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SPATIAL DATABASE MODELING FOR INDOOR NAVIGATION SYSTEMS

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Abstract

For many years, cartographers are involved in designing GIS and navigation systems. Most GIS applications use the outdoor data. Increasingly, similar applications are used inside buildings. Therefore it is important to find the proper model of indoor spatial database. The development of indoor navigation systems should utilize advanced teleinformation, geoinformatics, geodetic and cartographical knowledge. The authors present the fundamental requirements for the indoor data model for navigation purposes. Presenting some of the solutions adopted in the world they emphasize that navigation applications require specific data to present the navigation routes in the right way. There is presented original solution for indoor data model created by authors on the basis of BISDM model. Its purpose is to expand the opportunities for use in indoor navigation.

Keywords: geoinformatics, cartography, building modeling; indoor navigation, GIS, BIM

1. Introduction

The process of modeling spatial databases is one of the focus areas of geoinformatics and cartography. The goal for cartographers is to create space models (in particular geographical space models) to support a correct cartographic message. For this purpose geoinformation technologies and methods are used. The development of the theory and practice of cartography is related to, among others, the development of mobile navigation systems. One of the objectives of modern navigation applications defined by many authors is to ensure seamless indoor/outdoor navigation (Virtanen et al., 2004). The methodology of designing and producing outdoor mobile navigation systems is well-known and many kinds of applications are commonly used. The most recent challenge is to develop the concept and technology of indoor navigation systems. Users need to navigate seamlessly both outdoor and indoor, without interruption. Global Navigation Satellite Systems (GNSS), which provides the outdoor position of the user, does not work inside the building due to its construction. That is why users cannot use it when going into an underground parking or shopping center.

The process of designing indoor navigation systems consists of a number of tasks, among which the most important are (Gotlib & Marciniak, 2012):

1. The choice of positioning methods and algorithms to ensure the required quality of spatial location.
2. The determination of the model of spatial reference data providing the best description of the position of an object indoors.
3. The design of a clear representation of calculated routes and turn-by-turn directions.
4. The definition of a cartographical presentation of spatial reference data.

There are attempts to use positioning technologies based on radio infrastructure (WiFi, RFID[1] tags, Bluetooth, UWB[2]), ultrasounds, vision systems, dead reckoning and other experimental approaches.

The first applications for indoor navigation have just emerged along with geoportals presenting building interiors (Google Maps, Micello). The Nokia Company has launched a solution in Ovi Maps (Merritt, 2011; Nokia, 2011) which allows obtaining high positioning accuracy using directional antennas installed inside buildings. This solution is based on the AoA (Angle of Arrival) method and it utilizes an extension of the Bluetooth 4.0[3] protocol.

Apart from solutions designed for many locations, applications for navigation in selected buildings are also developed. An example of such a solution is the "Copernicus Science Center Guide[4]" issued by Samsung Electronics in April 2012. The application aggregates general information for visitors and navigates them around the site. Positioning is performed using WiFi signal based methods combined with readouts from inertial sensors. As a result of such an approach, the application operates on every mobile phone with the Android system. (Gotlib & Marciniak, 2012)

In November 2011 Google Maps 6.0 was launched with support for indoor navigation (Volpe, 2011). This product allows the users to create a plan of the building interior on their own and to make that plan available on the Internet. This solution allows the development of maps of building interiors all over the world, similarly to 3D models of objects in Google Earth.

Spatial databases and GIS systems to support management of buildings (university campuses, hospitals) have been created for years. Usually they are not mobile systems, but allow the implementation of a number of important functions e.g. seeking a hospital room based on selected parameters, acquiring information about the availability of free space for rent or searching for offices. In recent years, attempts are being made to develop the principles of modeling the interior of buildings for the needs of GIS systems and navigation systems. Currently there are several series of tests designed to determine the rules for modeling databases for indoor navigation based on BIM models. In literature we can also find some proposals for modeling the

[1] RFID - Radio Frequency Identification
[2] UWB - Ultra WideBand, technology based on sending ultrashort pulses
[3] Nokia expects to introduce a protocol extension to the Bluetooth standard in 2013.
[4] Copernicus Science Center is an interactive science center established in 2005 in Warsaw.

transition paths inside the buildings as well as the cartographic presentation of the data and the wide use of mapping methods. They will be briefly recalled in a later section of the article.

Much of these tasks are unresolved or only partially resolved. We are entering a phase of intensified research in this area. In this article we focus on the problems of designing the spatial database for indoor navigation purposes.

In order to provide reliable navigation, an appropriate spatial database is required in the form of an indoor map with additional data.

2. General requirements for the indoor data model for navigation purposes

A key component of navigation systems are spatial databases. Their quality is fundamental to the usefulness of indoor applications. At the moment, a spatial database model for the interiors of buildings for the purpose of navigation is not yet widely available and standardized.

Before starting to create a conceptual model of data for this type of system, it is worth to analyze the similarities and differences in relation to other databases used in navigation systems such as automotive, aeronautical and marine navigation systems. In each of these applications we can extract four groups of data.

Similarly to navigation products used outside of buildings, users of indoor systems need reference spatial information, allowing easy identification of their position in relation to external objects. This is usually topographic data, presented at different levels of generalization. The second group consists of data which enables the representation of communication networks, together with data regarding restrictions of the movement. The third group is data on some important user objects with their contact details. The fourth group includes information about user traffic and other users of the system and what, for example, allows detecting hazards and obstacles while moving. The comparison of the three above-mentioned groups of data in automotive and indoor navigation systems is presented in Table 1.

Table 1. The comparison of data in automotive and indoor navigation

The type of information	**Databases for indoor and automotive systems - similarities**	**Databases for indoor and automotive systems - differences**
Topographic data and address data (spatial reference data)	Common data on the object surroundings, common data on the building outline.	Different scale of presentation, different accuracy of the data, different object categories, different attributes and relations. Much bigger importance of the third dimension of the presentation.
Communication routes (typical trajectories of the user's movement)	Models based on graph theory, linear representation of the communication route , crossings, attributes informing about the availability for certain groups of users, defining restrictions regarding movement in nodes.	Routes defined for outdoor systems are based on real road axes. Routes in indoor systems often have an arbitrary nature and are much more difficult to define.. The significant difference between indoor and car navigation is that the trajectory of a tracked person is not restricted in a similar way as the position of a car on the road.
Points of Interest and address data	Marking locations as points, combining them with address data, basic attributes: category and name Addresses represented as points.	Most of the object categories, representation of smaller objects Addresses have different meaning, lack of standardization and uniqueness.

In each type of navigation systems different specific spatial data is collected. For example, there may be data describing the equipment of the building such as office furnishings and exhibits in a museum. This data is important because of the calculation of routes and searching for facilities. It may also have a significant role in the process of visualization (Fig. 1)

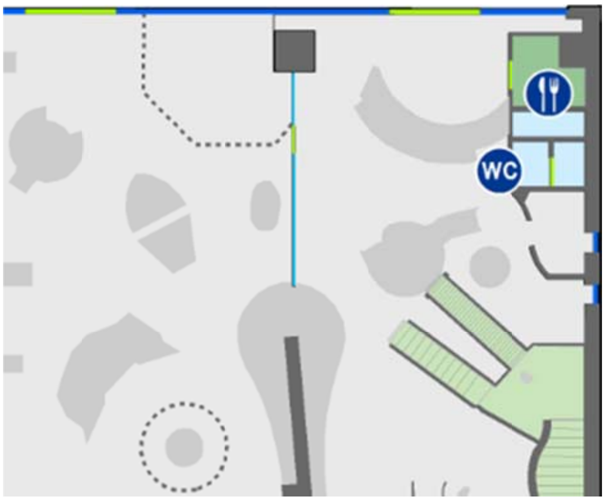

Fig. 1. The example of the presentation of furniture (elements of exposure) in an indoor navigation system.

During the design of a conceptual data model, it is important to take into account the availability of data sources. This is an extremely important factor, mainly for economic reasons. In case of indoor navigation systems there are now (and in the perspective of many years to come) primarily architectural and construction plans of buildings and BIM databases. There is no way in the deliberations so skip the principles of modeling the interior of buildings, which arise from the relevant design standards, in particular BIM standards. Although these models were not designed for the use in navigation, their characteristics significantly influence the extent of information that can be collected in navigation applications. In this context, two additional data sources should also be taken into consideration: a laser scanning measurement and the activity of the users' community. The laser scanning will be in future a very important professional geodetic method to collect 3D building data. On the other hand, it should take into account the fact that users of navigation systems will also acquire a lot of data themselves. This is indicated by the fact that we can observe intensive development in the areas of ubiquitous mapping, crowdsourcing and VGI. [5.]

3. Existing indoor spatial database models

There are many ways to describe the interior of a building in the form of digital data sets. Choice of method depends on the purpose of data use: design a building, building management or indoor navigation. Currently, these types of datasets are usually created by architects during the design phase of the building. These sets are later used during the construction of the investment or later still during the utilization of the building, as a resource needed in building management. This data is usually

[5] VGI (*Volunteered Geographic Information) - is the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals* (Goodchild, 2007).

created in accordance with the methodology of CAD. This methodology results in a set of drawings divided into layers, which are characterized by very detailed geometry, but almost no information about the attributes of the presented objects. These collections are difficult to use for spatial data management and navigation applications. That is why more and more data models are created inside buildings whose foundations are based on the methodology of GIS. In the majority of cases, they were designed mainly for the needs of building management or in order to obtain general information about the building's topography. A good example may be BISDM (Building Interior Space Data Model) developed by ESRI (ESRI, 2011), as well as models accessible in Google Maps since 2011.

One of the important features of BISDM is the possibility to easily use it in GIS technology. Feature classes are divided into the following groups:

- structure of the building (BISDM Core),
- infrastructure and equipment in the building (BISDM Assets),
- transportation network in the building (BISDM3 TransportationNetwork).

In BISDM we can find a class describing the communication routes. However, the topic is not fully resolved, because the model was not designed for use in mobile navigation applications.

In 2010, the expert group of the OGC formulated the document "Requirements and Space-Event Modeling for Indoor Navigation" (Open GIS Consortium [OGC], 2010). It contains guidelines that can become the basis for constructing database models for indoor navigation application. The general model is presented in Figure 2.

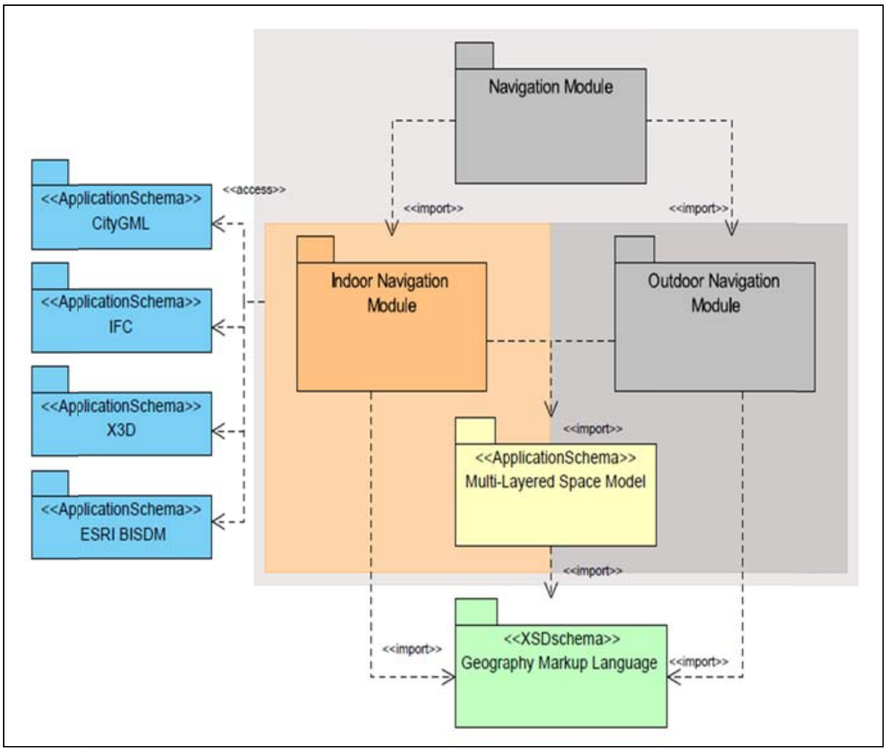

Fig. 2. UML package diagram of the framework for indoor navigation proposed by OGC.

The main assumption of this approach is:

- support for different and multiple localization methods/infrastructures
- support for different navigation contexts
- 3D topographic representation of the interior built environment complementary to existing standards like CityGML, IFC, X3D, ESRI BISDM, etc.

The first building models stemming from GIS were 2D models. It was a natural consequence of the popularity of 2D GIS. Two dimensional floor plans describing a building are easy to create, as they require the usage of well-established cartographic techniques. Existing GIS programs also offer many tools for visualization and processing of such data.

In some cases 2D-based models have limited usability. The lack of the "third dimension" in the data means that certain analyses and functions cannot be performed. This aspect is emphasized in mentioned OGC document. A good example is also the problem presented in the article (Mast & Wolter, 2013). The problem is related to generating navigation directions. The conclusions from this article show that in order to create fully useful navigation directions, one needs access to a building model based on 3D geometry. Currently available GIS models also allow creating such models.

The problem of 3D modeling appears among others in the work (Lee & Zlatanova, 2008). The authors consider this issue in the case of requirements that a data model should meet in systems aiding rescue missions in buildings. As a result, the authors present a 3D model based on 3D topological relations.

Furthermore, in the article (Isikdag et al., 2013) authors put forward the thesis that the deficiencies of current building models will be overcome thanks to using BIM[6] methodology. It was therefore suggested to fully utilize these models, at the same time defining a proposal of transforming them so as to fulfill the requirements of navigation systems. The following assumptions for transforming BIM data into an indoor navigation system database have been accepted:

1. The naming of BIM objects should be retained.
2. Certain characteristic classes of BIM should be removed, for example the "hole" class in building elements.
3. Spatial relations from BIM should be retained. This may allow determining for instance in which wall a door was placed.
4. The classes describing spatial relations should be removed from BIM. In the new model the relations between objects will be implemented in a more simple fashion.
5. The 3D geometry should be converted from the BIM model to a form compatible with ISO standard 19107.
6. Only these attributes of BIM useful for navigation systems and GIS should be used.
7. Geodetic spatial reference systems should be used. This will allow to a fitting the geometry of a building into its surroundings.

[6] BIM - Building Information Modelling - Building information modeling - an innovative new approach to building design, construction, and management introduced by Autodesk in 2002—has changed the way industry professionals worldwide think about how technology can be applied to building design, construction, and management (Autodesk, 2003)

According to the authors, the main advantages of a model meeting the above requirements are:

- a rich description of buildings. BIM provides not only information about the types of objects and infrastructure elements, but also functional properties (e.g. the way of using a room) and the condition (e.g. shut off stairs, closed doors after 6 p.m.)
- the structural elements of the building are represented in 3D geometrical form
- as the model's objects have the geometry storage format compatible with the ISO standard 19107 they may be used in GIS applications
- based on the special relations between the model's objects a connection graph can be built. It could assist navigation inside the building.

Another description of the use of BIM as a data source for navigation systems can be found in the paper (Li & He, 2008), in which the authors analyze the requirements for indoor navigation systems in a fairly comprehensive manner. The authors concluded that the systems should work in 3D, obtain data from BIM and use topological analysis. In their view, this will fulfill the needs for intelligent path finding in a ubiquitous computing environment. The authors of this work pay special attention to the technique of obtaining data that will be the basis for creating a navigation graph. Among other proposals, a conclusion stating that "future enhancement of the 3D indoor navigation includes the quick and reliable graph derivation algorithm in a complicated in-built environment, where many small rooms locate inside a big room and their inner relationships are flexible and hierarchical" appears.

The problem of defining navigation routes and their presentation of building interiors is also addressed in the work (Gotlib et al., 2012). This paper first introduced the issues of cartographical presentation of spatial data in indoor navigation systems. The research covers ensuring an appropriate map communication process from modeling spatial data (creating databases) to formulating a cartographical message for the final recipient. It is important to design a high-quality presentation of the building and navigation routes. This can be accomplished through the use of cartographic methods. The article indicates, among others, that in order to properly present a path along which the user wants to go, the application should use additional data structures which are associated with a navigation graph.

This data should represent the potential path of user traffic. The indoor data model for the navigation application should take into account the structure of the "dual graph".

Before starting the process of modeling the interior of buildings, it is also worth to analyze the rules resulting from the CityGML. CityGML is a common semantic information model for the representation of 3D urban objects that can be shared over different applications (OGC, 2007). It was designed as a multiscale model with 5 Levels of Detail (LOD). LOD 4 represents interior of buidings, so it must also be taken into account.

It's only the most important principles of modeling that has been proposed in the literature. Most of the proposed solutions are quite complex and their implementation difficult. In the case of using BIM models, there is also the problem of availability. BIM data sets were developed only for a small part of buildings in the whole world. Therefore, the proposed solutions found in the literature cannot be widely used in the near future in most cases.

4. Extended BISDM

Due to the relatively early stage of development of indoor navigation systems and high cost of acquiring 3D building models, the authors of this paper have proposed the use of a 2D data model based on the BISDM model (in the first phase of the development of an indoor application). For this purpose, it has been on one hand extended, and on the other hand simplified. The proposed solution can easily be used today in building modeling because it is a relatively simple solution. Using this model, as appropriate, enables to create:

- building models only for the needs of GIS systems for building management,
- building models only for navigation systems,
- building models designed for both applications.

The proposed approach allows scalability of the solution and ensures consistency between navigation systems and building management systems. A 3D version will also be possible in future. In order to obtain consistency with future OGC standards it was decided to use existing recommendations of the OGC as far as possible. Development of the proposed model was preceded by an analysis of the document "Requirements and Space-Event Modeling for Indoor Navigation" (OGC, 2010). It was decided to make maximum use of the recommendations arising from the provisions of this document.

It was assumed that the developed model will be the model for a typical class GIS systems. Spatial data will be stored in a database according to the vector data model, using simple geometric types, according to the ISO 19107 standard. It was assumed that the building models used in navigation applications will be created with the use of GIS technology and GIS application environment.

According to the aforementioned OGC document the model was divided into the following logical components:

- navigation layer,
- topographic layer.

The first layer should be used in the process of calculating and presenting the route to the user, while the other should be used for control, geovisualization and supporting the process of determining the user's position.

As a basis for the representation of the building topography the BISDM 3.0 model was adopted. Among the modifications of the model, the most important are:

- a change in the representation of doors, windows and other components by introducing a *FloorplanElementLine* class and *FloorplanElementArea* class,
- changing the method of room categorization in *SpaceCategory* class,
- adding classes: POI (*Point of Interest*) and *SensorPoint*,
- adding classes: *OutdoorPlanArea*, *OutdoorPlanLine*, *OutdoorPlanPoint*,
- adding a class *Furniture*.

In Figure 3, there is a part of a UML diagram of the proposed model with classes representing the topography of the building. Object classes derived from the BISDM model are marked with a darker color.

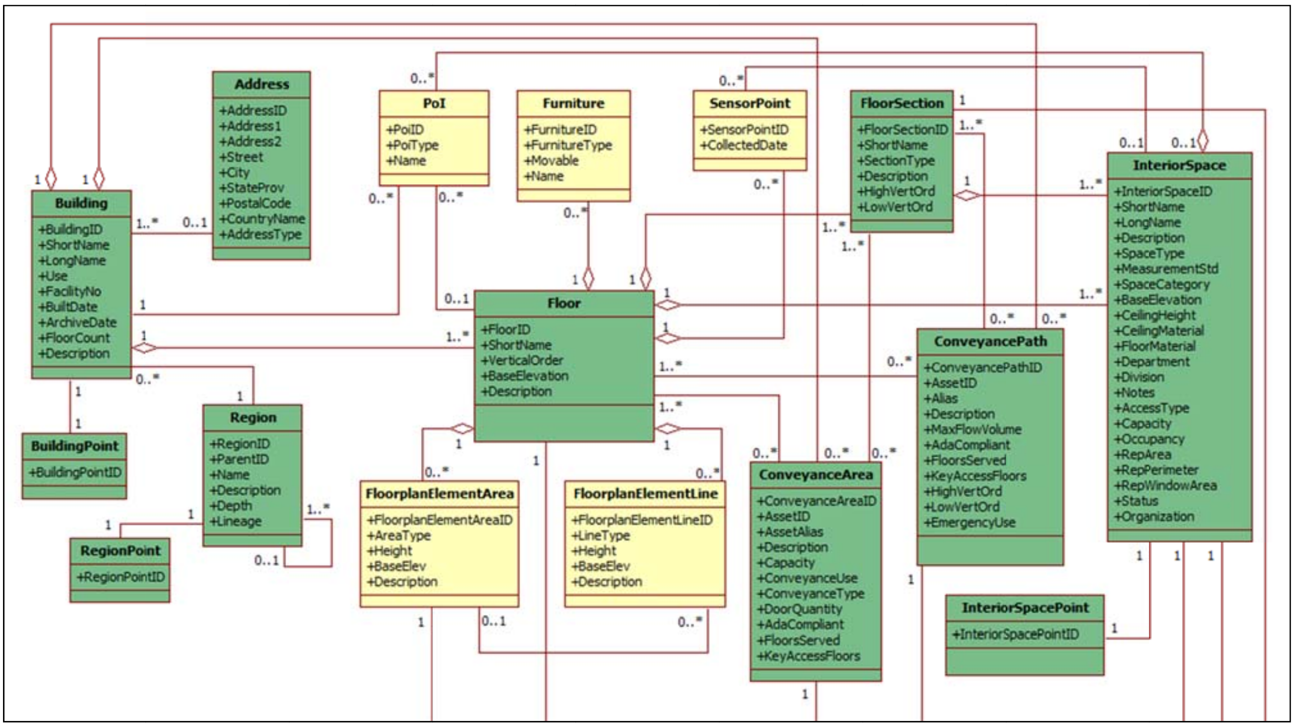

Fig. 3. Part of a UML diagram of the proposed model with classes representing the topography of the building.

While creating the conceptual model, guidelines described in (Gotlib & Marciniak, 2012) have been taken into account. That is why the navigation layer designed as an extension of the OGC model. It consists of two elements: object classes offered in the OGC document ("MultiLayerGraph") and new object classes representing a indoor communication paths like axes road ("road network") in automotive systems. The relationships between the navigation graph consistent with the OGC document and the proposed "indoor road network" are illustrated in Figure 4 in a simplified manner.

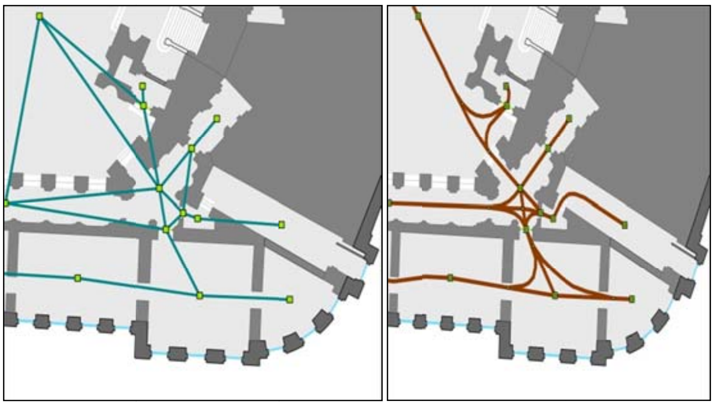

Fig. 4. The relationships between the navigation graph consistent with the OGC document and the proposed "indoor road network" (modeled as a GIS layer). Blue color - representation according to OGC, the brown - GIS representation

This concept has been modeled in UML as shown in Figure 5.

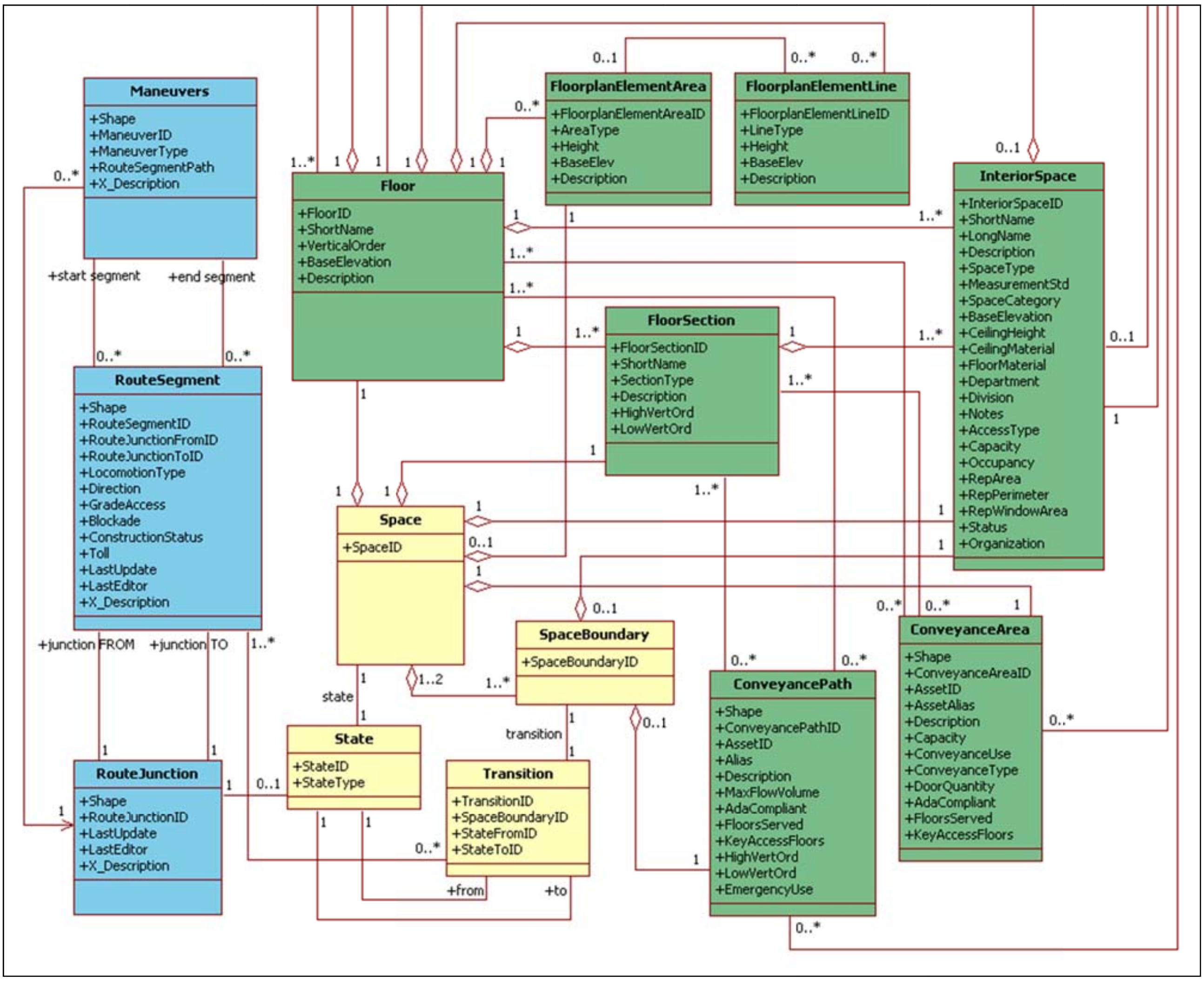

Fig. 5. The relationships between the object classes from the OGC model and the "indoor road network" object classes. Object classes derived from the BISDM model were marked with green color, those from the OGC document with yellow, and the proposed extension was marked with blue.

Among the most important classes of this model are:

- Object classes representing the topography of the building: *Floor, InteriorSpace, FloorplanElementArea, FloorplanElementLine, ConveyanceArea*,
- Object classes representing a communication network: *RouteSegment, RouteJunction, Maneuvers*,
- Object classes representing important objects and addresses: *PoI, Address*.

The *Floor* object class represents information about the floors of the building. The outline of the building at the level of the floor is collected. Objects classes: *ConveyanceArea*, *ConveyancePath*, *FloorplanElementArea*, *FloorplanElementLine*, *PoI*, *SensorPoint*, *InteriorSpace*, *FloorSection*, *Furniture* should reference this class. The *VERTICALORDER* attribute specifies the number of floors in order from lowest to highest. The *SHORTNAME* attribute allows to assign a name to every level of the building which has its own name.

The *InteriorSpace* object class represents information about all the rooms and other spaces in the building excluding stairwells and elevators, which should be described using the class *ConveyanceArea*. The geometry of the objects must be topologically consistent with the geometry of the following object classes: *FloorplanElementArea*, *FloorplanElementLine* and *Floor*.

The type of the room is defined by *SPACETYPE* attribute (e.g. Bedroom, Classroom, ComputerLab, ToiletSpace, Restroom, Corridor, Stairway, ElevatorCab, MuseumGallery, WarehouseSpace, ExhibitHall, WaitingRoom) and *SPACECATEGORY* attribute (e.g. OfficeAreas, ServicesAreas, RetailAreas, EquipmentAreas, EducationAreas, LaboratoryAreas). The *BASEELEVATION* attribute determines the height of the object relative to the base floor on which it is located. The *CEILINGHEIGHT* attribute determines the height of the ceiling relative to the floor.

The *FloorplanElementArea* object class represents structures of the building: e.g. footprints of walls, window openings, door openings. Objects belonging to this class are represented by polygons. Main attributes of the *FloorplanElementArea* object class are: *SPACEID, FLOORID, AREATYPE, HEIGHT, BASEELEV, DESCRIPTION*.

A very important attribute is *AREATYPE*. It can be assigned the values: ExteriorWall, InteriorWall, PartialHeightWall, SlopingWall, MovableWall, Door, CasedOpening, WindowFrame, WindowPane, Column, GlassWall, ChainlinkCage, Other.

The *BASEELEV* attribute specifies the height of the object relative to the floor on which it is located. The *HEIGHT* attribute allows to set the height of the object. This way the height of walls, doorways or windows can be represented. Using these attributes allows easy visualization of the data in a view 2.5D (perspective view).

The *ConveyanceArea* object class describes the areas of the building used for communication between floors. Objects that should be included in this class are listed in the dictionary attribute *CONVEYANCETYPE*.

The classes: *RouteSegment*, *RouteJunction*, *Maneuvers* form the base of a navigation layer. The relationship of the route segments to other topographic elements is modeled through the classes *State* and *Transitions*.

In the proposed model, we can still find object classes: *OutdoorPlanArea, OutdoorPlanLine, OutdoorPlanPoint* (not presented on the picture 3 and 4). It is only meaningful when a building model is created without reference to external GIS models. In this case, these object classes are used to store data regarding the topography of the area surrounding the building. This is a simplified approach for use in specific situations. It is recommended to create a full model of the building environment in a typical way for GIS.

According to the authors of this article, an essential complement to the BISDM model should be adding the class *Furniture*. It is necessary to represent the objects inside the rooms which are not part of the building structure, but are important in the process of navigation. These are items such as furniture, benches, sculptures, etc. Users of the BISDM model cannot find object classes that could fully meet these requirements. This problem is also omitted in the proposals of other authors.

A similar problem is the lack of the *PoI* class, which occurs in other databases used in navigation. This class should represent information about points of interests. Objects belonging to this class can be reference both floors or the building itself. This allows to identify PoI associated with a building, but lying on the outside of it.

Information about the type of the object is contained in the *POITYPE* attribute. PoI types of particular importance are Exhibition, Exposition, SpecificPlace, InfoBoard, Stand which may be useful in the process of navigation.

5. Cartographical presentation in indoor navigation applications

As argued in the work (Gotlib & Marciniak, 2012) spatial data in indoor navigation applications should be presented in compliance with the methodology of mobile cartographical presentation. The main concern is related to effective visualization on a small screen of a mobile device, using a wide range of map scales, and at the same time ensuring a proper contextual cartographical message.

Features of the used building model have a significant impact on the quality of its presentation. It is impossible to perform a high quality 2.5D or 3D presentation without having a data model adequate for this purpose available. Also, depending on the characteristics of a 2D model, different presentations of data can be made. When designing a spatial database for the building, a designer should consider how the information will be communicated to the user in the navigation application. An appropriate design of the model, and in particular the design of appropriate spatial and non-spatial relationships, may enable easier generalization of data. This is one of the most difficult processes, which allows to view the building at different scales and at different levels of generalization. An example is modeling the door and window openings and method of classifying spaces. Hierarchical classification facilitates their indoor cartographical presentation when we using zooming function and we have to present at the same time on a small screen entire building or single rooms (small and large scale).

In order to ensure high quality of the cartographical message, it is necessary to develop appropriate standards of geovisualization of indoor maps. Particular attention should be paid to the user's perception of interiors and adjustment of the cartographical message accordingly. The discussed methodology utilizes a series of geocompositions which consider the mobile application usage context and the type of device (Gotlib, 2011).

Cartographical presentation must also ensure integration of the indoor map with the geographic database of the building surroundings. While being inside the building, the user must have the possibility to see their position with reference to the surrounding area of the building (for example with reference to the entire commercial center with its megastores, parking areas, service facilities, access roads etc.).

Reasonable and user friendly presentation of many floors in a single building is a very difficult and untypical issue in the current cartographical experience. The process is additionally made more complicated by rooms which vertically exceed levels of particular floors, so-called entresols, internal yards, atria, staircases, connectors or terraces. This opens a variety of issues related not only to 2D, but also to 3D geovisualization. Examples of approaches to the presentation of multi-level interiors may be found in the paper „A Novel Design for Indoor Maps" (Nossum, 2011).

All aspects of the design indicated above allow us to conclude that in the near future indoor cartography will develop dynamically.

6. Final remarks

It seems that the optimum way to develop new standards is to combine efforts of architects and cartographers. Models, databases and drawings made in the process of designing and utilizing buildings should be easily used in the development of indoor navigation systems. Existing data models require some changes and adjustments in order to be effectively used for navigation.

The authors have attempted to use the BISDM model. Analyses and practical tests have shown that the use of this model for the purpose of navigation systems is relatively easy. At the same time, it is possible to obtain data from datasets developed in the standard BISDM. With this approach, it is easy to offer for building managers, the development of a typical GIS system supporting the management of a modern building with the possibility of sharing selected information of its mobile users such as customers, visitors or various types of special services: emergency services, security, technical team. Research and tests carried out at the Warsaw University of Technology (Mobile Cartography Reasearch Group, Cartography Department) have shown that the proposed model is useful in practice.

The proposed solution is not yet adjusted to full 3D modeling. Currently research on a new generation of indoor navigation applications using 3D models of buildings are conducted.

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