Tool Support for Building Graph Construction

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Abstract: Landmark-based navigation is one promising approach among the group of indoor navigation solutions. Using logical connections between areas in the building, users are able to follow a path via step-by-step instructions. This approach provides universally applicable navigation to complex buildings. However landmark-based indoor navigation requires a solid and reliable data structure which depicts regarded buildings. In this paper we present a tool for construction of such data structure. Using findings from prior experiments and well-established design principles and patterns, we were able to significantly improve the usability of the tool and lower the cognitive load of the user. Furthermore, the proposed improvements were integrated into landmark-based indoor navigation software to enhance the user experience and display a more familiar presentation during the navigation task.

1 INTRODUCTION

Mobile devices of all kinds penetrate our daily life and change it significantly. The build-in hardware becomes more complex and consequently, the range of application steadily grows.

Navigation is one of the many tasks that nowadays devices are capable of. The satellite-based Global Positioning System (GPS) became the standard for outdoor positioning in recent time. There exist not only stand-alone navigation solutions but many of today's sold mobile phones include the required soft- and hardware for outdoor navigation. However, there are limitations in the field of application for such devices. Even though navigation tasks on street level are very precise, the GPS approach reaches its limit at the entrance of a building. Since nowadays architectonic styles are changing to more individual and often more complex structures, it is indisputably important to support visitors in such complex buildings as airports, railway stations, hospitals, and museums. Completely new navigation approaches are required to navigate a person inside unfamiliar buildings. For this task exist several hardware-based solutions as well as approaches working solely with logical constraints of the building and human perception.

Landmark-based indoor navigation (Heiniz et al., 2012) is one of such solutions. Compared to navigation approaches based on precise geographic coordinates which are mapped on a floor plan of the building, landmark-based navigation relies heavily on the data structure that represents the covered building. This data structure, a so called building graph, consists of nodes and directed edges. Subdivided into logical areas within the building, such a building graph is an abstract representation of the human mental map that he subconsciously builds for indoor environments. It is crucial to design such a graph in a suiting, consistent, and precise way to cover most special cases within rambling building structures such as stairs, elevators, complex intersections, and large open spaces.

This paper is structured as follows: Section 2 briefly describes the aim of our work. Section 3 introduces several navigation models and presents techniques for indoor positioning and navigation. In Section 4, we describe landmark-based indoor navigation in detail. Additionally, Section 5 covers the data structure which is the foundation of this navigation approach and depicts the implementation and architecture of our system. In Section 6, we present the evaluation of our system. Finally, in Section 7, we summarize this paper and future steps for the system development are revealed.

2 APPROACH

This paper describes the design of a tool for creation of building graph data structure. The majority of

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this work is based on the navigation approach and resulting software from the work by (Heiniz et al., 2012). We extend and simplify the existing approach for graph creation. Sequential views from the initial implementation are extended by the wizard metaphor (Tidwell, 2010). This technique guides users through the creation of the graph by locking the user into a sequence of several well-defined views. Therefore, graph creation is done step-by-step in a logical order. This way we are able to lower user's cognition load and avoid misleading handling of the tool.

Furthermore, an additional view is introduced which is based on the floor plan of the building. This view adapts well to the touch interface of the application and allows a more natural handling of the graph. During the editing, users have an overview over the created graph and may update and delete data elements more easily. In case of missing floor plan for a building, the proposed procedure switches into a default setting, where the user places elements of the building graph on a white canvas. This option allows a touch-based visual handling in a symbolic space.

Additionally, the application for indoor navigation introduced in (Heiniz et al., 2012) is extended with the presented approach. Users often want a more conventional overview of the route while navigating with the application. Therefore, they are able to switch from the initial step-by-step view to an overview of the building to observe the passed steps and the route ahead. This way we introduce an additional view that supports users which experience difficulties with pure sequential instructions. Using this enhancement, we were able to combine the advantages of landmark-based indoor navigation (e.g., best-effort positioning and navigation approach based on human cognition) and the more common information from a building floor plan.

3 RELATED WORK

The following approaches base on the idea of supporting positioning through the data structure. Thus, the system is more independent from the existing technical infrastructure in the building.

Landmark-based indoor navigation (Heiniz et al., 2012) does not rely on additional sensors in the building or the navigation device to lead the user to his destination point in a building. This approach includes the user into the navigation task by letting him subconsciously collect visual impressions about his surroundings. The user has to perceive his surroundings and compare certain areas of the building to presented depictions in the application. He then actively informs the system about his position in the building by selecting certain areas from a list of preselected positions. Using physical constrains of the building and the human power of observation, it was possible to design a reliable navigation system. Landmark-based indoor navigation serves as the starting point to this work.

The navigation approach presented by (Chowaw-Liebman et al., 2010) provides an advanced data model for buildings. Users follow generated textual instructions and thus are guided through the graph structure of the data model. The position of the user is monitored via the device whispering approach (Krempels et al., 2011) during the navigation.

(Baras et al., 2010) presented an approach that leads users through a building without any hardware-based positioning. In this work, a model of the target building provides the route based on area identifiers such as room names or special locations. Objects which base on these identifiers are logically connected. Users are following the sequence of locations and reach their destination. However, the presented system provides very sparse information which lacks details. Furthermore, all information is presented as text, therefore, users need to be familiar with the building to follow the route.

Another approach working with imprecise positioning was introduced by (Jensen et al., 2009). The presented system encloses areas to logical objects which are connected in a building graph. Human movement is tracked by a technique based on RFID signal recognition. Even though this positioning approach shares the drawbacks of all hardware-based positioning solutions, the graph on its own provides strong constrains for possible actions within the building and thus the introduced navigation approach is still reliable. A proper building structure enables flawless navigation for this approach.

Apparently, it is possible to navigate a person through a building without precise hardware-based positioning. A proper underlying data structure is crucial to achieve a reliable indoor navigation approach. However, most of the introduced approaches still use floor plans to depict user location even though this position lacks precise coordinates. We will use this finding to evaluate human mapping of points on a map to areas in the building.

Usability aspects play an important role for design of the building graph construction tool. We recourse to a certain set of design principles and design patterns to create an accessible and user-friendly experience. To optimize the existing graph creation views, we adapted design patterns from (Shneiderman, 2003). Additionally, we implemented the wizard pattern for construction views from (Tidwell, 2010) to guarantee certain sequence of steps and simplify the usage of our tool.

4 LANDMARK-BASED INDOOR NAVIGATION

This section describes the approach for landmark-based indoor navigation in detail. First, we explain the idea behind the navigation approach, followed by the navigation data model of our system.

4.1 Navigation Approach

The concept of the developed navigation system follows the human cognitive navigation process. Subconsciously, the human brain constructs a unique cognitive map from the starting point to the endpoint of the route which is divided into single route sections of manageable sizes characterized by waypoints and landmarks known or communicated to the user (Downs and Stea, 1982). A landmark is a unique recognizable reference point in a section used for orientation and positioning of the user, whereas a waypoint is a special kind of a landmark, namely the starting or endpoint of a route section. Hence, the route consists of a sequence of waypoints which the user needs to pass in a predefined order. Each of these waypoints is connected to one or several landmarks which depict this exact position visually unique in the context of routing. During the human navigation process, a mental depiction of the route, the cognitive map, is continuously compared to the surroundings.

This subconscious procedure is modeled in the navigation system by (Heiniz et al., 2012). However, this approach does not only model the human navigation process but also human instructions in case of asking other people for the direction to a destination point. People tend to describe the route by providing two to three landmarks which are located on the way and build the directions using these unique areas. Landmark-based navigation system is based on the same principle. A route along waypoints is computed after defining a starting and an end point. The navigation system displays successively the next waypoint the user has to pass until he reaches the endpoint. To facilitate the navigation for each waypoint, textual instructions are attached which describe how to reach the next waypoint from the current position. Additionally displayed landmarks allow a continuous verification of the current position along the route.
The user is actively integrated into the navigation process by confirming his arrival at the target waypoint to be navigated to a successor located on the route.

4.2 Navigation Model

In this section we will focus on a data model called building graph. In our system, on the one hand the building graph is used as a structure the navigation relies on. On the other hand the system provides a module to construct such a structure for an arbitrary building.

In general, this graph consists of nodes and directed edges. The nodes represent specific logical areas in a building which comprises unique attributes, e.g., the entrance hall. They are used as navigation points and can obviously be applied as starting points or endpoints. We distinguish between waypoints which depict landmarks lying on the route and points of interest which are relevant navigation endpoints and a subset of waypoints. Both are discussed below.

The edges represent all possible routes between the nodes in the specific building. They have to be directed edges because some routes can be restricted with respect to their direction of movement, e.g., an escalator. Every edge contains a rough distance value between the connected nodes such that the user can estimate how long he has to walk to reach the next waypoint and can easily compare sections. An estimation of the distance is sufficient since a person can hardly estimate accurate distances in buildings (Cutting and Vishton, 1995). During the construction of a building-graph, we assign a geographic direction to each edge to compute the angle between two consecutive sections. In dependency on the angular degree, the user can be precisely navigated by adapting the textual instructions according to the computed value, e.g., turn left, turn right, turn around, follow the route. The direction patterns base on work presented in (Chowaw-Liebman et al., 2010).

Precise implementation of the building graph in our application and all required components are presented in detail in Section 5.1.

5 IMPLEMENTATION

The following section describes the implementation of the building graph construction tool and integration into the existing application.

5.1 Building Graph

Building graph is the central construct that acts as the base for landmark-based indoor navigation. It consists of all essential elements to describe a route through a building. Such a graph is identified by the address of the respective building.

A building is subdivided in different areas, e.g., different floors or departments which distinguish in a logical matter. An area can be a subarea of another one, e.g., there can be several departments on the same floor of a building. Partially intersecting areas are not considered in our implementation.

Another important entity is a landmark. It contains pictures of the reference point from the user's point of view, an identifying name, GPS-coordinates, and Wi-Fi fingerprints. The two latter attributes are necessary because a landmark just as a waypoint can be suggested to identify the starting point in the navigation process.

A waypoint is similar to a landmark and is described by the same attributes. The difference is that a waypoint contains a set of landmarks which are visible from this point and is not necessarily a discrete object. In fact, waypoints represent the nodes of the building-graph, i.e., the starting points and endpoints of every section of a route which have to be reached to continue with the next section, e.g., branches or stairs to the next floor. A point of interest (POI) is a special waypoint which can be the target of an entire route. They additionally contain a textual description of the target. A waypoint is associated to the area it is located in and to other adjacent waypoints by segment objects. Segments correspond to the edges of the building graph and have to fulfill the attributes discussed above. Especially, all landmarks positioned on a section are included into such a segment.

Landmarks and POIs are collected in logical categories: LandmarkCategory, POICategory, and POISubcategory. Landmarks are categorized by included attributes, e.g., stairs, corridors, pillars, lifts.

POICategory and POISubcategory are used to facilitate the manual choices of the endpoint.

To support the user by determining her starting point, GPS-coordinates and Wi-Fi fingerprints are assigned to landmarks and waypoints. With the appropriate infrastructure, the navigation system can suggest possible starting points based on hardware positioning. A GPS object contains a latitude, a longitude, and an accuracy value and refers to every landmark and waypoint with the same coordinates. The accuracy value specifies the accuracy during the measurement to determine the coordinates of a point in a building conditioned by shielding. The system suggests only estimated points whose coordinates stay within this value.

Wi-Fi fingerprinting (Chan et al., 2009) uses the signals of Wi-Fi access points for positioning. To determine the user position, the measured fingerprint of the navigation system is compared to the fingerprint objects in the database. Hence, every Wi-Fi fingerprint object requires the creation date, the access point identifier, the signal strength, and the references to the considered landmarks and waypoints.

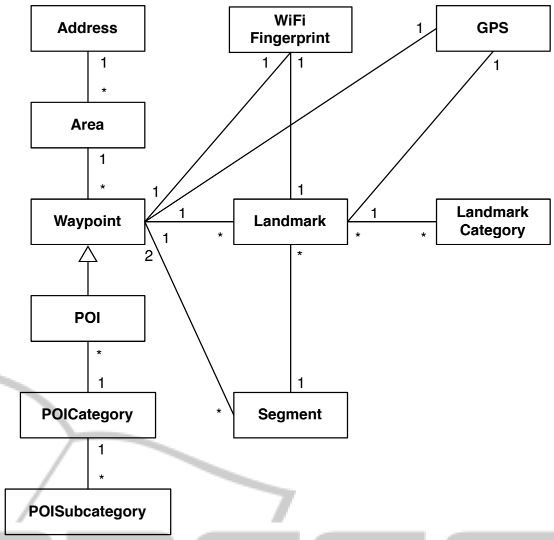


Figure 1: Building graph structure.

The overall structure of the building gragh is depicted in Figure 1.

5.2 Design Principles for Workflow Improvement

The initial version of graph construction tool used a loosely coupled collection of views bound by a central menu. Each of these views addressed a certain element of the building graph. Thus, these components were logically linked, e.g., a segment always had a starting and an endpoint. However, due to the nature of this approach, there were no clear sequences of required steps and the user had to figure out the right construction steps on his own (see Figure 3). Additionally, those views were not optimized for usability. Views were not consistent and lacked simplicity and clarity. The principles of reducing memory load and offer informative feedback are also addressed in the floor plan view described in the next section.

By redesigning the views according to the "Eight Golden Rules of Interface Design" by (Shneiderman, 2003) and adding a clear creation sequence of steps, usability of the tool should be clearly improved. We focused on principles of consistency within the views and easy reversal of actions. To approach the principles of designing dialog to yield closure and to reduce short-term memory load, we used the wizard design

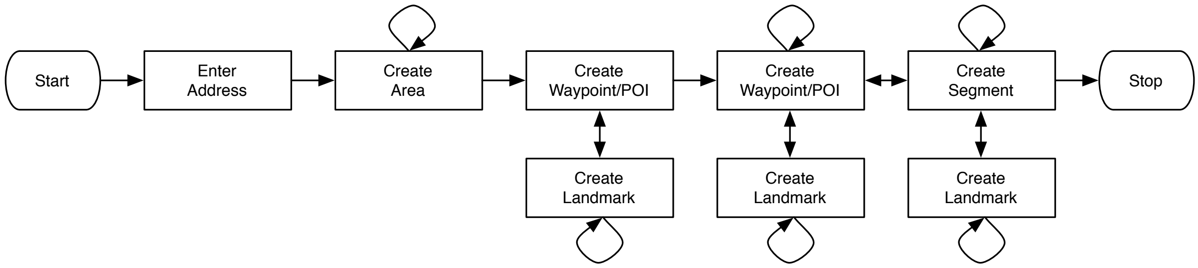


Figure 2: Logical building graph construction steps (sequence for wizard design pattern).

pattern for graph creation steps (Tidwell, 2010). User is locked in a certain sequence of views and therefore is not able to do wrong actions, e.g, user has first to create two waypoints to be able to create one segment (see Figure 2). He also does not need to remember all prior actions and is requested only to fill out information that is required as a logical consequence to his actions.

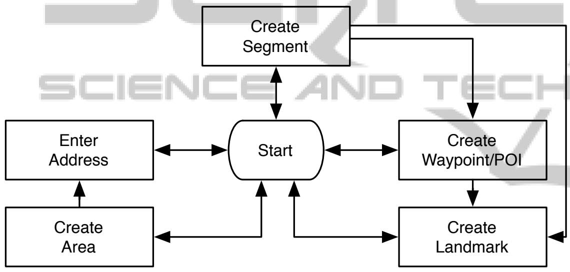


Figure 3: Initial building graph construction.

5.3 Floor Plan View

To achieve a more usable approach for building graph creation it was our aim to provide users with a familiar presentation. While a menu-based view is simple to implement, it requires a huge cognitive overhead to imagine and remember the created building graph. The depiction of that structure is abstract and user is required to build a mental map of the building in his head and synchronize it to the actual graph. Without visual feedback and a lot of experience it is a very difficult task to accomplish.

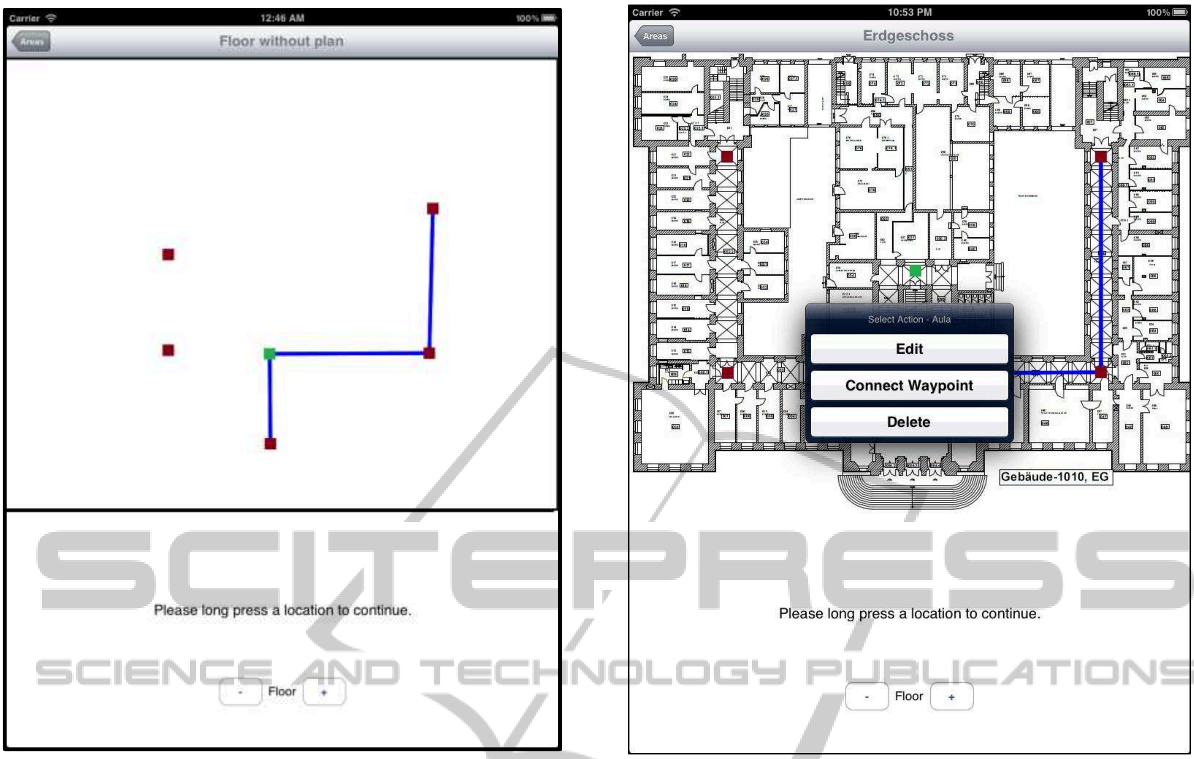
We decided to include a view into the tool which displays the ground plan of the target building. In terms of navigation, users are more familiar with the concept of a visual 2-dimensional presentation of the terrain from above known from most outdoor navigation systems and indoor plans. We differ between two kind of situations: either a floor plan does or does not exist for the target building. In case of the missing plan, we use a blank canvas, i.e., white background, to let users build the graph as a visualization of their mental maps (see Figure 4(a)). This way users may express their view of the building and create a clear structure. They may freely place waypoints in the building and combine these with segments of a defined length. The length of the segments is estimated by the creating user. These distances are only guide values for the navigating user and thus do not need to be precise. They serve to represent distance differences among the sections within a route. Finally, on the one hand, by using this view, we are able to help users while creating a building graph with a permanent visual feedback. On the other hand, this view helps during the navigation to visualize walking directions and route length with reference to the passed segments. However, in this view, we are missing the constraining features of a building plan. Hallways and clear separated rooms often help users orient themselves.

In case of an existing floor plan, users are able to create an even more informative and hence supporting building plan. Here, users are able to add, delete, and update graph elements like waypoints and segments directly on top of the floor plan image (see Figure 4(b)). Therefore, the building graph structure was extended for each visible element (i.e., waypoints and segments) to include reference points on the image to map the components to the visualization. Using these coordinates, we are able to create a navigation view that displays the entire route through the building (see Figure 5). Natural constrains of the building support the navigation. For this reason the floor plan view with a real plan of the building is always preferable to the black canvas approach.

Both navigation views were extended to support users. Calculated route within the building is marked blue, the passed route is grayed out, users current location is marked green and the target POI is depicted as a checked square. Using this clear coloring schema, users are always informed about their progress.

6 EVALUATION

In this section we discuss the evaluation of the imple-



(a) Graph construction on blank canvas (b) Graph construction on floor plan

Figure 4: Graph construction in floor plan views.

mented tool for building graph construction. Every participant had to complete two test routes within a building. On one test route he used the improved tool, on the other one he built a proper data structure for four areas in the building with the initial version of the software. Afterwards, the different approaches were compared based on time measurements and user feedback.

6.1 Test Procedure and Setup Description

The depicted navigation system was implemented in Objective-C on the Cocoa-Framework. During the test procedure the software ran on an Apple iPad 2 Wi-Fi with iOS 5.0.1.

The main building of RWTH Aachen University was chosen to conduct the user tests. This building has a complex architecture. It is rambling and consists of three upper floors, two basement floors, different kinds of stairways, and elevators. Although many university departments are located in the main building, most students are not acquainted with this building, thus, it can be assumed that the test results are not distorted. We used very detailed floor plans of the building as the background for the floor plan view (see 5).

The test group consisted of 2 female and 10 male students aged between 19 and 30. Self-evaluated technical skills of this group were well-distributed from poor to excellent. The users were given a verbal briefing before the first test run. Two test routes of the same length and complexity were selected for the study. The participants were asked to create building graphs for each of those two routes once with the initial tool and once with the altered version from this work. The resulting graphs consisted of four connected waypoints with appropriate landmarks and included one change of floor. Users were instructed where to mark a waypoint but had to estimate the distance of each connecting segment between two points in the resulting graph.

The main part of the evaluation bases on an online questionnaire. Users could evaluate both tool versions, write comments, and rate the usability of the system. The scale for the ratings ranged between 1 for poor results and 6 for excellent outcomes.

6.2 Outcomes

We observed that using our improved approach we could lower graph creation time significantly. The

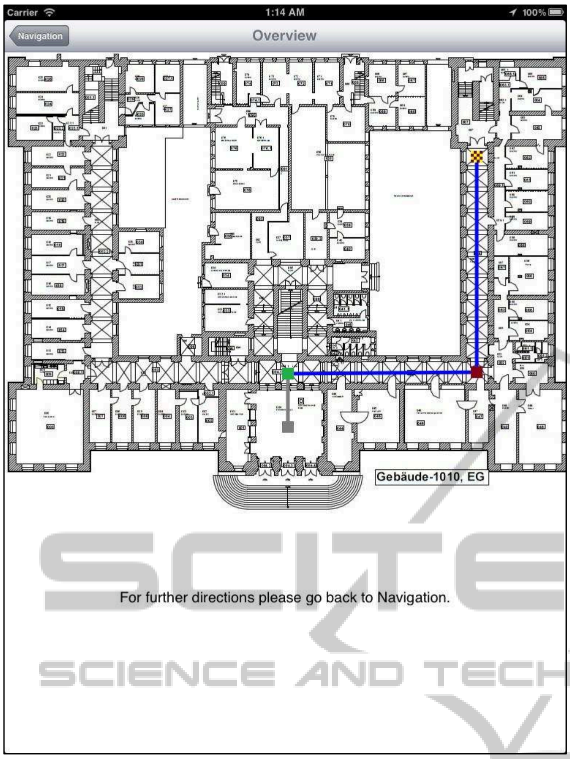


Figure 5: Route navigation.

prior approach was very struggling for the user and required a lot of additional instructions. Views and the proper sequence of creation steps were not clear and required a massive cognitive load from the user. After each action he had to reorient himself and rethink his next steps. Introducing the wizard approach for the views, we were able to create a clear step-by-step sequence of views. Users always knew the next required action and were able to fulfill the task more easily and more efficiently.

However, most users instantly switched to the floor plan view (see Section 5.3). Visual feedback and the overview of the created building graph must not be ignored and were highly preferred by the users. Views from step-by-step instructions required a certain abstraction level from users. Areas in building had to be mapped to textual descriptions and the cognitive map. This approach was often confusing and required experience with the tool and good memory. The floor plan view solves this problem by mapping the abstract structure of the building graph to an image of the building plan.

The questionnaire among test participants confirms that observation. Even though users declared that the visual floor plan is not especially helpful to find requested locations (average rating 2,83), it still seems to support the users subconsciously. Therefore, our test group rated the usability of the improved tool (average rating 4,42) significantly better than from the initial version (average rating 2,08). Supporting this outcome, all 12 users were aware of the improvement of the modified tool and most users were satisfies with this version (average rating 4,33). Consequently, all 12 users stated that they prefer the altered tool than the initial version of the software.

7 CONCLUSIONS & FUTURE WORK

Building graph is the central structure of landmark-based navigation and thus requires to be flexible, reliable and precise to guarantee proper indoor navigation. In this work, we introduced an improved tool to construct such a graph in a user friendly and convenient way. Existing views were improved and rearranged by using well-established design patterns and principles. An additional view, the floor plan view, was introduced. Users are now able to map the abstract structure of the building graph to a ground plan of the building. Thus, they have a permanent visual feedback over the progress and all created graph components.

The evaluation revealed that the modified version of the graph construction tool is clearly an improvement over the prior version. User study participants observed a noticeable enhancement of the approach and clearly stated to prefer the new version of the tool.

However, further work is required to improve and evaluate graph construction as well as the entire enhanced navigation approach. First, floor plan view with a blank canvas needs a proper evaluation. While creating a building graph on a depiction of the building works properly, construction of this data structure on a white background requires a more abstract procedure. Users must project their mental map of the surroundings into a visual representation. An evaluation needs to reveal user interaction with this approach.

Introduced floor plan view needs an additional evaluation. We will test usability and proper presentation for the navigation application. One introduced idea was to include the building graph visualization as the background for the step-by-step navigation instructions. This approach would combine the overview of the graph with the detailed descriptions of the route. User would not need to switch between views and therefore need less actions for navigation. However, we need to evaluate whether the added information is required and does not excess the acceptable amount of depicted information.

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