A 3D Routing Service for Indoor Environments

Marina Georgati, Carsten Keßler

Department of Planning, Aalborg University Copenhagen, Denmark
marinag@plan.aau.dk, kessler@plan.aau.dk

Abstract.

Large and complex buildings with substantial numbers of visitors require fast and effective navigation support to help first-time and infrequent guests to easily find their destination and avoid stressful situations. Most existing solutions are based on in-situ localization and routing, therefore requiring expensive indoor positioning infrastructure. In contrast, the objective of this research is the development of a cheap and easily deployable indoor routing service that visitors can use to plan the route to their destination before their visit. It visualizes both the interior space of a building and its users' individual routing paths in a virtual 3D environment. The proposed solution is entirely based on open source tools and has no installation requirements for the user. Its functionality is demonstrated in a building at the Aalborg University Copenhagen campus. This kind of ex-situ 3D digital navigation promises to help users gain a better understanding of the explored environment, and to improve people's cognitive spatial maps when combined with animated stimuli and landmarks.

Keywords. 3D navigation, indoor routing, 3D modeling, animation, landmarks

1. Introduction

The increased complexity of the contemporary urban environment has led to the widespread adoption of digital navigation systems for pedestrians in outdoor environments. However, even though people spend most of their time in indoor environments of growing structural complexity and scale, the use of indoor routing services is still limited due to three main reasons: the lack

LBS 2019
15th Conference on Location Based Services
Vienna, 11–13 November 2019

Published in "Adjunct Proceedings of the 15th International Conference on Location Based Services (LBS 2019)", edited by Georg Gartner and Haosheng Huang, LBS 2019, 11–13 November 2019, Vienna, Austria.

This contribution underwent double-blind peer review based on the paper.
https://doi.org/10.34726/lbs2019.50

of navigational organization in the interior of buildings, the need of addressing vertical connectivity issues and the existence of light objects such as furniture. Furthermore, existing solutions rely on mobile devices to display step-by-step routing instructions, which in turn depend on infrastructure for precise indoor positioning that needs to be deployed throughout the whole building.

The research presented here proposes an indoor routing service that motivates the future visitor of a building to memorize the desired routing path by using visually attractive stimuli: 3D virtual navigation, animations and landmarks. Instead of revealing the complexity of the building, the study deconstructs it to its basic components (floor slabs, open and closed spaces), highlighting its landmarks (i.e., unique and easily identifiable features in the indoor environment, such as reception desks or pieces of art) in a predefined routing network to all points of interest for its guests. The objective of the presented work is the prototype development of a comprehensive, yet affordable routing service with 3D visualizations. The next steps for this research include the experimental evaluation of the effectiveness of the above-mentioned visual stimuli and a comparative study against an in-situ online routing service.

2. Related Work

Dealing with the challenges of developing indoor routing services, Diakité and Zlatanova (2018) introduce the Flexible Space Subdivision framework that describes a realistic, non-abstractive 3D indoor space with dynamic scene changes and automatic identification of suitable navigational spaces. Following a more abstract approach, Jamali et al. (2017) show an automated method for 3D modeling of indoor navigation structured in cells without gaps between them. It relies only on geometrical and topological relationships, without spatial semantics. Particularly, the 3D model is considered as primal graph, while the indoor navigation network is generated by connecting surveyed benchmarks as dual nodes through a Delaunay triangulation. In contrast, the Indoor Emergency Spatial Model (Tashakkori et al. 2015) includes 3D indoor architectural and semantic information for advanced situational awareness in emergency response cases.

3. Conceptual Design

The study proposes an indoor navigation service in a virtual 3D environment for the calculation of routing paths between two points that allows users to plan the route to their destination before their physical visit. In order to support the user in memorizing the results and navigate independently in the corresponding spaces, cues enhancing spatial memory and orientation skills are being investigated. Imageability, which defines the probability of a space of '*evoking a strong image in any given observer*' (Lynch, 1960, p.9), is a fundamental component in wayfinding processes, while 3D models, landmarks and animations are of great importance in 'absorbing' spatial information before starting the physical research of the host places. Specifically, according to Xu et al. (2013), 3D models are more powerful than a 2D map in complicated indoor spaces because of the accuracy of their description, offering contextual information and representing not only the object and its location but also horizontal and vertical mobility with adequacy and realism.

Furthermore, Fallah et al. (2013) indicate that human navigation relies on landmarks, while Sharkawi, Ujang, and Abdul-Rahman (2008) notice that landmarks are easier recognizable in 3D models due to their high visual correspondence to real-world objects and increase the navigational value of the 3D map. Bederson and Boltman (1999, p.1) support that '*animation improves users' ability to reconstruct the information space*', while technologies for 3D visualization and interactive animation offer benefits regarding management and access of large information spaces (Robertson, Mackinlay, and Card 1991). Based on these considerations, the study develops an indoor routing service with these basic cues aiming at having guests prepare their routes before their visit. Additionally, the main characteristics of the building model are examined through a requirements analysis inspired by the Topographic Space of Brown et al. (2013), aiming to a more effective and understandable space for route planning accommodation. The building model as a means that provides topographic space information should fulfill various requirements dependent on the navigation tasks, the navigation environment, the users, the modes of locomotion and the scenario (Brown et al, 2013) providing consistent and complete description of its captured components. Regarding the technical requirements, the service should be technically robust, cheap, easy and quick to develop based on existing components. From the user's perspective, it should be easy to use, providing an attractive user interface running in a web browser without any installation requirements.

4. Implementation and Preliminary Results

The prototype is based on the case study of a building at Aalborg University in Copenhagen and consists of three elements: the 3D model, the network and the web service. Since there was no 3D model of the building available, a model has been generated by using the building's blueprints and extracting the three-dimensional volumes of its slabs and closed spaces in CAD format.

The 3D model is finally converted to CityGML and 3D Cesium Tiles for the web service using the FME Data Integration Platform.

The routing network has also been generated as a CAD 3D diagram representing all open and closed spaces. It is a graph model with connected edges among the decision points for each floor. Since this graph does not support routing yet, PostgreSQL with PostGIS and pgRouting has been used for the routing. To the best of our knowledge, this is the first application of pgRouting for 3D indoor routing applications.

Even though pgRouting does not support routing in 3D, the applied methodology relies on its original concept that the data need to be 'noded' in order to create a useful topology. In other words, a node needs to be where an intersection is formed and all path segments need to be broken at the intersection, '*assuming that you can navigate from any of these segments to any other segment via that intersection*.' (pgRouting Concepts — pgRouting Manual (2.6) n.d.). Consequently, each floor and vertical mobility graph is imported into the database as separate table storing its geometrical features in two-dimensional lines and the elevation in a separate attribute field. This approach allows building the routing topology and creating the table with the decision points for the network data by the corresponding queries of the pgRouting extension. Having achieved the routing calculations for each floor separately, all the data are combined in two final tables, one for the decision points and one for the path segments of the whole building. Points that are sufficiently close together between a floor and the vertical mobility intersection are found and connected accordingly. As a result, the so far disconnected two-dimensional graphs are converted to 'noded' data with three-dimensional topology.

Cesium JS has been used for the visualization of the routing path in the 3D virtual environment since it allows simultaneous visualization of the building, the routing path and the start and ending points (Figure 1). The 3D building model is supported in the service in the 3D Cesium Tiles format, while the route path is calculated on the fly in an SQL query based on users' input. The communication between the service and the database is achieved through PHP. Moreover, it offers various easy-to-implement, performant animation techniques (Figure 1) providing a user-friendly interface, which also allows the user to choose whether to use stairs or not, as shown in Figure 2. Lastly, the web service visualizes selected landmarks both in written instructions and on the 3D map for memory and vision initiations and guides the user through them, suggesting the easier recognition of the spaces.

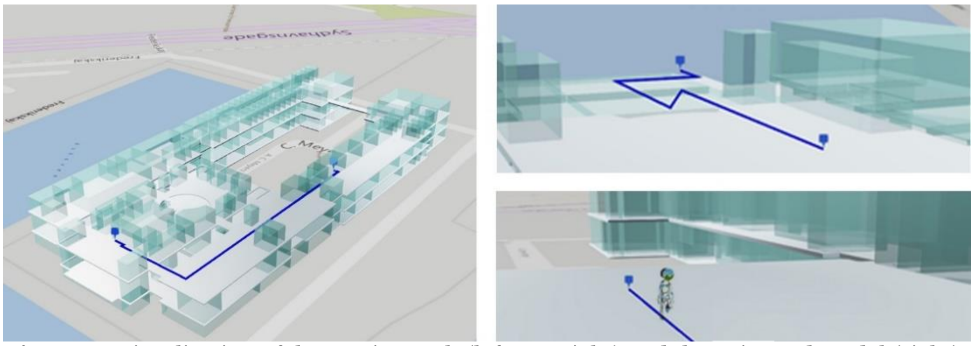

Figure 1. Visualization of the routing path (left, top right) and the animated model (right)

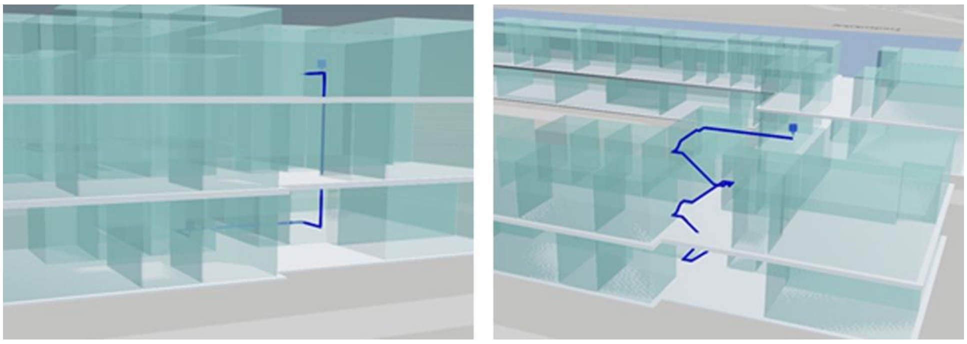

Figure 2. Routing between the same points using the elevator (left) and the stairs (right).

5. Conclusions and Future Work

This study suggests the development of more flexible and easily deployable indoor routing services that provide a tool for unfamiliar visitors in order to reduce the insecurity of navigating in complex indoor spaces. The research examines potential cues that affect spatial perception and orientation and attempts their implementation in the development of a routing web service with promising results for the preparation of the future visitors of complicated buildings. Based on the literature review, 3D digital navigation, animated stimuli and landmarks improve the initial perception of the host spaces, while their advantages in the preparation of the visitors and their performances in wayfinding will be explored in future work. The proposed service can easily be deployed based on floor plans or existing 3D CAD models.

Future work will focus on user and field experiments in the university campus to evaluate its performance against in-situ solutions, not only regarding the navigation performance, but also concerning the users' understanding of the building. Considering future development of the service, support for mobile devices and the inclusion of semantic information from the 3D model, such as conditionally accessible spaces or opening hours of specific rooms, are currently under consideration.

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