Creating a 3D Campus Routing Information System with ArcGIS Indoors

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Abstract: Humans spend an increasing amount of time indoors. While it is relatively easy to find the best route between buildings, it is more difficult to find the best route within a building. This is a particular problem for large, complex buildings with a high fluctuation of visitors like in university buildings. In this contribution, we show how an interactive web-based 3D campus routing and information system (CRIS) can be designed using ArcGIS Indoors and the ArcGIS platform. From a scientific point of view, we focus on the question how this system needs to be designed in order to facilitate effective and efficient indoor routing. The most important design elements of the CRIS were identified by conducting a user study with experts in Cartography. This study showed that the system can help users without prior knowledge in solving routing tasks.

1 Introduction and problem statement

The amount of time that humans spend in indoor spaces is significant. A series of studies carried out on different continents at different times indicates that the average person spends approximately 90% of their time in indoor environments (home, work, and other indoor spaces) (JENKINS et al. 1992; BRASCHE & BISCHOF 2005; SCHWEIZER et al. 2006). In the last decade, indoor navigation began to become a hot topic for research (FALLAH et al. 2013; CHO & CHOI 2015, DUDAS; GHAFOURIAN & KARIMI 2009). Furthermore, according to CHO & CHOI (2015) these days at least 170 companies work on topics like indoor location, indoor maps, building tracking and indoor navigation.

Humans are familiar to navigate outdoors and can use a wide variety of devices to orientate themselves (e.g. maps, navigation systems, street signs etc.). However, navigation within building premises is not an easy task to complete, especially due to the lack of familiarity with the premises, inadequate indoor maps and missing signage. Therefore, users often end up getting lost. According to CARLSON et al. (2010) this happens due to three main factors: (1) the spatial structure of the buildings, (2) the cognitive maps that users construct while navigating, and (3) the strategies and spatial abilities of the users.

Finding the way around and inside university campuses is a particular challenge, due to the special spatial structures. University campuses often consist of several buildings with various connection routes, entrance points, floor levels, dimensions, confusing numbering and naming systems, limited lines of sight, lack of local cues, missing signage, and a lack of well-designed and user-friendly indoor maps. These factors impair the indoor navigation process of various user groups on and between campuses. Moreover, university campuses deal with a high fluctuation of various user

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groups such as students (current and new students), staff members, and visitors. The process of indoor navigation in university buildings is particularly difficult for first-time students and visitors, who are not familiar with the architectural structure of the building.
To tackle these problems, we implemented a web-based 3D Campus Routing Information System that is designed to support users in finding their way on university campuses based on ArcGIS Indoors. A campus routing information system can be defined as a system designed and build to help various user groups to navigate in complex indoor spaces, such as university campuses, airports, shopping malls, etc. While this paper focuses on university campuses, the methodology can be transferred to several other campuses including shopping malls, airports, etc. The several steps for creating and evaluating the campus routing system will be discussed in the remainder of this article.

2 Creation of a 3D Campus Routing Information System

Building university Campus Routing Information Systems (CRIS) requires different steps to transform the raw data (e.g. building data CAD files) into an effective and efficient campus routing application with the help of different software, tools, and methods. These steps can be categorized in four main groups: (1) data pre-processing, (2) data processing, (3) web application, and (4) campus routing evaluation, as shown in Figure 1 below.

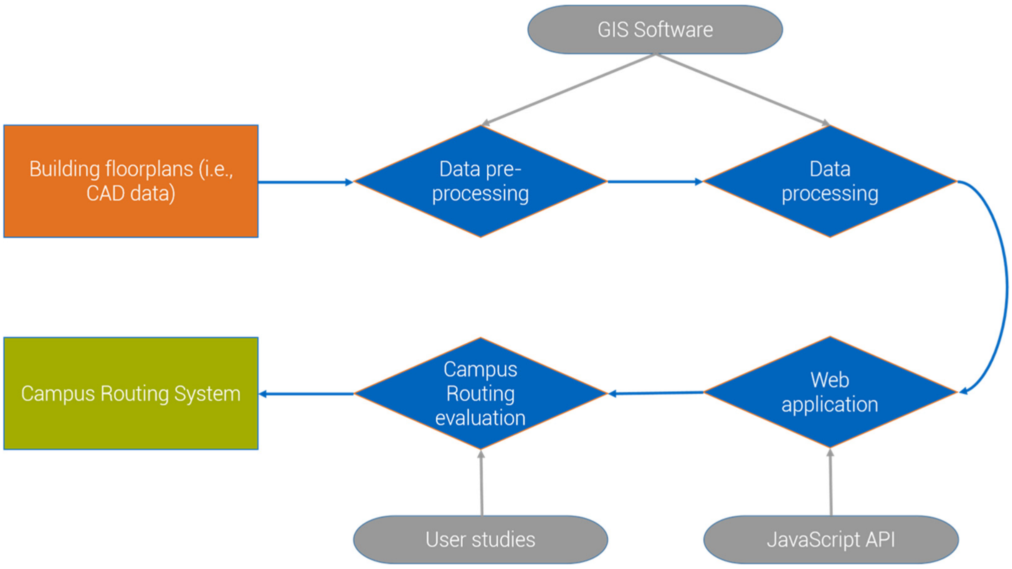

Fig. 1: Steps to design a Campus Routing Information System (CRIS)

For the implementation of our 3D CRIS, we chose Esri's ArcGIS platform. This platform solves the tasks of data pre-processing, processing and publishing very efficiently, because it consists of several components (ArcMap, ArcGIS Pro, ArcGIS Online, ArcGIS Server, ArcGIS API for JavaScript, Survey123) that can be seamlessly integrated with each other: CAD data can be transferred to GIS data with built-in tasks for ArcGIS Pro, spatial data from Desktop GIS (ArcMap and ArcGIS Pro) can be uploaded and hosted as web services with REST endpoint in ArcGIS Online, and these REST endpoints can be used in several web mapping applications, for instance with the ArcGIS API for JavaScript. The application itself can be evaluated with Survey123 for ArcGIS. Table 1 represents the different steps of our workflow, including the concrete process and the software component that was used.

Tab 1: Workflow, processes and software components necessary to create the CRIS

Workflow	Process	Software
Data pre-processing	Generalization and inspection of CAD files	ArcGIS Desktop 10.6
	Generating new CAD files	
	Projection	ArcGIS Pro
Data processing	Create and publish campus basemap	ArcGIS Pro and ArcGIS Online
	Create building interiors	ArcGIS Pro: ArcGIS Indoors and ArcGIS Server
	Create campus scene	
	Create and publish campus network	
	Publish campus scene and locator layers	ArcGIS Online
Web application	Setting up and configuring the 3D campus application	ArcGIS API for JavaScript 4.4
User studies	First evaluation: design and visualization	Survey123 for ArcGIS
	Second evaluation: usability and utility	

A similar approach for designing a CRIS was taken by WILKENING et al. (2018) for a campus routing system at the University of Applied Sciences in Würzburg[3]. However, the CRIS for Würzburg was built from scratch, without making any use of templates. For the scope of this contribution, we used ArcGIS Indoors, which is a novel indoor mapping product provided by Esri[4]. ArcGIS Indoors is a complete mapping system for assembling, managing and sharing building and campus information. It is used for location discovery and wayfinding, asset management, operational data analysis, and crowdsource reporting to keep the indoor environment functional. It constitutes a “one stop-shop” application to complete all the necessary steps to generate a 3D CRIS.

At the time of our study, a beta version of ArcGIS Indoors was available, which consisted of two major parts: (1) an ArcGIS Pro project including built-in tasks for all the necessary steps to complete the data processing steps, and (2) a web application folder, which contains a set of folders used to create a web application template.

ArcGIS Indoors covers the entire workflow for adding floorplan information to the ArcGIS platform. Once the indoor CAD data are converted to GIS data in the ArcGIS platform, they can be styled for 2D and 3D maps and scenes, published as web services, and consumed in a wide range of applications. ArcGIS Indoors’ web application folder is based on the ArcGIS API for JavaScript 4.4, which is used for the map and interface visualization process and interaction, and contains several HTML, CSS and JavaScript files.

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3 https://gis.fhws.de/campus/campus_roeri_3D.html

4 https://www.esri.com/en-us/landing-page/product/2018/arcgis-indoors

2.1 Case study: The Technical University of Munich (TUM) Campus

Our CRIS was implemented as a Master thesis project at the Technical University of Munich (TUM). While the TUM facilities are located at several sites in the Munich area, we focus on the main building of the Munich downtown campus at Arcisstraße as a case study for the implementation of the Campus Routing Information System.

This campus represents an ideal example where the indoor navigation process is not an easy task to handle, due to several reasons: presence of several buildings, many entrance points, different numbering and naming systems for each individual building, lack of signage, continuous construction sites, several connection routes in several floor levels, connections between the buildings, mezzanine floor levels, restricted access to several points, etc.

TUM provides different means to facilitate the process of indoor navigation: (1) floorplans at the entrance of each building, and (2) a web application service "Roomfinder"[5]. However, neither of these options solve the indoor navigation problem to a satisfying degree, as they do not provide room information, interactivity, 3D representations or options for route planning and communication.

LORENZ et al. (2013) state that existing indoor navigation systems make use of building blueprints to represent interior spaces, but they do not fulfill cartographic requirements for map design and visualization techniques. Moreover, WINTER et al. (2017) state that floorplan maps are notorious for their difficult reading, require advanced mental rotation and orientation skills. These factors impair efficient route finding also within the TUM campus to many users. Therefore, it is a crucial task to develop a more suitable application for facilitating the indoor navigation process within the TUM main campus.

3 Implementation steps: From CAD data to CRIS

In this section, we describe the workflow that we used to implement an interactive 3D web application with routing functionality based on CAD files as input data.

3.1 Data pre-processing

ZLATANOVA et al. (2013) state that the software tools used for indoor modeling are largely generic CAD or computer graphics tools. In addition, GOTLIB & MARCINIAK (2012) mention that the conventional way of representing indoor spaces cannot be used in indoor navigation systems due to the high level of detail, which will result in a cognitive load to the users. Therefore, to avoid confusion coming from the highly detailed CAD files, a pre-processing step is highly required to create a CRIS.

The CAD files for the TUM main campus were provided by the Chair of Cartography at TUM. These files are in DWG file format, which is a proprietary binary file format for storing two- and three-dimensional CAD data. Before converting these files to a GIS file format, a prior inspection should be performed to check the validity of CAD data.

[5] https://portal.mytum.de/campus/roomfinder

Our pre-processing considered the following aspects of the CAD files:

- *Generalization*, to identify if the CAD files depict relevant information for facilitating users' indoor navigation process.
- *Categorization of floorplan lines* based on their type (wall, door, window, stair, etc.), and applying the same naming scheme across the building (i.e., if the interior wall is labeled as "interior_wall" in one floor, it should have the same name in all the floors).
- *Categorization of interior spaces* based on their type (lecture hall, seminar rooms, office, hallway, etc.), with the help of annotations. Annotations enhance the CAD files with textual information related to the space function and identification number.
- *Projection* of CAD files to a real-world coordinate system, to align the input data to the right position in the map.

The data pre-processing constitutes a very important step, as it will provide the basis for all the following steps. In order to create an effective and efficient CRIS, a lot of manual work might be needed, whose benefits will be evident in the later steps.

3.2 Data processing with ArcGIS Indoors

Data processing makes use of the generated CAD files to create a customizable Indoor GIS and a point-to-point routing network that connects all the indoor spaces into a single network. An Indoor GIS does not only contain basemaps for visualization purposes, but also attributive data for the features such as buildings, floors, floorplan lines (wall, stairs, windows, etc), and indoor spaces (numbers, persons, room categories etc).

The data processing workflow includes the following steps: (1) creating building interiors, (2) visualizing and designing a campus scene, (3) creating a campus network, and (4) creating the web application. These steps are described in detail below.

3.2.1 Creating building interiors (CAD to GIS)

KRISP et al. (2014) point out that the functions of an indoor navigation system based on CAD file format are very limited, as indoor knowledge also includes topological relationships between indoor objects, which is not easy to identify. Indoor knowledge includes topological relationships between indoor objects. Converting CAD files to a GIS file format solves this issue. Therefore, this step constitutes the starting point in creating an Indoor GIS.

ArcGIS Indoors offers the possibility to add, view and manipulate CAD files. In addition, the building attributes stored in the CAD files are automatically converted into an Indoor GIS, using a configurable Excel file that is available in the ArcGIS Indoors download folder. This Excel file contains building properties information, CAD layer mapping and file information, which can be edited and modified.

The result of this CAD-GIS conversion step is an interactive 3D scene populated with building floorplan lines, interior spaces, floor and building footprint (see Figure 2). These features constitute the basis for our Indoor GIS and will be used further to visualize and design the campus scene to create a cartographically appealing CRIS.

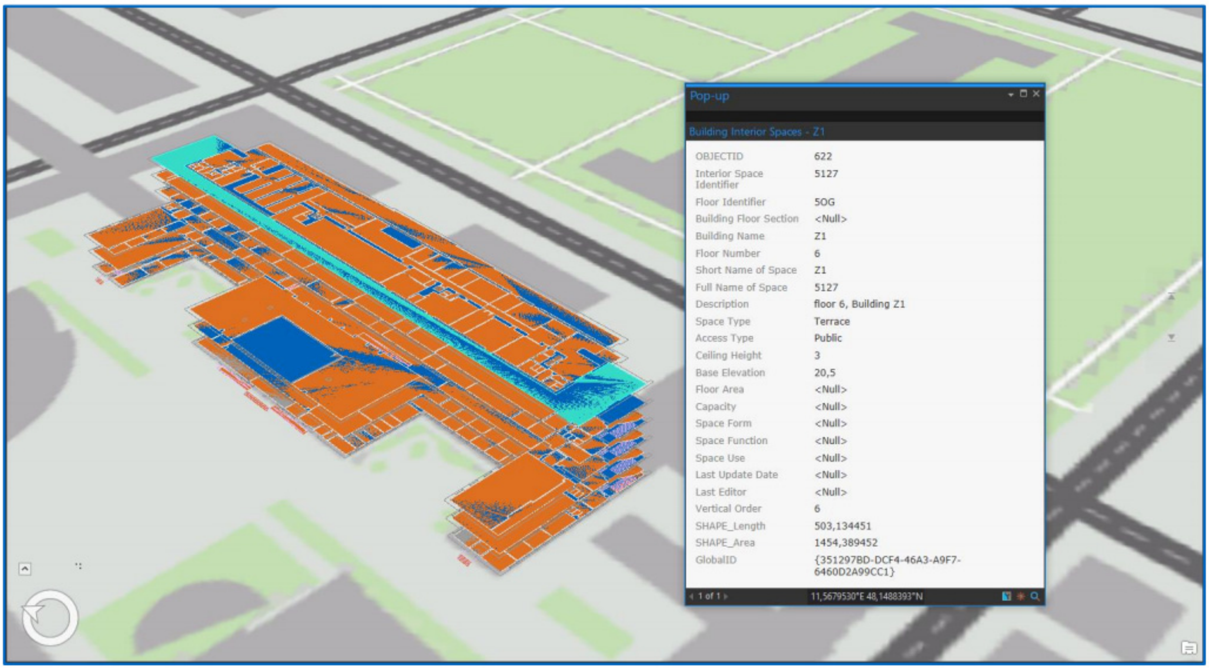

Fig. 2: The result of the CAD to GIS tool

3.2.2 Visualizing and designing a campus scene

The Indoor GIS layers can easily be styled and designed following cartographic design principles and allow a 3D visualization for a more realistic perspective, based on their enabled Z-values. This step was used to symbolize interior lines and spaces according to their type attributes and intended usage, as well as to symbolize the building façade.

The process of symbolizing interior lines was used to select non-traversable wall lines that are used to create the indoor network. Interior lines (walls and doors) are extruded to one-meter height to create partial-height lines, which are adequate to see the floorplan layout in 3D and not obscure the indoor route. The symbolization process of interior spaces was used to classify these spaces based on their intended usage (i.e., office, lecture halls, library, toilets, etc.). To symbolize these spaces, we applied a color-coded scheme. Furthermore, we used interior space polygons to generate interior space points (locator layers), which are used for network generation as “address” attribute for locating and routing between the interior spaces in the TUM CRIS. The designed campus scene and the locator layers were published as web services with REST endpoint in the in the cloud-based portal ArcGIS Online. These shared services formed the basis for the web application (see 3.2.4).

3.2.3 Campus network

Creating a campus network constitutes the most important step of the campus routing information system, as it enables a point-to-point routing in the campus routing web app. The campus network is based on the shortest-route algorithm. This algorithm will create a lattice-based (fish-net) network that covers every walk-able area of the building (see Figure 3).

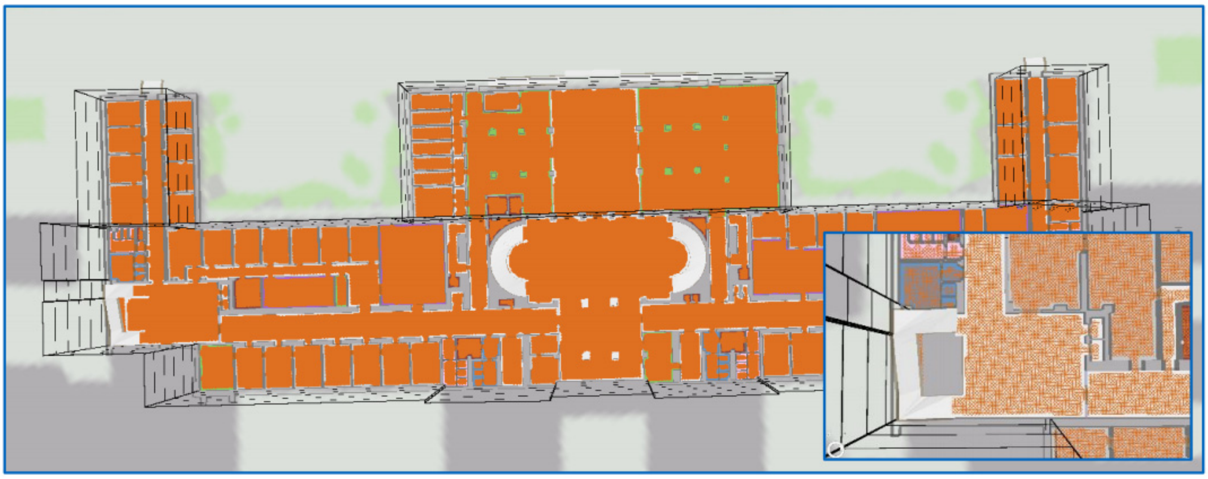

Fig. 3: Lattice-based network (detailed view in inset map on lower right corner)

The route is computed based on a more realistic approach of human walking behavior in open spaces (walking diagonally instead of walking parallel to the walls). In addition to creating an indoor campus network, ArcGIS Indoors offers the possibility to create and connect outdoor pathways around buildings in case the campus consists of several buildings. The developed CRIS for the TUM does not yet offer the possibility of localization to the users. Therefore, the users need to rely on visualized spatial structures such as doors, walls, windows, stairs, stair handlers, etc. to identify their position and to navigate within the TUM building. As networks cannot be shared as services to ArcGIS Online yet, we had to use our ArcGIS Server site to share the network as a web service. Thus, the network could be used within the web application as the routing service for the CRIS.

3.2.4 Web application

As described above, the ArcGIS Indoors ZIP archive contains a web application template based on the ArcGIS API for JavaScript. By default, the web application displayed the Esri Campus in Redlands, California. In order to display the TUM Campus data and the web services we created in the previous steps, we had to modify the "config.js" file with the URL of the REST endpoint and the ArcGIS Online portal IDs of the published services (campus scene, locator layers, and campus network). The JavaScript file is highly customizable and allows several changes on design and parameters.

The main view of the TUM CRIS is composed of a campus web scene in 3D view and various functionalities like search panel, information panel and navigation buttons (see Figure 4).

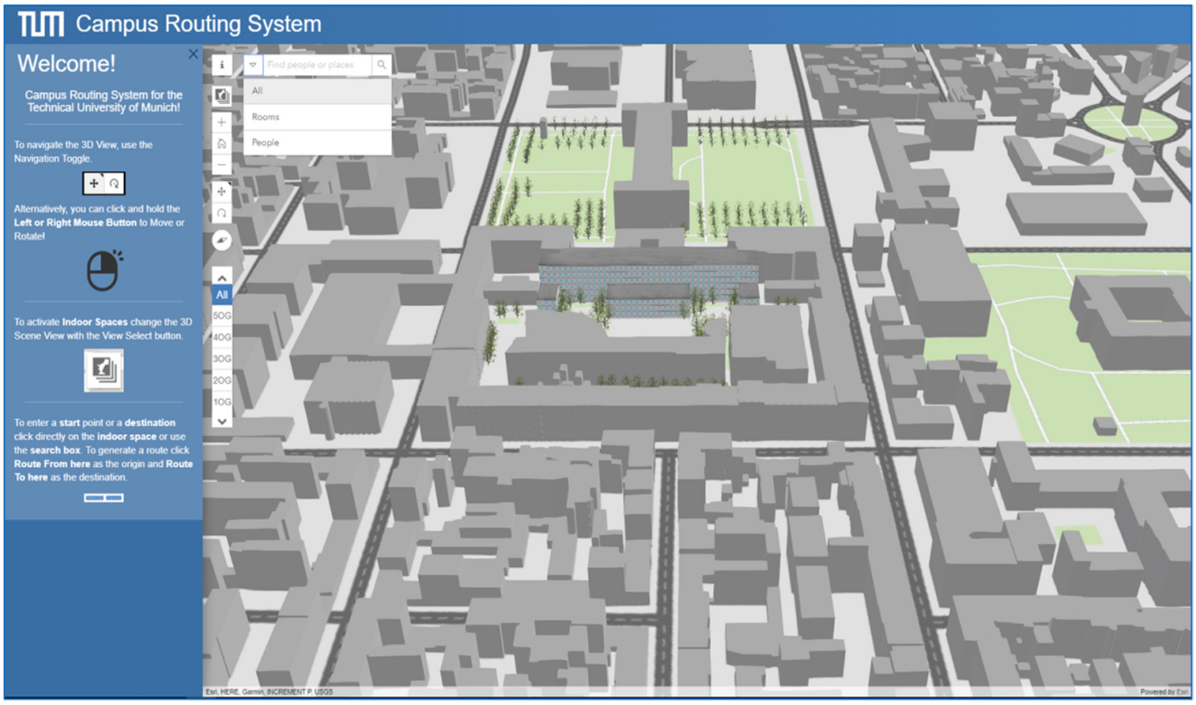

Fig. 4: The main view of the TUM CRIS upon launching the web application

These functionalities are designed to provide information and help users to interact with the system, and presented in the form of toggle buttons. Each of these buttons contains information upon hover. These functionalities are provided as part of the web application template.

Figure 5 demonstrates an example of the route communicated to the user via the TUM CRIS. The dark-yellow 3D polyline displays the default route visualization that follows the stairs. An office on the ground floor serves as the starting point of the route in the case study, while the destination point is an office on the 5th floor. In addition, the side panel provides users with the time and distance to reach the destination. If users toggle the "*Need an elevator*?" button, the route between the two spaces is re-calculated and uses the closest elevator to generate a route to the destination. This route is also represented in 3D and is visualized using a blue color.

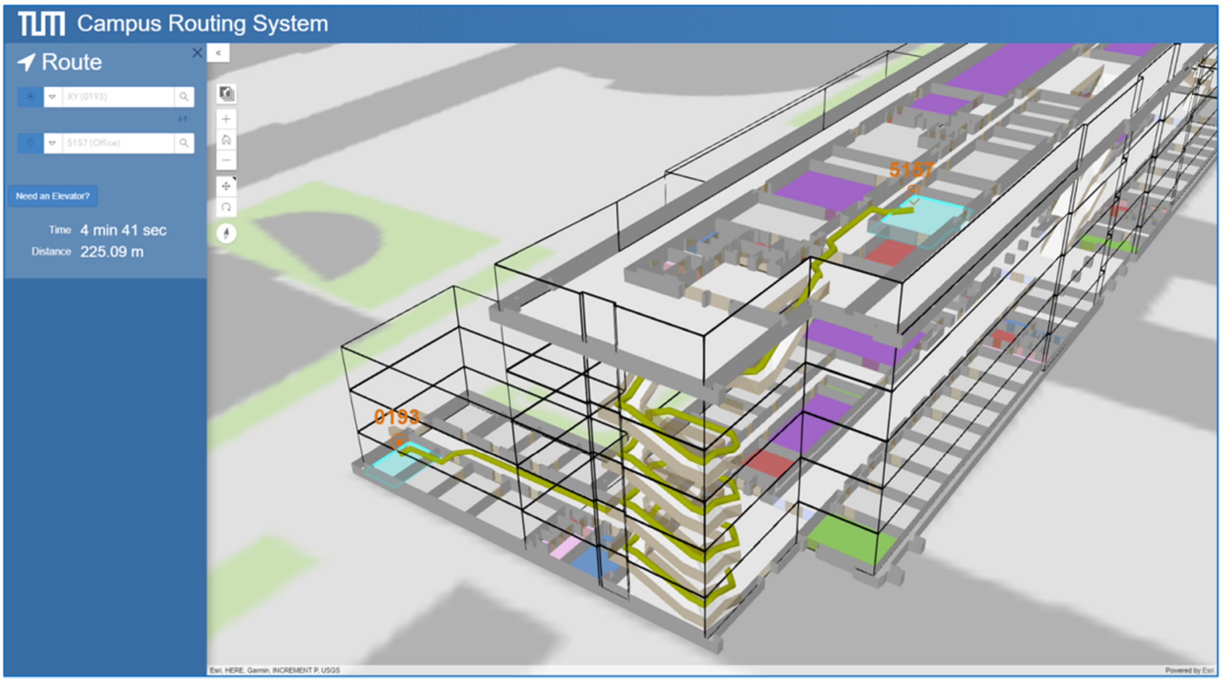

Fig. 5: Visualizing the default route in the web application

4 Evaluation

After implementing our CRIS for TUM, we conducted two user studies. The first study focused on map design and visualization, while the scope of the second study was the usability and the utility of the CRIS. The methodologies adopted for these studies varied from quantitative to qualitative, as well as mixed methods adopted for this purpose.

4.1 Map design and visualization

The first user study aimed to identify to which extent the applied designed principles for the modeling of indoor spaces were appropriate, and how our CRIS can be further improved. Based on the methods proposed by ROTH et al. (2017), the first evaluation is based on the expert-based method. Expert-based methods solicit input and feedback about an interactive map from consultants with training and experience in map and interface design and evaluation. It is important that an expert is a person from outside the project team, as it is necessary that he or she has little or no prior knowledge about the interactive map and the interface. Therefore, the selection of participants for this user study was chosen based on their background.

Forty-one participants from different countries participated in this evaluation, of which 24 participants were female and 17 male. The dominant age group of participants was 25 to 34 years. Most of them had a cartography (18 participants) or geography (12 participants) background. The educational level of participants was distributed as follow: Master (23), Bachelor (10), PhD (5), and higher than PhD (3).

The participants filled an online questionnaire designed with Survey123 for ArcGIS. In this questionnaire, participants were asked about their opinion regarding the applied design principles to visualize several indoor features. Most of the questions for this section were created in the form of a comparative evaluation, where the users were provided with various design methods, illustrated with screenshots taken from the CRIS. Afterwards, a statement was formulated to gather users' opinion. The answers were collected on a Likert scale and the results gathered from them are illustrated in Figure 6 below.

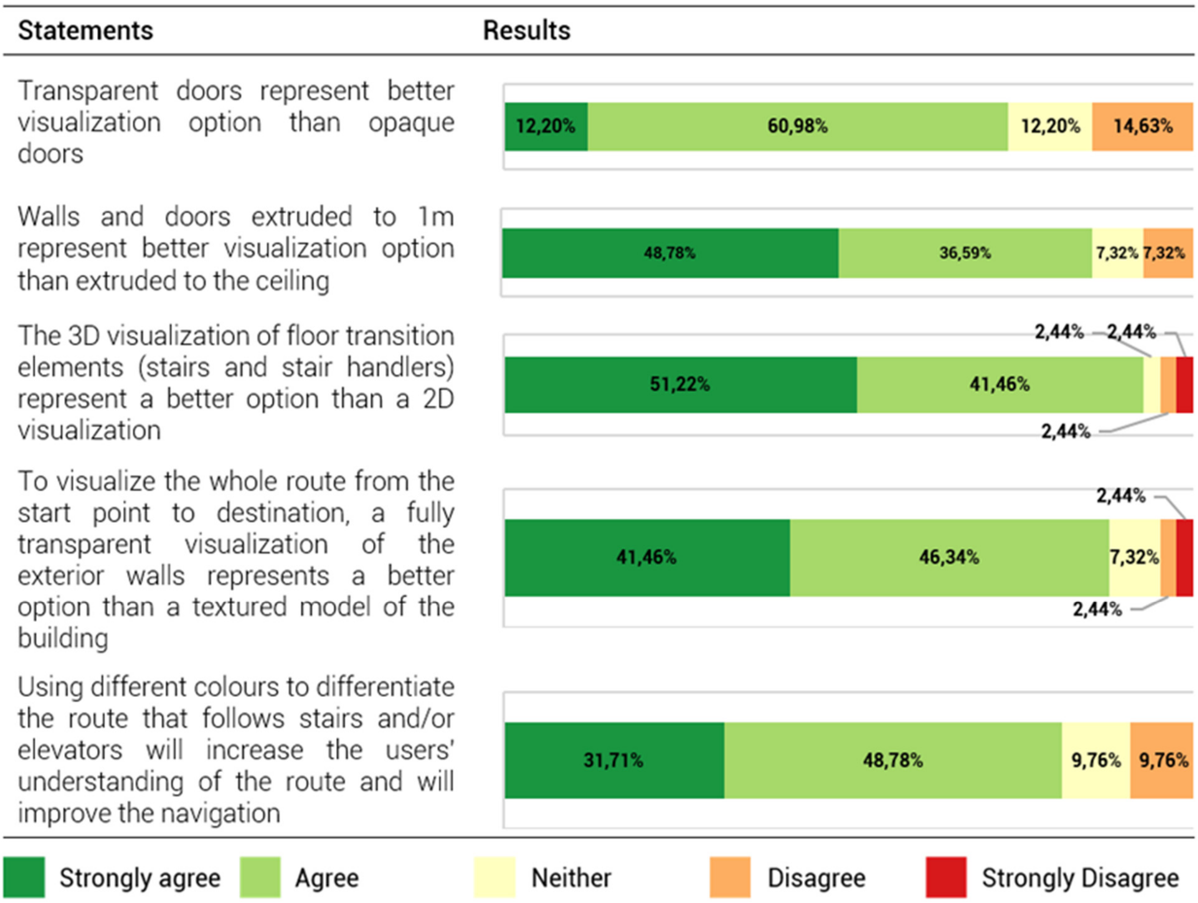

Fig. 6: Users' opinion regarding map design questions

In general, most of the participants (N=35) considered it easy or extremely easy (see Figure 7) to follow the route and reach the destination with our CRIS. 31 participants were satisfied or very satisfied with the 3D route representation (see Figure 8). Regarding advantages of a 3D map representation for indoor navigation systems, about half of the participants named a realistic representation as the biggest advantage, followed by the representation of vertical structures like walls, doors and stairs.

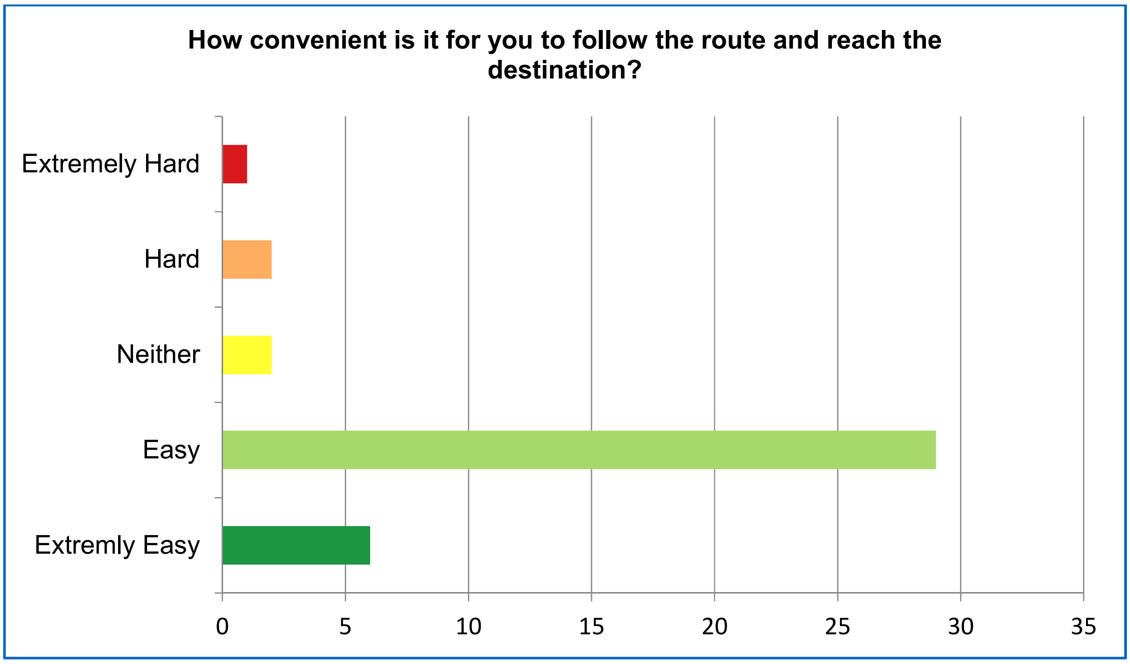

Fig. 7: Results of the question “How convenient is it for you to follow the route and reach the destination?”

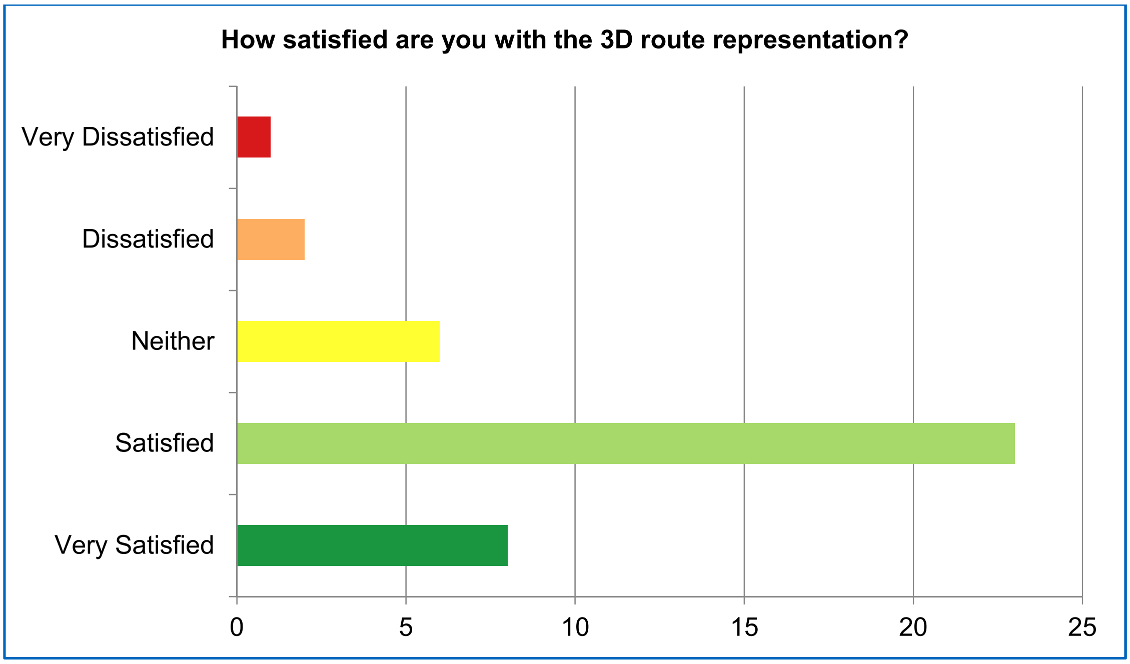

Fig. 8: Results of the question “How satisfied are you with the 3D route representation?”

After gathering feedback from this first user study regarding map design and map usage of the TUM CRIS, we developed the final version of the TUM CRIS based on the following design principles:

- Doors are visualized with a level of transparency, where the route is always visible.

- Interior features are extruded to 1m height to allow a visualization of the whole route and visible floorplan.
- Stairs and stair handlers are visualized in a 3D representation to facilitate users' indoor navigation among floor levels.
- The textured model of the building is used as the main view of the TUM CRIS, and when the users generate a route, the exterior walls of the building will be transparent.
- Two different colors are used to communicate the route that follows the stairs and elevators.

To test the effectiveness and efficiency of the final version of the TUM CRIS, a second user study was conducted.

4.2 Usability and utility

The purpose of the second user study was to evaluate the usability and utility of the developed CRIS for the TUM main building. The usability and utility were tested using a scenario-based design, which implies the test persons were asked to navigate from their starting point to a destination point with the help of the CRIS. The evaluation process is built on the user-based methods (ROTH et al. 2017), which solicits input and feedback about an interactive map and interface from a representative set of target users. First-time visitors were chosen as the target group to test the developed CRS because of their lack of familiarity with the TUM building. Their prior knowledge of the building spatial structure, naming and numbering system, presence of landmarks, etc. will not interfere during the interaction with the TUM CRIS. Additionally, they were chosen, since they are an unacquainted user group. Hence, if a visitor is able to use and navigate with the TUM CRIS, it is assumed that the CRS is effective and efficient also for everyday users of the TUM premises (students and staff members).

A mixed method of quantitative and qualitative data was adopted for this evaluation. The user study consisted of two main parts: (1) a user experiment conducted within the premises of the TUM main campus building, (2) a questionnaire to gather feedback provided after finishing the experiment. The study was conducted with five participants (3 males, 2 females).

Within the task, our participants were asked to identify their position in the building by using structural features as orientation points, as our system did not feature any indoor positioning functionality. All the five participants were able to identify their position, which was used later as starting point or origin of the route. The next step was to locate a certain room with a certain number. To solve this task, our participants had to make use of the search panel on the developed CRIS. As part of the thinking aloud adopted method, the participants were asked to describe what direction they had to follow to reach the destination. In addition to thinking aloud, users were asked to determine their position related to other structural features (stairs, doors, and stair handlers) as they moved along the route. Using these proposed landmarks, all participants were able to identify their exact location. As part of the user observation method, participants used the system every time they reached a decision point that required going up or down, or turning left or right. To determine their next move, they used the zooming, panning and rotation functions of the system.

All five participants mentioned that they would like to use a similar indoor navigation system for other indoor spaces in the future and agreed on the usability and utility of our system.

Based on the feedback form, the following conclusions can be drawn for the interface design of the TUM CRIS:

- The general information provided on how to use the TUM CRIS is relevant and useful.
- The search box to find an indoor space is easy to use.
- The process to generate a route between indoor spaces is easy to handle.
- The buttons and tooltips are needed and helpful to use the CRIS.

5 Summary and outlook

In this article, we have shown how to create and design a web-based 3D Campus Routing and Information system (CRIS) that facilitates orientation on university campuses. This method can easily be transferred to any other building complex and is not limited to university campuses. Many further developments are expected for ArcGIS Indoors that were not yet part of the product when conducting our study, such as a native mobile application or indoor positioning. Since most universities around the world can use the full stack of ArcGIS technology including a wide range of apps, ArcGIS Server etc. within site licenses, these developments offer a wide range of possibilities, both for developers and for researchers. Regarding future research questions, it is of particular interest whether and to which extent CRIS actually help users in finding their way more efficiently on campuses, and which elements of the CRIS contribute to this increase in efficiency. Regarding the design of campus applications, our evaluation suggests that indoor structures should be visualized with a transparent design, so that the route is always visible. This seems to be more important than a realistic opaque representation, which would imply that the thematically relevant information (the route) was less salient.

Based on the results of the evaluation tests it can be concluded that the TUM CRIS is an indoor navigation web based application, which makes use of structural features to plan and convey the route to various users in an effective and efficient way.

While our user studies have shown that our participants enjoyed using the CRIS, this does not automatically imply that a wide range of users would actually use this system on-campus: Most people (still) tend to navigate indoors without maps. Thus, it remains an open question for future research how a CRIS should be designed that users actually use it, and whether a CRIS actually can improve human indoor wayfinding.

6 Literature

BRASCHE, S. & BISCHOF, W., 2005: Daily time spent indoors in German homes – Baseline data for the assessment of indoor exposure of German occupants. International Journal of Hygiene and Environmental Health, **208**, 247-53.

CARLSON, L.A., HÖLSCHER, C., SHIPLEY, T.F. & DALTON, R.C., 2010: Getting Lost in Buildings, Current Directions in Psychological Science, **19**, 284-89.

CHO, Y. C. & CHOI, J.F., 2015: Spatial Information-Based 3D GIS for Indoor & Outdoor Integrated Platform Development from CRETA Platform, International Journal of Computer and Communication Engineering, **4**, 397.

DUDAS, P.M., GHAFOURIAN, M. & KARIMI, M.H., 2009: ONALIN: Ontology and Algorithm for Indoor Routing. Tenth International Conference on Mobile Data Management: Systems, Services and Middleware, 720-725.

FALLAH, N., APOSTOLOPOULOS, I., BEKRIS, K. & FOLMER, E., 2013: Indoor Human Navigation Systems: A Survey, Interacting with Computers, **25**, 21-33.

GOTLIB, D. & MARCINIAK, J., 2012: Cartographical Aspects in the Design of Indoor Navigation Systems, Annual of Navigation, **19**, 35-48.

JENKINS, P.L., PHILLIPS, T.J, MULBERG, E.J. & HUI, S.P., 1992: Activity patterns of Californians: Use of and proximity to indoor pollutant sources, Atmospheric Environment. Part A. General Topics, **26**, 2141-48.

KRISP, J., JAHNKE, M., LYU, H., & FACKLER, F., 2014: Visualization and Communication of Indoor Routing Information. Progress in Location-Based Services 2014, Gartner, G. & Huang, H. (eds.), Springer, 33-44.

LORENZ, A., THIERBACH, C., BAUR, N. & KOLBE, T.H., 2013: Map design aspects, route complexity, or social background? Factors influencing user satisfaction with indoor navigation maps', Cartography and Geographic Information Science, **40**, 201-09.

ROTH, R. E., ÇÖLTEKIN, A., DELAZARI, L., FILHO, H. F., GRIFFIN, A., HALL, A., KORPI, J., LOKKA, I., MENDONÇA, A. & OOMS, K., 2017: User studies in cartography: opportunities for empirical research on interactive maps and visualizations. International Journal of Cartography, **3**, 61-89.

SCHWEIZER, C., EDWARDS, R. D., BAYER-OGLESBY, L., GAUDERMAN, W.J., ILACQUA, V., JUHANI JANTUNEN, M., LAI, H.K., NIEUWENHUIJSEN, M. & KÜNZLI, N., 2006: Indoor time-microenvironment-activity patterns in seven regions of Europe, Journal Of Exposure Science And Environmental Epidemiology, **17**, 170.

WILKENING, J., SCHÄFFNER, R. & STAUB, T., 2018: Interactive 3D Route Planner for the Campus Röntgenring in Würzburg. AGIT Journal für Angewandte Geoinformatik, 35-41.

WINTER, S., TOMKO, M., VASARDANI, M., RICHTER, K.F., & KHOSHELHAM, K., 2017. Indoor localization and navigation independent of sensor based technologies, SIGSPATIAL Special, **9**, 19-26.

ZLATANOVA, S., SITHOLE, G., NAKAGAWA, M. & ZHU, Q., 2013. Problems in indoor mapping and modelling. Acquisition and Modelling of Indoor and Enclosed Environments, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science, **40**(4/W4), 63-68.