor navigation [Afyouni et al, 2012] [Domínguez et al, 2012], [Bandi, S. and D. Thalmann, 1998] [Zlatanova et al, 2014]. The majority of the indoor models found in current literature are still mostly 2D. They very often they ignore architectural characteristics such as number of doors, openings and windows. The granularity of the models is still very low, i.e., they not take into consideration moveable obstacles (such as furniture), of functional spaces such as ‘coffee corner’, ‘resection area’, etc. Still most of the topological models used for navigation are predefined, pre-computed and cannot reflect dynamic changes as closing because of renovations. There is a vast amount if research in the area of indoor navigation and localization. Several conferences have been organized annually by various international organizations (ACM SIGSPATIAL, ISPRS, LBS, ICA, etc.). For example the Indoo3D conference organized in December 2013 discussed topics related to Indoor model definition, model generation, indoor localization and indoor navigation applications.

Agreeing on standards for indoor models is one of the most investigated topics. It is well understood that standards will speed up the application development. Some researchers take into consideration not only the internal structure of a building but also the manner people can be localized indoors to be able to give directions. Commonly geographical coordinates do not make sense to humans. Humans, however understand expressions such as ’10 m left from the door’, ‘at front of the restaurant’. [Xiong et al] Presented the work on a multi-dimensional indoor location and information model, which aims to define absolute, relative, semantic and metric expression of location. The model is complementary to 3D concepts such as CityGML and IndoorGML and is accepted as Chinese standards for coding location. Research on semantic expression of spatial relationships, directions and locations such as “in room 321”, “on the second floor”, as well as, “two meters from the second window”, “12 steps from the door”, has been discussed by a number of researches e.g. [Billen et al, 2014]

As mentioned previously the 3D indoor models can be generated in various ways. [Becker et al, 2013] presented an approach based on shape grammars, applied to point clouds. Shape grammars have been proven to be successful and efficient to deliver volumetric LOD2 and LOD3 models, the next challenge is its application to indoor modelling, i.e., LOD4 models. In building interiors, where the available observation data may be inaccurate, the shape grammars can be used to make the reconstruction process robust and verify the reconstructed geometries. The potential benefit of using the grammar as a support for indoor modeling was evaluated in the study based on an example in which the grammar has been applied to automatically generate an indoor model from erroneous and incomplete traces, gathered by foot-mounted MEMS/IMU positioning systems.

Point clouds are widely used for generation of 3D indoor models. They can be created using difference range techniques or from images and videos. Obtaining the vector model can be also done using many different approaches and algorithms. [El Meouche et al, 2013] investigated automatic reconstruction of 3D Building Models from Terrestrial Laser Scanned Data. They proposed a surface reconstruction technique for buildings by processing data from a 3D laser scanner. [Funk et al, 2013] presented a paper on implicit scene modelling from imprecise point clouds. The authors stated that when applying optical methods for automated 3D indoor modelling, the 3D reconstruction of objects and surfaces are very sensitive to both lighting conditions and the observed surface properties. This ultimately compromises the utility of the acquired 3D point clouds. The authors presented a reconstruction method which is based upon the observation that most objects contain only a small set of primitives. The approach combined sparse approximation techniques from the compressive sensing domain with surface rendering approaches from computer graphics. The amalgamation of these techniques allows a scene to be represented by a small set of geometric primitives as well as generating perceptually appealing results. The resulting surface models are defined as implicit functions and may be processed using conventional rendering algorithms, such as marching cubes, to deliver polygonal models of arbitrary resolution.

[Wohlfeil et al, 2013] expressed the importance of using multi-scale sensor systems and photogrammetric approaches in 3D reconstruction. The authors discussed that 3D surface models with high resolution and high accuracy are of great importance in many applications, especially if these models are true to scale. As a promising alternative to active scanners (e.g., light section, structured light, laser scanners, etc.) the authors believe that new photogrammetric approaches are attracting more attention. They use modern - structure from motion (SfM) techniques-, using the camera as the main sensor. Their research combined the strengths of novel surface reconstruction techniques from the remote sensing sector with novel SfM technologies resulting in accurate 3D models of indoor and outdoor scenes. Starting with the image acquisition, all particular steps to a final 3D model were explained in their study.

The most prominent topic in indoor navigation is indoor localization. The indoor localization is in demand for a variety of applications within the built environment and an overall solution based on a single technology has not been determined yet. This research is developed rather independently from the indoor modelling. The focus is on the technology, that would allow localizing a person in a building and therefore the indoor model is used mostly for visualization of the location. In the context of localization, 3D indoor models have been used for improving the localization accuracy [Girard et al, 2011], [Liu et al, 2015]. Many different localization technologies are investigated indoors as well [Fallah et al, 2013]. Much attention is given to WLAN applications, which does not require a person carries specialized devices. Two research papers presented at the workshop focused on the use of WiFi technologies in indoor positioning. [Verbree et al, 2013] investigated how WiFi based indoor positioning can be used in museum environment to navigate three categories of users: visitors, employees and emergency services. They compared two different WiFi based localization techniques. The first one is based on WiFi scanners, i.e., Libelium Meshlium WiFi scanner. The second method was the traditional WiFi fingerprinting. In a similar research [Chan et al, 2013] worked on improving WiFi fingerprinting by applying a probabilistic approach, based on previously recorded WiFi fingerprint database. In addition, the authors developed a 3D modeling module that allows for efficient reconstruction of outdoor building models to be integrated with indoor building models. The architecture consisted of a sensor module for receiving, distributing, and visualizing real-time sensor data; and a web-based visualization module for users to explore the dynamic urban life in a virtual world.

Research on algorithms for indoor navigation is also very intensive with the aim to adapt them to the human perception and understanding. Particular indoors, well-known outdoor strategies as the shortest and the fastest path might be not relevant, while the safest, or less crowded might be of relevance. Applications that support indoor navigation and way finding have become one of the booming industries in last couple of years. In spite of this, the algorithmic support for indoor navigation has been left mostly untouched so far, and most applications mainly rely on adapting Dijkstra's shortest path algorithm to an indoor network. In outdoor spaces, several alternative algorithms have been proposed by adding a more cognitive notion to the calculated paths and adhering to the natural way-finding behavior (e.g. simplest paths, least risk paths). The need for indoor cognitive algorithms is highlighted by a more challenging navigation and orientation requirements due to the specific indoor structure (e.g. fragmentation, less visibility, confined areas). [Vanclooster et al, 2013]

Figure 6: Visualization of a navigation path in 3D environment: Paris airport (left) and Hubei Museum (right) (Xu et al, 2013).

Today, various indoor applications are available on the market. Google maps, Open Street Map (the 3D indoor project), airports, museums and shopping malls have their own indoor navigation applications. The real 3D applications are however still very sparse. One of the reasons is that 3D visualization of enclosed indoor spaces is usually more disturbing then guiding, the other reason is that the calculations are performed on 2D plans and 3D models are therefore not maintained. Xu et al, 2013 presented a 3D model based indoor navigation system for a museum in Wuhan, China. The systems was based on 3D model, organized in DBMS on a server and game engine for visualization on android device. The authors argue that 3D models are more powerful because 3D models can provide accurate descriptions of locations of indoor objects (e.g., doors, windows, tables), which are exhibited in walls and shelves. The experimental system is an example of a flexible client-server, user-oriented applications. The system is composed of three layers: mobile app, web services and a database (PostGIS). There were three main strengths of this system;

- It stores all data needed in one database and processes most calculations on the webserver which makes the mobile client very lightweight.
- The network used for navigation is extracted semi-automatically and renewable.
- The graphic user interface (GUI), which is based on a game engine, has high performance of visualizing 3D model on a mobile display.

Facility management

Facility management is an area of research, which is increasingly gaining attention. Building owners are actively seeking for models that can give answer to questions as 'how much paint I need floor the renovation of floor x', 'what is the area of the windows frames that have to be pained', 'how many square meters carpet I need for room y'. Facility managers need to have information about pipes and cables in case regular checks and/or failures. Local governments, institutions performing taxation and so forth are also becoming interested in systems, which can easily compute net areas and volumes of apartments and offices. All these questions usually require information about vertical elements, internal structure of buildings and even ‘invisible’ information about pipe and cables integrated in walls and floors/ceilings. IFC and CityGML are very often compared and discussed, but still there is not agreement which model is more appropriate. For daily building and facility management, IFC appear to be too heavy and complex and numerous solutions are investigated considering CityGML.

Several 3D indoor models have been developed with the ultimate goal to find an intermediate solution between IFC and CityGML. [Hijazi et al, 2012] presents a model that integrates the building structure concepts of CityGML with the IFC concepts to provide simplified 3D model for maintenance of utility networks. The model is accessed by a simple application, which allows facility managers to explore and query their electricity and water facilities (Figure 7).

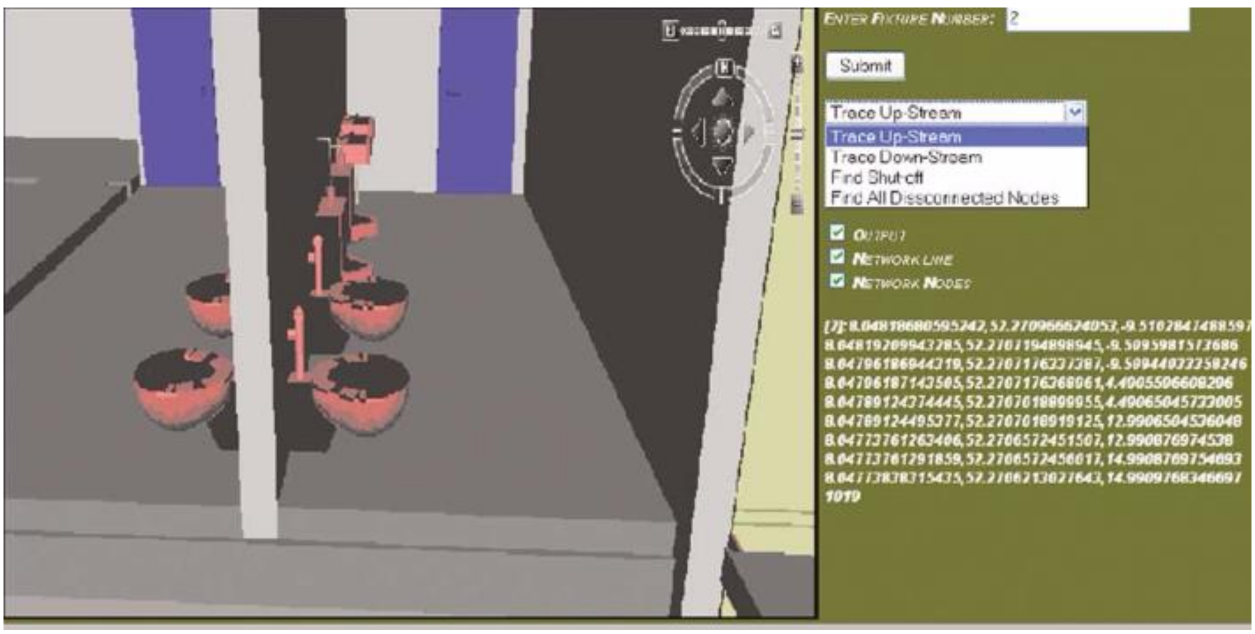

Figure 7: Google Earth- based prototype of the 3D facility management application (Hijazi et al, 2012)

[Boeters et al, 2015] argue that CityGML should be extended with more indoor LOD to be able to deal with some the building taxation issues such as area and volume computation. The authors propose a new LOD2+ which enriches LOD2 with floor indoor information (Figure 8). The floors are volumes; the thickness of exterior walls is taken into consideration. The LOD2+ is created automatically from LOD2 and additional information about floors and year of building, which is used to estimate the thickness of the walls.

Figure 8: Example of a LOD2+ buildings with indoor information about floors (left) and the he same building in reality (right)

Monitoring of indoor environments

Internet-of-Things (IoT) will be a key concept in monitoring of Indoor Environments. The IoT concentrates on making every physical and virtual “Thing” a publisher of information. The IoT approach enables “Things” to publish information once a state change occurs in them or in pre-determined intervals. For instance, in a building that implements the IoT concepts, a door will publish information such as “I am closed now!”, or a light bulb will indicate “I am on at the moment”. In addition, the “Things” will become capable of taking actions based on messages coming from other “Things” or Humans. A building will be considered as a living entity and applications will require information from the “Things” (i.e., real and virtual) and the “Models” (such as City GML/ IndoorGML) in real time. In essence, applications such as Smart Buildings would require the fusion of information acquired from multiple resources, such as Things, Models, Virtual Objects, and Real Objects. The efficient monitoring of indoor environments will be directly proportional with the effectiveness in provision and fusion of real-time information related to indoors. By the utilization of ubiquitous monitoring of indoors the information regarding building elements would be available 24/7 regardless of the situation (i.e., which can be emergency or non-emergency). Building and City Dashboard applications would be the main consumers of this ubiquitous information. Combining semantic information coming from the indoor models with IoT data provides advantages in answering the emergency scene questions such as “Would you provide the average CO2 level in the rooms which are not affected by the fire?”, “Would you provide the number of doors which are open in the floors that are affected by the flood?”. As another example, in a fire response operation an emergency responder will acquire information from the sensors located in each floor regarding the spreading of the fire, in response, he can then invoke the web services to interact with IoT Nodes which will then invoke the actuators to close the doors in certain floors to prevent spreading of the fire to other floors. Furthermore, Machine-to-Machine (M2M) autonomous interaction is also possible and a sensor can collect information regarding the emergency situation, and interact with another IoT Node to perform a preventive action. As another sample, sensors in the building can interact with the actuators to close doors to prevent some parts of the building from being flooded by water, in fact if there would be people in these parts of the building, they can be trapped as they cannot get out. In this situation, the people in the rooms can interact with the IoT nodes (to control sensor and actuators) to let them out of that building part. IoT provides unique opportunities for indoor monitoring.

Future directions

3D indoor models are going to be further explored, adjusted and explored as the demand for indoor is increasing. Research in support of indoor mapping and modelling has been an active field for over thirty years. 3D indoor modeling research is related to all aspects of creating of digital models of the real world: data acquisition, data structuring, visualization techniques, applications and legal issues and standards. The research topics are investigated by a large group of scientist coming from photogrammetry, computer vision and image analysis, computer graphics, robotics, laser scanning and many other technologies. 3D indoor models are no longer a research area of engineers, planners, constructors, and designers. GIS specialists as well as governments, commercial enterprises and individuals are also beginning to seek and apply 3D indoor models in their business applications. This reshaping of the users poses higher requirements to the models and the tools that would use them. There are many problems, before the 3D indoor models become commonly available, standardized and used for the development of flexible user-oriented applications. [Zlatanova et al, 2013] argue that there are many challenges to 3D modelling and they attempted to create an overview of existing and emerging problems (Figure 9).These problems can be categorized as related to acquisition and sensors, data structures and modelling, visualization and guidance, navigation, applications, legal issues and standards. Furthermore. Many of the challenges in creating 3D models are not new. They are inherited from current 3D outdoor modeling and applications. For example sensor fusion, data processing or data standards. However there are many new challenges specific for indoor, such as real-time data acquisition, simultaneous localization and mapping, integration of BIM and GIS models, appropriate 3D graphic user interfaces to avoid ‘tunnel’ effect in indoor visualization and interaction. The area of indoor applications will boost, if cognitive approaches for navigation, orientation and localization will be developed. In this respect semantic annotations of 3D indoor models will play a critical role. Further research is essential in order to develop more functional models for better positioning and navigation systems.

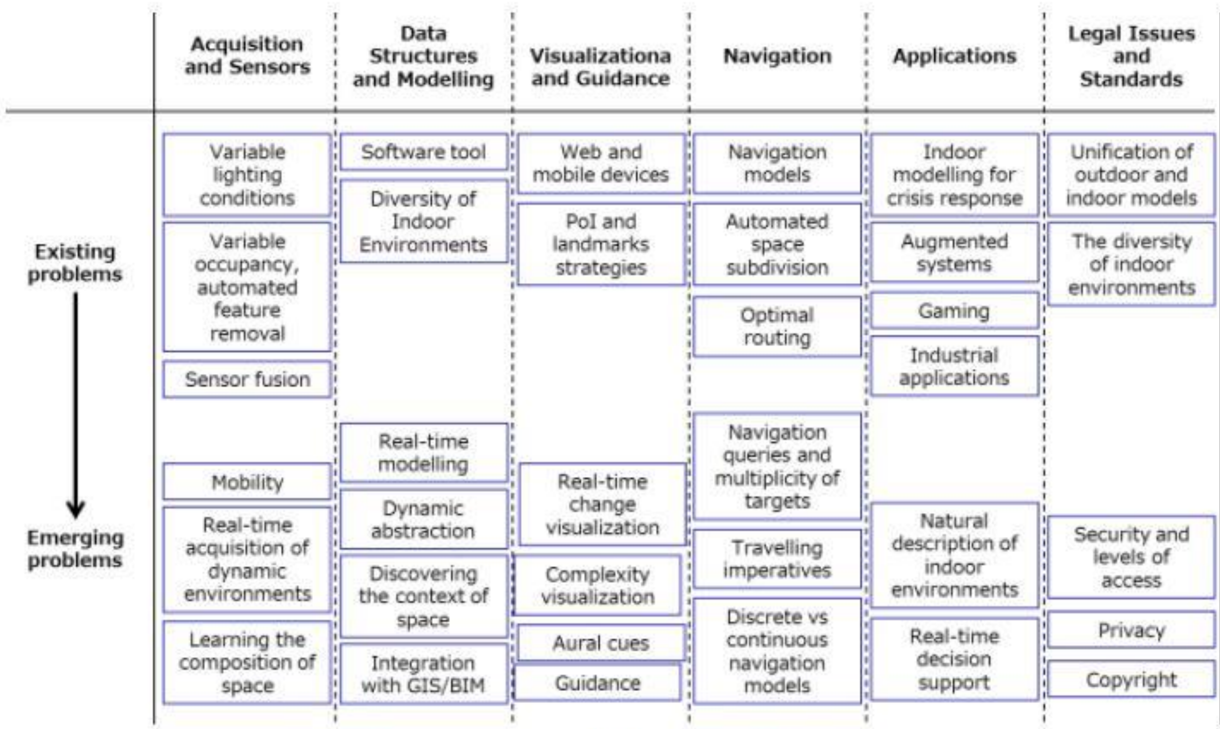

Figure 9: Challenges in indoor mapping and modelling

References

Afyouni, I., Ray, C., Claramunt, C., 2012 Spatial models for context-aware indoor navigation systems: A survey, Journal of Spatial Information Science, 4, 85–123

Azri,S., Isikdag,U.,Abdul-Rahman., ,A. (2012) Automatic Generation of 3D Indoor Models: Current State of the Art and New Approaches, Proceedings of International Workshop on Geoinformation Advances, Malaysia,2012

Bandi, S. and D. Thalmann, (1998) Space discretization for efficient human navigation, Wiley Online Library, 1998

Becker, T., Nagel, C., and Kolbe, T. H., A Multilayered Space-Event Model for Navigation in Indoor Spaces, (2008), Lecture Notes in Geoinformation and Cartography - 3D Geo-Information Science,

Becker S., Peter,M., Fritsch,D., Philipp,D., Baier,P.,Dibak,C. (2013) Combined Grammar for the Modeling of Building Interiors, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., II-4/W1,1-6

Billen, R, A.-F. Cutting-Decelle, O. Marina, J.-P. de Almeida, M. Caglioni, G. Falquet, T. Leduc, C. Métral, G. Moreau, J. Perret, G. Rabino, R. San Jose, I. Yatskiv and S. Zlatanova, (2014), 3D City Models and urban information: Current issues and perspectives, European COST Action TU0801, EDP science, 130p

Boeters, R. K. Arroyo Ohori, F. Biljecki and S. Zlatanova (2015) Automatically enhancing CityGML LOD2 models with a corresponding indoor geometry. International Journal of Geographic Information Science 29:2248–2268,

Chan, S., Sohn, G .,Wang,L. Lee, W. (2013) Dynamic WIFI-Based Indoor Positioning in 3D Virtual World , Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-4/W4,1-6

Domínguez, B.; García, Á.; and Feito, F., 2012, Semantic and topological representation of building indoors: an overview, International Conference on Computer Graphics Theory and Applications,

El Meouche, R., Rezoug M., Hijazi I., Dieter, M. (2013) Automatic Reconstruction of 3D Building Models from Terrestrial Laser Scanner Data, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., II-4/W1, 7-12

Fallah, N., Apostolopoulos, I., Bekris, K., and Folmer, E. (2013) Indoor Human Navigation Systems: A Survey, Interacting with Computers, 2013, 25 (1) 21-33

Funk E., Dooleya,L.S., Boernerb,A., Griessbachb, D. (2013) Implicit Surface Modeling from Imprecise Point Clouds, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-4/W4, 7-12

Girard, G., Côté, S., Zlatanova, S., Barette, Y. St-Pierre, J., Van Oosterom, P. (2011) Indoor pedestrian navigation using foot-mounted IMU and portable ultrasound range sensors. Sensors, 11(8), 7606–7624

Hijazi, I., M. Ehlers and S. Zlatanova (2012) NIBU: a new approach to representing and analyzing interior utility networks within 3D geo-information systems, In: International Journal of Digital Earth, Vol. 5. Issue 1, pp. 22-42

Liu, L., W. Xu, W. Penard, and S. Zlatanova (2015) Leveraging spatial model to improve indoor tracking, In: T. Fuse and M. Nakagava (Eds.), ISPRS Arch. Photogramm. Remote Sens. Spatial Inf. Sci, XL-4/W5, pp. 75–80

Montello, D. (1993). Scale and Multiple Psychologies of Space. Spatial Information Theory: A theoretical basis for GIS. A. Frank and I. Campari. Berlin, Springer Verlag. Lecture Notes in Computer Science 716: 312–321

Vanclooster, A., Viaenea,P, Van de Weghea, N., Fack, V. , De Maeyer,P. (2013) Analyzing the applicability of the least risk path algorithm in indoor space, ISPRS Ann. Photogramm. Remote Sens. Spatial Inf. Sci., II-4/W1, 19-26

Verbree, E., Zlatanova,S., van Winden,K., van der Laan,E. Makri,A. Taizhou,L..,Haojun A. (2013) To localise or to be localised with WiFi in the Hubei museum? Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-4/W4,31-35

Wohlfeil J., Strackenbrock, B. ,Kossykb, I. (2013) Automated high resolution 3D reconstruction of cultural heritage using multi-scale sensor systems and semi-global matching, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-4/W4, 37-43

Worboys, M. (2011) Modelling Indoor Space, Proceedings of the third ACM SIGSPATIAL International Workshop on Indoor Spatial Awareness, 1-6

Xiong, Q., Zhu, Q, Zlatanova, S. Huang, ,L., Zhou,Y. Du, Z. (2013) Multi Dimensional Indoor Location Information Model, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-4/W4, 11–13

Xu W., Kruminaitea, M. Onrusta, B., Liu. H. , Xiong Q., Zlatanova S. (2013) A 3D Model Based Imdoor Navigation System for Hubei Provincial Museum , Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-4/W4, 51-55

Zlatanova,S. , Sithole, G., Nakagawa, M. Zhud'Q. (2013) Problems In Indoor Mapping and Modelling, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-4/W4, 63-68

Zlatanova, S., Liu, L., Sithole, G., Zhao, J., Mortari, F. (2014), Space subdivision for indoor applications, GISt Report 66, 2014