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TOWARDS THE INTEGRATION OF INDOORGML AND INDOORLOCATIONGML FOR INDOOR APPLICATIONS

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ABSTRACT:

This paper introduces and compares two types of GML-based data standards for indoor location-based services, *i.e., IndoorGML* and *IndoorLocationGML*. By elaborating the advantages of the both standards and their data models, we conclude that the two data standards are complementary to each other. A jointed data model is presented to show the integration of the two standards. *IndoorGML* can supply subdivision of building for data of *IndoorLocationGML*, and the semantics of locations defined in *IndoorLocationGML* can be added to *IndoorGML*. By proposing two use cases, we take the initiative in attempting to combine the use of the two standards. The first case is to collect details from files of the two standards for an indoor path; the second one is to generate verbal directions for indoor guidance from files of the two standards. Some future work is given for further development, such as automatic integration of separate data from both standards.

1. INTRODUCTION

Indoor activities such as indoor navigation greatly rely on indoor spaces, *i.e.,* regions with physical boundary or conceptual area without boundary (*e.g.,* the dining area of a hall). Applications in the real world requires clear and sufficient space definitions, indoor navigation models (*e.g.,* three-dimensional (3D) networks) simplifying building interiors and indoor routing/wayfinding systems (*e.g.,* a pathfinding engine or signage system in the building) (Worboys, 2011; Lee and Kwan, 2005; Brown et al., 2013; Meijers et al., 2005; Becker et al., 2009; Thill et al., 2011; Boguslawski and Gold, 2010; Teo and Cho, 2016). Such information is partially organized in different data models and technical standards (Lee and Kwan, 2005; Worboys, 2011; Brown et al., 2013; Becker et al., 2009; Lee et al., 2014; Liu and Zlatanova, 2012). In addition, indoor navigation requires good expressions of location to be able to position one in the spaces or to navigate to a *Point of Interest (PoI)* with ease (Sithole and Zlatanova, 2016; Wijewardena et al., 2016; Kim and Li, 2016).

Crossing the current research one of the primary problems is to properly define and describe indoor spaces and locations, their relationships and other significant information (semantics, important attributes and geometry) (Worboys, 2011; Goetz and Zipf, 2011; Brown et al., 2013). Many explorations have been devoted in this direction. A typical and established piece of work for indoor modelling is *IndoorGML* (Lee et al., 2014), a data standard of *Open Geospatial Consortium (OGC)* about navigation network of indoor environments. It provides a concise expression of indoor navigation networks and related indoor spaces with their semantics. Another interesting study is an emerging Chinese data standard *Multidimensional Indoor Location Information Model (IndoorLocationGML)* focusing on indoor location, which aims to address urgent requirements on indoor location modelling (Zhu et al., 2016). It proposes a framework that can manage both accurate and relative descriptions of indoor locations, enrich locations with semantics, and maintain topology of locations (*e.g.,* distance, direction, order, *etc.*).

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In this paper we investigate the two data standards of *IndoorGML* and *IndoorLocationGML* and aim to bridge the two standards to support more indoor navigation cases. The two standards concentrate on different aspects of indoor navigation, and thus they are complementary to each other for indoor navigation applications. *IndoorGML* focuses on navigation networks where pathfinding can be conducted, but *IndoorLocationGML* covers the issues related to indoor locations. Thus *IndoorLocationGML* aims for location-based services. In fact, the both standards can be used together for two main types of cases presented as follows:

- Support different indoor subdivision results.
- Generate verbal guidance for indoor navigation.

The rest of this paper is organized as follows: Section 2 will introduce the two data standards, Section 3 will present the uses of the both standards to each other. Section 4 will present two use cases by linking the two standards. This paper is closed with conclusions and some future work in Section 5.

2. INDOORGML AND INDOORLOCATIONGML

The two data standards are both presented with data model in *XML* schema (*i.e.,* technical model) and based on *Geography Markup Language (GML)* (Portele et al., 2007). *IndoorGML* is based on connectivity of indoor spaces, and defines rules for navigable network; *IndoorLocationGML* focuses on ontology and application of indoor locations (*e.g.,* absolute and relative locations,

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and direction). Therefore, the two data models can be complementary to each other on different aspects for indoor navigation. This section will introduce the key features of the two standards. Section 2.1 will present the overview of *IndoorGML* and section 2.2 will explain the data model of *IndoorLocationGML*.

2.1 IndoorGML

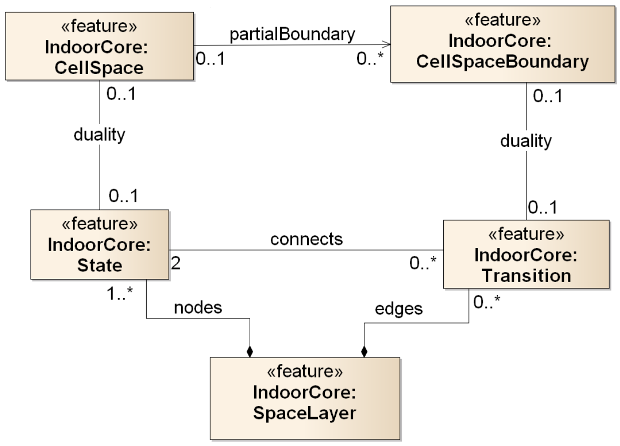

Figure 1. Main classes of Core module of IndoorGML (from Lee et al., 2014)

As mentioned before, *IndoorGML* is a data standard of *OGC* that aims to define navigation network of indoor environments (Lee et al., 2014). It consists of an open data model and *XML* schema and it has two modules. The first one is *Core* module (see Figure 1). Basically it is about a topological representation of cellular spaces. These spaces and their boundaries correspond to *CellSpace* and *CellSpaceBoundary*. Other two primary classes of *State* and *Transition* link to *CellSpace* and *CellSpaceBoundary* according to Poincaré Duality (Whitney, 1932; González, 1984), respectively.

States and *Transitions* represent nodes and edges of the dual graph (Whitney, 1932) of indoor space. The two terms are the same as those in *Multi-Layered Space Model (MLSEM)* (Becker et al., 2009), *i.e.,* another data model about indoor space information related to *IndoorGML* standard (Nagel, 2014). *MLSEM* proposes a semantic conceptual model for indoor spaces, and provides the geometric and topological representations of indoor spaces based on Poincaré Duality. Inspired by these indoor space representations in *MLSEM*, *IndoorGML* is designed as a common schema framework for indoor navigation applications (Lee et al., 2014).

The second module is *Navigation* which focuses on semantic features of indoor spaces. The *Navigation* module extends the *Core* module and defines semantics of spaces in the context of indoor navigation. The root classes about spaces are *NavigableSpace* and *NavigableSpaceBoundary*. They are subclasses of *CellSpace* and *CellSpaceBoundary*, respectively. The subclasses of *NavigableSpace* define all types of indoor spaces, such as *NavigableSpace*, *GeneralSpace (e.g., common rooms)*, *TransitionSpace (e.g., Hallway or Stairway)* and *AnchorSpace (e.g., main entrance linking indoors and outdoors)*. The *Navigation* module also represents indoor paths: classes of *RouteNode*, *RouteSegment* and *Route*. *RouteNode* associates to *State*, *RouteSegment* associates to *Transition*, and *Route* represents navigable paths. In such a way, space semantics (*e.g.,* a *TransitionSpace*) can be reflected in a *RouteNode*.

In general, *IndoorGML* defines and expresses the network of indoor spaces (*e.g.,* connectivity graph) and indoor paths. In addition, space semantic features are defined which can be used to enrich the semantics of indoor network and paths.

2.2 IndoorLocationGML

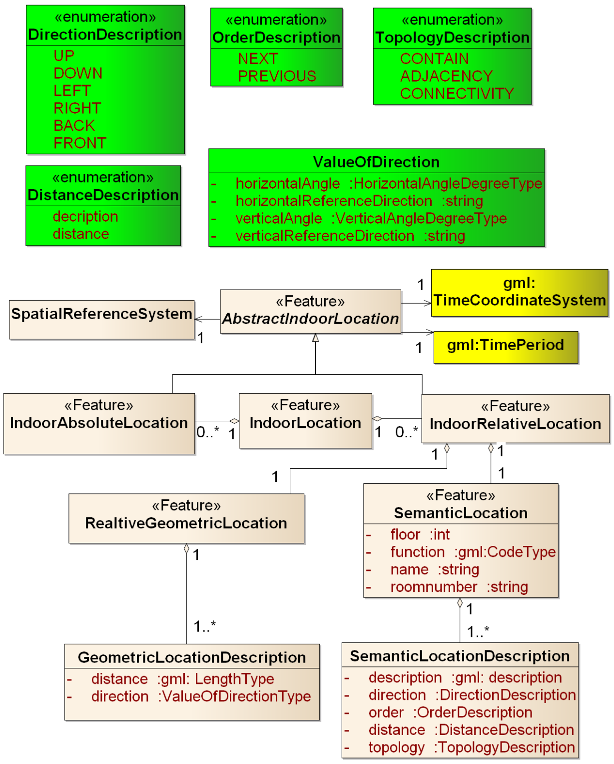

Figure 2. Main part of *IndoorLocationGML* (remade from Zhu et al., 2016)

As mentioned before, the developing Chinese standard *IndoorLocationGML* concentrates on definition and description of indoor location (Xiong et al., 2013; Zhu et al., 2016). The abstract class *AbstractIndoorLocation* stands for the general notion of indoor locations, which associates to three other classes: *gml:TimeCoordinateSystem, gml:TimePeriod* and *SpatialReferenceSystem* (Figure 2) . The first two are classes of *GML Encoding Standard* (Portele et al., 2007) and indicate the temporal features of *AbstractIndoorLocation*. *SpatialReferenceSystem* refers to an absolute or local coordinate system which provides measurement for instances of *AbstractIndoorLocation*.

Two subclasses of *AbstractIndoorLocation*, *IndoorAbsoluteLocation* and *IndoorRelativeLocation*, represent locations described in the coordinate system or with the relationships with other objects/locations, respectively. An *IndoorLocation* is composed of both *IndoorAbsoluteLocation* and *IndoorRelativeLocation*, which indicates the two types of measurement applied for one location. *IndoorRelativeLocation* have two subclasses: *RelativeGeometricLocation* and *SemanticLocation* (see Figure 2). The classes *RelativeGeometricLocation* contains the values of distance and direction (*e.g.,* angles) to other reference objects; *SemanticLocation* provides descriptions of distance, direction (*e.g.,* up, down, left and right), order (*e.g.,* previous and next) and topology (*e.g.,* connectivity and containment) to other reference locations. In general, the data model of *IndoorLocationGML* centers all classes on indoor locations (*e.g.,* PoI).

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In order to present the relationships between the data models of the two standards, we integrate the core parts of the two models in one UML class diagram (see Figure 3). Two essential associations, *IndoorLocation* to *CellSpace* and *RouteNode*, are the key to integrate the two types of data model. The class *IndoorLocation* from *IndoorLocationGML* depicts any location in a space (*i.e., CellSpace*), and an *RouteNode* represents a space. In the association of *CellSpace* and *IndoorLocation*, the multiplicity on the *IndoorLocation* side is from 0 to multiple, which means a *CellSpace* may contain none or many *IndoorLocation*. Reversely, an *IndoorLocation* can associate only one *CellSpace* (*i.e.,* the multiplicity 1). In the association of *RouteNode* and *IndoorLocation*, the multiplicity on the *IndoorLocation* side is none or many and that on the *RouteNode* side is none or one. It means that an *RouteNode* can either link to *IndoorLocation* or none, while an *IndoorLocation* can be either a location of a path (in *RouteNode*) or just an independent PoI.

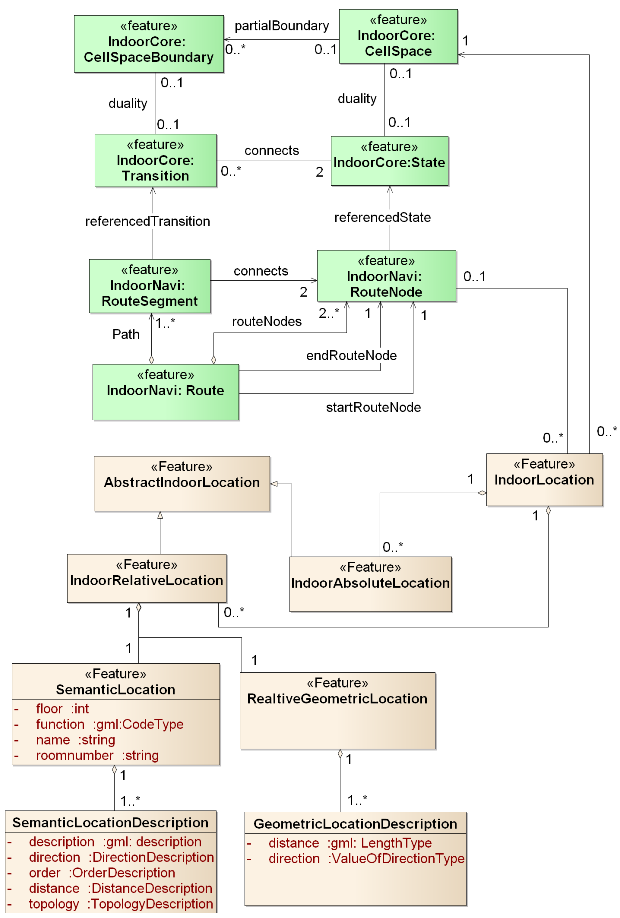

Figure 3. The jointed class diagram of *IndoorGML* and *IndoorLocationGML*

To sum up, *IndoorLocationGML* provides the complete description and measurement of indoor locations and models the relationships of indoor locations. Therefore, it can describe a sequence of locations and their relative relationships, such as locations in a path (*e.g.,* to describe the motion from the previous location to the current location in distance and angle).

3. COMBINED USE OF INDOORGML AND INDOORLOCATIONGML

As addressed before, *IndoorGML* and *IndoorLocationGML* emphasize different aspects of indoor modelling. Thus the both standards can be use together for indoor navigation. Section 3.1 will show the use of *IndoorLocationGML* complementary to *IndoorGML*; and Section 3.2 presents the features of *IndoorGML* complementary to *IndoorLocationGML*.

3.1 IndoorLocationGML complementary to IndoorGML

Although in the *Navigation* module of *IndoorGML* semantics of spaces are provided, there is no definition of *PoI*. PoI can be frequently used in indoor navigation as position reference, especially when they can be added and deleted by users (see Figure 4). In this case, a PoI can be represented by instances of *IndoorAbsoluteLocation* and *IndoorRelativeLocation*. Coordinates of the PoI are reflected by the *IndoorAbsoluteLocation* and the semantics of the PoI (*e.g.,* floor information and function) can be recorded in the *IndoorRelativeLocation*. Consequently, we can form a file containing the *IndoorGML* and *IndoorLocationGML* code snippets. For example, for a node the *IndoorGML* part includes the code of *RouteNode* and *RouteSegment*; and the *IndoorLocationGML* part contains the piece of *IndoorAbsoluteLocation* and/or *IndoorRelativeLocation*.

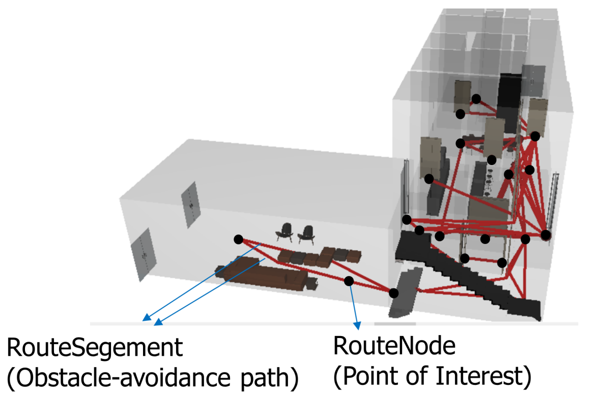

Figure 4. Example of RouteNode and RouteSegment which can be enriched by IndoorRelativeLocation instances

Another case is about *TransitionSpace* in *IndoorGML*. The class *TransitionSpace* refers to corridor, stair and subspaces of hallway (Lee et al., 2014). Generally it is about the horizontal and vertical connection parts of a building. However, the *IndoorGML TransitionSpace* does not specifically distinguish between horizontal and vertical spaces. Consequently, this ambiguity can be passed to the related instances of *RouteNode*. In this case, instances of *IndoorRelativeLocation* can be added to clarify whether the *RouteNode* related to *TransitionSpace* is horizontal or vertical.

Besides *RouteNode*, the semantics of *RouteSegment* can be also enriched by instances of *IndoorRelativeLocation* of *IndoorLocationGML*. For example, the relative position (up/down or left/right) of nodes on a *RouteSegment* can be depicted, and thus they can be perceived with ease. In addition, the room number can be also reflected with the *IndoorRelativeLocation*, which support the query about the room containing the *RouteSegment*.

In summary, the *IndoorGML* may lack location information for some applications. The semantics defined and depicted in *IndoorLocationGML* can be used for the network described by *IndoorGML*. In this way, the semantics of nodes and edges of this network can be enriched.

3.2 IndoorGML complementary to IndoorLocationGML

IndoorGML can supply data for *IndoorLocationGML* when space-related information is required. Subdivisions of building can be reflected in *IndoorGML* files which is missing in *IndoorLocationGML*. A specific subdivision of building results in a number of indoor spaces. Besides the subdivision according to building structure (*e.g.,* walls as boundary), other subdivisions can be achieved by using functionalities of indoor space (Krūminaitė and Zlatanova, 2014). According to *(MLSEM)* (Becker et al., 2009), the same building can be organized in different layers with different subdivision results. For example, one layer represented by a group of navigable spaces for a user and another layer consisting of the coverage area of a *Wi-Fi* transmitter in the whole building. For each layer, a network can be generated and described by *State* and *Transition* instances in an *IndoorGML* document. This information can be integrated with an *IndoorLocationGML* file.

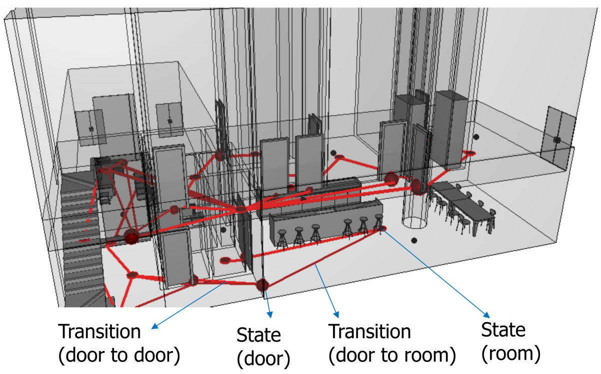

Figure 5. Example of subdivision result of a residence building.

Figure 5 shows a case that doors are regarded as space. Normally a thin door is considered as 2D surface and thus the connectivity graph of spaces is constructed for rooms. But in *IndoorGML* a thick *Door* with depth attribute is also considered as space. In the presented example, the connectivity graph is about rooms and doors. This connectivity graph can be depicted by instances of *State* and *Transition*. A *State* can represent a *Room* or a *Door*. In this way, three types of *Transition* can be identified: 'door-to-door', 'door-to-room' and 'room-to-room'. Such semantic information from the subdivision can be added to the related *IndoorLocationGML* file.

Space semantics in the *Navigation* module of *IndoorGML* can also be passed into an *IndoorLocationGML* file. For example, an instance of *State* is assigned with semantics of the related space (*e.g., TransitionSpace*). Corresponding indoor locations organized in the *IndoorLocationGML* file can be assigned the semantics according to their relationships to these *State* instances.

In a word, *IndoorGML* carries the subdivision result of buildings, which can flexibly describe different indoor networks. This information can be added to *IndoorLocationGML* and semantics of the space containing indoor locations could be clarified.

4. USE CASES

Previously the features of *IndoorGML* and *IndoorLocationGML* have been explained. It is feasible to combine these two data standards for indoor navigation applications. By integrating the two types of data model, examples of indoor navigation that are benefited by this combination could be:

Case 1: Path detail enrichment

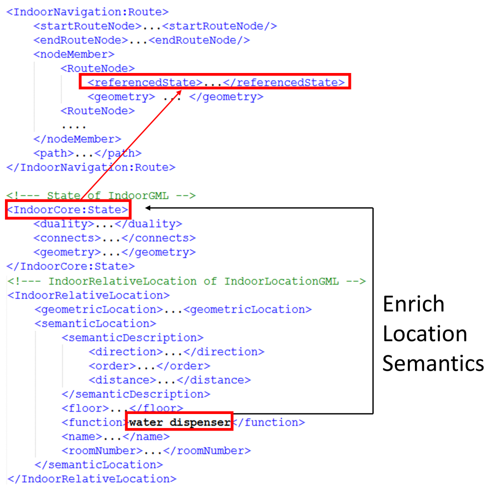

Figure 6. IndoorLocationGML provides detailed location semantics for Route instances

IndoorGML and *IndoorLocationGML* both contain path-related information. The class *Route* of *IndoorGML* maintains indoor paths. By using *IndoorLocationGML*, other characteristics of this path can be revealed. For example, each *RouteNode* of a *Route* can be enriched with nearby locations (*Wi-Fi* active points or smoke detectors) described in *IndoorRelativeLocation*. In such cases, it is easy to count the resource locations that a path involves, such as *query points, kiosks* and *water dispensers* in the path. In Figure 6 each *RouteNode* of a *Route* has related *State*. An *IndoorRelativeLocation* instance supplies this *State* with the location semantics (the function 'water dispenser'). This combination provides diverse information about a path for different users.

A path can be also conveyed by *IndoorLocationGML* if the path is represented by a sequence of locations. The path contains both the coordinates and the sequence of these locations. Semantic information of these locations are also conveyed with the class *SemanticLocation*. In addition, *IndoorGML* can supply space subdivision result for the path (see Figure 7). A *State* related to *CellSpace* follows the subdivision contained in *partialboundedBy*. This information is also supplied to the related instance of *IndoorRelativeLocation*.

In practice, the integration of separate datasets from both standards can be performed in two possible ways. The first one is to generate a unified data document according to the jointed UML data model. The other one is to develop a parser which can acquire the data of the two types of dataset. This paper discusses only the integration of the two standards on the conceptual level. The implementation of such integration is left to the future work.

Case 2: Generation of verbal directions

This contribution has been peer-reviewed. The double-blind peer-review was conducted on the basis of the full paper.
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Figure 7. IndoorGML supplies subdivision result for IndoorRelativeLocation instances

Verbal directions are used to improve user's understanding of path derived from indoor navigation (Russo et al., 2014). For a given path, verbal directions regarding guidance for users can be generated by using *IndoorGML* and *IndoorLocationGML* together. *IndoorGML* can represent indoor path in spaces as *RouteNode* and *RouteSegment*. Specifically, space of rooms and doors are represented by *RouteNode*; and a *Route* can present an abstact path in 'room-to-room', 'door-to-door' and 'room-door-room' styles. However, *RouteNode* does not include its direction and distance information to other nodes. Besides, *RouteNode* does not necessarily include all POI in the related space. For instance, in Figure 8 instances of *RouteNode* are *N1, N2, N3* and *N4*. *N1* and *N3* are specific nodes which stand for Office1 and Corridor1, respectively. *N2* and *N4* are the reference nodes of two doors. By *IndoorGML*, this *Route* of *N1-N2-N3-N4* is a 'room-door-room' path. The point of interest *POI1*, representing the location of a pillar, cannot be indicated by the class *RouteNode*.

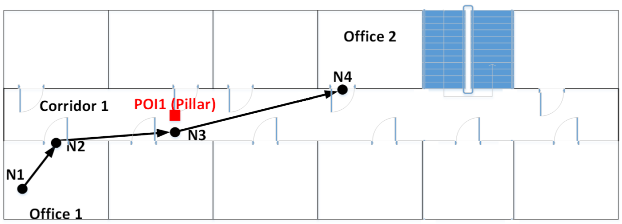

Figure 8. Example of a path in a floor

Semantics from *IndoorLocationGML* supports directional/topological and geometric details to *N1, N2, N3* and *N4*. *IndoorLocationGML* can supplement detailed location semantics and relative positions between the locations, such as *N2 is next to N1, and N2 is in the front-right of N1*. The unity of two standards can give an complete overview on the path (see Figure 8). The geometric locations of *N1, N2, N3* and *N4* are on the same floor. According to the related *IndoorLocationGML* document, *N2* is next to *N1* in 3 meters(m) and on right of it in the direction of 60 degree. Similarly the relative position of *N3* to *N2* and that of *N4* to *N3* can be decoded from the *IndoorLocationGML* document. Specially, the geometric location *POI1* can be used to assist the user to better locate her/his movement: the user can confirm the direction between *N2* and *N3* when she/he perceives *POI1*. Finally, we can obtain verbal directions for this path shown below:

'This path is on the same floor, started from office 1*, through one corridor and ended at* office 2*. Each step is assumed 70cm.'*

*'Started from the location (*N1*) and turn* front-right*. After 4 steps you can move out through the door (*N2*) and then turn* right *on the corridor.'*

'Keep this direction, after 6 steps you must see a pillar on your left*.'*

'Turn front-left*, after 10 steps you could see a door (*N4*) on the* left*. Then you arrive at office 2.'*

5. CONCLUSION

This paper presents the possibility to use two indoor-related standards for indoor applications, *i.e., IndoorGML* and *IndoorLocationGML*. We briefly present and compare the two standards. They focus on aspects of indoor modelling. *IndoorGML* focuses on indoor navigation networks and space representation of different subdivisions. While *IndoorLocationGML* concentrates on a complete representation and description of indoor locations. For indoor navigation, the two standards are complementary to each other: the subdivision information carrying by *IndoorGML* can be added to *IndoorLocationGML*, and the semantics of locations defined in *IndoorLocationGML* can be complementary to *IndoorGML*.

In this paper we propose first ideas to a conceptual integration of the two indoor standards. On the level of data model, the essential class of *IndoorLocationGML* named *IndoorLocation* associates with two *IndoorGML* classes, *i.e., CellSpace* (Core module) and *RouteNode* (Navigation Module). Based on the relationships, two types of applications are considered: 1) supply subdivision details (*e.g.,* indoor spaces) from *IndoorGML* to *IndoorLocationGML* datasets; and 2) supplement location details (*e.g.,* direction, distance and all PoI) from *IndoorLocationGML* to *IndoorGML* datasets. We also present the related use cases considering the combined use of the two standards as initiatives. The result shows it is feasible to utilize the two data standards together for path detail enrichment and verbal directions generation.

In the future, the combination of the two standards can be further explored, such as to incorporate *IndoorLocationGML* semantics for different subdivisions depicted by *IndoorGML* (*e.g.,* functional subdivision). Another work is to create a jointed format to integrate data from the two standards, which can facilitate their use for realistic applications. Based on the jointed format, automatic integration of separate data from both standards can be investigated. Tests need to be conducted to generate data files with the two standards for the same dataset. In this way, applications can be developed to load and visualize data of indoor networks and locations.

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