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OGC IndoorGML: A Standard Approach for Indoor Maps

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1 Introduction

Many recent technological progress in the field of information and communication technologies are not achieved by a single dominant technology but a combination of diverse technologies. This diversity provides a fundamental of technology progress and even accelerates it. The interoperability is a crucial condition to bind diverse technologies, and the standardization is one of the most promising approaches to get the interoperability. It offers a linking mechanism to integrate several technology building blocks to setup an ecosystem. The ecosystem achieved by integrating diverse technologies through standards is expected more flexible than by a single dominant technology.

Indoor location and spatial information services and technologies that mostly started from 2000s have different backgrounds. It includes indoor positioning technologies mostly developed by communication communities, building construction technologies by architectural engineering communities and architecture, Simultaneous Locationing And Mapping (SLAM) by robotics communities, and indoor spatial information technologies from geospatial information communities. And all these background technologies comprise building blocks of indoor location and spatial information services and systems (Afyouni et al., 2012). It is therefore crucial to provide a mechanism to integrate different technologies into an ecosystem.

A very important component of the ecosystem for indoor spatial information is the indoor map. An indoor map may contain a lot of information, just like an outdoor map. But the requirements and specifications of indoor maps are differently defined depending on divers perspectives as listed earlier. For example, indoor maps for indoor positioning are much different from those for simple visualization. We therefore need common specifications of indoor maps to integrate different indoor spatial technologies

Geographical and Fingerprinting Data for Positioning and Navigation Systems. https://doi.org/10.1016/B978-0-12-813189-3.00010-1

to an ecosystem. The OGC IndoorGML (OGC, 2012b) has been developed to respond to this challenge.

The IndoorGML serves as a standard data model and exchange encoding rule in XML for interfacing different components in an ecosystem of indoor spatial services. And an extension has been also defined to meet the requirements for indoor navigation. We will discuss the details of these concepts in the following sections. First, we will discuss the requirements of indoor maps in Section 2 and explain the basic concepts of IndoorGML in Section 3. The data models of IndoorGML composed of the *Core Module* and the *Navigation Module* are to be explained in Section 4. Important technical issues for implementation will be discussed in Section 5 and use-cases for real applications will be presented in Section 6. We will summarize this chapter in Section 7.

2 Requirements for Indoor Maps

In this section, we investigate the requirements of indoor maps, which served as the starting points of OGC IndoorGML design. More detail discussion on the requirements is found at Kang and Li (2017). Note that the simple visualization of indoor maps is not within the scope of our study and we rather focus on the requirements for application services of indoor spatial information.

2.1 Complex Structures of Indoor and Connectivity

Let us assume an example of map application; distance estimation between two points. Computing distances in indoor space is, however, a complicated process not only because of the constraints such as walls, doors, and other obstacles, but also due to vertical structures between multiple floors and lifts and moving walks. It is in fact one of the most important differences between indoor and outdoor spaces. Even indoor space is a type of constraint space, it differs from other types of constraint spaces in outdoor space such as road network spaces due to the vertical connections.

Therefore, a key requirement of indoor maps is how to properly represent the constraints and structures in indoor space. The structure of indoor space is mainly determined by architectural structures that have unique properties. First, the indoor space consists of a number of cells surrounded by architectural components, such as walls, ceilings, and floors, where each cell is separated from the others. Cells in indoor space are horizontally or vertically connected in sophisticated ways via specific types of architectural components like doors and stairs. Furthermore, indoor spatial properties, such as cell geometry and the connectivity structures between cells, differ depending on the type of buildings. For example, subway stations are normally composed of long hallways and platforms on different levels, while office buildings have normally a number of small office rooms connected via corridors.

Second, indoor spaces of complex buildings are often composed of areas with different purposes. For example, a shopping mall has a number of stores, warehouses, control

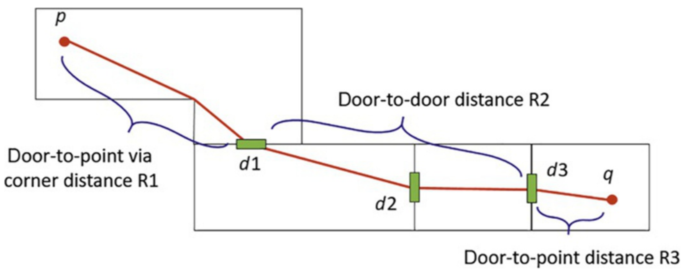

FIG. 1 Indoor distance.

rooms, cinemas, sports centers, subway stations, etc., each of which has unique requirements and functions. This complex buildings make the indoor space very complicated. Third, a single indoor space may be interpreted in different viewpoints. For example, an indoor space is partitioned into rooms and corridors, while it is also partitioned into public areas and private areas regarding its security levels. Since each interpretation forms a space layer with a proper partitioning criteria, an indoor space may have multiple space layers.

We therefore conclude that indoor maps should contain the information about indoor structures, particularly the connectivity. First, the indoor connectivity, called the indoor accessibility graph (Li and Lee, 2008; Lu et al., 2012), has to be prepared, as we need a road network graph to compute distance on the road network. An indoor accessibility graph is represented as $G = (V, E)$, where a node $n \in V$ is a room or a space unit in indoor space and an edge $e \in E$ represents the connectivity between two adjacent space units, for example, via the door. The edge may contain any additional attributes such as the length of the connection.

However, a simple edge connecting two nodes does not fully reflect the distance information particularly when the room connected to the edge has a big area or complicated geometry (Xie et al., 2015). In order to address this issue, we need the geometry information of the room or space unit surrounded by architectural components, such as walls and doors. Once indoor geometry information is provided, the indoor distance is computed by dividing the total path into point-to-door and door-to-door distances as shown in Fig. 1. In this figure, the path from point p to point q is divided into several subpaths; the first subpath from p to door d_1, the second from d_1 to door d_3, and the third path from d_3 to q. While the distances from p to d_1 and from d_3 to q are called point-to-door distance, the distance from d_1 to door d_3 is called door-to-door distance. The point-to-door distance may be computed by line-of-sight (Yuan and Schneider, 2010) or the Minkowski sum (Xie et al., 2015), while the door-to-door distance can be easily computed by the shortest path algorithm with precomputed door-to-door graph (Yuan and Schneider, 2010).

2.2 Cell-Based Context Awareness

In order to provide proper indoor spatial services, the contextual information of user is a fundamental component. As claimed by an early work on ubiquitous and context-aware computing (Schilit et al., 1994), the context has three important aspects; where you are, with whom you are, and what resources are nearby. The first aspect is related with the location of the user, which is normally represented as (x, y, z) coordinates in outdoor space. However, it is more relevant to represent the location of the user in indoor space with the room number than (x, y, z) coordinates, since the context is mainly determined by the type or function of the room. For example, staying in a classroom for an hour has a totally different context from staying in a washing room for an hour. This concept of location is also useful for the second and third aspects. For example, it is possible to implement an interesting service of exchanging digital name cards between the users in the same room. In this example, the concept of location based on room number is more useful than (x, y, z) coordinates.

One of the most basic functions of indoor context awareness services is therefore to identify the room or space unit where the user is currently located. In general, we call the unit of indoor space the *cell*, and rooms, corridors, and staircases are examples of cells. Therefore, the indoor spatial data model should contain the notion of cell to support the *indoor cell awareness*. The indoor cell-awareness is defined as being aware of the cell where the user is currently located. In order to implement it, indoor maps must meet the following requirements. First, the geometry of cell must be clearly defined either in 2D or 3D to facilitate the point-in-polygon or point-in-polyhedra operations. Second, each cell must contain semantic information such as its classification, usage, and other relevant attributes.

2.3 Integrating Multiple Data Sets

Like maps for outdoor space, indoor maps contain multiple layers, each of which has its own data source and interpretation. Overlaying and integration of multiple data sets is a fundamental requirement of indoor maps. First, the integration of indoor and outdoor spatial data sets is crucial for seamless services between indoor and outdoor spaces, for example, indoor parking services. Second, several standards for indoor spatial information have been developed, such as IFC (BuildingSmart, 2009), CityGML (OGC, 2012a), and IndoorGML (OGC, 2012b), each of which has its strengths and weakness. Third, it is often necessary to interpret and configure a single indoor space from multiple viewpoints. For example, the layout of an indoor space is given as a topographic map, while another layer for CCTV coverage is also useful for security purpose.

In general, there are two approaches for the integration. The first approach is a physical integration of multiple data sets of different standards into a single data set. For example, CityGML provides a mechanism called Application Domain Extension (ADE) (OGC, 2012a), which extends CityGML to include additional information. A spatial data model in another standard may be redefined as an ADE of CityGML, and a conversion process from a data set to CityGML ADE is required. The second approach is to link multiple data sets in different standards via external references without physical integration. For example, each feature in a data set D_A of a standard data model has an external reference or foreign key to a feature in another data set D_B of a different standard data model and vice versa. This approach is simple and practical when the correspondence between features in D_A and D_B is one-to-one. Thus, the standard data model should support the integration via the extension mechanism or an external reference.

3 Basic Concepts of OGC IndoorGML

In order to respond to the requirements discussed at the previous section, a common standard data model and encoding schema has been published by Open Geospatial Consortium (OGC) (OGC, 2012b). In addition to the requirements for indoor maps, several requirements for a standard data model have been also considered as below:

- Reflecting the properties of indoor space
- Cellular space model
- Minimal set of specifications
- Interoperability with other standards
- Extensibility

As discussed in Kang and Li (2017) and in the previous section, the indoor cell awareness is a basic requirement of the indoor spatial data model. For this reason, the key concept of IndoorGML is based on the *cellular space model.* A cellular space is defined as a set of nonoverlapping cells, where each cell has an identifier and the union of cells is a subset of the entire indoor space. A cell in this model means a unit space in indoor space such as a room and a corridor. Note that no overlapping between cells is allowed, and the union of all cells is a subset of the given indoor space. This means that there may be shadow areas, which are not covered by any cell.

Based on the cellular space model, IndoorGML introduces four main concepts: cell geometry, topology between cells, cell semantics, and multilayered space model. We study details of each concept in the subsequent sections.

CELL GEOMETRY

The geometry of a cell is defined as a 2D surface or 3D solid of ISO 19107 Standard (ISO TC211, 2003), which provides a basic set of geometry types used in spatial information systems. There are three options to define the cell geometry. The first option is to exclude any geometric description from a data set in IndoorGML and only to include topological relationships between cells, which will be explained in the next section. The second option is to include its geometry within IndoorGML data. For example, the geometry of a cell is defined as a 3D solid of ISO 19107. The third option is to include references to objects in external data sets that may contain geometric data. For example, a cell in IndoorGML data has a pointer to an object in CityGML via GML identifier (OGC, 2007), where the object in CityGML has geometric property. These options are not exclusive and may be combined together. For example, while no geometry is included in an IndoorGML data (Option 1), it contains external references to objects in other data set (Option 2). And it does not always require 3D representation of indoor map but multilevel 2D floor plans, since 2D geometry is also allowed in IndoorGML.

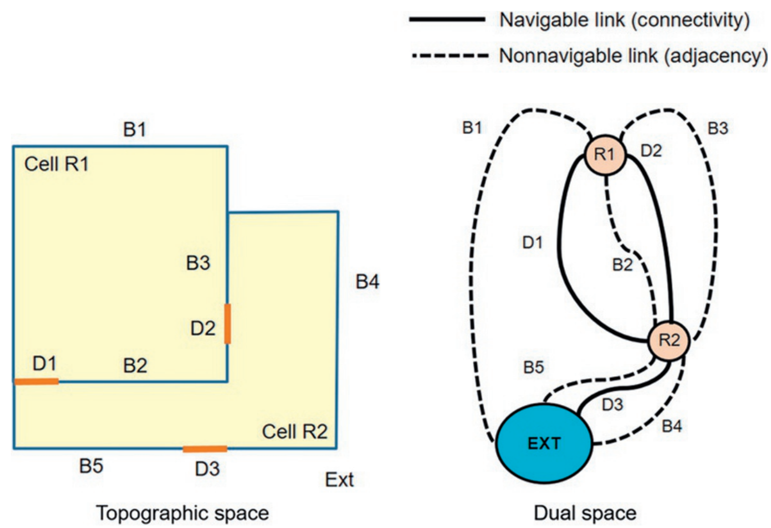

FIG. 2 Derivation of the adjacency graph from cell geometry (OGC, 2012b).

TOPOLOGY BETWEEN CELLS

Once cells are determined with their identifiers and geometric properties, topological relationships between cells have to be determined, which are essential to most of the indoor navigation applications. The topology between cells in IndoorGML can be derived from cell geometries by Poincaré duality (Lee, 2004). A k-dimensional object in the N-dimensional topographic space is mapped to a $(N-k)$-dimensional object in the dual space. The 3D geometry of a cell is, for example, transformed to 0D node of the corresponding graph in dual space and a 2D boundary surface shared by two cells is transformed to a 1D edge of the graph in dual space. This transformation with Poincaré duality results in a topological graph connecting adjacent cells in indoor space as shown in Fig. 2. Furthermore, several application graphs can be derived from the adjacency graph considering edge properties or constraints. With the edges representing doors, we may, for example, derive the connectivity graph, where each edge represents a connectivity between two cells. By using more attributes such as distances, directions, and types of doors on the edge, it may be possible to derive more divers graphs. Note that the edge may contain a line string geometry to depict the path between two rooms via a door. The geometry property of edge is useful particularly when we compute distance in indoor space.

CELL SEMANTICS

Since every cell in indoor space has its proper function and usage, we need to specify the semantics of cells. In the current version of IndoorGML, we classify the types of cells in terms of indoor navigation and expect that other classifications would be necessary for different applications, such as indoor facility management. A detail classification of cells is given as code list with hierarchical classification in the building by OmniClass (ISO/TC59/SC13, 2015). In addition to cells, the semantics of cell boundary are also useful to describe the types and properties of boundary.

MULTILAYERED SPACE MODEL

A same indoor space can be interpreted and represented in different ways. A mechanism, called the multilayered space model is offered in IndoorGML to represent an indoor space by multiple interpretations (OGC, 2012b; Becker et al., 2009). Each interpretation corresponds to a cellular space layer with its own geometric and topological properties. For example in Fig. 3, there are two different layer configurations of an indoor space due to a step in Room 3; the walkable layer and wheelchair layer. Since each layer forms a cellular space, it includes the geometries of cells, topologies between cells given as a graph and cell semantics. In addition to simple aggregation of cellular space layers, a special type of edge, called interlayer connection, is also offered in IndoorGML to represent the relationships between nodes in different layers. In Fig. 3, we have Room 3 in the walkable space layer corresponding with Room 3a and Room 3b in the wheelchair layer because Room 3 is partitioned into Room 3a and Room 3b due to a step. The multilayered space model is also useful for many applications, such as in describing the hierarchical structure of indoor space or in tracking moving objects from sensor data. Further detailed discussion is found in Becker et al. (2009).

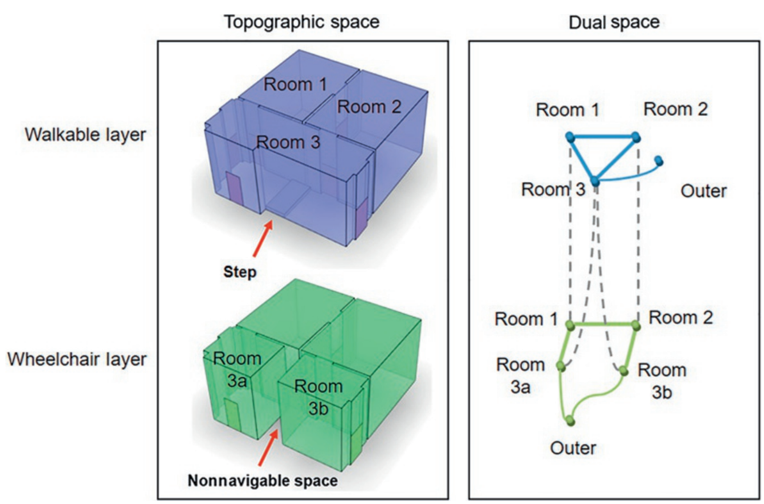

FIG. 3 Example of the multilayered space model (Becker et al., 2009).

4 Modular Structure of IndoorGML

For the sake of extensibility, IndoorGML has a modular structure as shown in Fig. 4. The core module of IndoorGML contains the data model for cell geometry, topology, and the multilayered space model. The indoor navigation extension model, which is the semantic extension model for indoor navigation, is so far the only extension module defined on the top of the core model. Many other extension modules may be defined for each application area such as indoor cadastral extension (Alattas et al., 2017), indoor geo-referenced multimedia extension, indoor facility management extension.

4.1 IndoorGML Core Module

The Core Module of IndoorGML defines the common framework of indoor spatial data model, which includes the cell and cell boundary geometry model, topological model, and multilayer space model. The primitive spatial types of this module come from those defined by ISO 19107. The UML class diagram of the Core Module is given as Fig. 5. Note that the Core Module is also given as a XML schema to express indoor maps in XML documents.

The Core Module includes four basic types: State, Transition, Cell Space, and Cell Space Boundary. While Cell Space and Cell Space Boundary belong to the indoor topographic space representing cell and cell boundary, respectively, State and Transition belong to the topological graph derived from Cell Space and Cell Space Boundary by Poincaré duality.

Cell Space defines a basic unit type of the cellular indoor space model, such as room, corridor, and hall. It basically contains a GML identifier (OGC, 2007) with proper attributes.

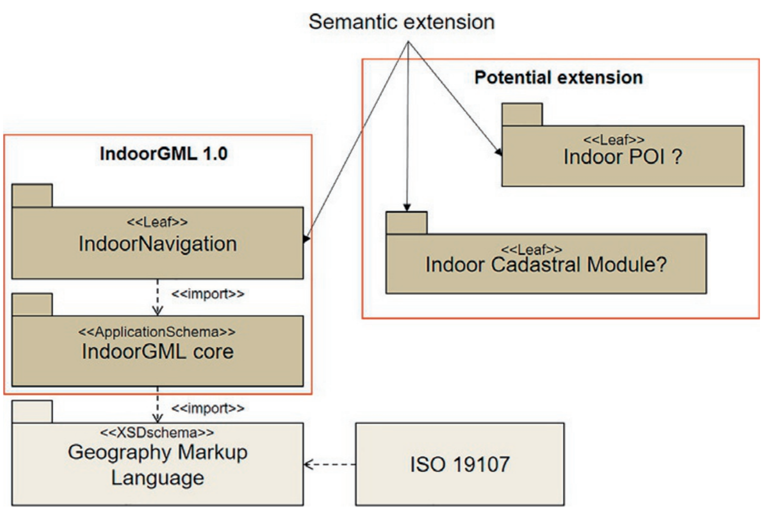

FIG. 4 Modular structure of IndoorGML (OGC, 2012b).

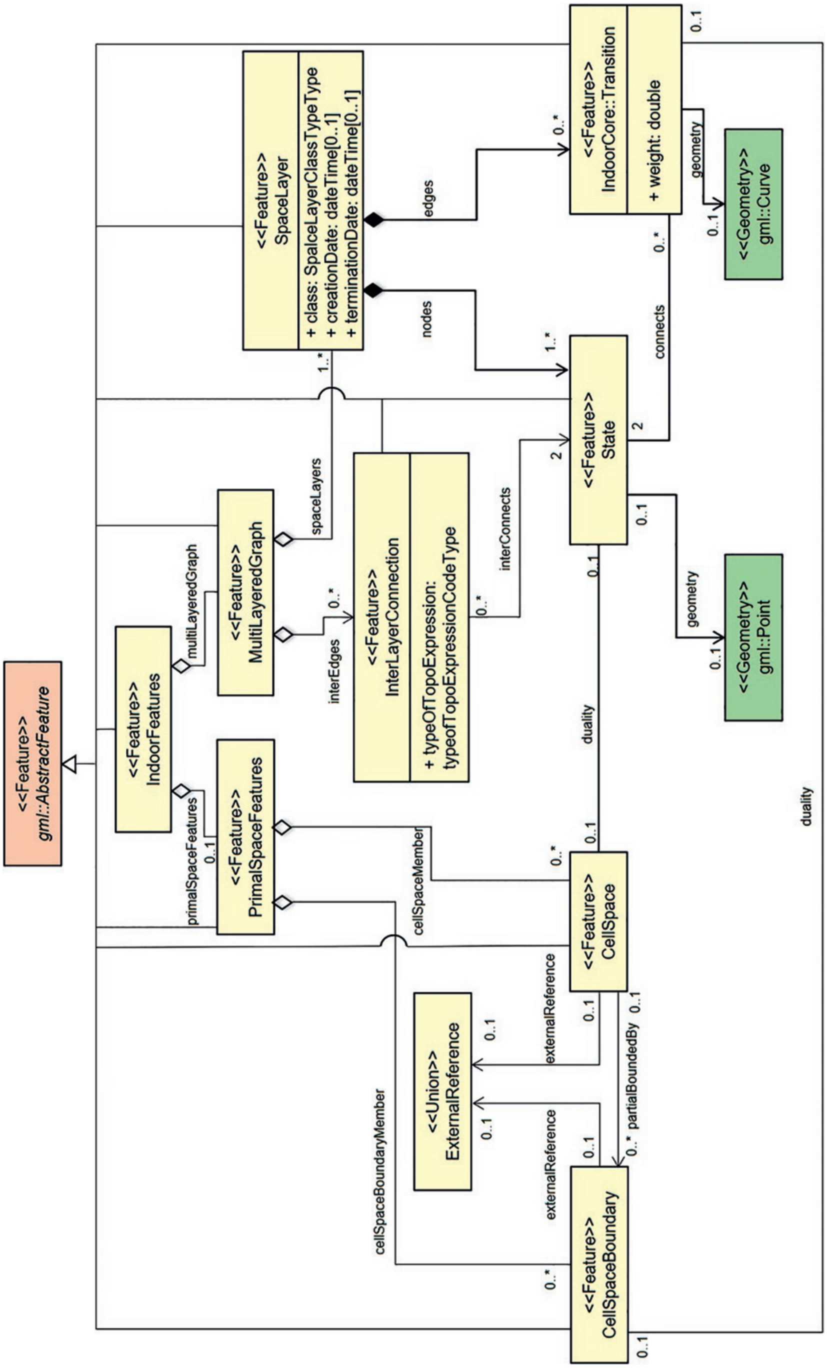

FIG. 5 OGC IndoorGML Core Module (OGC, 2012b).

It may also contain a reference to an external object, which may provide additional information. The geometric type of Cell Space may be either a solid or surface depending on the dimensionality of the space. It may not contain any geometry as discussed in the previous section. While Cell Space represents a cell in indoor space, Cell Space Boundary defines the boundary geometry of a Cell Space object, and its geometry may be a surface or curve depending on the dimensionality. State and Transition define the feature types of the topological graph corresponding with Cell Space and Cell Space Boundary in terms of connectivity topology.

4.2 IndoorGML Navigation Module

While the core module defines the basic feature types in indoor space, we may extend it for specific application areas. As indoor navigation is a typical and one of the most demanded application, the current version of IndoorGML includes the first extension for indoor navigation. Fig. 6 shows the UML class diagram of the indoor navigation module.

The feature types of the indoor navigation module are divided into two categories; cells space and cell boundary. The feature types belonging to cell spaces are illustrated in Fig. 7. Among the feature types in the navigation module, it is worthwhile to pay attention to Anchor Space and Anchor Boundary. It allows the connection between indoor and outdoor spaces as depicted in Fig. 8 and the seamless navigation can be implemented using the anchor. In addition to the connection between indoor and outdoor spaces, we may define extra attributes such as building address, the URL of the building, or the transformation parameters for two spatial reference systems of indoor and outdoor spaces.

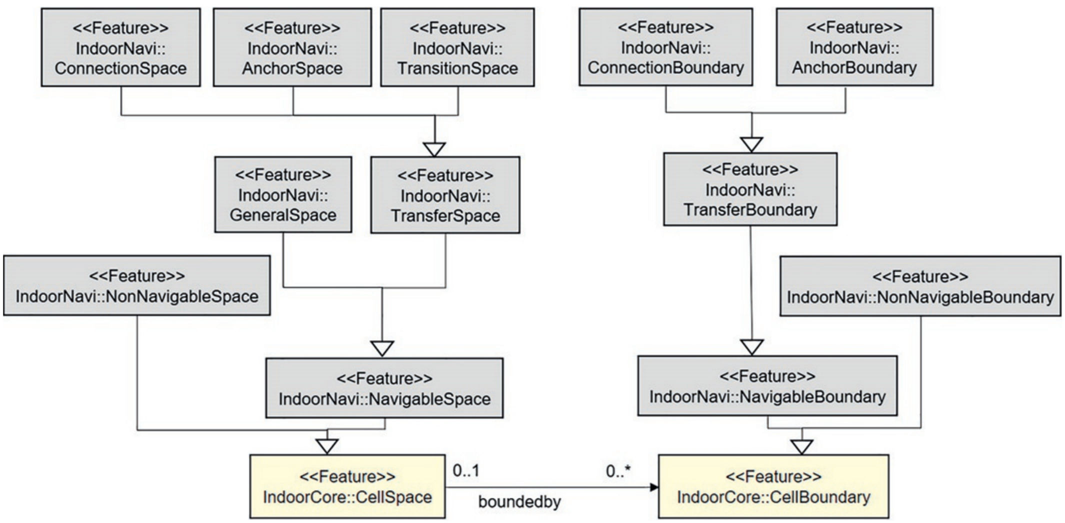

FIG. 6 IndoorGML Navigation Module (OGC, 2012b).

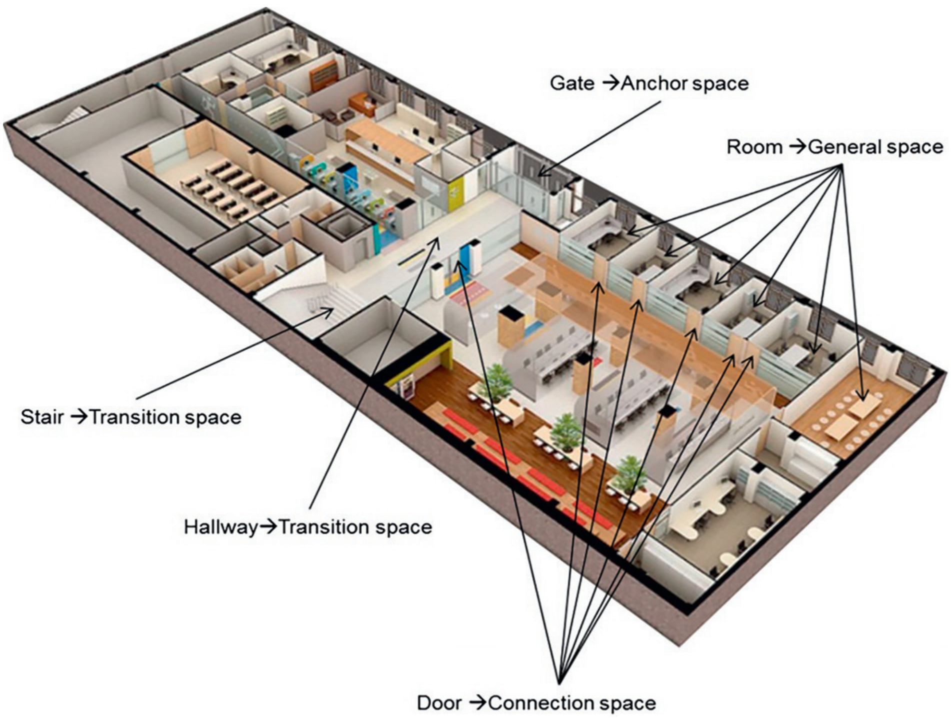

FIG. 7 Features in Indoor Navigation Module (OGC, 2012b).

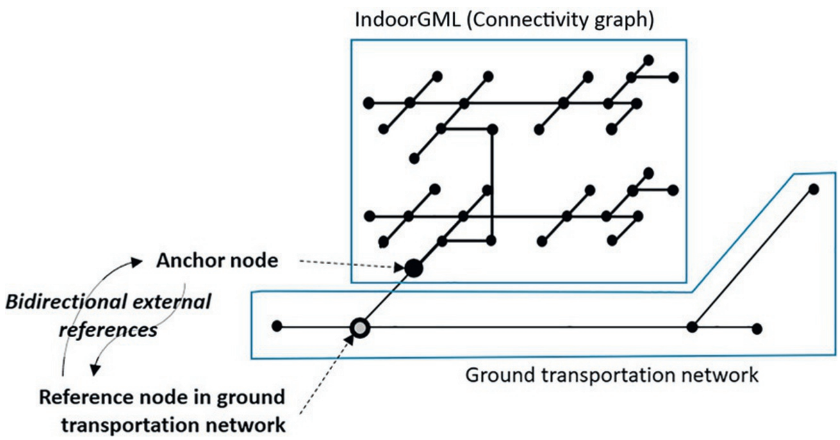

FIG. 8 Anchor (OGC, 2012b).

5 Implementation Issues

In this section, we discuss major issues on implementing IndoorGML. A more detail discussion is also found in Kang and Li (2017).

CELL DETERMINATION AND DECOMPOSITION

Since cells are the basic units of indoor space, the construction process of indoor maps in IndoorGML starts from the determination of cells. In many applications, we often find cells as shown in Figs. 9 and 10 . In order to assign semantics to each cell, it is required to decompose them in proper ways. The decomposition of a big cell depends on the type of indoor spaces and applications. For example, in airports, the space is divided from functional perspectives such as arrival, departure halls, office area, and so on, where the arrival hall is also divided into transit areas, immigration and passport control areas, and baggage claims. The decomposition rules in airports should be much different from

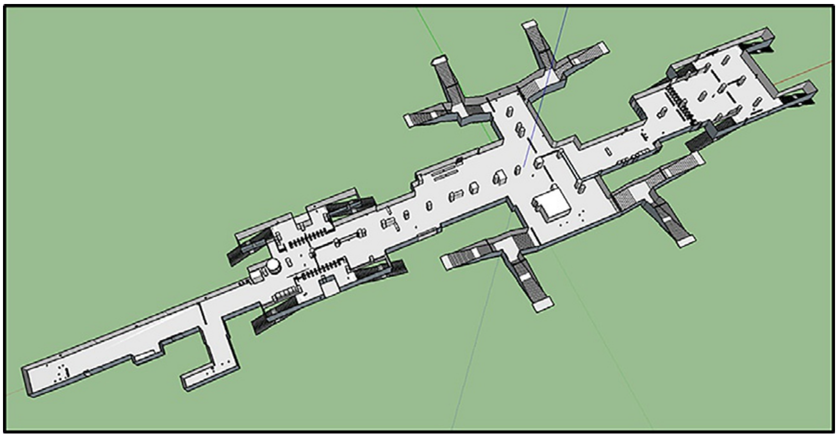

FIG. 9 A big cell at a subway station in Seoul (Ryoo et al., 2015).

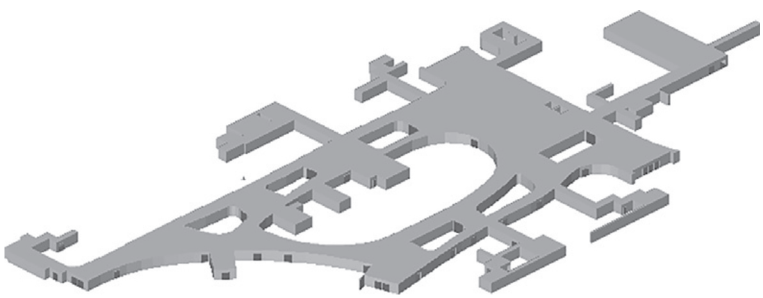

FIG. 10 A big cell at a shopping mall in Seoul (Ryoo et al., 2015).

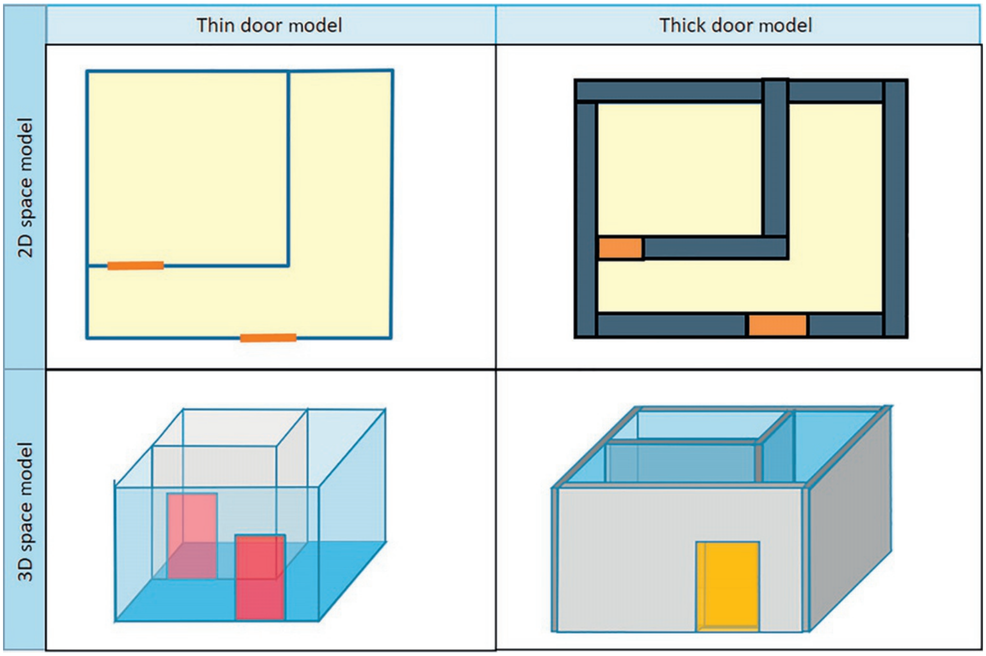

FIG. 11 Thin door model versus thick door model (OGC, 2012b).

subway station like Fig. 9 and shopping malls as Fig. 10. It is therefore necessary to prepare a set of decomposition rules for each indoor type (Diakité and Zlatanova, 2018).

THICK DOOR MODEL VS. THIN DOOR MODEL

There are two approaches to model an indoor space using IndoorGML—thin wall model and thick wall model. While the wall or door are represented as a surface in thin door model, they have a certain thickness in thick wall model as shown in Fig. 11. Note that the wall itself is also regarded as a nonnavigable cell in thick door model.

PATH GEOMETRY

The edge in connectivity graph does not only indicate the connectivity between two nodes but also its geometry, where the edge may be either a straight line or curve. Then the geometry of edge is useful to compute indoor distance and to represent paths of indoor transportations such as robots.

SPACE CLOSURE

In CityGML, a cell can be represented only as an instance of Room, where its geometry of Room is either a Solid as closed space or as a Multi-Surface, which is not necessarily closed. For example, stairs are considered as Interior Building Installation, whose geometry is a MultiSurface as shown in Fig. 12. If we want to close the space, then we need to define an additional feature of Closure Surface or Floor Surface of CityGML, which may

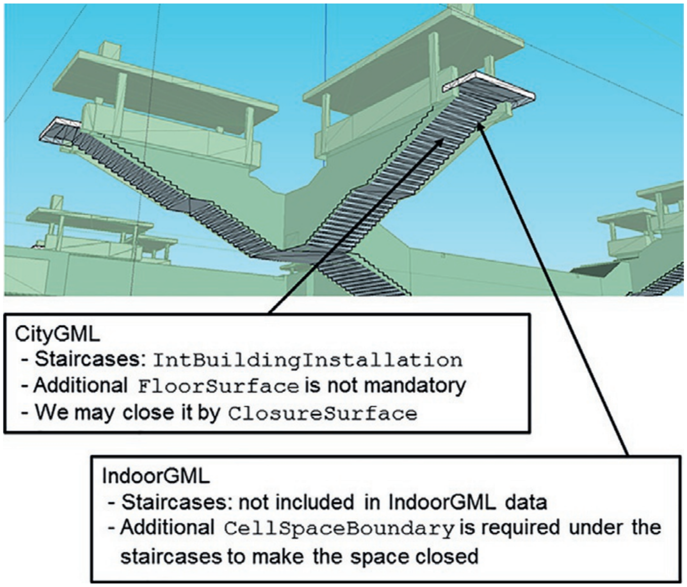

FIG. 12 Closed space—Staircase (Ryoo et al., 2015).

be very easily missing in practice. However, stairs are not included in IndoorGML since the representation of indoor installations is not within the scope. But stair case is represented as a cell of closed space, which is a Solid in 3D space or a Surface in 2D space. In both cases, the geometry of cell is always closed and it facilitates spatial operations such as point-in-polygon or point-in-polyhedron.

HIERARCHICAL STRUCTURE

Most indoor spaces have hierarchical structures. An efficient way to represent hierarchical structures of indoor space was introduced in Stoffel et al. (2008). It is possible to redefine the hierarchical graph for indoor space by the multilayered space model of IndoorGML (Kang and Li, 2017; Kim and Li, 2016). Each level of hierarchy is defined as a single space layer of the multilayered space model, and the relationships between two levels are represented by the interlayer connection of IndoorGML. An example is shown in Fig. 13. Therefore, G_0 is the single-layered graph of the bottom level. The highest level G_h, namely the root graph of the hierarchical graph, contains only a node without edge, where h is the height of the hierarchical graphs. Fig. 13 shows an example of the hierarchical structure for an indoor space by the multilayered space model of IndoorGML. S_1 and S_2 in Level 1 are the aggregations of $\{R_1, R_2, C_5, R_6\}$ and $\{C_3, C_4, R_7, R_8\}$ in Level 0, respectively. T_1 is the entire indoor space as the aggregation of $\{S_1, S_2\}$. Then, the G_0 layer indicates the base graph of the indoor space; G_1 is the next level layer of the hierarchy; and G_2 is the layer for the root level. The relationships between layers are given via interlayer connections. Note that the topological properties of interlayer connections in Fig. 13 are INSIDE.

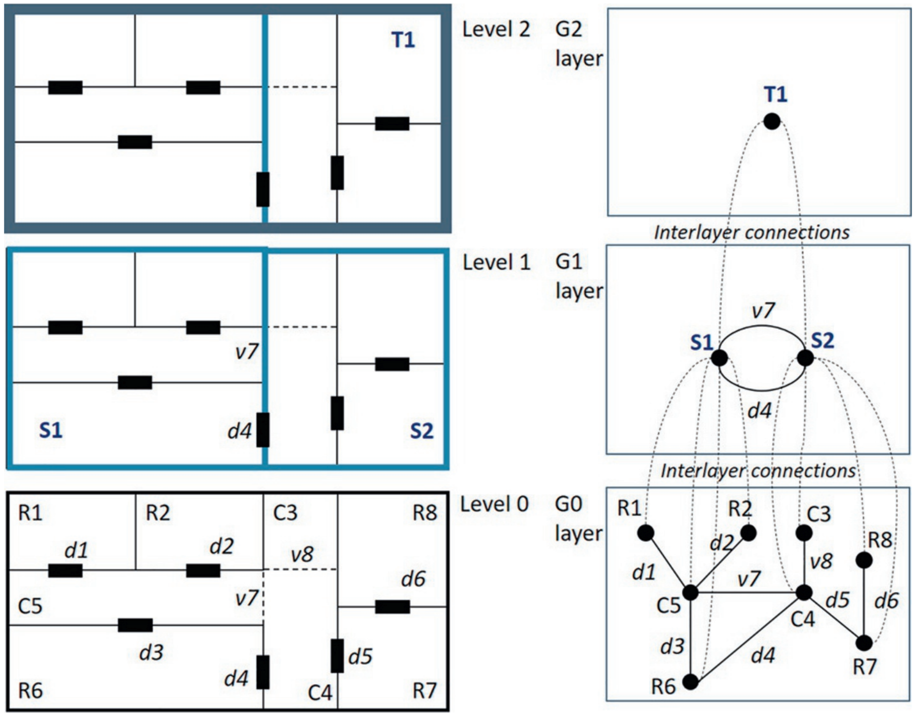

FIG. 13 Hierarchical structure and multilayered space model of IndoorGML (d_i and v_j indicate the connections via the ith door and the jth virtual boundary, respectively) (Kang and Li, 2017).

WALL TEXTURE

Unlike CityGML where every wall surface is considered as a feature with attributes and textures (OGC, 2012a), it is optional in IndoorGML to define wall surface as an independent feature. Furthermore, we cannot assign texture to wall surface in IndoorGML, since the visualization is not among the purposes of IndoorGML and more precisely no orientation is defined for wall surface.

VERTICAL CONNECTION

The indoor space has a set of connections between floors such as lifts, escalators, and stairs as well as horizontal connections. However, they may be differently implemented by IndoorGML as shown in Fig. 14. In the case of elevators, the elevator shaft is regarded as a cell and the vertical connections are established via the elevator shaft cell. In the contrary, the staircase can be divided into small cells, each of which has a connection to the corresponding floor. The vertical connections via elevators are differently represented in IndoorGML. Since each escalator does not own its space extent in indoor space unlike elevators, it is simply considered as a transportation mode between floors. The connection via escalator is therefore treated as vertical doors shown in right-hand side of Fig. 14.

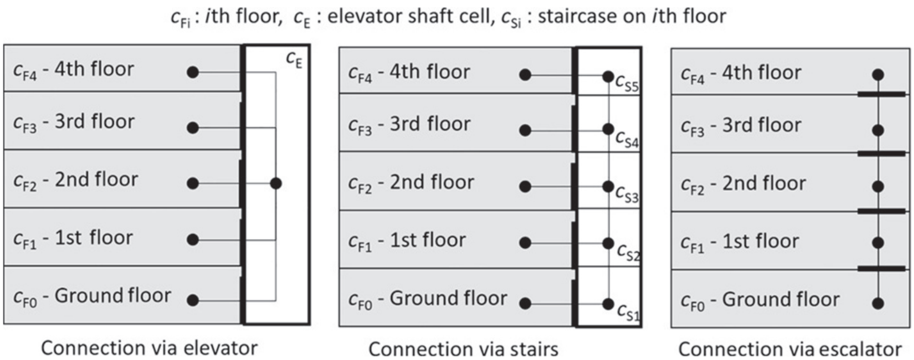

FIG. 14 Implementations of vertical connections by IndoorGML.

6 Use Cases

The robustness and soundness of the previously illustrated conceptual model underpinning IndoorGML has been already validated in the context of several use cases. To this extent, an interesting set of use cases have been validated in real-life conditions by the project i-locate "i-locate—Indoor/outdoor LOCation and Asset management Through open gEodata" (Conti and Eccher, 2014). The project, which has been funded by the European Commission (EC), delivered one of the first implementations of IndoorGML (Conti, 2015b) together with a suite of associated tools, including a middleware, an online portal (i-locate project, 2015), and a IndoorGML plug-in for JOSM the popular authoring tool for OpenStreetmap (Conti, 2015a). Perhaps equally interesting, the project has also assessed the use of IndoorGML in the context of two key use cases, namely user navigation and asset management, within different verticals such as healthcare, museums, etc. The assessment has been carried on in the context of 13 pilot sites across Europe, for a duration of a year in real operational scenarios. All the pilot sites shared two macro-use cases, albeit applied in different vertical domains, that is, indoor and outdoor guidance of people and real-time asset management.

The 13 sites included four major hospitals (in Malta, Romania, Italy, and Greece), two university campus (in the Netherlands and Germany), a major international museum in Romania, several public buildings from four municipalities (in Croatia, Romania, and Italy), a nursing home in Romania, and business park in Luxembourg. While a comprehensive description of each pilot, Morganto et al. (2015); Napoleoni et al. (2016) is clear beyond the scope of this chapter, nevertheless it is worth highlighting that the size, heterogeneity and duration of the pilot (12 months) allowed for a very significant assessment of the potential of IndoorGML in real operational scenarios, ranging from creation of multiple graphs using the online portal or JOSM plugin (see Fig. 15) to their use across the i-locate service stack in order to provide tailored services to final users using a variety of location technologies using, for instance, ZigBee, Ultra-Wide Band, Bluetooth, Wi-Fi, cell-ID, GNSS (EGNOS), as well as camera-based systems.

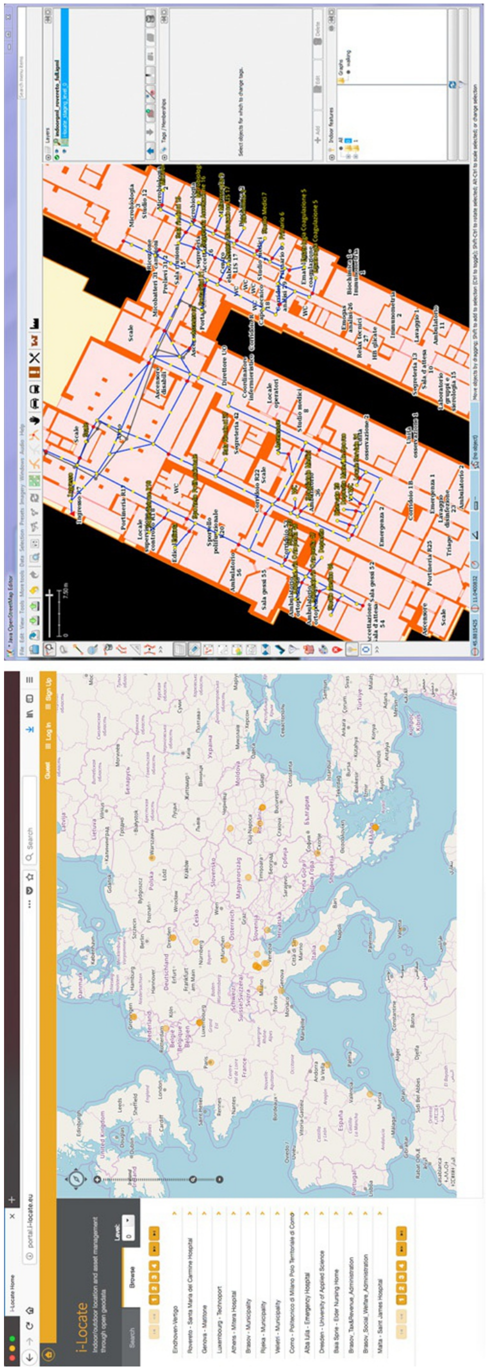

FIG. 15 Images of the i-locate portal (*left*) (i-locate project, 2015) and JOSM featuring the i-locate plugin (*right*) (Conti, 2015a) showing the connectivity graph, encoded as IndoorGML (i-locate project, 2015), of the hospital where i-locate technology has been used.

All the pilots have shared two macro use cases, that is indoor way finding and management of both of people or asset. The typical wayfinding use case has seen the final users being routed indoor and outdoor, through the i-locate App, to reach a given destination. To do so each IndoorGML graph has been further connected, via an anchor node, through the OpenStreetMap outdoor road network, in order to allow for hybrid indoor and outdoor navigation. The resulting hypergraph, that is a graph of graphs, has then been compiled and used by a specifically developed web services providing navigation and routing capabilities. Most interestingly, the serviced has designed to allow for indoor to indoor, outdoor to outdoor, and, most interestingly, outdoor/indoor navigation, calculating optimized paths according to a set of customizable criteria which, in turn, defined the weight functions used by the routing system (Feng et al., 2015; Konstantinidis et al., 2017).

While the following examples have shown use of IndoorGML in traditional use cases, albeit applied to a variety of different verticals, an additional example may help show the potential that be unleashed by leveraging on the IndoorGML concept of cell. In most use cases, cells are used to refer to rooms, or indoor spaces of a building with a specific functioning connotation. An example could be the different check-in desks of airport departure hall, that, although not physically separated each other, could be modeled as cell and used to provide indoor guidance to each of the different desk. The work carried on by two ongoing EC projects, UNCAP and then CAPTAIN, is instead emergence of predictors of cognitive decline among elderly adults.

Body movements of elder adults are continuously detected by using 3D sensors (Nively, 2015). By deriving their body spatial configuration (position in space of different body parts) in real time, it is possible to define, among other activity indicators, trajectories, and speed over time of the senior. In turn, this information can be used to extract important information on behavioral patterns related to the their Activities of Daily Living (ADL). By applying Density-Based Spatial Clustering of Applications with Noise (DBScan), it has been possible to cluster position data over time according to the minimum distance between two neighboring points (eps parameter) and the minimum neighborhood points that are sufficient to constitute a cluster (minPts parameter). The resulting clusters, technically referred to as High-Density Regions (HDRs), are further processed to calculated the smallest convex polygon that surrounds the points of each HDR, which is finally used to define the IndoorGML cell. In this case the cell represents a portion of space associated with a specific behavioral pattern.

In the work illustrated in Konstantinidis et al. (2016, 2017), the methodology was applied to user's activity data collected over a 12-month period while cells were generated to highlight possible behavioral variations over time at a monthly frequency. While each cell is related to a specific spatial behavior within a given timeframe, the connectivity between different cells, derived through statistical analysis of the activity data, can be used to model transitions with highest occurrence between cells, whose variation over time can in turn be used to infer changing of usual behaviors. The initial encouraging results (Konstantinidis et al., 2016, 2017), are being extended to include outside data analysis collected by leveraging on high-precision GNSS (Galileo) and by leveraging, as in the previous example, on the concept of anchor node, to expand the scope of the aforementioned method to indoor and outdoor spaces.

7 Conclusion

As indoor maps are a fundamental component of indoor spatial information services including indoor LBS, a number of different map formats has been developed by standard development institutes and vendors. Each approach reflects its requirements and viewpoints. However, indoor spatial information services consist of several building blocks from spatial technologies as outdoor information services. In order to provide the interoperability between different building blocks and setup an ecosystem, we need a common data model and format of indoor maps. The OGC has published IndoorGML as a standard for indoor spatial information.

The main features of IndoorGML include the cellular space model, the geometric, topological, and semantic models of cells, and the multilayered space model. IndoorGML provides only the features that are not found in other standard data models and formats, and particularly emphasizes the indoor cellular space model and network topology in indoor space. However, it does not form a complete set of all features for indoor maps and therefore has to be integrated with other standards such as OGC CityGML, IFC, KML, etc., to develop an indoor spatial information application.

In this chapter, we also discussed the implementation issues of IndoorGML from different viewpoints as well as use cases, such as cell determination and decomposition, thick-door model, path geometry, cell space closure, hierarchical structures, and vertical connections, which we currently believe the most important ones. However, it is not possible to limit the application scopes of indoor maps and IndoorGML, and a number of implementation issues may be expected. Particularly we may need more specific implementation specifications for each type of applications, such as robotics, indoor asset managements, indoor security controls, and so on. These specifications can be added as extensions modules of IndoorGML, which are also future works of IndoorGML community.

Acknowledgments

Part of the work described in this chapter has been co-funded by BK21PLUS, Creative Human Resource Development Program for IT Convergence, the European Commission through the projects i-locate (Grant Agreement no. 621040), UNCAP (Grant Agreement no. 643555), and CAPTAIN (Grant Agreement no. 769830), and by the Ministry of Land, Infrastructure and Transport of Korean Government (Grant agreement no. 17NSIP-B135746-01). This document reflects only the views of the authors and the European Community is not liable for any use that might be made of the information contained within the document.

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