Context Aware Indoor Route Planning Using Semantic 3D Building Models with Cloud Computing

Aftab Ahmed Khan, Zhihang Yao and Thomas H. Kolbe

Abstract In recent years, an increasing number of route planning applications and services have been developed and were brought to the market for different specific use cases. Most of those products are based on the client-server framework that typically combines the database server with the application server for storing the relevant network model, performing the routing calculation, and sending the result back to the client. However, this client-server framework mostly restricts users from changing, modifying, or augmenting the network model with respect to their specific contextual routing requirements. This paper presents a new approach for context aware route planning through coupling of a multilevel cloud-based system architecture with the complex IndoorGML data model, which is an upcoming OGC standard for representing and exchanging semantics, geometry, and topology information of indoor 3D building models. The geometric and logical network model can be rapidly extracted from the IndoorGML data model within the framework of the Multilayered Space-Event Model (MLSEM). Unlike the classical two-tier client-server architecture, the proposed multilevel cloud-based system allows exporting and uploading the network model from a database server to the cloud services that serve as an intermediate system-level to make the exported network model modifiable over the Internet without altering the original data. All changes of the network model with respect to different specific events will be applied in real-time, and the corresponding route planning calculations can then be carried out at the client-side respectively.

Keywords Indoor route planning · CityGML · IndoorGML · Cloud computing · WebGIS

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1 Introduction

Indoor route planning has been widely investigated in Robotics, Computer Graphics, and Geographical Information Science for emergency evacuation, automation, and indoor navigation. Traditionally, most applications or services supplied for route planning are constructed by means of the client-server model that typically combines the database server with the application server for storing the relevant network model, performing the routing calculation, and sending the result back to the client. However, this client-server based approach mostly restricts users from changing, modifying, or augmenting the network model with respect to their specific contextual routing requirements. However, there is a strong demand of developing a systematic approach that allows users to customize the network model according to their particular context in order to obtain the desired route planning result without needing to alter the original data stored in the central database.

In the context of a Smart Campus project at the Technical University of Munich (TUM) a campus information system is currently being developed. This project is intended to create an integrated platform that provides benefits for managing all kinds of building information and supports for various application fields like indoor route planning. The IndoorGML data model, which allows to model and describe the geometric, topological and semantic information of the complex indoor environment, can be utilized as the information backbone stored in a central database for all indoor navigation aspects of the Smart Campus platform. Normally, the datasets stored in the database should remain unchanged to ensure stable database maintenance. However, for the individual route planning use cases the users always demand to customize the dataset to perform the routing calculations accordingly. For instance, in case of a conference on the campus, the local organizing committee may want to exclude some areas and hallways from route planning by modifying the original datasets through adding some obstacles into the network model. However, this is neither supported nor permitted by the facility management department, who maintains the central database. Furthermore, IndoorGML has a complex data structure, and it is therefore very difficult for the normal users to use and customize this data model.

In this work, we propose a specific three-tier cloud-based system architecture. Which on the one side facilitates the IndoorGML data model managed within a 3D geodatabase to represent the complex interior environment and supports to carry out complex reasoning tasks like the determination of routing plans according to different contextual requirements of different users. On the other side it provides an intuitive and simple user interface realized by a 3D webclient. Both levels are linked by a dedicated information and application layer which employs cloud computing to provide the possibility for the normal user to customize the network model of the building according to their specific needs without altering the original data. The proposed approach allows exporting and uploading simplified subset of the complex IndoorGML data model to the cloud services serving as an intermediate system-level to make the exported network model easily accessible and modifiable over the Internet and for performing context-dependent route planning. The results of the route planning calculations are visualized and can be explored in the 3D webclient in a highly intuitive and user-friendly way.

The rest of the paper is organized as follows: Section 2 discusses related work, Sect. 3 describes IndoorGML, Sect. 4 presents the system architecture to couple the IndoorGML database with a multilevel cloud-based system, Sect. 5 shows example scenarios and their implementation on TUM main building model, and Sect. 6 discusses conclusions.

2 Related Work

The notion of context plays a key role in the development of indoor navigation systems (Becker et al. 2009a, b). Contextual information defines as any information that relates and uses to enrich the knowledge about the user's state, his or her environment, and capabilities (Afyouni et al. 2014). Context changes with respect to the requirements of the specific application and the user's activities in the given environment. Context aware indoor routing which is comparatively a new area of research (for the last two decades) many projects and research works are carried out to facilitate the user for indoor route planning in various indoor applications, e.g., facility management, disaster management, etc. Some of the related work is discussed in the following.

The Cyberguide system is one of the first indoor guiding system to guide tourists through both indoor and outdoor environments (Abowd et al. 1997). The system is 2D map based and gives location information to user through displaying an arrow on a room map according to the user's location. Furthermore, the system is equipped with the information of interesting sights within the building, or pathways that the user can access and visit. The authors' main wish list to improve their system at that time was modifiable information base so the real contextual information can be collected from the user and give him response from the system in real time.

One of the early 3D indoor routing application is presented by Meijers et al. (2005). For the purpose of routing for evacuation the authors extracted the graph model of 3D building model and used Oracle Spatial 10g to store and manage geodata in the application. The application has limitations to consider real contextual situations, for example, cannot put a walking restriction on a specific room considering a specific situation. It only computes the shortest path from one place to the other or the exit areas. The application's limitation to modify graph model according to users' requirements make its usage limited to a few scenarios.

iNav an indoor navigation system is presented by Kargl et al. (2007) for the real time routing and navigation, which is based on client-server architecture. The navigation system can be used on different PDA devices and consists of many distributed web services. The system provides user with his location information and details of events occurring around him. The events are regularly updated by service providers. So, it makes the system more contextually aware. iNav has major performance issues and its restriction on the user to modify the base information according to his needs makes the system dependent on service providers, and flow of the contextual information (from service provider to user) become one sided in indoor space.

Using the similar approach of client-server architecture Inoue et al. (2008) have provided indoor mobile navigation system which has some main features those include providing the current position of the user on a 2D floor map, changing the floor map according to the user's position, and showing the routes from current location to destination. The system lacks flexibility in terms of dealing with contextual requirements of users (e.g. user cannot modify in floor map if he require to change).

Karimi and Ghafourian (2010) introduced an indoor application to consider different requirements of the users to facilitate indoor navigation. The application considers user's capabilities (checking mobility impaired or visually impaired) and provides graph of the building accordingly for the routing purpose. The application lacks flexibility, the graph model of the building which is the base information for all users cannot be modified by user according to his contextual needs.

Another 3D indoor routing application for the decision support in the emergency situations is presented by Schilling and Goetz (2010). The application utilizes a 3D building model in CityGML and uses client-server architecture. The application is implemented through three system domains; federal, regional, and local to help the clients or users in rescue operations. In case of fire eruption, it provides a local spatial map of danger zone on request of the client from the event location. The application has a major drawback that is users (rescue staff at the event location) cannot modify or create constraints on the building routes (graph models) which are affected by fire to restrict other users to navigate. A similar 3D indoor routing web application is developed by Goetz (2012) using crowdsourced (OpenStreetMap) indoor geodata. The system provides routing services for the static situations based on the pre-computed routes making system's application limited to some predefined scenarios. It also restrict users to make on-demand route or modify route considering user's contextual requirements.

Apart from above discussed research motivated indoor routing systems there are 2D visualization web-based indoor routing maps developed by commercial companies like Google Indoor Maps (GoogleIndoorMaps 2014).

From the above brief overview, it is apparent that there are several research motivated and commercial indoor navigation systems to facilitate user considering its contextual requirements. However, most of the above discussed indoor applications or navigation systems are based on 2D maps, although some of the systems are implemented on 3D building models. They operate on traditional client-server architecture which restrict end users to modify or change in 3D or 2D maps at their source according to his or her contextual requirements. Because the system always intends to ensure consistency in source geodata. Furthermore, most of the systems use only 2D visualization for the end user in contrast to the fact that 3D visualization is advantageous.

On the other hand, there is a new indoor representation model, i.e., IndoorGML which is based on Multi Layered Space-Event Model (MLSEM) (Becker et al. 2009a, b; IndoorGML 2014b). The MLSEM allows to represent different thematic decompositions of indoor space through multi space layers, e.g., sensor space, topographic space, etc. Further it provides technique to integrate different layers to utilize for indoor navigation or localization of the subject or object. As the multi-layers represent different themes of indoor space they collectively make a complex representation of a 3D building model represented in IndoorGML to understand and use for the normal user. Therefore, there is a need of an approach that should simplify, extract, and utilize the complex representation of 3D building model represented in IndoorGML for the normal user to use in different applications, e.g., context aware routing. In addition, it should enable users to modify or change the topographic space layer according to his contextual requirements without modifying the main sourced geodata, and visualize results in a 3D visualization tool.

3 IndoorGML Representing 3D Indoor Building Model

IndoorGML, a draft standard of the OGC represents and allows for exchanging of geoinformation that is required to develop and implement indoor navigation systems. It contains essential features that play a crucial role in indoor navigation. It is considered complementary to other 3D building modelling standards, e.g., CityGML and IFC in providing indoor spatial information concentrating on indoor navigation.

IndoorGML consists of two frameworks which are the Structured Space Model and the Multi-Layered Space-Event Model (IndoorGML 2014a). The Structured Space Model (SSM) explains how each space layer evolved systematically within four segments. The SSM subdivides 3D building models into four subdivided segments; primal space and dual space on the one hand, and geometry and topology on the other hand shown as in Fig. 1. The topological relationships between 3D (or 2D) spatial objects are represented in topology space. The 3D spatial objects (Cells) in primal space are transformed to nodes (OD) in dual space using the Poincare duality transformation. Similarly, the topological adjacency relationships between 3D objects which form the boundary geometry in primal space are transformed to edges (1D) in dual space. Moreover, the nodes and edges of the Node Relationship Graph (NRG) are called state and transition respectively. An adjacency graph is formed in dual space representing a specific contextual primal space, e.g., topographic or sensor space. Furthermore, based on semantic information the adjacency graph is transformed into connectivity graph. The connectivity graph forms a unique space layer that consists of nodes and edges geometries. As the indoor space can be thematically decomposed into different cellular spaces. For example, a corridor can be represented as topographic area while it is also represented as WiFi

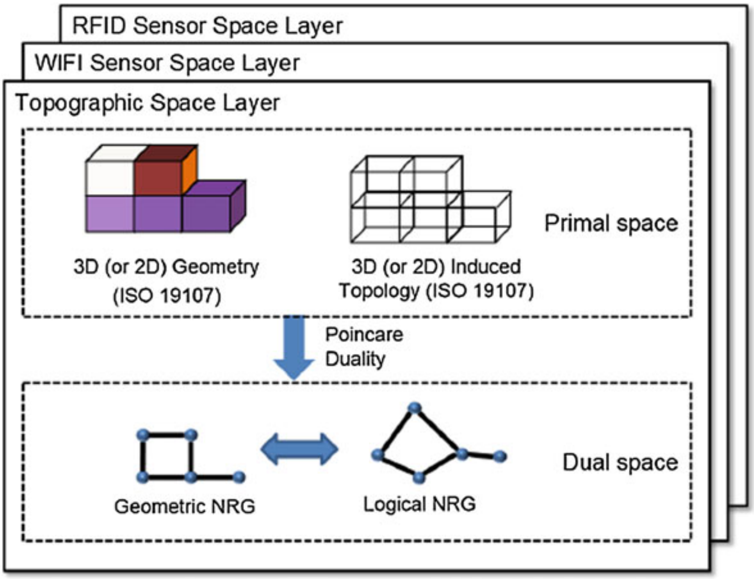

Fig. 1 Multiple space layers and structured space model within each layer (IndoorGML 2014a)

coverage area and Bluetooth sensor coverage area. Each thematic interpretation area will form a different space layer in dual space through SSM architecture. This representation or the whole framework of multiple space layers is called Multiple Space-Event Layered Model (MLSEM). Further, the MLSEM provides method for integrating multiple space layers to support indoor location and information services shown in Fig. 2 (Becker et al. 2009a, b). IndoorGML also defines key concepts those include to reference any object in external datasets such as CityGML or IFC, connection with outdoor spaces, subspacing, and modularization to define extensions of IndoorGML to cover a specific thematic field.

Furthermore, the authors (IndoorGML 2014a, b; Nagel 2014) have provided details and application examples of IndoorGML. They further concluded that IndoorGML is a very flexible and have a sound mathematical foundation to represent and manage different thematic contexts of indoor semantic 3D building models for indoor localization and information services required for indoor navigation systems. But, the representation of a 3D indoor building model using IndoorGML containing different space layers to represent different thematic contexts of building with their mutual and hierarchical relationships makes a complex model for a normal user who may be only interested in one thematic context, e.g., indoor routing. Therefore, we extract the required information for indoor route planning and, thus, simplify the data structures for the end user to use for context aware indoor routing by coupling IndoorGML with a multilevel cloud-based system.

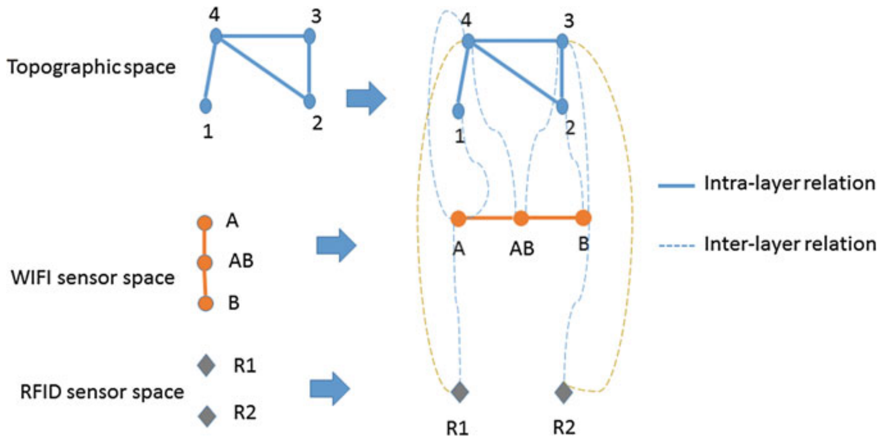

Fig. 2 Multiple space layers in dual space (IndoorGML 2014a)

4 Coupling IndoorGML with Multilevel Cloud-Based System

As we discussed in Sect. 2 most of the indoor navigation systems or applications are constructed by the client-server architecture. The client-server based approach mostly restricts clients from modifying the base information on servers according to their specific contextual routing requirements. However, there is need of developing an approach that enable users to create subsets (e.g. routing network models) of the base information (e.g. main topographic network model) and modify in those subsets according to their specific contextual needs without changing in the original base information. Furthermore, the intended approach should use of new technologies based on the Internet that should enable users or clients to have a quick access to the stored data to address their real time contextual routing requirements. In addition, the normal user or the client should be able to access his relevant subset (network model) and give him a simple view from the complex base information (main routing network model) to deal with his contextual routing requirements. Considering these requirements, a new approach is developed through which a user will be able to create subgraphs of the main topographic network graph according to his contextual needs using a 3D user interactive and user friendly webclient. The subgraphs of the main network model can be modified, updated, and uploaded with the corresponding 3D building model to the cloud service to store in a Google Spreadsheet in real time. The uploaded subgraph and the corresponding 3D building model will be accessible to other users over the Internet instantly.

In recent years, the advent of cloud computing has enable to address the problems of resource scarceness, finite energy, and low connectivity (Satyanarayanan et al. 2009) on client devices to execute many useful programs that could aid the user and response to his queries in real time. Cloud computing is a combination of applications delivered as services and the hardware and systems software in the datacenters that provide those services over the Internet (Armbrust et al. 2010). Once these datacenters provides services to the general public in a pay-as-you-go manner, it becomes a public cloud. The main advantages of cloud computing are the availability of infinite computing resources on demand, enable cloud user to start at small scale, and increase resources only when there is an increase in their demand. In our proposed system we used a cloud service to facilitate the context aware indoor routing for the users.

The generic idea of coupling the IndoorGML data model with a multilevel cloud-based system to perform context aware indoor route planning is illustrated in Fig. 3. The whole system architecture consists of three tiers; information backbone, cloud service, and 3D webclient. In the information backbone tier, the semantic and geometric model of building are stored in an IndoorGML database, which allows to store and manage different contexts of indoor environment, as well as the mutual

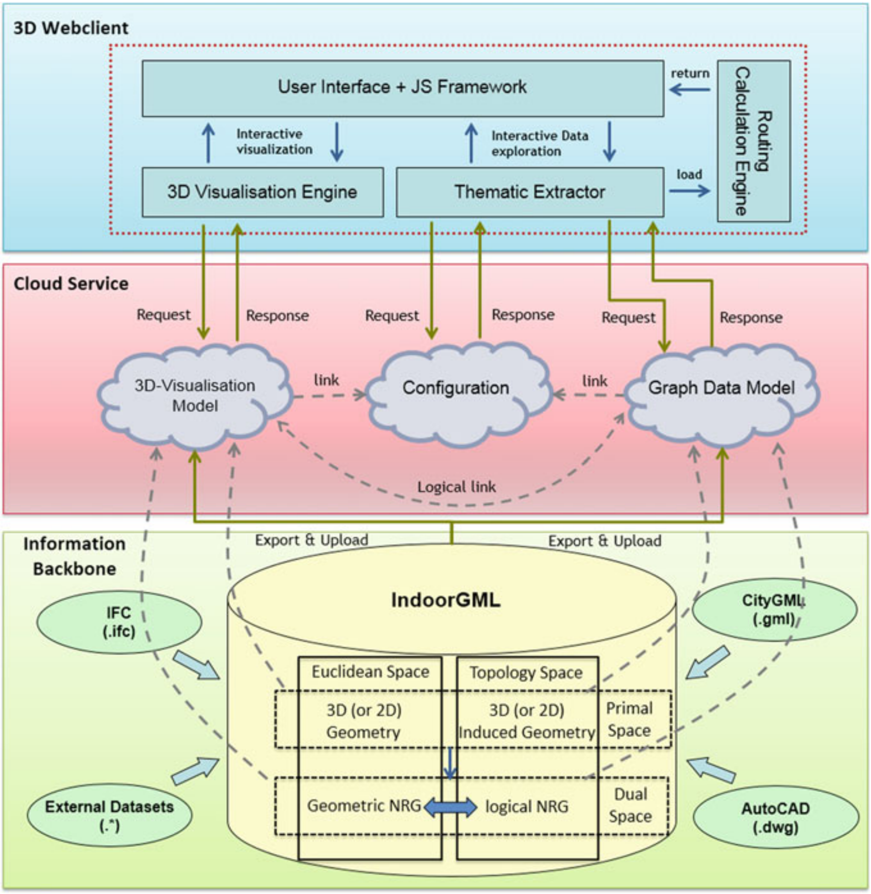

Fig. 3 Specific three-tier system architecture for user-modifiable indoor route planning application

relationships of building parts. Other 3D data model standards like IFC, DWG, and CityGML, which are well-known in GIS, Architecture Engineering, and Construction (AEC) community, can be imported into the IndoorGML database. The network model can be extracted from the topographic space in IndoorGML using Multilayered Space-Event Model (MLSEM) method, which paves the way for the integration of multiple space layers such as topographic space, sensor spaces, and logical spaces to support navigation services (Becker et al. 2009a, b).

A specific 3D webclient acts as user interface to the end-user. It is developed to perform the functions such as route planning computation, interactive 3D visualization, and exploration. The main features and working architecture of the 3D webclient related to the context aware routing are explained in the following.

Web-based and friendly user interface: The client application is web-based and therefore available from any location with Internet access. Users can view the 3D webclient over the internet using a web browser to use directly without having to install any other software locally. It is a JavaScript-based static application and can operate with any webserver like Apache without the need of an application server which reduces the administrative effort. The basic structure of the user interface is created using the ExtJS JavaScript-based web framework. The 3D webclient enables to visualize graphical representation of the 3D building models and perform spatial operations such as geocoding. Furthermore, user can control the dynamic elements of 3D building models using JavaScript commands embedded with the Google Earth Plugin and the Google Maps API. Through an interactive 3D visualization a variety of features are available to display information of the target area. For example, panning, zoom, rotation with 3D view are provided by the Google Earth Plugin with its tools that provide the basic functions for navigation in the 3D map. In addition, the 3D webclient allows to select one or more objects and display their attribute values in a table. The selected objects can be both highlighted in the 3D view, as also be hidden from the current view.

Interactive modification of thematic properties of the building model: The editing feature of the webclient allows authorized users to change the thematic properties of the building model interactively for individual objects or entire groups of the selected objects (e.g. corrections, updating or adding more information). The edited property data is automatically stored in Google Spreadsheets.

Context aware routing: By means of this cloud-based system architecture it is possible to export arbitrary subgraphs of the main routing graph of the building model which are generated based on the different contextual requirements of the user and upload these to the cloud services to make them accessible over the Internet. Besides, a 3D visualisation building model linked with the exported subgraph can also be generated and exported in a similar way.

Furthermore, more than one pair of the exported datasets (graph data model and 3D visualisation model) can be grouped and referenced using one configuration document that allows users to control the distribution of different datasets and facilitates web applications to fetch sets of distributed datasets at once for speeding up loading time. The criteria to create subgraphs from the super graph of the building depends on the specific user and his authority to modify the main graph as well as his contextual requirements. The 3D webclient provides opportunity to each user to directly create constraints or edit attributes of building elements in an interactive way to create subgraphs which can be further uploaded to the cloud service to serve other users.

Integration: By using the Google Spreadsheet web application users can add more columns or other properties to the indoor objects. In addition, arbitrary KML files published through web or cloud services can be loaded into the webclient as a separate layer. This can either be a simple raster data such as OGC Web Map Services or 2D and 3D vector data.

Queries: Thematic inquiries are frequently used by analytical methods in GIS applications. In the webclient tool the building objects can be filtered by simple conditions on one or more attributes. In the described application context aware routing, for example, search for a specific type of rooms (e.g. lecture halls) or office of a specific person. Selected objects can be highlighted graphically and their relevant thematic properties can be displayed.

Visualization of the topographic layer and the network model: The main topographic space layer from IndoorGML building model is selected and uploaded as a layer into the cloud service to make it accessible over Internet. Furthermore, the corresponding network model from IndoorGML is uploaded as another layer to the cloud service. Both the 3D building model and the corresponding network model of the building with their semantic information are accessible from the webclient to visualize and analyse.

Path computation and visualization: The computation of the route plan from one room to the other amounts to the calculation of the shortest route between the two locations is performed directly in the webclient. In the application of the context aware routing, by simply selecting an initial room and target room the route for the user can be calculated. The result of the computed route will contain the list of rooms or corridors through which the person has to walk can be highlighted. As shown in Fig. 1, a 3D visualisation engine is embedded in the 3D webclient. It is responsible for the rendering of the visualisation model. Another client component named "thematic extractor" is involved to fetch and interpret the network model of the 3D building model stored in the cloud services. The users can utilize the "routing calculation engine" that performs the route calculation at the client-side with high performance due to the local caching of the network model. The results of route planning calculations can be directly visualized in the 3D webclient in an intuitive way.

5 Application Scenarios

The work flow supported by the mentioned system architecture in Sect. 4 is illustrated in Fig. 4. Users can be typically categorised into three groups: building administrator, scenario manager, and navigating user.

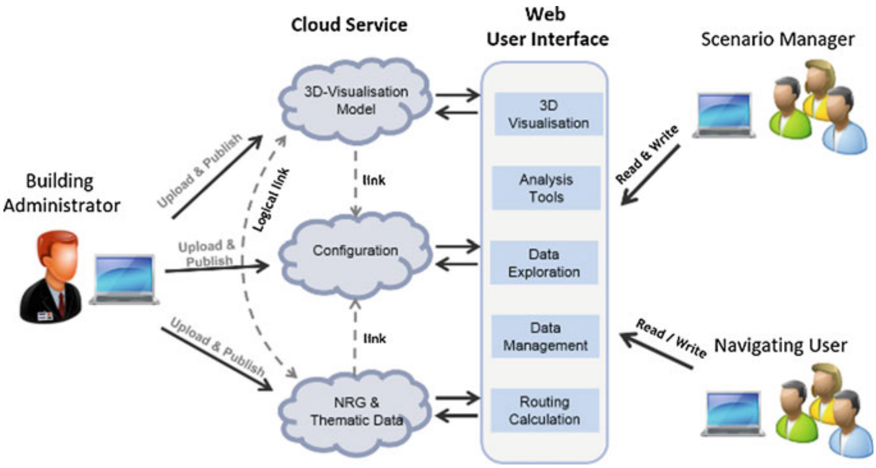

Fig. 4 Application scenarios with three user groups with different access rights to perform functions on information backbone

The building administrator can export the configuration file associated with 3D visualisation models and network models, and upload to the cloud services to make them accessible from the 3D-webclient. These outsourced network models can be added, deleted, or modified by the authorized users (e.g. scenario manager) at any time without altering the original datasets stored in the central database (Herreruela et al. 2012). This strategy allows the scenario manager to modify and customize the network model in order to adapt it for the specific use cases. The modified network model can be fetched immediately from the cloud services by the 3D webclient for the route planning calculation. The desired route planning result will be intuitively presented to the navigating users via the 3D webclient. Since the cloud services provide support for access control, privileged navigating users or user groups can also be authorized by the scenario manager or the building manager, so that they are able to modify the network model by means of the functionalities shipped with 3D webclient such as exploration, query, and aggregation. On the other hand, since more than one outsourced dataset can be grouped and referenced in a separate configuration document, it is therefore possible to handle several application scenarios within one web application session, and one web application instance can also be used by more than one user or user group in turn. Example scenarios and screen shots of the results are given in the following paragraphs.

Example scenario 1: Consider a scenario in the main building of Technical University of Munich, where a GIS conference is going to be organized between dates 10–12 July, 2014. To facilitate conference participants with accurate indoor routing according to their specific requirements the building administrator assigns the task to the scenario manager and provides him the main topographic model of the building with the network model shown in Fig. 5 (2D view of a building). The scenario manager studies the conference plan and sessions' schedule and came to

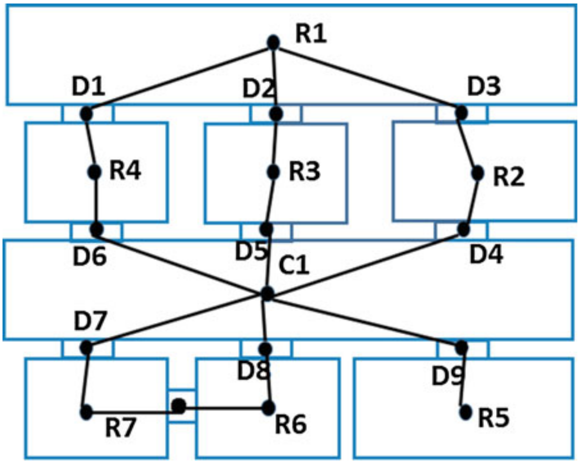

Fig. 5 2D view of the topographic model and the network model of the building provided by the building administrator

the decision that for two days room R3 and R4 must be closed to walk through by all participants because those are booked for private discussions. Therefore, he makes those rooms inaccessible (blocked) for all participants by editing the graph directly using the webclient and upload the new network model shown in Fig. 6 to the cloud service to access for participants so whenever they compute the route plan then those two rooms will be inaccessible and will not appear in their route computation by the system. Now the participants will be able to compute routes with 3D visualization of the building model considering the specific context (in this case without disturbing the private discussions in room A and B) during the conference.

Example scenario 2: In continuation of scenario 1, the conference has many sessions and each session is chaired by a session chairperson. Scenario manager provides the network model shown in Fig. 6 to the each session chairperson with

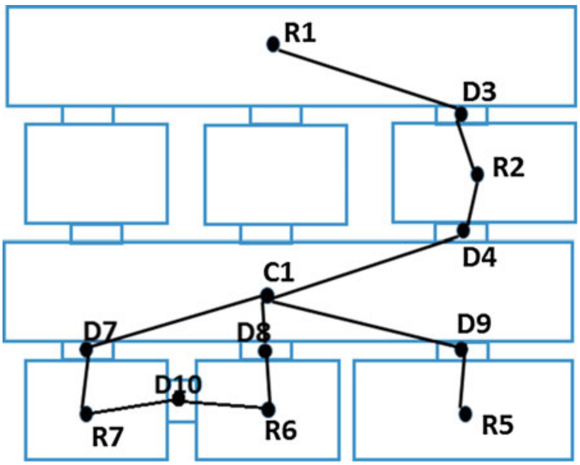

Fig. 6 2D view of the topographic model and the network model of the building after blocking rooms R3 and R4 by the scenario manager

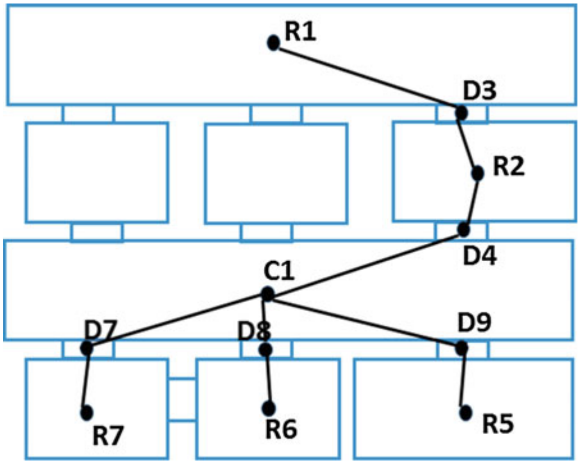

Fig. 7 2D view of the topographic model and the network model of the building after blocking door D10 by the session chair

permission to modify it according to specific requirements for the session participants. The conference has a visualization theme and its session is chaired by Mr. Yao in room R7 which has two entry doors D7 and D10. After having details of the conference sessions, and considering the requirements of the session participants he came with idea to close or block the door D10 for participants because it would be disturbing for the other session in room R6 that will be in progress during the closing and starting of his session. So participants should not walk through R6 to reach R7. Considering this visualization session's contextual requirement Mr. Yao modifies the network model of building and he blocks D10 for the participants of his session. He uploads the modified network model and the 3D visualization model of the building as shown in Fig. 7 to the cloud service so that the participants will get adapted routes without disturbing the session in R6.

The system architecture and example scenarios discussed in Sects. 4 and 5 are realized in the context of a Smart Campus project at Technical University of Munich (TUM) where a campus information system is currently being developed. This project plans to create an integrated platform that provides benefits for managing all kinds of building information. It will facilitate personnel of different departments and will support for various application fields like indoor route planning. The visualization of the 3D model of the main building of TUM and its network model in the webclient are shown in Figs. 8 and 9 respectively. From Fig. 8 it can be observed that apart from the 3D visualization of the building model the webclient provides a user friendly user interface to visualize all the attributes of each element of building which can be also edited by user. In Fig. 9 the network model or dual space of building is given where each node and edge represent room space cell and boundary cell of the building model respectively from primal space. Figure 9 further shows, webclient gives direct access to the user to interact and modify network model based on attributes of building model. In Fig. 10 the route plan (list of room numbers to go through and rooms are highlighted in yellow color)

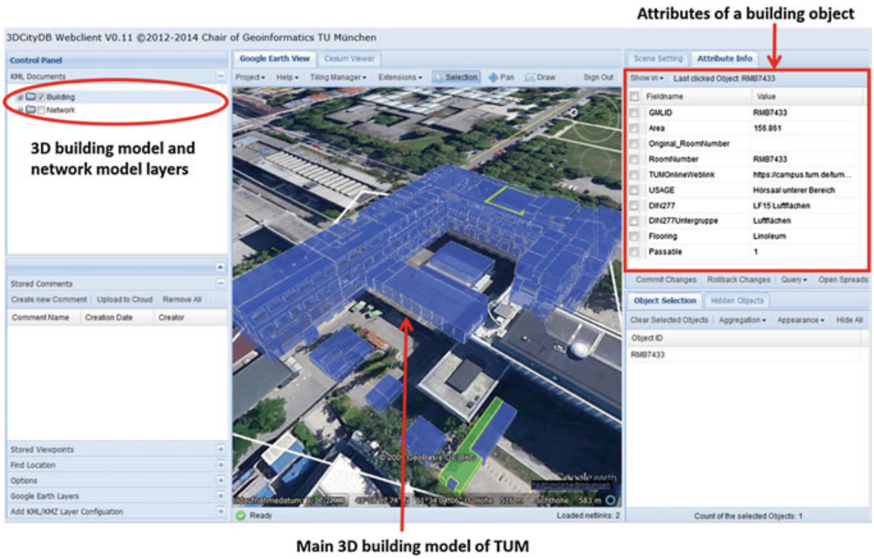

Fig. 8 Excerpt of the 3D model of the main building of TUM in the 3D webclient (only interior rooms are shown)

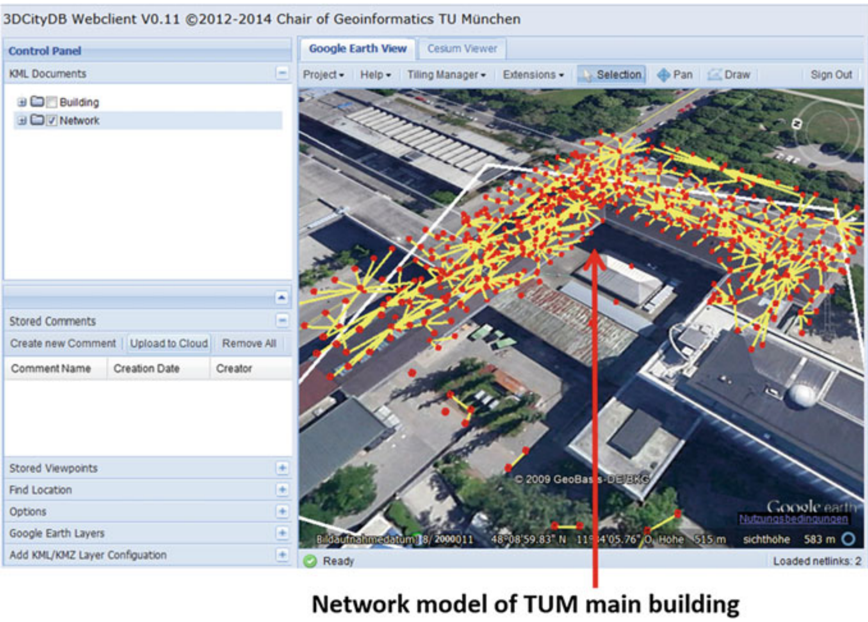

Fig. 9 Network model layer of TUM main building in webclient

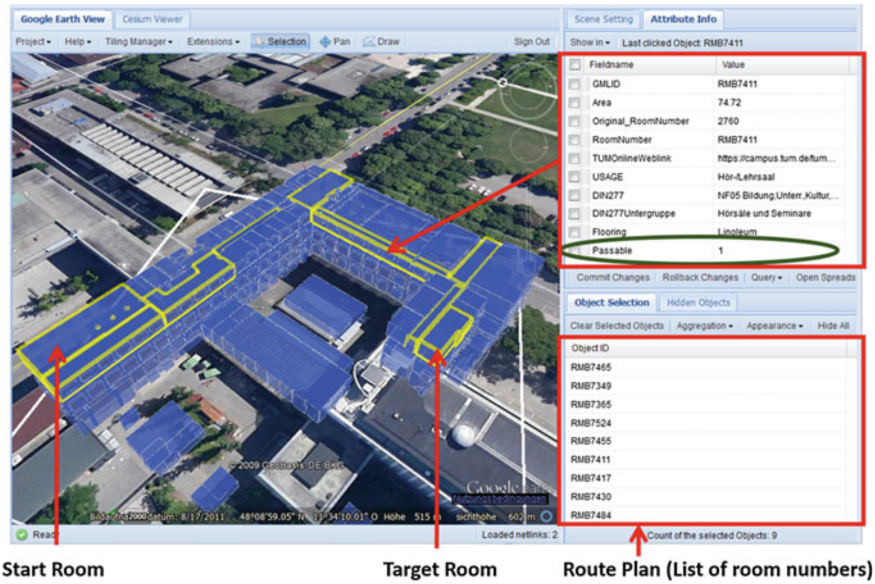

Fig. 10 Route plan with all the semantic and geometric information of the route from the start room to the target room based on the main network model provided by the building administrator

for the user is computed through Dijkstra's algorithm by selecting two rooms (start and target room) of building based on the main topographic layer (network model provided by the building administrator explained in example scenario 1 shown in Fig. 9). Figure 11 shows the computed route plan (rooms are highlighted in yellow color) for the user by selecting the same two rooms (start and target selected earlier in Fig. 10) after putting restriction on room no RMB7411 to pass through for users by scenario manager due to some construction work. It can be observed that the rout plan in Fig. 10 differs from the route plan shown in Fig. 11 due to the fact that the users were provided two different network models by building administrator and scenario manager.

Furthermore, the webclient gives opportunity to users (building administrator, scenario manager, session chairperson, or normal user) according to their accessibility and modification rights to put constraints on the building elements through different attributes, for example, based on flooring type, usage, area, etc. and generate corresponding network model to upload into cloud service to use for a user or user group. The constraints applied through this webclient on the indoor space can also be used for the subspacing according to different locomotion types (walking, driving, flying) using their specific constraints (Khan and Kolbe 2012, 2013).

Fig. 11 Route plan for the user from start to target room based on the network model provided by the scenario manager after restricting room no RMB7411 to pass through

6 Conclusions

In this paper we have presented a structured approach to combine two frameworks (multilevel cloud-based system and IndoorGML) to facilitate users for context aware indoor route planning. Based on IndoorGML, the network model along with the semantic and geometric information of the building can be completely stored in an IndoorGML database, which allows to carry out complex analyses on the one side and to generate and export arbitrary subsets of the original network model on the other side. The proposed system architecture utilizes cloud services to store the exported network model that can be dynamically customized and applied in different scenarios and disciplines for the route planning calculation, whose outcomes can be visualized and interactively explored via a specific 3D webclient. There are three groups of users (building administrator, scenario manager, and navigating user), and access rights are set accordingly to the role. Moreover, the presented approach coupling the IndoorGML data model with the specific cloud-based system, can also be investigated and applied for other applications that deal with other thematic contexts of the indoor environment based on network model, e.g. sensors' covering areas, etc. and their analysis.

The proposed system architecture also can be used to model navigation constraints generating from indoor space according to different contextual requirements, which can be directly stored in IndoorGML database by taking the input from user through webclient interface. The constraints stored in IndoorGML database given by the user through webclient will support the different types of locomotion in their navigation of the indoor space. It can support the navigation in outdoor environments provided if the system is connected with outdoor navigation model (e.g. to determine if a building is possible to navigate for the specific locomotion type from outdoor).

References

Abowd GD, Atkeson CG, Hong J, Long S, Kooper R, Pinkerton M (1997) Cyberguide: a mobile context-aware tour guide. Wirel Netw 3(5):421–433

Afyouni I, Ray C, Claramunt C (2014) Spatial models for context-aware indoor navigation systems: a survey. J Spatial Inf Sci 4:85–123

Armbrust M, Fox A et al (2010) A view of cloud computing. Commun ACM 53(4):50–58

Becker T, Nagel C, Kolbe TH (2009a) A multilayered space-event model for navigation in indoor spaces. In: Lee J, Zlatanova S (eds) 3D geo-information sciences. Lecture notes in geoinformation and cartography. Springer, Berlin, pp 61–77

Becker T, Nagel C, Kolbe T H (2009b) Supporting contexts for indoor navigation using a multilayered space model. In: 10th International conference on mobile data management: systems, services and middleware, Taipei, May 2009. IEEE, pp 680–685

Goetz M (2012) Using crowdsourced indoor geodata for the creation of a three-dimensional indoor routing web application. Future Internet 4(2):575–591

GoogleIndoorMaps (2014) Google Indoor Maps. https://www.google.com/maps/about/partners/indoormaps/. Accessed 13 June 2014

Herreruela J, Nagel C, Kolbe TH (2012) Value-added services for 3D city models using cloud computing. In: Löwner M, Wohlfahrt R, Hillen F (eds) Mobilität und umwelt, proceedings of geoInformatik, Braunschweig, March 2012. Shaker Verlag, Aachen

Hijazi I, Ehlers M (2009) Web 3D routing in and between buildings. In: Proceedings of the 4th national GIS symposium, Al-Khobar, Saudi Arabia, 4–6 May 2009

Inoue Y, Ikeda T, Yamamoto K, Yamashita T, Sashima A, Kurumatani K (2008) Usability study of indoor mobile navigation system in commercial facilities. In: Proceedings of the 2nd international workshop on ubiquitous systems evaluation (USE'08), Seoul, Korea, 21 Sept 2008

IndoorGML (2014a) Open geospatial consortium (OGC) indoorGML draft. OpenGIS specification. OGC's document no. OGC 14-005r1, Version. v.0.9.0.

IndoorGML (2014b) www.indoorgml.net. Accessed 13 June 2014

Kargl F, Geßler S, Flerlage F (2007) The iNAV indoor navigation system. In: Ichikawa H, Cho W, Satoh I, Youn H (eds) Ubiquitous computing system. Lecture notes in computer science, vol 4836. Springer, Heidelberg, p 110–117

Karimi HA, Ghafourian M (2010) Indoor routing for individuals with special needs and preferences. Trans GIS 14(3):299–329

Khan AA, Kolbe TH (2012) Constraints and their role in subspacing for the locomotion types in indoor navigation. In: Proceedings of the international conference on indoor positioning and indoor navigation (IPIN), Sydney, Nov 2012. IEEE, pp 1–12

Khan AA, Kolbe TH (2013) Subspacing based on connected opening spaces and for different locomotion types using geometric and graph based representation in multilayered space-event model (MLSEM). In: ISPRS annals of photogrammetry, remote sensing and spatial information sciences, 13(II-2/W1), pp 173–185. doi: 10.5194/isprsannals-II-2-W1-173-2013

Lee J, Zlatanova S (2008) A 3D data model and topological analyses for emergency response in urban areas. In: Zlatanova S, Li J (eds) Geospatial information technology for emergency response. Taylor & Francis Group, London, pp 143–165

Meijers M, Zlatanova S, Pfeifer N (2005) 3D Geo-information indoors: structuring for evacuation. In: Proceedings of the 1st international ISPRS/EuroSDR/DGPF-workshop on next generation 3D city models (EuroSDRBonn), Bonn, 21–22 June, p. 6

Nagel C (2014) Spatio-semantic modelling of indoor environments for indoor navigation. Ph.D. thesis. Institute of Geodesy and Geoinformation Science, Technical University Berlin, Germany (in press)

Satyanarayanan M, Bahl P, Caceres R, Davies N (2009) The case for VM-based cloudlets in mobile computing. Pervasive Comput IEEE 8(4):14–23

Schilling A, Goetz M (2010) Decision support systems using 3D OGC services and indoor routing—example scenario from the OWS-6 testbed. Paper presented at the 5th 3D geoinfo conference, Berlin, Germany

Yao Z, Sindram M, Kaden R, Kolbe TH (2014) Cloud-basierter 3D-Webclient zur kollaborativen Planung energetischer Maßnahmen am Beispiel von Berlin und London. In: Kolbe TH, Bill R, Donaubauer A (eds) Geoinformations system, proceedings of the Münchner GI-Runde, 24–25 Feb 2014, Munich, pp 40–52