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# The Right Data at the Right Moment for the Right Person — User Requirements and Their Implications for the Design of Indoor Navigation Systems

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***Abstract*—Indoor Navigation Systems are constantly improved in a variety of technological fields, but often without considering individual user requirements. As a direct consequence, navigation information is not sufficient for the variety of all users. By combining and evaluating user requirements and data models for indoor representation, five categories of indoor navigation information were compiled. OpenStreetMap (OSM) serves as a basis to form items for an online survey for able-bodied, visually and motorically impaired people. Based on the results, we determined: User groups are an important element in indoor navigation. Individual preferences and time dependence of information need to be considered additionally. These results are then used to derive implications for several stages and components in the technological development process. We argue that following these implications by including user requirements in these processes will lead to a higher satisfaction with Indoor Navigation Systems for all users.**

***Keywords—Indoor Navigation System, User Profiles, Indoor Mapping, OpenStreetMap, Simple Indoor Tagging, Accessibility, User-Centered Design***

## I. Introduction

Navigation applications have become indispensable in everyday use. Outdoor navigation includes a wide range of applications [1, 2]. In contrast, indoor navigation services are rarely offered and hardly used. This begins with the lack of technical prerequisites: broad-based and reliable localization technology is needed on all premises, data for each individual building must be maintained, prepared and supplemented. Many research projects deal with indoor navigation, often by proposing their own new systems [3, 4, 5] or focusing on specific technical improvements [6, 7, 8]. This leads to a lack of focus on the implementation of user requirements in technical developments. The implementation of an indoor navigation system should follow a holistic approach [9]. The presented paper evaluates available navigation information in an online survey. The results give a fundemental understanding about the relevance of information for different users and how this impacts the development of navigation applications.

The way in which navigation information is created differs essentially for outdoor and indoor environments [10, 11, 12] and is inherently more small-scale for the latter. For example, distances must be more precise, movement takes place in three-dimensional space [11], and there is a lack of fixed labels such as street names. Thus, existing routing- and rendering-libraries need to be adaptable to indoor environments. Moreover, navigation information must be semantically enriched and precise. This can be considered most important for visually and motorically impaired persons, who often need additional information about their navigation environment. We argue that this information basis might promote overall autonomy in public spaces, facilitate movement and improve safety for potential users with impairments. It is already known that the need in the information depth of navigation instructions differs according to the group of users and the time of use [13]. Based on these needs, targeted information can be offered and redundancies in navigation instructions minimized. For the design and implementation of indoor navigation systems, it is necessary to include user requirements and wishes as early as possible in the development. The mapping of buildings needs to include all relevant data, routing algorithms need to be computed according to the abilities of the users, incorporating the exact position; navigation instructions need to present comprehensive information, the rendered map has to be understandable, and even the output mode needs to be customizable. The requirements and wishes are as diverse as the potential users. While more detailed information is often an advantage for people with disabilities, it is important to

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consider the level of detail. In a study by [14], about one-third of the visually impaired participants said they would prefer less or no contextual information in complex buildings as they are worried about overstimulation.

This paper presents which information is desired during navigation and for the preparation of navigation. The results are divided into three user groups ("*able-bodied*", "*visually im-paired*" and "*motorically impaired*") for which different require-ments have to be considered and fulfilled. We offer direct implications for various technical implementations of indoor navigation. This includes the processes of mapping, routing, rendering and generation of navigation instructions in order to develop a comprehensive indoor navigation application for all users.

## I. Related Work

First, the need arises to gather requirements for indoor navigation. As a focus, requirements of people with mobile and visual impairments are presented. Considering their individual needs and skills expands general requirements for navigation applications and might offer a set of holistic requirements. Subsequently, data models that mainly structure spatial building data are examined as a basis to extract user requirements for information representation. OSM is chosen and presented as a platform able to incorporate user requirements in spatial building data that represents the real world.

### A. User requirements

Legislatures in several countries already established regulations, standards and norms to make buildings accessible. One of these is the Americans with Disabilities Act (ADA), which was taken as a basis by [15] for a graph model. They created semantic links between building elements and the accessibility requirements according to ADA. The requirements apply to both people with physical and visual impairments. These include, among other, type of doors (automatic or manual), heights of usable objects (buttons, sinks, ...), the required turning space for wheelchair users, handrails as well as number and height of stairs. While legal regulations exist, not all buildings meet them. The existence of accessible entrances and toilets for example is a minimum necessity, as can also be seen in various volunteer works like Wheelmap [2]. Studies have shown that more metadata is relevant to people with disabilities [13, 16, 14]. This is especially true for people with a visual impairment as is shown in a study by [16] which demonstrates that most visually impaired people rely on sighted guides in unfamiliar places. Distances are often estimated by using several senses and information from the environment. Sighted guides, landmarks and environmental cues (floor structure, noises, smell, ...) are used to find the current location, navigate, and orientate. Unfamiliar spaces are always difficult to navigate, especially if they are big or cluttered with furniture. The authors name obstructions like automated or glass doors, a noisy environment, slippery ground, and obstacles on various heights. The findings of an online survey [13] validate and extend this. Their survey focuses on the preparation of and navigation in unfamiliar places among people with visual impairments. The participants name apps as aids to visit unfamiliar places, additionally to sighted guides. While a general building description helps to form an initial mental map, detailed environment descriptions along the way as well as indications of possible obstacles are needed. While the obstacles are similar to the ones named by [16], [13] add knowledge about the absence of assistive devices as a requirement. Handrails, adequate signage, or braille lettering can lead to a greater independence. When these aids are not present, people with visual impairments may be more inclined to take a sighted companion with them. A small study conducted by [14] tested different levels of detail in a navigation application for visually impaired people. Two thirds of the participants would prefer the version with the additional context information about the environment. The others would not use this option as they worry that the amount of information may overwhelm them.

From the above-mentioned works, we can extract several requirements for people with impairments. An Indoor Navigation System that aspires to include all users should be developed in a user-centered way and integrate the following strategies and information:

- Needs-based approach
- Landmarks
- Information on accessibility
- Obstacles
- Missing aids
- High levels of detail
- General building information

### B. Integration of user requirements in indoor data models

All building data includes structural elements that are already known by established navigation applications. The elements are composed of floors, corridors, rooms, walls, doors and so on. In the next paragraph, we present several models that show relationships and information about buildings. The differences in the data models lie in the applications they are built for, their format and which metadata they include for building elements. This also includes information about accessibility, not as building elements like ramps and elevators, but orientation systems for visually impaired, braille or information about automatic doors.

Already in 2006, [17] turned 2-D building plans into a data model that built the basis to create structured floor plans, graphs or attribute lists. [18] developed a human centered indoor navigation system that was built from several ontologies. These were created and applied to path computation, routing algorithms, and indoor positioning to provide a customized navigation. Another model for indoor navigation was presented which used a Unified Modeling Language (UML) class diagram as a structure [19]. The information was extracted through a 3-D Building Information Model and CityGML. A 3-D Building Information Model was also a basis for another indoor navigation system for people with visual impairments [20]. The author created a semantic spatial model that uses classes to describe different building elements. Back in 2011, [21] proposed an ontology for mapping buildings in OSM, which did not gain acceptance in this form in the OSM community. The tags used in OSM to describe spatial contexts serve as the basis for this data model. The level of detail depends on how much information the users want to add. Simple Indoor Tagging (SIT) [22] is the established standard for indoor mapping in the OSM community that was initially created in

2014. The model is adaptable for all levels of details and provides a basis for indoor navigation, 3-D floor plans and other customized applications. A universal framework for the spatial representation of buildings was presented by [23] for people with visual impairments. The framework consisted of several layers which related to individual contexts for information representation.

Table 1 shows how the presented data models address the previously listed user requirements. The requirement *general building information* is excluded in the table as the inherent basis for the models. *Landmarks* as a definition is used variably by each author, but generally means rooms and objects that are important during navigation. The *needs-based approach* is only marked if the model is explicitly built for people with impairments. Some models are marked as only partially implemented: The model of [20] has a focus on visually impaired persons which leads to missing accessibility features for motorically impaired people. Assistive aids are included, but it is not clear if their absence is marked. Due to the OSM tagging scheme, [21] and [22] include landmarks and obstacles, but do not tag them explicitly with these labels. Assistive devices are not generally included in [21], but can be tagged in the more open SIT as explicitly nonexistent. OSM evolved from a simple mapping platform to a tool that allows users to use geographical data for their own projects [24]. This is due to nearly 7.5 million voluntary contributors [25] who crowdsource data and make it openly available. The community has standardized processes to establish new forms to map (or in their term, tag) geospatial information. SIT as the established standard specifies a minimum amount of tagging information necessary to map a coherent indoor environment. Even this minimum amount of information is often not applied [26] and it is even more rarer to have the necessary level of detail for people with impairments. Proposals to the OSM community to expand the SIT standard need to be added to achieve more detailed indoor maps [27].

To summarize, people with disabilities need a high level of detail to navigate self-sufficiently in indoor environments that are unknown to them. The spatial information needed to construct navigational information is dependent on the building structure and can be annotated with additional metadata to reach this necessary level of detail. OSM and its inherent information structure can generally serve as a basis to map, catalog and annotate building data. With this basis, the routing algorithm can then give the users the necessary data for a satisfying and successful indoor navigation.

TABLE I. INTEGRATED USER REQUIREMENTS IN INDOOR DATA MODELS

| **Related Work** | **Requirements[a, b]** | | | | | |
|---|---|---|---|---|---|---|
| | ***Needs-based approach*** | ***Land-marks*** | ***Information on Accessibility*** | ***Obstac-les*** | ***Mis-sing Aids*** | ***High level of details*** |
| [17] | - | - | - | - | - | ✓ |
| [18] | ✓ | ✓ | ✓ | ✓ | ✓ | - |
| [19] | - | - | - | ✓ | - | - |
| [20] | ✓ | ✓ | (✓) | ✓ | (✓) | ✓ |
| [21] | - | (✓) | (✓) | (✓) | - | - |
| [22] | (✓) | (✓) | (✓) | (✓) | (✓) | (✓) |
| [23] | ✓ | - | - | ✓ | - | - |

[a] Without general building information
[b] (✓) marks requirements that are only partially implemented

While some of the mentioned literature considers user groups and accessibility requirements, it is unclear how relevant possible navigational information is for individuals. This relevance can be deduced by including user groups that regard individual requirements. These groups may need to be subdivided, and the relevance for some navigation information may be time-dependent. Current research is lacking a com-prehensible inspection of different user groups and which navigational information is considered relevant for indoor environments for a certain individual at a specific time.

## III. STUDY

In order to determine the relevance of information for navigation, an online survey was conducted. Based on the OSM SIT scheme, questionnaire items were created as navigation information and appraised by the respondents in their importance for supporting the navigation process. The evaluation took place in two parts, so that both the preparation for a navigation (i.e. before starting the trip to the building) and the navigation itself can be considered in the evaluation.

The data was collected by means of an online questionnaire in which a total of 82 people participated. Of these, 56 questionnaires were completed in full and included in the evaluation (f = 26, m = 28). The average age was 44.59 years and thus represents a sample from the middle of society. The questions were divided into five categories with a total of 53 items, which could be answered by means of a 5-point Likert scale from 1 = "strongly disagree" to 5 = "strongly agree". The questionnaire was in German.

### A. *Item construction*

Already existing OSM tags were used as a basis to select the questionnaire items. These tags were collected and checked for possible extensions regarding accessibility and indoor context [21]. Since the tags are generally designed for the exterior, they were extended to represent the details of indoor spaces. This deepening of the level of detail took place by including the needs of people with visual and motorical impairments, as the literature review shows the lack in existing data models. Subsequently, the selected tags were converted from the OSM "key=value" format (e.g. "room=corridor", "handrail=yes") to linguistically common labels to increase comprehensibility for the participants. Where appropriate, multiple tags were summarized in umbrella terms to minimize the length of the questionnaire and promote a higher percentage of participation. This includes for example attributes for the surface conditions like material or smoothness, which are tagged separately in OSM. These edited tags represent the items of the questionnaire.

The items were thematically divided into the categories established by the related work, as can be seen in Table 2: *general information and building data*, *route descriptions*, *distinctive points*, *obstacles*, and *missing aids*. These categories were used as thematic dividers for the questionnaire. In the design of the questionnaire, a conscious decision was made not to include a category of landmarks or points of interest, as these categories could not represent the diversity of the category of distinctive points in an indoor environment that are included here. The term *distinctive points* was chosen to describe this category as it was a more under-standable term for the participants in the original German questionnaire.

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TABLE II. ITEM CATEGORIES WITH DESCRIPTIONS AND EXAMPLES

| Item categories | Description | Example |
|---|---|---|
| General building information | Information about usage or structural conditions of building | Accessible entrance, address, opening hour |
| Route description | Items that provide directions and are used to navigate | Exits, room types, intersections |
| Distinctive points | Essential items for orientation or usage of the building | Signs, distinctive furniture, toilets |
| Obstacles | Obstructive elements | Thresholds, large halls |
| Missing aids | Assistive objects where an absence can be a barrier | Missing braille, ramps, or handrails |

These five categories were constructed primarily from the literature listed in the related work. There, obstacles and missing aids were mainly mentioned by people with visual impairments as important information about unknown places [13, 16]. General building information is also mentioned in this context to help users get a first impression of the building structure or use [13], as well as salient points whose placement in the building is important information both for easier orientation [28] and for building use. The last category, *route descriptions*, was introduced to distinguish semantic information about the building structure and navigation information typically given by a navigation app. The items constructed from OSM tags were assigned according to their general usage and by applying the data models from the related work.

## B. *Sample*

At the beginning of the questionnaire, participants were asked about their motor and visual limitations. For visual limitations, more detailed answers had to be given afterwards. Here, the questions were divided into short-sightedness, farsightedness, color vision impairment, and into the degree of visual impairment and blindness according to German regulations [29]. By these questions the participants were divided into three groups: "*able-bodied*" (n = 32) (also) including persons with shortsightedness or farsightedness, "*visually impaired*" (n = 19), and "*motorically impaired*" (n = 8). The group "*motorically impaired*" can only give a possible outlook on the results, since the number of subjects was too small to compare them with the other groups and three participants overlap with the group "*visually impaired*".

# IV. RESULTS

To better show the subjective importance of the individual information items, the percentages of positive ratings in relation to the overall ratings were calculated (Table 3). Specifically, this means that when asked whether individual items were supportive in navigation (counting both scores "before" and "during" to calculate a total score), only responses of 4 or 5 (corresponding to "agree" and "strongly agree") on the Likert scale were scored. This approach is also called Top 2 Box scoring. This total was related to the total number of responses, resulting in the percentage of positive scores for individual items. The items are ranked according to their subjective importance for the entire sample and presented separately by category. These were additionally color-coded, graded between 50 %, 70 % and 90 %. This means that the top items in each category were rated as particularly important in terms of their subjective importance for navigation.

TABLE III. SUBJECTIVE IMPORTANCE OF INDIVIDUAL ITEMS

| Categories | Items | Groups | | | |
|---|---|---|---|---|---|
| | | *All* | *Able-bodied* | *Motori-cally impaired* | *Visually impaired* |
| General information and building data | Building structure | 82.1% | 79.7% | 68.6% | 89.5% |
| | Information/service point | 76.8% | 67.2% | 68.6% | 100% |
| | Access and access restrictions | 73.2% | 75.0 % | 86.7% | 66.7% |
| | Opening hours | 66.1% | 71.9% | 68.8% | 60.5% |
| | Address | 58.0 % | 57.8% | 75.0% | 57.9% |
| | Contact details | 52.7% | 45.3% | 62.5% | 68.4% |
| | Accessible entrance | 42.9% | 31.8% | 100% | 47.4% |
| | Information on the outdoor facilities | 32.1% | 26.6% | 50.0% | 39.5% |
| Route description | Exits | 85.6% | 85.7% | 68.8% | 94.7% |
| | Information/service point | 79.3% | 82.5% | 62.5% | 94.7% |
| | Corridor/hallway | 79.3% | 74.6% | 62.5% | 97.4% |
| | Turning points and junctions | 78.4% | 76.2% | 75.0% | 86.8% |
| | Room type | 77.5% | 73.0% | 75.0% | 84.2% |
| | Elevator | 73.9% | 74.6% | 87.5% | 65.8% |
| | Access and access restrictions | 73.0% | 74.6% | 68.8% | 68.4% |
| | Staircase | 71.8% | 66.1% | 68.8% | 86.8% |
| | Escalator | 63.1% | 58.7% | 62.5% | 76.3% |
| | Doors | 60.9% | 56.5% | 50.0% | 76.3% |
| | Distinctive points | 60.4% | 60.3% | 56.6% | 68.4% |
| | Horizontal escalator | 49.9% | 38.1% | 56.25% | 60.5% |
| | Information on accessibility | 45.1% | 23.8% | 100% | 65.8% |
| | Tactile paving | 38.7% | 12.7% | 50.0% | 86.8% |
| | Handrails | 35.1% | 19.1% | 68.8% | 55.3% |
| | Information for braille | 34.2% | 11.1% | 50.0% | 76.3% |
| | Information on floor surface characteristics | 33.0% | 16.4% | 68.8% | 55.3% |
| | Wheelchair ramps | 22.7% | 14.3% | 80.0% | 21.6% |
| | Stair lifts | 22.7% | 24.2% | 50.0% | 15.8% |
| Distinctive points | Information/service point | 87.5% | 82.8% | 81.2% | 100% |
| | Toilets | 75.9% | 70.3% | 100% | 78.9% |
| | Staircases | 75.9% | 75.0% | 62.5% | 86.8% |
| | Purpose-oriented equipment | 73.2% | 75.0% | 75.0% | 68.4% |
| | Emergency exits | 61.6% | 64.1% | 75.0% | 57.9% |
| | Signs | 56.3% | 70.3% | 43.8% | 34.2% |
| | cloak room | 55.4% | 54.7% | 56.3% | 63.2% |
| | Sitting accommodations | 50% | 50.0% | 68.8% | 50.0% |
| | Mailboxes | 46.4% | 50.0% | 50.0% | 47.4% |
| | Vending machines | 37.5% | 34.4% | 50.0% | 47.4% |
| | Furniture | 34.8% | 34.4% | 50.0% | 39.8% |
| | Windows | 28.6% | 32.8% | 18.8% | 26.3% |
| Obstacles | Doors | 42.9% | 42.2% | 37.5% | 50.0% |
| | Big halls | 39.3% | 32.8% | 31.3% | 60.5% |
| | Number of steps | 35.7% | 32.8% | 68.8% | 28.9% |
| | Floor surface characteristics | 29.5% | 15.6% | 68.8% | 44.7% |
| | Threshold | 24.1% | 20.3% | 50.0% | 21.1% |
| | Furniture | 22.3% | 21.9% | 31.3% | 28.9% |
| Missing aids | Missing signs | 48.7% | 62.5% | 50.0% | 24.3% |
| | Missing elevators | 47.8% | 54.7% | 81.3% | 24.3% |
| | Missing accessibility information | 40.9% | 31.3% | 93.8% | 41.8% |
| | Missing tactile paving | 34.2% | 15.6% | 50.0% | 70.3% |
| | Missing handrails | 31.8% | 27.0% | 56.3% | 32.4% |
| | Missing braille | 30% | 15.6% | 43.8% | 58.3% |
| | Missing audio output | 29.1% | 12.5% | 31.3% | 63.9% |
| | Missing wheelchair ramp | 26.4% | 23.4% | 68.8% | 19.4% |

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To determine whether there are differences between "*able-bodied*", "*visually impaired*" and "*motorically impaired*" with respect to their assessment of the items, further comparisons of means were made. Group differences were calculated between "*able-bodied*" and "*visually impaired*" using an independent-samples t-test (Table 4). Table 4 shows only items for which the difference between the groups proved to be significant. Due to the difference in group size between "*able-bodied*" and "*motorically impaired*" and lack of normal distribution of the data, the non-parametric Mann-Whitney U test was applied. 14 items showed a significant difference. Seven of them matched with items from Table 4, such as "handrails" or "missing braille". There were items from each category, such as "toilets", "number of steps", "accessible entrance" or "missing wheelchair ramps".

Another aim of this study was to distinguish whether the subjective importance of items differs before and during navigation, so the mean values of subjective importance were compared separately (Table 5). A dependent-samples t-test was calculated for this purpose. For 19 of the 53 items, a statistically significant difference concerning time-related importance is shown for all subjects. These differences in the time-dependent representation of items were also separately compared for all subjects who could be categorized in the groups "*able-bodied*", "*visually impaired*" and "*motorically impaired*". Table 5 shows only items with significant group differences but keeps the order of items present in Table 3.

TABLE IV. T-TESTED GROUP DIFFERENCES FOR INDIVIDUAL ITEMS

| Categories | Items | Group differences between [a] | | | | |
|---|---|---|---|---|---|---|
| | | *Visually impaired* | | *Able-bodied* | | |
| | | ***Mean*** | ***Standard deviation*** | ***Mean*** | ***Standard deviation*** | ***P-value*** |
| General information and building data | Information/service point | 4.89 | 0.27 | 3.86 | 1.32 | .002 |
| | Contact details | 3.97 | 1.01 | 3.20 | 1.20 | .018 |
| | Information on the outdoor facilities | 3.26 | 1.06 | 2.52 | 1.23 | .027 |
| Route description | Information on floor surface characteristics | 3.37 | 1.25 | 1.98 | 1.12 | .000 |
| | Tactile paving | 4.53 | 0.74 | 1.71 | 1.24 | .000 |
| | Information on accessibility | 3.68 | 1.37 | 2.23 | 1.37 | .001 |
| | Information for braille | 4.18 | 1.25 | 1.61 | 1.15 | .000 |
| | Handrails | 3.45 | 1.50 | 2.15 | 1.30 | .004 |
| | Information/service point | 4.74 | 0.42 | 3.92 | 1.18 | .006 |
| Distinctive points | Information/service point | 4.92 | 0.19 | 4.34 | 0.97 | .014 |
| | Signs | 2.79 | 1.41 | 3.97 | 0.99 | .001 |
| Obstacles | Floor surface characteristics | 3.16 | 1.17 | 2.45 | 1.21 | .047 |
| | Big halls | 3.58 | 1.26 | 2.83 | 1.27 | .047 |
| Missing aids | Missing signs | 2.36 | 1.33 | 3.77 | 1.36 | .001 |
| | Missing tactile paving | 3.94 | 1.04 | 1.86 | 1.33 | .000 |
| | Missing braille | 3.62 | 1.34 | 1.84 | 1.33 | .000 |
| | Missing audio output | 3.65 | 1.27 | 1.86 | 1.17 | .000 |

[a] independent-samples t-test
[b] standard deviation
[c] p-value <0.05 (alpha level is 5%)

## V. DISCUSSION

The results are discussed below in three separate parts. In each, they are first generally outlined and then formulated as statements for the technological development of indoor navigation systems. This includes the processes of mapping, localization, routing, rendering, creation of indoor navigation information and the user interface.

### *A. Subjective importance of informational tags*

Looking at the holistic response behaviour (Table 3), one can see that the groups with impairments seem to have a higher need for information than the "*able-bodied*" group. This assumption can be extracted from the fact that considerably more items were marked as supportive by at least 50 % of participants. The contrast is particularly clear for the categories *obstacles* and *missing aids*. Here, only the items "missing signs" and "missing elevators" were identified as a relevant information by "*able-bodied*", while "*visually impaired*" and "*motorically impaired*" considered all items in these categories important overall. The exceptions are the items "furniture" and "window", which were not considered supportive by any group of at least 50 % of the participants. In the category *route descriptions*, items, that are contributing to an elementary navigation, are relevant for all groups. One reason for this universal appreciation could be their functional nature for navigation. These items include, for example, "corridor/ hallway", "elevator", "staircase", "room type" and "exits". Finally, some items can be considered indispensable for individual groups. For example, "information/service point" for "*visually impaired*" or "accessible entrance" for "*motorically impaired*". It is interesting to note that "*able-bodied*" do not identify any such indispensable items.

**Technical implication**

Only two items are insignificant for all groups. From that, the results only give a limited insight into whether information is completely negligible for the mapping process. The building elements that can be interacted with have to be mapped, as basis for a navigation process. In addition to these basic building elements indispensable information for people with impairments must be included in every mapping process. All indispensable information should be marked on the map clearly and distinctly. This includes *obstacles* and (*missing*) *aids* for impaired people and should be rendered with customized symbols for the relevant groups.

### *B. Group differences concerning the subjective importance of navigational tags*

User requirements can be inferred from the differences in the importance of items according to the user groups. "*Able-bodied*" have a lower interest in (*missing*) *aids* and in *obstacles*. Looking at these categories in more detail in Table 3 and the data for the group "*motorically impaired*", the pattern points to a functional requirement concerning the implied items for both impaired groups. However, it becomes apparent that not all items are of equal importance for people with impairments.

Items such as "information on floor surface conditions", "information on accessibility" or "handrails" do occur in both groups and seem to fulfil a function of general assistance for impaired people. However, as expected, the requirements for

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TABLE V. TIME RELATED IMPORTANCE OF INDIVIDUAL ITEMS

| Categories | Items | Groups | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *All* | | | *Visually impaired* | | | *Able-bodied* | | | *Motorically impaired* | | |
| | | before | during | *p-value** | before | during | *p-value** | before | during | *p-value** | before | during | *p-value** |
| General information and building data | Building structure | 4.1 | 4.32 | .298 | 4.42 | 4.63 | .408 | 4.06 | 4.16 | .609 | 4.13 | 4.25 | .025 |
| | Access and access restrictions | 4.07 | 3.82 | .075 | 4.06 | 3.59 | .119 | 3.97 | 3.75 | .243 | 4.29 | 4.43 | .001 |
| | Information/service point | 4.2 | 4.16 | .699 | 4.89 | 4.89 | 1 | 3.91 | 3.81 | .540 | 3.88 | 4.13 | .001 |
| | Opening hours | 4.52 | 3.23 | .000 | 4.37 | 3.37 | .006 | 4.69 | 3.19 | 0 | 4.38 | 3.75 | .242 |
| | Address | 4.41 | 2.55 | .000 | 4.26 | 3 | .006 | 4.56 | 2.25 | 0 | 4.38 | 3.63 | .448 |
| | Contact details | 3.73 | 3.11 | .000 | 4.32 | 3.63 | .028 | 3.56 | 2.84 | .004 | 3.5 | 3.63 | .001 |
| | Information on the outdoor facilities | 3.02 | 2.57 | .004 | 3.47 | 3.05 | .149 | 2.78 | 2.25 | .013 | 3.25 | 3.28 | .001 |
| Route description | Corridor/hallway | 4.05 | 4.38 | .023 | 4.32 | 4.37 | .749 | 4.06 | 4.45 | .050 | 3.5 | 4.13 | .140 |
| | Information on floor surface characteristics | 2.61 | 2.51 | .252 | 3.42 | 3.32 | .682 | 2 | 1.97 | .813 | 4 | 3.25 | .048 |
| | Information/service point | 4.05 | 4.25 | .077 | 4.79 | 4.68 | .429 | 3.74 | 4.1 | .014 | 3.88 | 3.88 | 1 |
| | Elevator | 3.96 | 4.16 | .151 | 3.74 | 3.74 | 1 | 3.94 | 4.26 | .039 | 4.5 | 4.5 | - |
| | Escalator | 3.58 | 3.77 | .151 | 3.79 | 4.26 | .035 | 3.58 | 3.55 | .823 | 3.5 | 3.63 | .351 |
| | Horizontal escalator | 2.89 | 3.25 | .033 | 3.26 | 3.79 | .047 | 2.68 | 2.94 | .244 | 3.13 | 3.5 | .351 |
| | Distinctive points | 3.44 | 3.88 | .007 | 3.63 | 4.05 | .028 | 3.39 | 3.84 | .050 | 3.5 | 3.75 | .563 |
| | Doors | 3.67 | 3.96 | .014 | 4.16 | 4.26 | .607 | 3.5 | 4.03 | .001 | 3.38 | 3.5 | .785 |
| | Exits | 4.18 | 4.59 | .003 | 4.58 | 4.68 | .607 | 4.1 | 4.65 | .005 | 3.75 | 4.25 | .104 |
| Distinctive points | Furniture | 2.66 | 3.2 | .001 | 2.95 | 3.11 | .331 | 2.5 | 3.22 | .003 | 3.38 | 3.75 | .285 |
| | Toilets | 3.86 | 4.13 | .024 | 3.95 | 4.26 | .163 | 3.69 | 3.97 | .083 | 4.75 | 4.75 | - |
| | Vending machines | 2.8 | 3.2 | .008 | 3.11 | 3.37 | .172 | 2.63 | 3.16 | .017 | 3.63 | 3.5 | .732 |
| | Purpose-oriented equipment | 4.09 | 3.98 | .204 | 4.05 | 3.74 | .010 | 4.09 | 4.09 | 1.0 | 4.13 | 4 | .351 |
| | Emergency exits | 3.54 | 3.89 | .003 | 3.32 | 3.74 | .104 | 3.66 | 4 | .014 | 3.88 | 4.13 | .351 |
| | Staircases | 4.07 | 4.23 | .107 | 4.47 | 4.42 | .667 | 3.97 | 4.28 | .023 | 3.75 | 3.75 | 1 |
| Obstacles | Floor surface characteristics | 2.43 | 2.7 | .015 | 3.05 | 3.42 | .090 | 1.91 | 2.16 | .088 | 3.75 | 3.88 | .351 |
| | Number of steps | 2.68 | 2.95 | .018 | 2.37 | 2.68 | .111 | 2.59 | 2.88 | .083 | 4 | 4.25 | .351 |
| | Doors | 2.95 | 3.43 | .0 | 3.32 | 3.79 | .083 | 2.78 | 3.28 | .001 | 3.13 | 3.5 | .08 |
| | Furniture | 2.32 | 2.77 | .001 | 2.74 | 2.89 | .331 | 2.09 | 2.75 | .002 | 2.88 | 3.13 | .170 |
| Missing aids | Missing handrails | 2.54 | 2.73 | .038 | 2.72 | 3.11 | .168 | 2.29 | 2.55 | .043 | 3.5 | 3.5 | 1.00 |
| | Missing accessibility information | 2.96 | 2.78 | .063 | 3.18 | 3.06 | .718 | 2.59 | 2.28 | .023 | 4.88 | 4.5 | .197 |
| | Missing audio output | 2.58 | 2.38 | .040 | 3.82 | 3.47 | .188 | 1.91 | 1.81 | .263 | 2.75 | 2.5 | .170 |

* p-value < 0.05 (alpha level is 5 %)

"*visually impaired*" lie with items such as "missing braille/tactile writing", "missing audio output" or "big halls". This information is important for blind and visually impaired people to find their way around buildings. For "motorically impaired" on the other hand, the focus is on "thresholds", "(missing) wheelchair ramps" and "number of steps", because these structural conditions can represent potential insurmountable obstacles or general problems during navigation. In line with this, Table 3 shows that "motorically impaired" rate "emergency exits" as subjectively more important than the other groups, which could be an effect of the small group size. Nevertheless, emergency exits often contain stairs that may be difficult or impossible to climb for this group. It is therefore possible that this information is more important to know about an unfamiliar building for "motorically impaired" people. Although distinctive groups can be built, the results strongly suggest that the available information needs to be more customizable. In the case of a navigation application, this refers to the user interface, the rendering of the map and an individualization of the detailed navigation information. People with multiple disabilities are quite common, and generally it can be said that needs, as well as skills, differ greatly for each individual [30]. It is possible that a person may choose one user group, while still prioritising some information that is typical for another one to achieve an individualized navigation

### Technical Implications

All mapped information must be filtered for the computation of the routing path and individualized map rendering. En route, people with impairments rely on more detailed information for the navigation instructions. Although this study had no focus in this, certain typical behaviors probably also need to be included in the routing algorithm. Visually impaired people, for example, may tend to walk near walls and not in the middle of corridors or rooms as a means of using the wall for orientation. Thus, furniture situated at or close to walls needs to be considered while computing a routing path for this group. Able-bodied people do not need very detailed navigation instructions. For permanent building properties that can help or obstruct, an advance warning or information is beneficial. This includes statements about the general opening mode of doors (swinging or sliding, automatic or manual, and their opening direction), obstacles and missing aids. For the positioning and localization, it is essential that obstacles can be displayed in the navigation instructions as accurately as possible.

While user groups imply some general indications on what should be included in the navigation path, it is important to distinguish subgroups. Visually impaired people range from having low vision to being completely blind [29] and motorically impaired is a collective term for a diverse range of people with diverse skills and needs. As such, the item "number of steps", for example, can be the decisive piece of information for whether a staircase can be used to access another floor or not. Not every motorically impaired person depends on a wheelchair and might therefore be capable of using shorter stairs. An important note is the inclusion of accessibility information for emergency routes in a navigation application. As most of them include stairs, people with visual or motorical impairments need information about accessible routes or alternatives in case of an emergency. The routing path must further not only include user groups and their determined preferences in its computation. Individual decisions concerning the preferred route restrictions have to be taken into account in the calculation. Consequently, user groups are only sufficient to construct default settings in the user interface. It is more important to keep in mind that all users must be free to further restrict or arbitrarily extend default settings according to their personal needs and preferences.

### *C. Significant differences in the importance/support of information before and during navigation*

The results show a partial difference in the assessment whether the information is provided before a navigation for familiarization with the environment or during the navigation itself. Group differences can be found here as well. However, in the questionnaire, the query about the importance of information before a navigational task always came before the query about the importance during the navigation itself. The order of questions was not randomized to not confuse the participants with an incongruent order of events. A bias can therefore not be ruled out.

Especially in the group "*able-bodied*", significant differences in the desirability of information before or during a navigation can be observed. A possible explanation is that it may not be as relevant for this group to create a mental map before visiting an unfamiliar building. *Route descriptions* on site are all the more important for this group. "*Motorically impaired*" show only a few significant differences in agreement, that can be attributed to the small sample size. For the groups "*able-bodied*" and "*visually impaired*", the items "opening hours", "address" and "contact details" are significantly more important before a navigation. As this is a logical assessment, it shows that the participants understood the intent of both conditions (before and during) for the quesionts in the survey, which serves as a manipulation check. "Escalators", "horizontal escalators" as well as "distinctive points" (e.g. statues) are more important for "*visually impaired*" in the category *route descriptions* during a navigation. When detached furniture is considered as part of the item "distinctive points", all named items can represent possible obstacles, hazards, or at least building sections that require more attention.

#### Technical implications

The results show that not all information about a building is relevant for the navigation itself. "Opening hours", "address" and "contact details" for example are more important in the general information category for all groups as information before navigation. This is explainable, since they are essential for the journey and the planning of a visit. This information can be shown in a separate window or notification in the user interface if the need arises to look it up. The time-dependent importance is also individual for each user group.

#### Limitations of the study

The number of participants in the questionnaire turned out to be quite small overall, which is why no strong statements can be made for "*motorically impaired*". If there were more participants, it would probably be possible to form additional groups that could be differentiated more precisely. It is also possible that there are intersections among the groups like the ranking of the item "missing tactile paving" emphasizes for "*motorically impaired*" in Table 3.

## VI. Conclusion

In this paper we showed that navigation information depends on various factors. User groups can be differentiated by their individual needs and wishes. Although the user groups already indicate classification of necessary navigation information, individualization should be available in an application. The need for information depth seems to differ according to the user groups and can be supplied with varying details at separate stages of the navigational process. Informational needs during different stages of navigation are a subject of further study.

Further research is necessary to include more user groups and validate the findings of this study. These groups should not only include further impairments like cognitive or hearing impaired people, but also people with temporary impairments like crutches or buggies. The presented results offer a groundwork on user-centered requirements and how they might be addressed in the stages of technological development. Based on these fundamental results, future research needs to look into the presentation of this data. Route descriptions might differ substantially for varying user grous. Also, within the context of indoor navigation the impact of cognitive load has to be evaluated, especially when applying additional details to navigational instructions as well as the map presentation itself. Furthermore, future works should address the familiarity with a building as well to include further refinements in the granularity that is necessary for an indoor navigation.

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