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Indoor Landmark and Indoor Wayfinding: The Indoor Landmark Identification issue

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Master's Thesis

Submission: 07.07.2017

Study Course: Cartography M.Sc.

Supervisor: M.Sc. Juliane Cron, M.Sc. Hao Lyu

2017

Declaration of Originality

I hereby declare that the submitted Master's thesis entitled

Indoor landmark and indoor wayfinding: The indoor landmark identification issue

is my own work and that, to the best of my knowledge, it contains no material that has been published previously, or substantially overlapping with material submitted for any other degree or other purposes at any institution, except for the sources where acknowledgement is made in the text.

Munich, July 7, 2017

Rohini Gangaputra

Acknowledgement

I would like to express my greatest gratitude to my supervisors, Juliane Cron, PhD candidate and programme coordinator of the international Master of Science programme in Cartography at the Chair of Cartography at Technical University of Munich and Hao Lyu, PhD candidate in Chair of Cartography at Technical University of Munich, for the two have immensely supported me in the process of this thesis work.

Furthermore, I would like to thank all the Professors in Munich, Vienna and Dresden who have helped me in various aspects of my Master's programme.

I also would like to express my special thanks to Natasha Pirani, Moris Zahtila, Bryant Huether, Armand Kapaj, Jessica Gosling-Goldsmith, Natalie Barbosa Mejia, Maria Turchenko, Karen Byrne, Sarah Phillips, Roar Engell, Laura Eichler, Maia Zumbulidze, Nita Maulia, and Martin Hilljegerdes, Cartography students of 2016 intake for taking part in the user test and contributing to my thesis work.

I would like to thank my classmates for having shown endless friendship and supporting me in my hardships and for giving me some very precious moments which are unforgettable and will be cherished for this lifetime.

And finally, a heartfelt thanks to my dear husband and to my family for being with me irrespective of time and situations.

Abstract

Based on the recent decades' researches, it can be seen that way finding and navigation are playing a vital role and are being the most popular research areas of Location Based Services. Although wayfinding and navigation, when concerned with the outdoor environment is a vastly explored area, it has been gaining more attention in the indoor environment in recent times. Indoor navigation as compared to outdoor navigation has its dependence on the technology (Lyu, H. et al., 2015) which has some limitations concerning the accuracy of location information, required output media and also cognition of the user concerning the indoor environment.

In spite of all the theories on indoor landmark and indoor wayfinding and many experiments being conducted, indoor navigation still needs to be explored and explained in order to make navigation in an indoor environment easier. Through this thesis, an attempt is made to make navigating in an indoor environment easier. The paper focuses on developing a more vivid definition for indoor landmark, a flowchart on how an indoor landmark could be derived, comparison between an indoor and an outdoor landmark and characteristics of an indoor landmark. The feasibility of the developed theories are proved by conducting case study.

The user test gave desired results. The definition given in the hypothesis is vivid and completely explains and defines an indoor landmark. From the questionnaire feedback, it was seen that most of the participants could differentiate between an indoor and an outdoor landmark and have gained knowledge about the characteristics of an indoor landmark. Though, more than half of the participants were from a similar educational background, they said that the user test had given them a much clear impression of the difference between indoor and outdoor landmark and navigation in an indoor structure. As the indoor objects can be classified into three different types such as figural level, vista level, environmental level, one of the findings of this thesis along with fulfilling the above mentioned proposals is that indoor landmarks should fall under vista and environmental level. An indoor landmark falls into figural level only if there are no prominent landmarks that fall under vista and environmental level in the chosen location as figural level objects are replaceable.

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1 Introduction

1.1 Navigation in Indoor and Outdoor Environments

Navigation refers to the study that involves the determination of position and direction. It is a known fact that outdoor navigation has gained utmost prominence in the past decade. Technically, scientifically and academically, navigation focused on the outdoor cartography and less prominence was given to indoor cartography. In fact, outdoor navigation has become so prominent that it is used in a person's day-to-day life with different tools like maps, GPS, smartphone apps. Nevertheless, it is seen from recent publications on indoor cartography that lately, indoor navigation is being the main focus for researchers which resulted in developing relevant theories for academia and also leading to technical developments. In spite of the contributions made, the indoor navigation stream is in need of a constant development and attention, which means that to take the indoor navigation on to a practical level, lot more research has to be done and the results should be accessible to the audience. It can be said that lack of accurate data and expensive technology are two of the main reasons for indoor navigation to fall behind in development than outdoor navigation.

Through this thesis, an attempt is made to contribute theoretically to the field of indoor navigation.

Indoor navigation is becoming a much bigger topic day-by-day because of the complexity it is causing in a person's daily life. Navigation is supposed to be one of the simplest tasks in one's life to make travelling easier. But, in today's urban world, navigation is no more an easy task. Especially, when it is related to a complex indoor structure, it is becoming almost impossible at times to reach the desired destination. This thesis, as the title denotes, addresses the issue of indoor navigation and indoor landmark identification. In the fast growing field of Geographic Information Systems, it is absolutely important that we use navigational equipment such as GPS (Global Positioning System) and maps to make our lives simpler and save time. But this scenario is true only when outdoor environment such as roads are considered, as there is already sufficient data and media that is being implemented into the navigational systems that are being used in a person's day-to-day life. Also, there is constant attention to detail of the data being uploaded and with the increasing technology, it is becoming easier to update the navigational systems for more accurate information. In order to implement this indoors such as in university buildings, airports, shopping malls, etc., the researchers are finding inhibitions with the technology which has some limitations concerning the accuracy of location information, required output media and also cognition of the user.

1.2 Background and Motivation

Lyu, H. et al. (2015) proposed guidelines for the users to perform better navigating and orienting in an indoor environment by building mental maps, reasoning of a route plan, and re-orienting for maintaining the right direction. There are sometimes failures in navigating in an indoor environment because of the poorly executed design of the building and the poorly designed sign system and numbering system.

Indoor wayfinding is usually performed in two situations: 1) when people plan their route across multiple rooms in a complex indoor structure and 2) when people want to find a place in a big complex building. Reorientation takes place when people face choices between different directions (or routes). Landmarks are important in both the above mentioned tasks for which spatial knowledge is also required.

Spatial knowledge for wayfinding can be categorized into three levels, i.e. landmark knowledge, route knowledge and survey knowledge. Landmarks are served in wayfinding for multiple purposes, such as organizing space structure, indicating orientation, and denoting location (Lynch, K., 1960; Presson, CC. and Montello, DR., 1988; Lovelace, K. et al., 1999). For navigation applications, landmarks are also considered as important elements (Burnett GE, 1998; Hölscher, C. et al., 2006; Millonig, A. and Schechtner, K., 2007).

The research done till today in the field of indoor navigation has truly achieved notable success along with theoretical, scientific and technical developments. Although, while revising the context of the previous papers, there is an unoccupied space where a clear definition of an indoor landmark is lacking. Or, it can be said, a more vivid definition is required in order to understand the scenario of indoor landmarks and indoor navigation along with which we also need to understand the workflow of how to derive an indoor landmark and how it is different from outdoor landmark and navigation.

Therefore, the aim of this thesis is to develop a vivid definition for indoor landmark and study the existing research papers of Lynch, Presson and Montello and Lovelace as well as Burnett, Hölschcer, Millonig and Schechtner on indoor landmark extraction and indoor navigation. In addition, the thesis focuses on deriving a flowchart on how indoor landmarks would be identified and derived, comparisons between an indoor and an outdoor landmark and also on defining the characteristics of an indoor landmark. A user test is conducted in order to prove the hypotheses developed.

1.3 Problem Statement and Goals

Ohm, C. et al. introduced in 2014 the entities that could be indoor landmarks, for example, doors and stairs (Ohm, C., 2014). But, a vivid definition of an indoor landmark is still to be developed, along with this, the differences between and indoor and an outdoor landmark, extraction process of an indoor landmark and identification of the characteristics of indoor landmarks are to be given insights for the development of indoor navigation. To address these problems, the goals of this thesis are listed as follows:

1. To give a theory on differences between an indoor landmark and an outdoor landmark and describing the characteristics of an indoor landmark.
2. To develop a vivid definition for the term ‘indoor landmark’ that can be used by the future researchers.
3. To develop a flow chart that describes the flow of actions performed in identifying a geographical or a structural entity as a landmark.
4. To perform a user test in order to verify the above mentioned theories.

1.4 Hypotheses and Research Questions

1.4.1 Indoor Landmark Definition

Lynch, K. (1960) defined landmarks as external points of reference that are not part of a route. While this definition forms the basis of any landmark, the definition of the indoor landmark is given through a hypothesis as:

An ‘Indoor Landmark’ is a point of interest in the inside of a structure which could be a route maintenance point, an external point of reference or a route decision point that can either help the person to navigate and explore inside the building or to locate the desired point of interest.

The above definition explains that any entity that is helpful in maintaining the route taken, deciding which route has to be taken and/or can be taken as a point of reference in any indoor structure can be considered as a landmark. This landmark can be either used to reach a particular destination or to explore in the inside of the structure.

1.4.2 Research Questions

The potential research questions, based on the above mentioned goals of this thesis include:

1. What is the difference between and indoor and an outdoor landmark?
2. What are the characteristics of an indoor landmark? What feature or quality belonging to an entity would serve as a landmark in an indoor structure?
3. How can an indoor landmark be defined?
4. What are the indicators on how these indoor landmarks should be extracted?

1.5 Methodology

To answer the research questions mentioned above, certain methods are adopted for each of the questions.

The behaviour of the participants, during and after the user test is studied in the process of determining the differences between an outdoor landmark and an indoor landmark. The user test also helped further in determining the characteristics of an indoor landmark.

For defining indoor landmark, screening of the existing definitions of an indoor landmark by preparing matrix tables of keywords of the definitions from the previous papers was performed. Also, two landmark tables were prepared for two different routes of Technische Universität München (TUM) main campus by describing the landmark category and the information related to the landmark. A whole new and vivid definition is developed by considering the results of previous research works and the results of user test conducted in the process of this thesis.
The flow chart for showing the procedure of deriving a landmark is developed by observation of the participants' behaviour during the user test, pre-test procedure results and also from previous results of the research done on indoor landmark and indoor wayfinding.

As mentioned in the above paragraph, a pre-test is done by taking two different routes from the TUM main campus into consideration to give the participants an idea of what an indoor landmark is, what necessary information is to be provided while describing a route. This is continued with a user test.

1.6 Thesis Structure

Chapter 2 of this thesis consists of the literature review on the previous scientific results i.e. the previous scientific papers on indoor landmarks and indoor navigation are studied and a literature review is given based on the results of the studied papers.

The next chapter 3 includes a landmark keywords table which is developed using the previous definitions of indoor landmarks. Also, the chapter includes two other landmarks tables that were developed to perform the user test of two different routes within the TUM main campus building.

The fourth chapter of the thesis describes the user test and its analysis. By performing the user test, the behaviour of the participants is analysed in attributing a particular structure to a landmark, which further contributed in explaining about an indoor landmark, indoor navigation and the characteristics of an indoor landmark.

Chapter 5 explains the thesis results which starts by defining an indoor landmark, followed by determining the characteristics of an indoor landmark, comparison and differences between an indoor and an outdoor landmark, a flow chart which describes the steps that can be followed in order to derive a landmark and extraction of a set of potential landmarks.

Conclusions and further research that can be conducted in the field of indoor navigation in described in chapter 6.

2 Literature Review and Scientific Background

Navigation is all about ascertaining one's position, planning of a route from that position to a destination and following the route. From day-to day navigation experience, it can be said that, for planning of a route from one location to another, spatial knowledge is required. Spatial cognition plays an important role in planning a route between two or more locations. According to Denis, M. and Loomis, JM. (2007), spatial cognition refers to the acquisition, organization, utilization, and revision of knowledge about the spatial environments. These capabilities enable humans to manage basic and high-level cognitive tasks in everyday life which include navigating indoors as one of the main tasks. Researchers have been working on indoor navigation focusing on various aspects along with spatial cognition. These aspects include visual salience, structural salience, semantic salience, cognitive model of indoor environment, representation of indoor places, and several others. In the following sub-chapters, a clear elaboration of these aspects are given one after the other, initiating with the importance of spatial cognition for wayfinding.

2.1 Spatial Cognition for Wayfinding

Spatial cognition researches have shown that humans often need landmarks for an easy and successful wayfinding and when indoor scenario is considered, the indoor navigation systems are required to contain landmark information to improve their usability. From the research work by Wang, RF. and Brockmole, JR. (2003); Hölscher, C. et al. (2006), it is stated that people in buildings can hardly maintain a sense of global orientation, they also tend to assume the same configuration on different floors, and get confused when floors change. From this, it can be said that wayfinding in unfamiliar buildings is never an easy task. Therefore, during way-finding, people need to build up mental maps, reason a route plan, re-orientate and keep the right direction (Lyu, H. et al., 2015). They may lose their path, whenever a mistake takes place. These mistakes may occur due to unconventional architectural design, poorly designed sign system and numbering system. Navigation systems with automatic routing function shall be useful for way finders. Landmarks are needed to increase the usability of navigation systems (Gluck, M., 1991).

Many landmark based indoor navigation applications have been reported, but most of them use pre-defined landmarks, while only a few of them considered landmark selection process (Lyu, H. et al., 2015). In the already mentioned publication, Lyu et al. attempted to enrich the landmark concept with theories on cognition, affordance and space syntax by proposing

several salience indicators and a computational method for the extraction of indoor landmarks from a geo-database. The paper gave a conclusion that indoor navigation is still on its early stage.

Knowledge about human spatial cognition is very important for explaining, predicting and understanding people's behaviour in a geographic space (Mark, D., 1997). Human spatial cognition is a part of the interdisciplinary research area of cognitive science. Researchers from many academic disciplines, such as psychology, linguistics, anthropology, philosophy, and computer science investigate about mind, reason, experience, and people's conceptualizations of the world in which they live (Lakoff, G., 1987). In particular, cognitive science deals with the study of human intelligence in all of its forms, from perception and action to language and reasoning. The exercise of intelligence is called cognition (Osherson, D. and Lasnik, H., 1990).

Mark et al. (1999) present a hypothetical information flow model for spatial and geographical cognition. It consists of four stages: 1) acquisition of geographical knowledge, 2) mental representations of geographical knowledge, 3) knowledge use, and 4) communication of geographical information. Spatial cognition refers to both perceptual and conceptual processes involved in understanding the physical environment. Therefore, wayfinding theories need to integrate a link between perception and cognition if they want to serve as plausible accounts of people's everyday experience (Allen, G., 1999).

2.1.1 Navigational Tasks and Communication of Navigational Information

Navigation has two fundamental tasks: wayfinding and motion. These tasks are performed iteratively until people reach their destinations. The term 'wayfinding' was originally introduced by Lynch, K. (1960). Golledge, R. (1999) described it as a purposive, directed and motivated activity of determining and following a path or route between an origin and a destination. During wayfinding in an unfamiliar environment, people cannot use an internal map but have to rely on the external sources to satisfy their information needs (Gluck, M., 1991). Positioning and re-orientation are two major parts of navigation. It is given in this paper that positioning takes place when people need to check their location. Mental maps or external tools such as GPS receiver or maps are often involved in positioning. Re-orientation takes place when people face choices between different directions or routes. Landmarks are important in both of these tasks. According to Golledge, R. (1999), basic geometry of space and its cognitive maps can

be summarized in terms of points, lines, areas, and surfaces. Thus, wayfinding environment is usually represented as route network and referenced with landmarks.

Findings in spatial cognition have shown that humans need landmarks for an easy and successful wayfinding.

There are two different kinds of route directions to convey the navigational information to the user, either in terms of description (verbal instructions) or by means of a depiction (route map). According to Tversky, B. and Lee, P. (1999) the structure and semantic content of both is equal. It is important to consider information needs because people trying to find their ways in unfamiliar environments do not have a previously acquired mental representation. Therefore, they depend on external information. Simulating people's wayfinding behaviour in a cognitively possible way requires the integration of structures for information perception and cognition in the underlying model. Raubal, M. and Winter, S. (2002) used a cognizing agent to simulate people's wayfinding processes in unfamiliar buildings. The agent-based model consists of two tiers: simulated states of the environment and simulated beliefs of the agent according to the authors. The agent is modelled with state, an observation schema, a specific wayfinding strategy, and common sense knowledge.

2.1.2 Knowledge in the World-Dependency on External Information

Wayfinding and orientation form integral parts of people's daily lives. Many a times, we have to find our ways through cities, through buildings, along streets and highways, etc. At times, the environment to be navigated is unfamiliar. People visit the place for the first time and have to find a goal without the help of a previously acquired mental map. Therefore, they depend on external information or what Norman, D. (1988) calls knowledge in the world. Such knowledge involves the environment and is communicated through signs, guidance systems, and architectural clues. In many cases people find it difficult to perform wayfinding tasks in an unfamiliar environment because they are not provided with adequate or sufficient knowledge in the world. The main reason for environments being too complex to facilitate wayfinding is deficiency of clues (Raubal, M. and Egenhofer, M., 1998). They either lack sufficient wayfinding information or their architectures are poorly designed and therefore not readable.

Previous research focused on the development of computational models that simulate wayfinding in familiar environments. Route-planning tasks are solved with the help of a simulated cognitive map. During wayfinding in an unfamiliar environment people cannot use

an internal map but have to rely on other sources to satisfy their information needs (Gluck, M., 1991).

Human wayfinding research investigates the processes that take place when people orient themselves and navigate through space. Theories try to explain how people find their ways in the physical world, how they communicate directions, and how people's verbal and visual abilities influence wayfinding. Allen, G. (1999) and Golledge, R. (1999) describe wayfinding behaviour as purposeful, directed, and motivated movement from an origin to a specific distant destination that cannot be perceived directly by the traveller. Such behaviour involves interactions between the traveller and the environment. Human wayfinding takes place in large-scale spaces (Downs, R. and Stea, D., 1977; Kuipers, B., 1978). Such spaces cannot be perceived from a single viewpoint, therefore people have to navigate through large-scale spaces to experience them. Examples for large-scale spaces are landscapes, cities, and buildings. Wayfinding tasks can be categorized according to their functional goals. Allen, G., (1999) distinguishes between travel with the goal of reaching a familiar destination, exploratory travel with the goal of returning to a familiar point of origin, and travel with the goal of reaching a novel destination. Raubal, M. (1997) focuses on the task of finding one's way to a novel destination in an unfamiliar environment. In such situations, people have to rely on symbolic spatial information communicated to them through the environment. Key processes for this type of communication relate to abilities such as matching real-world features against knowledge schemas of those features and understanding the symbols commonly used to represent real features (Golledge, R., 1999).

People's spatial abilities mainly depend on the following four interactive resources: 1) perceptual capabilities, 2) fundamental information processing capabilities, 3) previously acquired knowledge, and 4) motor capabilities (Allen, G., 1999). These abilities are a necessary prerequisite for people to find a way from an origin point to a destination point. They are supposed to use environmental information, representations of spatial knowledge, and move through the environment. Wayfinding in a building is mainly concerned with the interactions between a mobile observer and large stationary objects. The foundation for this class of spatial abilities is sensitivity to perceptual information. Examples are obstacle avoidance and path integration. As for the spatial abilities, the cognitive abilities also depend on the task given. Finding one's way in a street network (Timpf, S. et al., 1992; Car, A., 1996) uses a different set of cognitive abilities than navigating from one room to another in a building (Gärling, T. et al., 1983; Moeser, S., 1988).

Research on people's wayfinding performance helped to establish practical guidelines on how to design public buildings to facilitate wayfinding. Arthur, P. and Passini, R. (1990) introduced

the term environmental communication (i.e., “transfer of orientation, wayfinding (direction), and other information within the built environment by means of signs and other communications devices or architectural features to enable people to reach destinations”), arguing that the built environment and its parts should function as a communication device. They mention two major aspects regarding the understanding of buildings: 1) a spatial aspect that refers to the total dimensions of the building and 2) a sequential aspect that considers a building in terms of its destination routes. Destination routes should eventually lead to the so-called destination zones. These are groupings of similar destinations within buildings into clearly identifiable zones (Arthur, P. and Passini, R., 1992). In order to facilitate wayfinding to such destination zones the circulation system should be of a form people can easily understand.

2.2 Characterization of an Entity as a Landmark

Sorrows, M.E. and Hirtle, S.C. (1999) proposed three types of landmarks. The authors presumed that the **visual**, **semantic**, and **structural attraction** of features in geographic space determine their use as landmarks in human spatial reasoning and communication. The description of the three types of attractions to characterize an entity as a landmark is given by the authors as below:

Visual Attraction: Landmarks qualify as visually attractive if they have certain visual characteristics such as a sharp contrast with their surroundings or a prominent spatial location. The formal model given by the authors of this paper for landmark saliency includes four measures regarding visual attraction: Façade area, shape, colour, and visibility.

- Façade Area: The façade area or simply, the front facing of an object is an important property for determining its contrast to surrounding objects. People tend to easily notice objects whose façade areas significantly exceed or fall below the façade areas of surrounding objects. For example, figure 1 shows a building with a contrasting facade area.

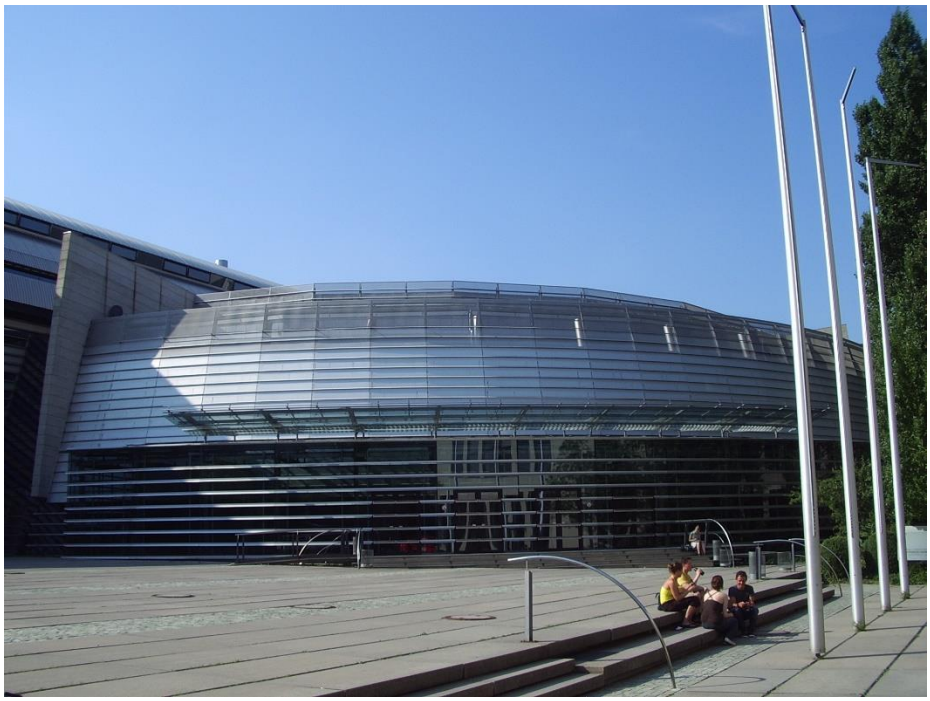


Figure 1: Façade area of TUM Audimax

- Shape: Visual attraction of an object is also determined by its shape. Unorthodox shapes like the shape of the office building of the fisheries department in Hyderabad shown in figure 2, amidst conventional rectangle-like shapes strike one's eyes. Formally, specification of the shape measure of an object is done by considering its shape factor and also the deviation of its shape from that of a rectangle. The shape factor represents the proportion of height and width. For example, skyscrapers have a high shape factor, whereas long and low buildings have a low shape factor. The value of deviation is the difference between the area of the minimum-bounding rectangle of the object's façade and its façade area.

Figure 2: Office building of fisheries department, Hyderabad, India

- Colour: An object can stand out from surrounding objects based on its colour. For example, imagine a red fire department building in the midst of a set of grey buildings or pink, yellow and green coloured buildings like seen in figure 3.

Figure 3: Pink, yellow and green coloured buildings having uniqueness of their own

- Visibility: The final property to be measured is the prominence of spatial location as seen in figure 4, where the Rathaus building is located in the centre of the city. The authors, Sorrows and Hirtle proposed to measure this property by calculating two-dimensional visibility. Visibility is considered for the space used in the actual mobility mode. It is assumed that visibility is limited by recognisability, for which reason a pre-defined buffer zone limits the considered space (and reduces computational complexity).

Figure 4: Rathaus at Marienplatz, Munich

- Other Visual Properties: Other properties of an object, such as its texture and condition also influence the contrast to surrounding objects as seen below in figures 5 and 6 respectively. The texture of an object is often hard to identify, both from databases and in the real world. The condition of an object refers to its age and cleanliness. According to the authors, age is easy to determine from a database, but often very hard to guess in the real world. For example, a building may be very old but due to a recent renovation looks new. Cleanliness is a subjective measure and therefore hard to specify within formal terms.

Figure 5: A building showing glass textured facade

Figure 6: An old house with poor maintenance

Semantic attraction: The authors' notion of semantic attraction is similar to that of cognitive attraction, which focuses on the meaning of a feature. Semantic measures for the formal model of landmark saliency comprise cultural and historical importance of an object, and explicit marks.

Structural attraction: A landmark is structurally attractive if it plays a major role or has a prominent location in the structure of the spatial environment. Examples are intersections and down-town plazas.

The definitions which are seen in the following chapter 2.3 are defining an indoor landmark based on the characteristics stated in chapter 2.2.

2.3 Analysis of Existing Definitions of an Indoor Landmark

As already mentioned above, the definition of landmark is given by Lynch, K. (1960) as an external point of reference that is not part of a route. Sorrows, M.E. and Hirtle, S.C. (1999) defined landmarks as points that serve multiple purposes in wayfinding as organizing concept which help people build up structured spatial knowledge representation and navigational tools. According to Raubal, M. and Winter, S. (2002), navigation services communicate optimal routes to users by providing sequences of instructions for these routes. Each single instruction guides the way finder from one decision point to the next. The instructions are based on geometric data from the street network, which is typically the only dataset available.

Presson, CC. and Montello, DR. (1988) proposed two kinds of landmarks based on wayfinding activity, i.e. route decision landmarks, which are cues for turnings at decision points; route maintenance points, which help to keep human on the routes.

As indoor landmark extraction is still on its early age, analysing such theories as mentioned above would contribute in developing new theories for indoor cartography. Existing cognitively based computational models for wayfinding focus primarily on the exploration of mental representations rather than focusing on the information needs for wayfinding. It is important to consider information needs because people trying to find their ways in unfamiliar environments depend on external information as they do not have a previously acquired mental representation. Lyu, H. et al. (2015) have shown that automatic selection of indoor landmark is still on its early stage and a quality-measurement system is missing.

A taxonomy proposed by Montello, DR. (1993) is introduced to help build this cognitive model for indoor wayfinding. The taxonomy contains three levels of indoor objects: **figural level** objects, **vista level** objects and **environmental level** objects. The description for these three levels is given in the following chapter.

2.3.1 Figural, Vista and Environmental Level Entities

In the year 1993, Montello, DR. proposed definitions for figural, vista and environmental level as follows:

Figural level denotes objects that are smaller than or nearly equal to the size of the human body. People can directly perceive their properties or manipulate them from one place without any location change.

Vista level denotes objects that are larger than the human body but can be visually perceived in a single view. Few examples of vista level objects include simple rooms and corridors.

Environmental level contains objects that are significantly larger than the human body. To completely perceive them, people have to make a considerable position change. Objects at this level include irregularly shaped rooms, floor configurations and entire buildings.

These classifications helped in performing the user test and deriving the landmarks. Also, what category of objects are most likely to satisfy the definition of a landmark will be seen further in this thesis.

2.3.2 Salience of a Landmark

The selection and the assessment of landmarks especially in large scale indoor environments is not very frequently examined. It is a fact that pedestrians prefer route instructions based on landmarks since they are considered to be the most effective way to communicate navigation instructions (Ohm, C. et al., 2014). The importance of this type of navigational aid is well reported. Ohm, C. et al. (2014) findings on a user study conducted in the University of Regensburg by assessing the visual attraction of objects with an eye tracker show that functional landmarks like doors and stairs are most likely to be looked at and named as an

indoor landmark. They could also prove that measuring visual salience is not enough to identify landmarks with regard to the use in a pedestrian navigation system. Previous spatial knowledge is crucial for way finding decisions and thus for selecting landmarks (May, A.J. et al., 2003).

A landmark's salience is considered to result from visual, semantic and structural properties, accompanied by its advance visibility (Sorrows, M.E. and Hirtle, S.C., 1999; Winter, S., 2003; Winter, S. et al., 2004). However, it is still an open question, what are the features of an object that are most essential to assess its suitability to serve as a landmark. This is problematic when indoor environments are considered. Instructions require a higher density of landmarks since the route usually contains more turns but then there is a smaller choice of landmark categories despite the high diversity of distinct objects available (Brunner-Friedrich, B. and Radoczky, V., 2006; Radoczky, V., 2007). Even though there is strong evidence that people tend to get lost indoors more easily than outdoors, there is still a lack of scalable and practical solutions for navigation systems in large-scale indoor environments (Brunner-Friedrich, B. and Radoczky, V., 2006). According to the user study conducted in the University of Regensburg as mentioned above, visual attraction of a landmark does not seem to be the most important feature when it is used for indoor pedestrian navigation systems and show that functional landmarks are most suitable for indoor guidance. Elevators, escalators, stairs, doors, plants, information boards and signs were selected as potential landmarks and were later assigned to one of the four landmark categories (Ohm, C. et al., 2014): 1) Architecture: pillars and fronts, 2) Function: doors, stairs and elevators, 3) Information: signs and posters and 4) Furniture: tables, chairs, benches and vending machines

The above mentioned categories are not used in this thesis but the examples that are given for the four landmark categories are used as indoor landmarks.

2.3.3 Wayfinding Instructions using Landmarks

According to Raubal, M. and Winter, S. (2002), navigation services communicate optimal routes to users by providing sequences of instructions for these routes. Each single instruction guides the way finder from one decision point to the next. These instructions are based on geometric data from the street network, which is typically the only dataset available to us, as already mentioned. Raubal, M. and Winter, S. (2002), focus on enriching such wayfinding instructions with local landmarks. The main challenges are the automatic definition and

extraction of appropriate salient features, i.e., landmarks, from the available datasets. Among the different meanings of landmark is that of an object or structure that marks a locality and is used as a point of reference (Merriam, G. and Webster, N., 2001).
Allen, G. and Golledge, R. (1999), describe wayfinding behaviour as purposeful, directed, and motivated movement from an origin to a specific distant destination, which cannot be directly perceived by the traveller. Such behaviour involves interactions between the traveller and the environment. Human wayfinding takes place in large-scale spaces (Deakin, A., 1996; Kuipers, B., 1978). Such spaces cannot be perceived from a single viewpoint. Therefore, people have to navigate through large-scale spaces to experience them. Examples for large-scale spaces are landscapes, cities, and buildings. The authors also say that people use various spatial, cognitive, and behavioural abilities to find their ways. These abilities are a necessary prerequisite to use environmental information or representations of spatial knowledge about the environment. The spatial abilities are task-dependent and seem to involve mainly four interactive resources: 1) perceptual capabilities, 2) information-processing capabilities, 3) previously acquired knowledge, and 4) motor capabilities (Allen, G., 1999). Allen distinguishes further between three categories of wayfinding tasks: 1) travel with the goal of reaching a familiar destination, 2) exploratory travel with the goal of returning to a familiar point of origin, and 3) travel with the goal of reaching a novel destination.

Landmarks are used in mental representations of space (Habel, C., 1988) and in the communication of route directions (Michon, P.E. and Denis, M., 2001; Deakin, A., 1996; Werner, S. et al., 1997). Studies show that landmarks are selected for route directions preferably at decision points (Maaß, W. and Schmauks, D., 1998; Lovelace, K. et al., 1999). Another study (Lynch, K., 1960) has shown that mapped routes enriched with landmarks at decision points lead to better guidance, or less wayfinding errors, than routes without landmarks. Lynch characterizes the quality of a landmark by its singularity, where singularity is bound to a clear form, contrast to the background, and a prominent location. The principal factor is the figure-background contrast (Metzger, W., 1936). The contrast can be produced by any property, such as uniqueness in form or function in the local or global neighbourhood. Sorrows, M.E. and Hirtle, S.C. (1999), categorize landmarks into visual (visual contrast), structural (prominent location), and cognitive (use, meaningful) ones, depending on their dominant individual quality. A landmark will be stronger the more qualities it possesses. The authors had a basic assumption that route directions enriched by local landmarks are easier to understand than the ones which are only direction and distance based.

2.4 Summary

In this chapter, an overview of the current status of indoor navigation is provided, based on the theories developed and research done till date. The most importantly discussed topics were spatial cognition for wayfinding, analysis of the existing definitions of landmark and characterization of an entity as a landmark. Spatial cognition for wayfinding briefly implies that spatial knowledge attaining should be given utmost importance for wayfinding and navigation. The existing definitions on landmark provided certain keywords defining landmarks such as external points of reference, points serving multiple purposes in wayfinding, entities that help in route decision and route maintenance. In characterizing an entity as a landmark, the previous theories on landmarks have provided with information that could help differentiate between objects and objects that could be landmarks. Visual, semantic, and structural attraction of features in geographic space determine their use as landmarks in human spatial reasoning and communication which helps in better navigation.

To contribute more to the literature review, a user test is done. A pre-user test, in which developing of a new definition of an indoor landmark takes place, as described in detail in the next chapter.

3 Developing a New Definition for an Indoor Landmark

After analysing the papers and drawing conclusions of what the papers defined an indoor landmark to be, a keyword table is formed to develop a new definition of an indoor landmark. The table is described in the chapter 3.1 and chapter 3.2 shows the two tables that were used for the pre-test in order to develop the new vivid definition of an indoor landmark. This pre-test was further performed with the two routes to derive the landmarks that fall along both the routes and to analyse the characteristics of these landmarks. This was necessary to verify the output of pre-user test with that of the results of user test and draw conclusions on what characteristics makes an entity to be defined as an indoor landmark.

3.1 Keywords for Indoor Landmark Definition

As seen below, the table is derived from the previous definitions given on landmark from various authors namely, Lynch, K. (1960), Sorrows, M.E. and Hirtle, S.C. (1999), Merriam, G. and Webster, N. (2001). These authors defined landmark clearly as already analysed in the previous chapter. The keywords of these definitions were selected as these words explain the term landmark, which helped in the further research of this thesis to develop a whole new definition for an indoor landmark.

Authors	Definition of a Landmark	Keywords
Lynch, K. (1960)	A landmark is an external point of reference that is not a part of a route.	External point of reference
Sorrows, M.E. and Hirtle, S.C. (1999)	Landmarks are points that serve multiple purposes in wayfinding as organizing concept which help people build up structured spatial knowledge representation and navigational tools.	Wayfinding, Structured spatial knowledge
Merriam, G. and Webster, N. (2001)	Landmark is that of an object or structure that marks a locality and is used as a point of reference.	Locality marker, Point of reference

Table 1: Table for keywords of indoor landmark definition by various authors

As it can be seen from the above table, the keywords that were used in defining a landmark are external points, wayfinding, structured spatial knowledge, locality marker and point of reference.
External points are the entities that are not a part of the route taken. These could serve as landmarks to maintain the route. Maintaining the route while navigating is extensively required and that makes landmarks as important as reaching the destination.
Wayfinding and structured spatial knowledge are related to spatial cognition and are the most important aspects of navigation. This is discussed in chapter 2.1.

As the keyword locality marker explains for itself, it is any entity that helps in remembering and recollecting a particular locality by making a mental representation of a landmark in a given geographical area. This marker is also used or known as a point of reference.

Deriving of the above mentioned keywords from previous definitions contributed in developing a new vivid definition by giving clues about what kind of entities could possibly be considered as landmarks.

The next sub-chapter, includes two landmark tables of two different routes taken from the TUM main campus building. These tables were developed to discover more landmarks that relate to the keywords derived in the table above. To develop these tables, a pre-test was performed by the author of this thesis along the two selected routes, which happen to be the routes including prominent locations like library, student service centre, lecture halls, snack automats etc. To give the participants of the user test an idea of some of the potential landmarks, landmark categories, giving information about the selected landmark, was the motive to perform this pre-test.

3.2 Landmark Tables

In this sub-chapter, the two landmark tables are given. The pre-test was performed with two routes as a clear elaboration of the indoor landmark concept was necessary to explain the participants before performing the user test. These two routes happen to be different from each other containing various entities as landmarks. These landmarks could vary from one route to another in any of the indoors of a structure based on its functionality. For example, landmarks in a shopping mall, airport and university building are different from one another.

The TUM was used as an example building for performing the user test as it is highly complex, wayfinding is not that easy and the building contains a good number of potential landmarks. Additionally, the chosen user group is familiar with the campus building.

The first route starts from the main entrance of the TUM main building, passing through the library, the goal is to reach room no. 0714. This particular route was selected as it had prominent entities that could be identified as landmarks like elevators, paintings, fire extinguishers, staircases etc.

The second route starts from administrative office (Student Service Centre) in the main campus building of TUM, via Carl von Linde Hörsaal to the Cafeteria on the terrace of the main building. The selection of this route was made based on the important landmarks the route has like lecture halls, elevators and a little complexity it causes.

The tables below show a total of 17 and 14 landmarks respectively for first and second route Along with the landmarks, information related to the landmark and the category into which the landmark falls are given in the table.

3.2.1 Landmarks of Route 1

The table 2 below gives information about the landmarks that were selected along the route from Main Entrance (Arcisstraße 21) to room no. 0714 via Library. As it can be seen from the table, the details that are belonging to the landmarks are also given like the information content of the landmark and the category of landmarks a selected entity belongs to. A total of 17 landmarks could be selected for this route.

S.No.	**Landmark**	**Wayfinding Instruction**	**Landmark Category**	**Keyword Related to the Landmark**
1	Main entrance door (start)	Arcisstraße 21	Vista level	External point of reference
2	Information centre	Towards left	Vista level	Locality marker
3	Staircase (right)	14/EG, Destination: Library	Environmental level	Structured spatial knowledge

4	Staircase (left)	13/EG, Destination: Library	Environmental level	Structured spatial knowledge
5	Trash boxes in yellow and blue	13/EG, Destination: Library	Figural level	External point of reference
6	Coffee machine, Snack automat, Wardrobe	13/EG, Destination: Library	Vista level	External point of reference
7	WC	Entrance of the corridor	Vista level	External point of reference
8	Fire extinguisher	Towards the exit of the corridor	Figural level	External point of reference
9	Info. Board- 0507 Bestelmeyer Nord	On the right	Vista level	Locality marker
10	Room no. 1779	End of the corridor	Vista level	External point of reference
11	Room no. 1777	'Lehrstuhl für Kartographie' (Chair of Cartography)	Vista level	External point of reference
12	Corridor exit door		Vista level	External point of reference
13	Entrance Verkehrstsechnik	On the left, walk straight	Vista level	Locality marker
14	Staircase (down)	On the right	Environmental level	Structured spatial knowledge
15	Fire extinguisher		Figural level	External point of reference
16	WC- B2/EG	U-turn	Vista level	External point of reference
17	Room no. 0714 (destination)	On the right	Vista level	External point of reference

Table 2: Pre-tested route 1 from Main entrance (Arcisstraße 21) to room no. 0714 via Library

As it can be seen from the above table, most of the landmarks fall into the category of vista level objects. It is always important that landmarks belong to either vista level or environmental level objects as figural level objects could be replaced from one position to another (chapter 2.2).

As can be seen in table 1, trash boxes of different colours, staircases, WC etc. were selected as indoor landmarks. Trash boxes were selected as landmarks because of the colour of the boxes. As seen in chapter 2.2, an entity can be identified as a landmark based on its colour varying from its surroundings. Similarly, a staircase could be a landmark based on its visibility, which is one of the characteristics to define an entity as a landmark. In addition to this, coffee machine and snack automat contribute to the category of landmarks as these entities are commonly used and are easily recognizable. A fire extinguisher could be considered as a landmark as it commonly seen in every indoor structure in almost all the floors, also it is easy to recognize because of its red colour. Most of the landmarks derived in the above table exhibit the characters that were analysed from the literature review.

3.2.2 Landmarks of Route 2

Below, the table 3 shows the landmarks that fall along the route from Administrative Office (Student Service Centre) via Carl von Linde Hörsaal to Terrace Cafeteria. Also, information regarding the landmark and the category of the landmark is also provided. A total of 14 landmarks were extracted along this route.

S.No.	**Landmark**	**Wayfinding Instruction**	**Landmark Category**	**Keyword Related to the Landmark**
1	Main entrance (start)	Arcisstraße 21	Vista level	Locality marker
2	Stair case (left)	13/EG	Environmental level	Structured spatial knowledge
3	Stair case (right)	14/EG	Environmental level	Structured spatial knowledge
4	Entrance door between staircases	Administrative office on the left	Vista level	External point of reference

5	Stair case (left)	Way to 'Carl von Linde Hörsaal'	Environmental level	Structured spatial knowledge
6	Trash boxes	On the right	Figural level	External point of reference
7	Entrance door (1.OG-0501/0510)	On the right	Vista level	Locality marker
8	WC	On the left	Vista level	External point of reference
9	Elevator	On the right	Vista level	External point of reference
10	Corridor exit door	Elevator on the right	Vista level	External point of reference
11	Entrance door to Carl von Linde	On the left	Vista level	Locality marker
12	Carl von Linde Hörsaal	Straight through the entrance and on the right	Environmental level	Locality marker
13	Elevator	Cafeteria on the 5th floor	Vista level	External point of reference
14	Staircase	On the left of the entrance (exit direction)	Environmental level	Structured spatial knowledge

Table 3: Pre-tested route 2 from Administrative office to Carl von Linde Hörsaal to Cafeteria

Similar to route 1, route 2 also has most of the landmarks that fall into the category of vista level objects. The landmarks derived for route 2 are similar to that of route 1 except for a few such as elevators and Carl von Linde Hörsaal lecture hall. Elevator is described as a landmark because of its functionality as recognisability. The lecture hall Carl von Linde Hörsaal is a landmark because of its semantic attraction. It is convenient to find objects than are larger than the size of the human body than smaller objects. Vista level and environmental level entities are easier to locate than to locate figural level objects.

Completion of the pre-user test along with its results now lead to the user test in chapter 4, where the user group perform wayfinding and locate the landmarks that fall along the two routes where the pre-user test was performed.

4 User Study for Indoor Wayfinding

This chapter holds a user test in order to answer the research questions mentioned in chapter 1.4.2. To perform this user test, students of M.S. Cartography, 2016 intake were taken into consideration. All the 20 students of this intake were asked to participate in the user test. However, at the end 14 students participated but the results can be considered as acceptable. Before starting with the user test, a presentation describing the term landmark, idea of the user test, drive through the idea, the routes to be tested and the execution procedure was given to the participants. The entire presentation is given in the annex (chapter 8.1). The hypothesis definition was not given because a proof was required for the hypothesis definition and also to avoid influencing the user group. Instead of the hypothesis definition, a simple definition of landmark was chosen to explain the participants the overall concept of identifying an entity as a landmark as given in figure 7 below.

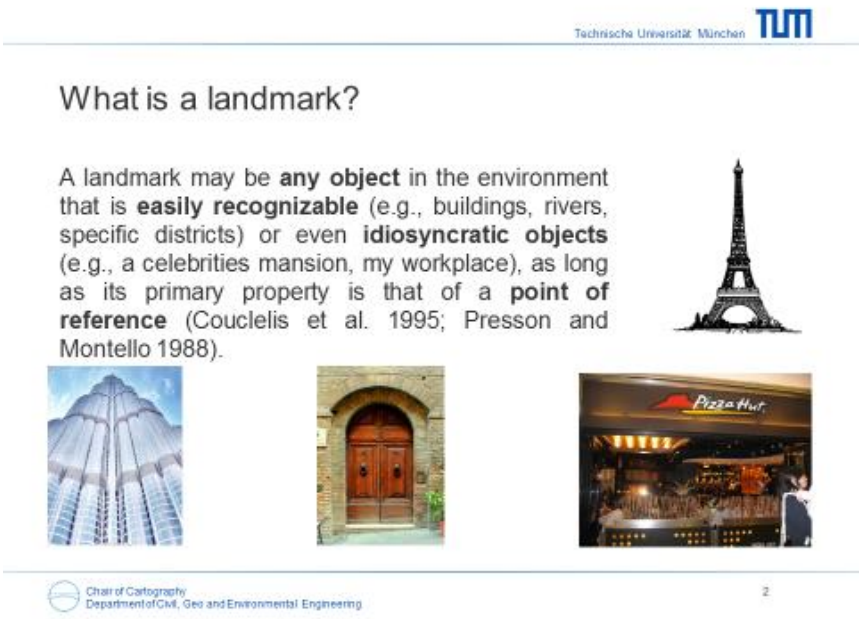


Figure 7: Landmark definition given to the participants of the user test

4.1 Task Description and User Group

After performing a pre-test of the two routes as mentioned in chapter 3.2.1 and 3.2.2, the user test was ready to be conducted. To give the students an insight about the thesis goals and explain what indoor navigation is, a presentation was given as described above and the pre-test result sheets were handed over to the participants.

Task of this user test is to derive landmarks along the two given routes, analyse the characteristics that makes the selected entities as landmarks, identify the differences between an indoor landmark and an outdoor landmark and identify already given landmarks from the results of the pre-tested routes. After the user test, a questionnaire is handed over to the participants of the user test to fill in. The results of this questionnaire are further analysed to study the knowledge gained by the participants about indoor wayfinding and indoor landmark.

	Route 1	Route 2
Group 1 (7 students)	Given: Pre-tested landmarks table	Task: New route: 12-15 landmarks
Group 2 (7 students)	Task: New route: 12-15 landmarks	Given: Pre-tested landmarks table

Table 4: Division of groups and tasks for the user test

As seen in the above table, the user test is conducted with 14 students. These 14 students are divided into 2 groups of 7 participants each. Among these 14 students, 8 were female and 6 were male, aged 22-27 on an average. The background of most of the participants was Geography, Surveying and Geo-Information. The students of group 1 analyse the pre-tested route 1 and perform wayfinding for new route 2 and vice-versa as seen from the figure above. The pre-tested route was given before performing the new route wayfinding in order to verify if the participants were influenced by the landmarks that were derived during the pre-test.

Each task takes about 15-20 minutes. To complete the user test, the time consumed is around 1 hour 10 minutes.

The questionnaire to be filled in by the participants is mentioned in appendix user test material under chapter 8.2. This questionnaire includes queries that are related to the participants' previous experience and knowledge on indoor wayfinding and navigation, the knowledge they have gained after performing the user test about indoor navigation and how it differs from outdoor navigation.

Students' knowledge about Navigation and landmarks before the user test:
Before starting the user test, students were asked to give their ideas on landmarks. Most of the students with similar background like Geology, Geography, Geological engineering, Surveying, Urban engineering had an idea of what a landmark is and what factors contribute for a feature to be a landmark. The bar chart in figure 8 below shows the students and their educational background information more precisely.

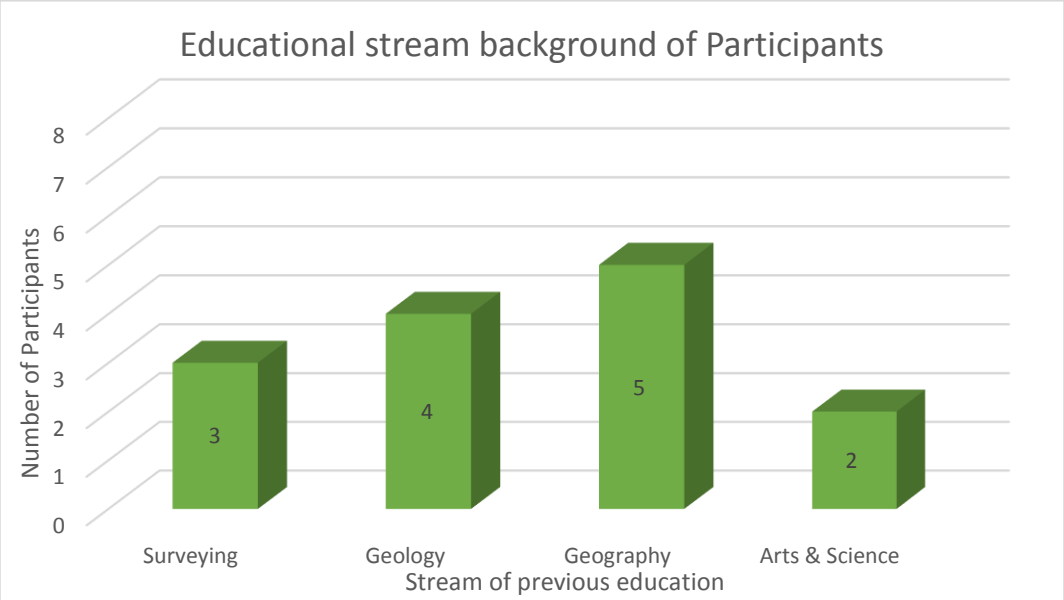


Figure 8: Educational stream background

Previously performed navigation tests in an Indoor environment:
The user test was conducted with 14 students. Out of these 14 students, only 4 students have performed a similar user test previously as the user test given to them for this thesis. These were these students with Geographic Information Systems and Geography background. This is represented graphically with a pie-chart in figure 9.

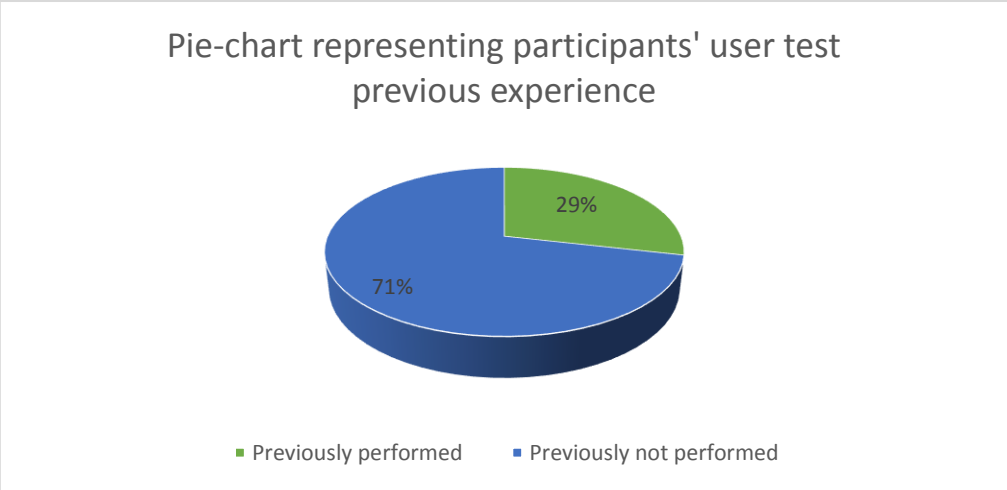


Figure 9: Previous experience of user test participants possess

4.2 User Study Motive

The motive of performing this user test is to contribute to the existing theories on indoor landmark and discover new landmarks from users' perspective. Additionally, the user test also aims to analyse the definition of a landmark and factors influencing the derivation of a landmark. This will be derived based on the behaviour of the participants while performing the user test. Additionally, the test aims to describe the differences between an indoor and an outdoor landmark. This would help the future researchers to develop vivid explanations and contribute more precisely to the field of indoor navigation. Also, the user test helps in analysing how wayfinding behaviour is exhibited in indoor environment by observing the areas of focus by the participants taking part in the user test. Based on the behaviour of the participants in the user test, a flowchart is derived depicting how a landmark can be extracted from a given geographical data.

A flow chart in figure 10 shows graphical depiction of the procedure to be followed to fulfil the motive of the user test.

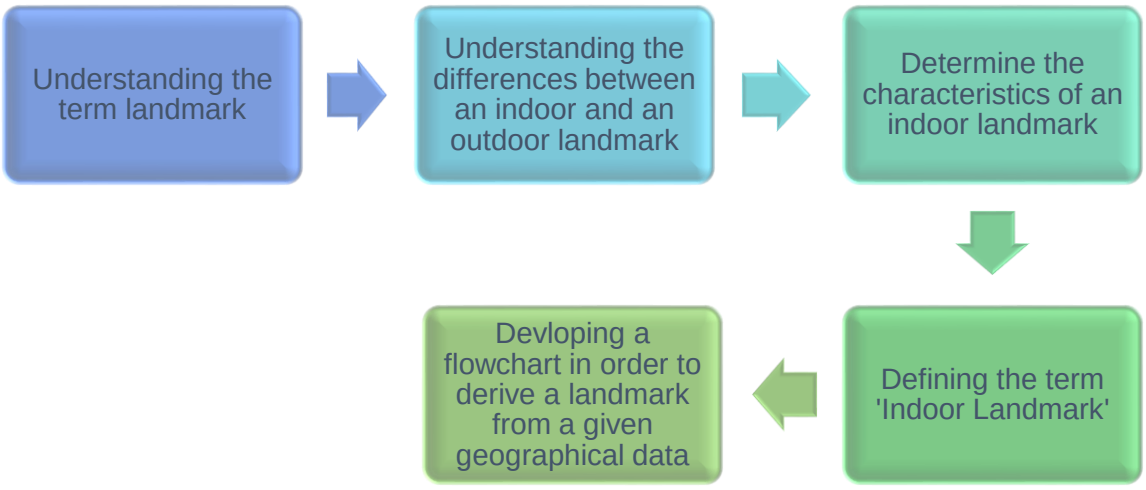


Figure 10: A flow chart describing the motive of performing the user study

4.3 Execution of the User Test

For the user test to be executed, the procedure followed is as follows:

There are two routes given as described in chapter 3.2 in which the participants are supposed to find their way and locate the landmarks which takes 15-20 minutes for each group.

While performing the identification of landmarks from the pre-tested routes, each group exhibited a behaviour of analysation which further helped them to locate the landmarks of a new route. Although, for not all the students it was easy to locate the landmarks. The students who had previous experience of performing such user test performed the task with an ease while the other faced difficulties finding the landmarks and the route to be taken. To ease the students facing difficulty, a few wayfinding instructions were given like which route to take.

While the choice of elevator available, some of the students opted to find their way through the staircase. The other users who hadn't opted for the elevator and the students who opted to use the elevator, both the groups seemed to find the consecutive destination in a similar manner.

Most of the students found route 1 to be easier than route 2 as route 1 leads to one of the lecture halls of the students that they already know. The other route 2 was quite unfamiliar

route which caused the difficulty. The participants are also asked to draw the route maps of the new route for which they are finding way and landmarks. All the participants drew the maps of the respective routes taken while only some of the maps were considered which were visually attractive and informative as visual attraction plays an important role in defining an entity as a landmark. The considered maps are shown in annex 8.3.

The anticipated results were derived based on the pre-user test and described in the following chapter 4.4

The user test was completed with the filled-in questionnaires, where the next task was to analyse the results of the user test (chapter 5).

4.4 Anticipated Results of the User Test

The anticipated results were derived as a result of the pre-user test and to answer the research questions as mentioned in 1.4.2.

The expected results should ideally contain a minimum of 10 landmarks in each given route. In addition to the landmark, the participants are also expected to provide information about/of the landmark or wayfinding instruction considering the pre-tested route as an example.

The given questionnaire is expected to be filled out by every participant from which the characteristics of indoor landmarks could be derived along with the development of a vivid definition of an indoor landmark.

As a result, the output would have the definition of the landmark, differences between an indoor and an outdoor landmark and wayfinding, a flow chart on how a landmark can be extracted from a given geography, characteristics of indoor landmarks and examples of a set of indoor landmarks.

One of the results of maps drawn by a student who took part in the user test is given in figure 11.

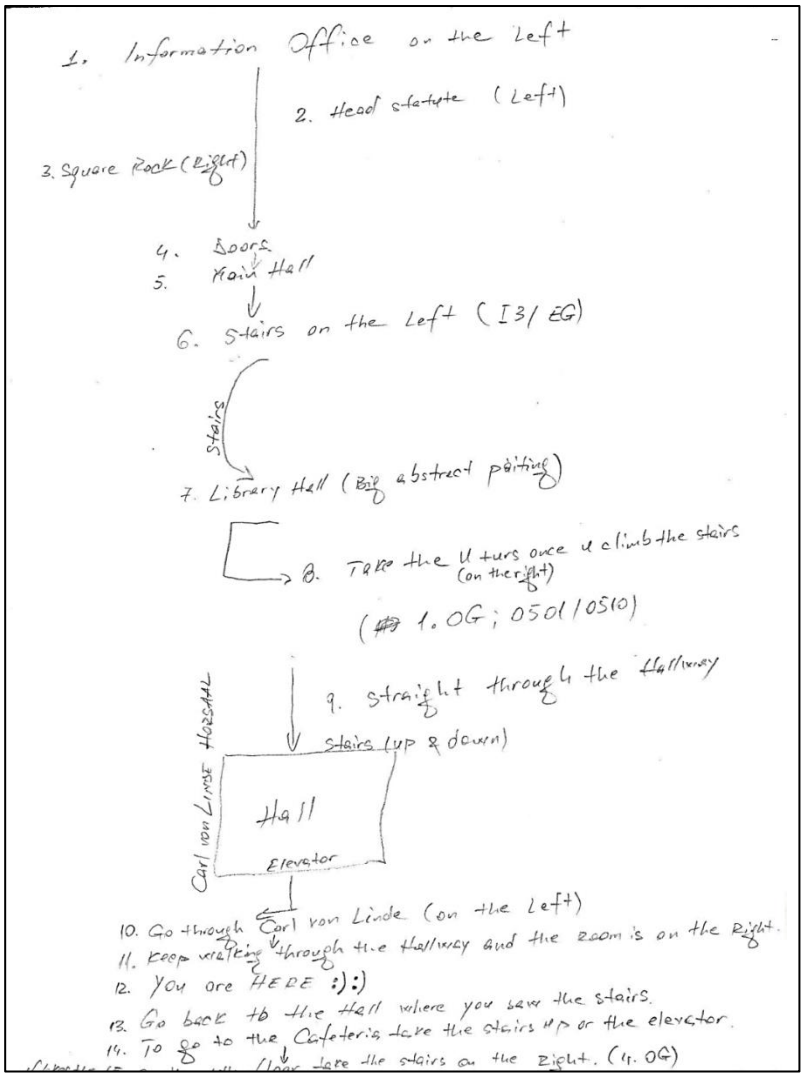


Figure 11: Route map depiction of route 2 by one of the users

The route map shows route 2. From the map, it can be seen that the participant was comfortable using arrows, wayfinding instructions and names of the entities to navigate through an unknown route rather than using symbols for landmarks.

A set of potential landmarks are also derived both from pre-user test and user test. Most of the participants derived the landmarks with ease while for a few it was difficult as they lacked previous experience of wayfinding and identification of landmarks in an indoor structure. A few of the indoor landmarks extracted included trash boxes (figure 12), information boards (figure 13), staircases and lecture halls with room numbers.

Figure 12: Trash boxes: figural level objects of indoor landmarks

Although trash boxes fall under the category of figural level objects, they can still be considered as landmarks where there are no other potential sources of landmarks or these can also be additional reference points apart from the main landmark.

Figure 13: Information board showing direction for different point of interests

In figure 13, an information board can be seen that shows 6 different destinations along the straight path from its position. Information boards, though belong to figural level category of the indoor objects, can be considered as landmarks because the information that they contain is most likely to not get replaced, for example, lecture halls, auditoriums and other important rooms. Therefore, information boards form a very good source of indoor landmarks.

Indoor landmarks could be varying from one indoor structure to another. The derived indoor landmarks in this thesis are examples of landmarks in a university building. Landmarks could be different in an airport, in a hospital and in a shopping complex. For example, in a hospital, landmarks could be emergency ward (figure 14), reception, a vending machine etc. In a shopping mall, one could use the shop names, WC's, food court (figure 15), seating area as landmarks. Similarly, at an airport, landmarks could be different attractions like trees (figure 16), gate numbers (figure 17), shops, WC's, baggage claim, etc.

Figure 14: Emergency ward in a hospital building

Figure 15: Food court at Century City

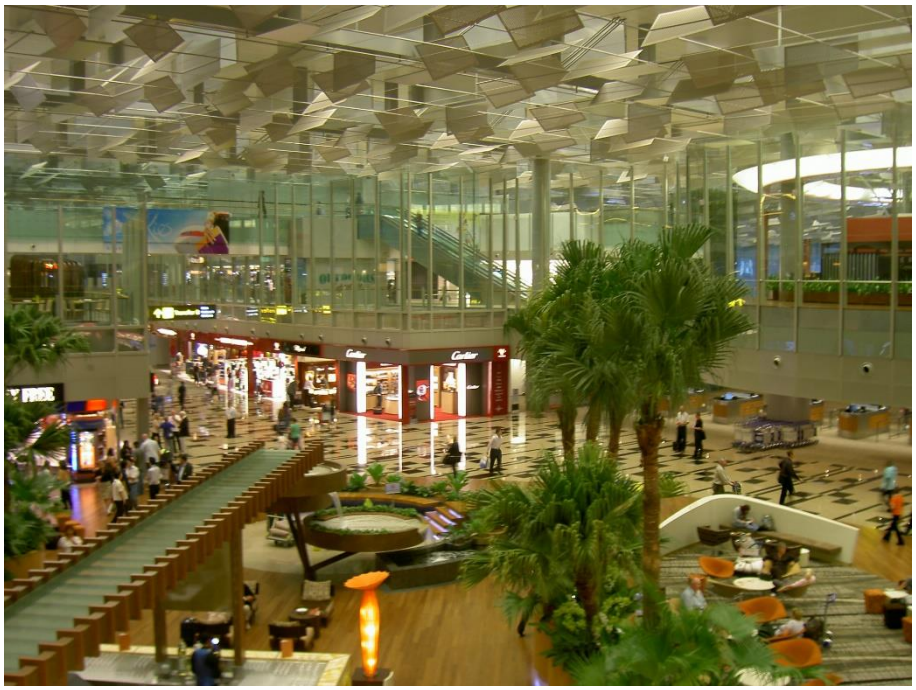


Figure 16: Inside Changi International Airport, Terminal 3, Singapore

Figure 17: Gate numbers as landmarks in airports

The landmarks derived from the user test relate to the landmarks mentioned in the paragraph above in their characteristics. For example, the emergency room board in a hospital building is similar to the information board that is derived while performing the user test, the food court is similar to the terrace cafeteria which is the destination point of route 2. The landmarks

derived in different indoor structures might be different but they do relate with each other based on the characteristics they own.

While the above mentioned scenario is an anticipation of the results, with the completion of the user test, the next chapter 5 is about the results that are derived based on the literature review, pre-user test and user test conducted.

5 Results and Discussion

In the previous chapter, the description of the user test and the procedure of how the user test is carried out was described. In this chapter, the results of the user test performed is presented along with the analysis of the findings and the further research that can be done by considering the results of the user test.

5.1 Questionnaire Results

The questionnaire's results are given along with the questions asked below. The questionnaire is given in appendix 8.2. The questionnaire starts with some general questions like gender, age, country of origin and previous educational background followed by 12 questions focusing on the previous experience of the participants with navigating indoors and outdoors and other related questions as seen below:

The result of question 1 (user test experience) is already explained in chapter 4.1.

Question 2: Difficulty level experienced by the students for locating a landmark in an indoor structure**:**
Most of the students experienced moderate level of difficulty to locate a landmark in an indoor structure until they performed this user test. A very few students have experienced low level difficulty and these students happened to have had similar background related to GIS and Cartography.

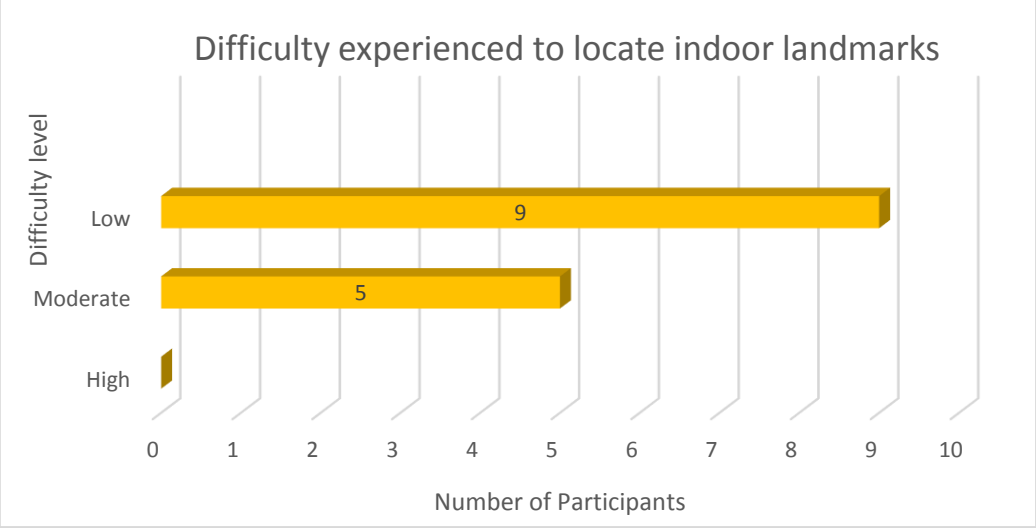


Figure 18: Difficulty level to locate the indoor landmarks

Question 3: In a typical day, how often does navigating indoors make you feel inconvenient?
The students have said that navigating in indoors made them feel inconvenient only when the structure was a maze and huge. For small buildings, navigating was never a difficult task because of the simple structure and planning.

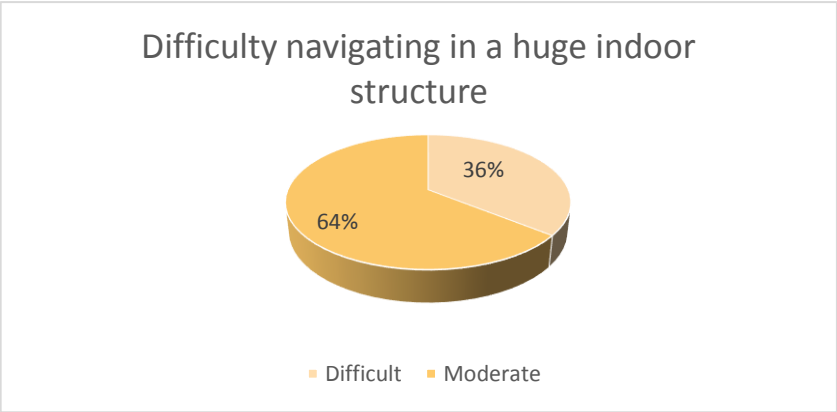


Figure 19: Difficulty level faced to navigate in a huge indoor structure

Question 4: How often are printed maps used in an indoor environment?
When the students were asked about the pace of using printed maps in an indoor environment, most of the students replied saying 'sometimes' while a few replied saying 'rarely'. Usage of maps in an indoor environment is based on the size and complexity of the indoor structure which is why it is sometimes difficult to navigate indoors.

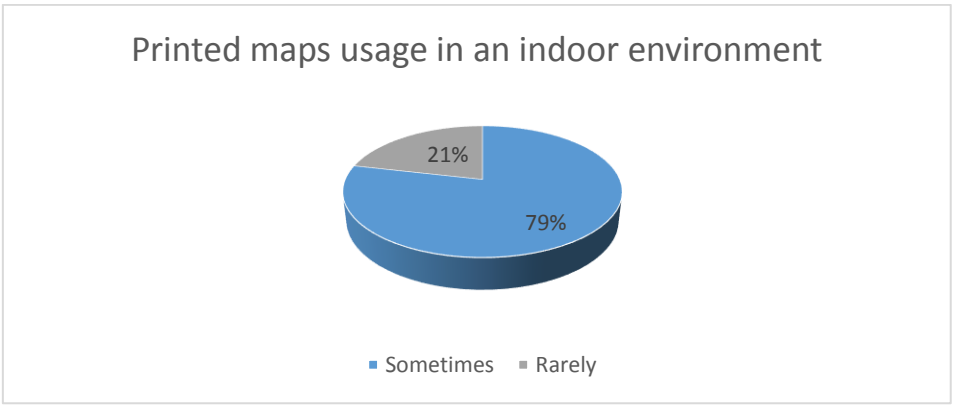


Figure 20: Usage of printed maps in an indoor environment

Question 5: How often are technology oriented navigating tools like GPS, Smartphone are used in an indoor environment?

Technical devices like Smartphones and GPS are rarely used to navigate in an indoor environment. The reasons being data unavailability and technical on-going development in the field on indoor navigation.

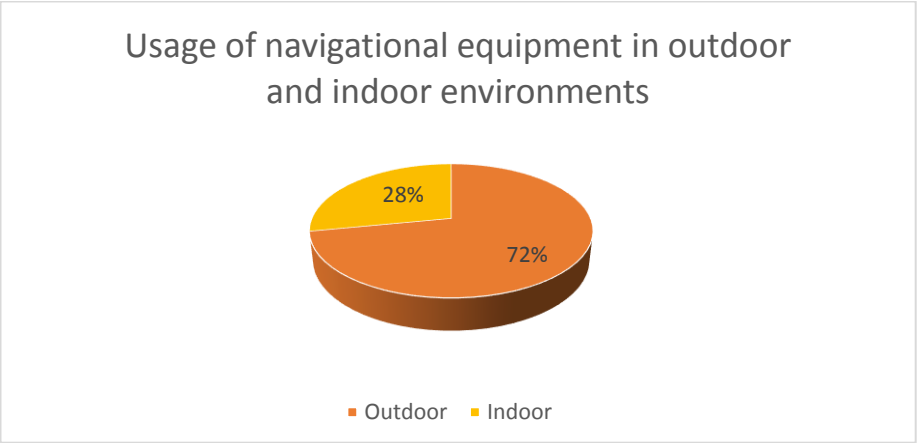


Figure 21: Usage of navigational equipment in outdoor and indoor environments

Question 6: Is navigation easier in an outdoor environment or an indoor environment?
The questionnaire result shows that some students find navigating in an outdoor environment is easier because of the ease to locate landmarks and already available geographical data and output media while some find navigating in an indoor environment easier.

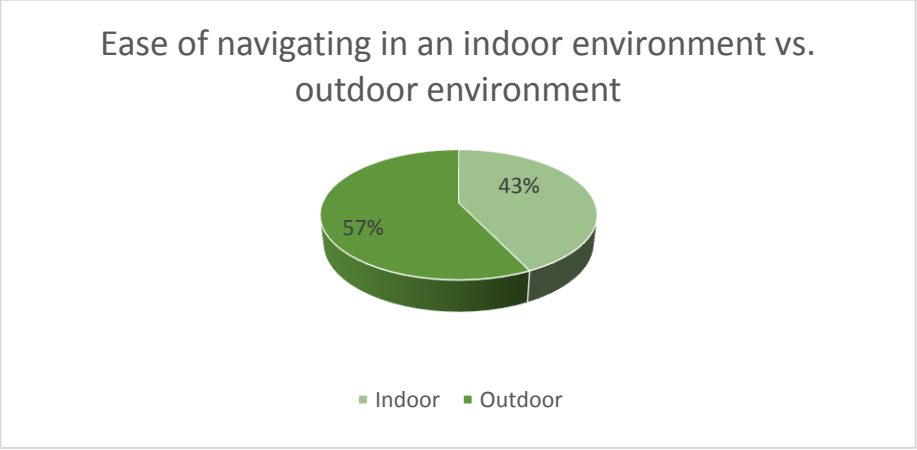


Figure 22: Ease of navigation in indoor vs. outdoor

Question 7: How easy was it to locate the landmarks of a new route in the TUM main building after looking and walking through the pre-tested route locating the given landmarks?

After having walked through the pre-tested route, it was moderate for some of the students to locate the landmarks in a new route while for some students it was easier as they possessed previous knowledge about the subject area.

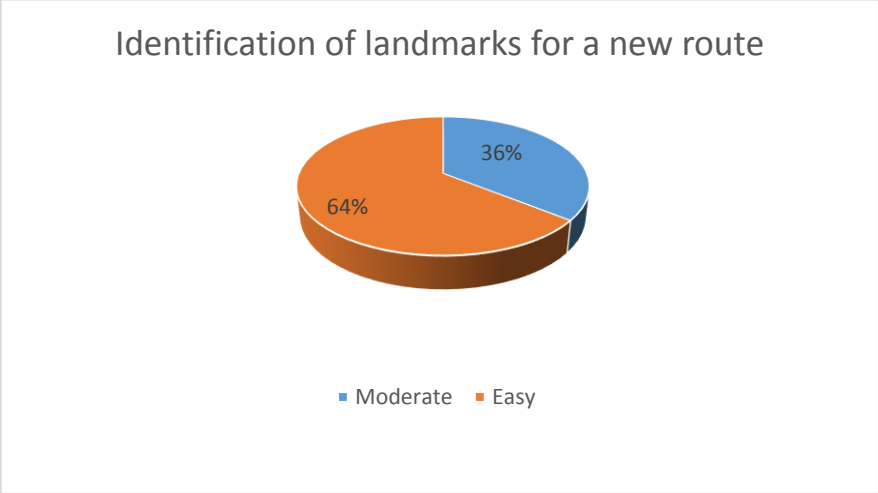


Figure 23: Difficulty level faced while locating landmarks for a new route

Question 8: Through this user test, did you gain new knowledge about indoor navigation and indoor landmarks?
To this question, all the students answered saying 'yes', which is proved in other questions of the questionnaire related to indoor wayfinding and indoor landmark.

Question 9: Understanding of the term indoor landmark after the user test by the students:
After the user test, the students gave different descriptions of their understanding of the term indoor landmark, which are the following:

- An indoor landmark is a distinctive marker. (Given by 2 students)
- An entity that allows us to clearly identify the way that is required to be taken.
- An easily identified object which should serve as orientation object related with a specific place.
- A prominent feature of an indoor especially those that cannot be moved, like stairs. (Given by 2 students)
- A well recognizable feature that can be used for orientation (can be a sign, an architectonic feature, furniture and similar).
- An object that is either prominent or conspicuous that can serve as a guide for finding our way. For indoors, it could be staircase or a hallway.

- An indoor landmark is a reference point (object, entity) that helps us to orient in an indoor space. (Given by 3 students)
- A distinctive entity which is visually/ spatially dominant and/or informative for spatial orientation.
- A recognizable feature in the scene that is a potential reference point.

From these definitions, an indoor landmark can be explained as an easily recognizable entity that is visually and spatially dominant and is also a distinctive marker that helps orientation when an indoor space is considered.
Although 14 students filled in the questionnaire, only 9 definitions were taken into consideration as the other 5 definitions were similar to the other 9 definitions mentioned above.

Question 10 and 11: Difference between an indoor and an outdoor landmark:
The user test completion proceeded with questions of differences between an indoor and an outdoor landmark to the students. The feedback included that there are significant differences between an indoor and an outdoor landmark by most of the students. The responses given are as follows:

- Types of features, example: staircase vs. traffic light. (Given by 4 students)
- The indoor landmarks are more limited and of different type (more sophisticated) and concentrated in much smaller area.
- For indoor landmarks could be parts of an interior structure and for outdoor landmarks, entities from outdoor environment are used. (Given by 4 students)
- The indoor landmarks rather tend to be smaller objects while as an outdoor landmark can also be served by a building or a nature object such as trees, hills, water bodies etc. (Given by 4 students)
- Outdoor landmarks need to hold up or be visible against potential distractions outside. There may be fewer distinctive interior landmarks i.e. no names for hallways the way we have for streets.

Therefore, it can be said that an indoor landmark differs from an outdoor landmark based on visibility, types of feature, information content and availability of options for selection of entities as landmarks.

The last question 12 had general character and the participants were asked if they are available or willing to volunteer in a similar user test in future and all the participants agreed.

As mentioned in the above question, only 5 results were taken into consideration out of 14 as the other results were similar and included the same content as the 5 results chosen.

In the following chapter 5.2, the results of the user test are described in detail based on the analysis of the questionnaire results and the route maps drawn by the participants, pre-user test results and findings of literature review. These answer the research questions of this thesis.

5.2 Thesis Results

In this chapter, the results for all the research questions mentioned in the chapter 1.4.2 are given initiating with the definition of an indoor landmark as follows:

5.2.1 Definition of an Indoor Landmark

The definition for an indoor landmark is derived from the results of user test and based on the keywords derived from the previous definitions of landmarks as described in the table 3.1. From the results obtained and the study done, the definition is given as:

An 'Indoor Landmark' is a distinctive point of interest that is visually, spatially dominant and informative for spatial orientation in the inside of a structure which could be a route maintenance point, an external point of reference or a route decision point that can either help the person to navigate and explore inside an indoor structure or that helps to reach the desired point of interest.

The above definition explains that an indoor landmark can be any object that is attractive like paintings as shown in figure 26 or dull with reference to its surroundings and is spatially dominant. It also needs to be informative like information boards in university buildings as shown in figure 30. A landmark can be used to maintain a taken route, as a point of reference to navigate or to decide the route to be taken which helps in finding way in the indoor structure.

5.2.2 Characteristics of an Indoor Landmark

Characteristics of an indoor landmark can be defined as a feature or a quality belonging typically to the category of indoor entities that serves in identifying them as landmarks. Apart from the characteristics mentioned in chapter 2.2., the additional characteristics that make an indoor entity eligible to be considered as a landmark are as follows:

Uniqueness: an entity should be clear in its form to serve as a landmark, i.e. it should be unique among its surroundings. More like an irregularly shaped building, a fountain in a big shopping area etc.

Contrast: a structure or an entity that is considered as a landmark should be in contrast to the background. For example, a textured façade building among plain façade buildings, a red building amongst all the dull-shade coloured buildings, a sky-scraper amongst all the buildings that are one to multi-floor.

Spatial prominence: the prominence of location also plays an important role in proving an entity as a landmark. For instance, a landmark located in the city centre has more prominence that the one located in a residential street. Although, this might differ depending on the area of interest.

Cognition: another characteristic that plays an important role in determining an entity as a landmark is its cognition. A landmark has to be a meaningful entity by itself. Any landmark gains importance apart from satisfying the above mentioned characteristics if it is useful.

An entity can be assigned as a landmark if it satisfies the above mentioned characteristics along with those mentioned in chapter 2.2.

5.2.3 Comparison between an Indoor and an Outdoor Landmark

Indoor and outdoor landmarks have many characteristics other than the known fact that indoor landmarks are in the indoor of a structure and outdoor landmarks are in the outdoor environment. Through the research done for the literature review and the user test performed, the characteristics of an indoor and an outdoor landmark are derived which are as follows:

The first basic comparison done between an indoor and an outdoor landmark is the size of the selected landmarks. Indoor landmarks, most of the times have smaller size when compared to the outdoor landmarks which are larger or significantly larger in size. For example, while walking in an indoor structure, a door, trash boxes, and corridors are considered as landmarks. While in an outdoor environment, large buildings, sky scrapers, shopping malls, natural attractions like trees, water bodies are considered as landmarks.

Secondly, indoor landmarks are much limited when compared to the outdoor landmarks. While selecting outdoor landmarks, one has many options such as high rise buildings, restaurants, fountains, shopping malls, airports, trees, mountains, water bodies such as lakes, rivers and many others. In indoors however, the options are less.

Outdoor landmarks need to hold up or be visible against potential distractions like tall trees, rocky mountains, high-raised buildings. This is not necessarily true for indoor landmarks as indoor landmarks are seen without any obstructions most of the times.

Outdoor landmarks are more distinctive when compared to indoor landmarks. For example, outdoor landmarks are easier to locate like street name boards, flexi boards, malls and restaurants. Where as in indoors, no corridor names are given, and not always information boards are seen in indoors. There are less distinctive entities which makes navigating in indoors a difficult task.

5.2.4 Indicators on Extracting Landmarks from Heterogeneous Geographic Data

It is clear from today's technology that navigation using technology has grown enormously over the past decade. In this thesis, focus is given to indoor navigation as there is not as much growth as there is for outdoor navigation. The reasons for this situation are various like accuracy of location information, required output media and also cognition of the user as discussed above. However, various theories that are now focusing on indoor landmarks and indoor navigation are studied for the literature review of this thesis. From the recent developments, it can be said that sooner there is going to be tremendous improvement even in the field of indoor navigation.

Extraction of landmarks or identification of landmarks is an important task when it comes to fulfilling the tasks of preparing a navigational equipment, let it be maps, smart phone apps, GPS devices or any other. The differences are that outdoor navigation like street navigation has exact locations and landmarks, it also has relevant media which supports the navigation. Whereas, indoor navigation has no such drastic development as of yet.

However, there are certain indicators that could help the researches in locating landmarks from a heterogeneous geographic data. A heterogeneous geographic data consists of different categories of entities which include man-made structures like buildings, sky scrapers, hospitals, shopping malls, airports, fountains etc. It also includes natural entities like trees, water bodies, mountains etc.

In indoor environment, navigation is not easier for the reasons like unconventional architectural design, poorly designed sign system and numbering system. Despite these, the characteristics discussed above would be helpful in extracting the landmarks in an indoor as well as outdoor environments.

Cognition of the user is one of the most important indicator in determining an entity as a landmark. Given a heterogeneous data, every person's cognition is different to that of others. From the user test conducted, a behaviour analysis was done is determining what factors make an entity to be a landmark which are as follows:

Size of the object: most students happened to select larger objects varying in size from a human body to the size of a room door as landmarks as they are easier to view and identify.

Colour of the object: colour of the entity plays an important role in description of an entity as a landmark. Contrast of an object from its surroundings was one of the qualities that was involved in the selection of the landmarks. Students selected trash boxes as landmarks.

Shape of the object: any object that is irregularly shaped gets a prominence which also helps is defining an entity as a landmark. For example, staircase is not a regularly shaped structure which is why it has such a cognitive importance as is selected by the students as a landmark during the user test.

Texture of the object: texture of an object plays an important role in the cognitive world. This also is a useful factor when locating indoor landmarks where there are not many prominent entities. To give an example, paintings and elevators are selected as landmarks for an indoor structure by the students which keep differing from one structure to another.

5.2.5 Extraction of a Set of Potential Landmarks

The results showed that most of the landmarks derived by the participants in the user test are same as the landmarks derived during the process of pre-user test.

The 9 landmarks extracted are as follows:

1. Fire extinguishers

Figure 24: Fire extinguisher: one of the most prominent landmarks found in almost every indoor structure

Fire extinguishers could be an indoor landmark as it is seen in all the indoor structures and is easy to locate because of its colour and information content on the box as seen in the figure 21.

2. Trash boxes

Figure 25: Trash boxes: Identical because of the colours

Although trash boxes fall under the category of figural level objects, they can still be considered as landmarks where there are no other potential sources of landmarks or these can also be additional reference points apart from the main landmark as already mentioned in 4.4. Trash boxes were extracted as landmarks based on visual attraction as they exhibit different colour which differs from one structure to another.

3. Paintings

Figure 26: Paintings: Eye-capturing landmarks

Paintings form unique landmarks as their specification and way finding instruction is easier to give because of its colours and content. In indoors, paintings are most commonly seen indoor entities. They are found in university buildings, hospitals, offices, shopping malls and also in houses. Their prominence makes it an easy entity for indoor wayfinding.

4. Doors with door numbers or names

Figure 27: Lecture halls with unique names- noticeable landmarks

In university buildings, most commonly occurring entities are lecture halls. These could be with room numbers or with specific names as seen in the figure 27. Their identification is easier because of the information content they hold.

5. Staircases

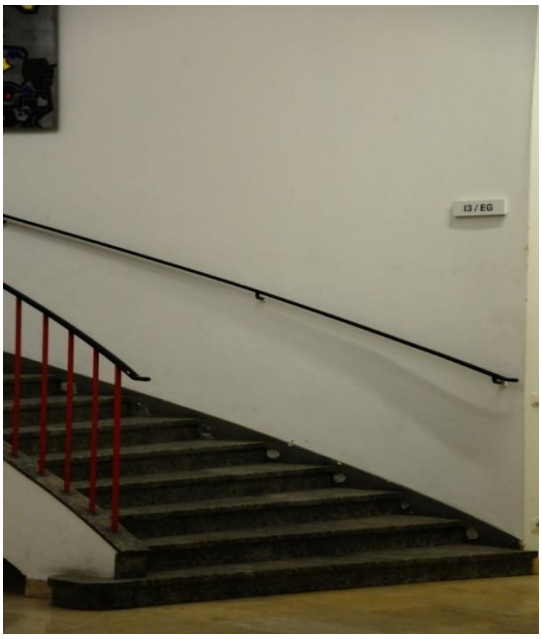


Figure 28: Staircases- Most commonly found landmark

Staircases are the most commonly seen indoor entities for a structure holding more than ground floor. They form the basic indoor landmark for any indoor structure.

6. Snack automat machines

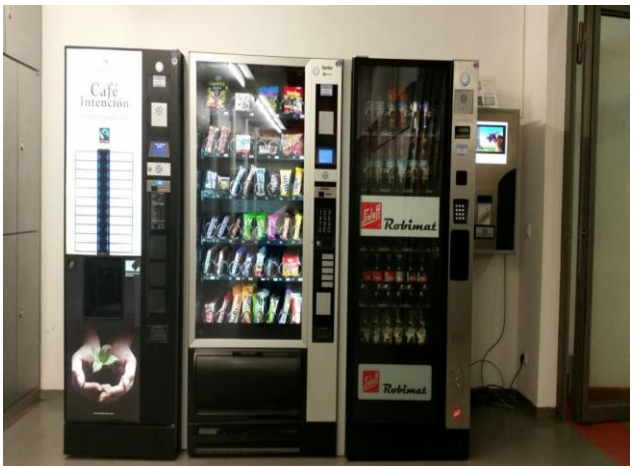


Figure 29: Snack Automats- Easily recognizable

Snack automats are most common in university buildings, hospitals and airports. These are again easy-to-find indoor landmark entities.

7. Information boards

Informational boards are most useful for wayfinding as they speak for themselves with the information they hold. Not every indoor structure has information boards, but when these are present, they form the most useful landmarks.

Figure 30: Information boards- Usually the most important landmarks

8. WC

Landmarks, as described in the above chapters, can be derived based on usage. One such entities are washrooms which are the most commonly used rooms in an indoor structure.

Figure 31: Washrooms, common landmark

9. Elevators

Figure 32: Elevators

Elevators are seen in most indoor structure holding more than three floors. The elevator specifications might be different in different countries. The characteristics that makes an elevator essential for wayfinding are its façade and texture as they from one indoor structure to another.

All the above listed landmarks were chosen both in pre-user test and user test. Although, some of the landmarks selected by the participants in the user test like benches, construction machinery were removed from the results as they are easily replaceable figural and vista level objects respectively.

5.2.6 Flowchart for Extraction of Landmarks

To extract the landmarks, a procedure is required to analyse whether the extracted landmark is appropriate or not, or to be said, if the landmark satisfies all the criterions that are to be fulfilled by a potential landmark or not. Previously, in the sub-chapter 5.2.2, we have seen the characteristics of an indoor landmark. Also, from the user test conducted, the behaviour of the participants was analysed in the process of locating landmarks. With the knowledge of these areas, a flowchart has been derived to show the steps of deriving a landmark which is as follows:

1. Study the map of the building or the indoor location being chosen for navigation.

2. Analyse the structure based of the study of the map, to analyse means to look at the symmetric/asymmetric nature of the structure.

3. Mark the most convenient route of all the routes to your destination from the map. Most convenient route might be the shortest or the easiest according to the perception of the user.

4. Start navigating through the route and mark the potential landmarks you see through this route. The potential landmarks, as discussed earlier should obey the characteristics of being unique to its surroundings, be in contrast with the background, the landmark should be in a prominent location and finally, it has to own a cognitive importance.

If an entity is chosen by the above mentioned procedure, then it definitely results in being a potential landmark.

The flow chart is depicted graphically in figure 33.

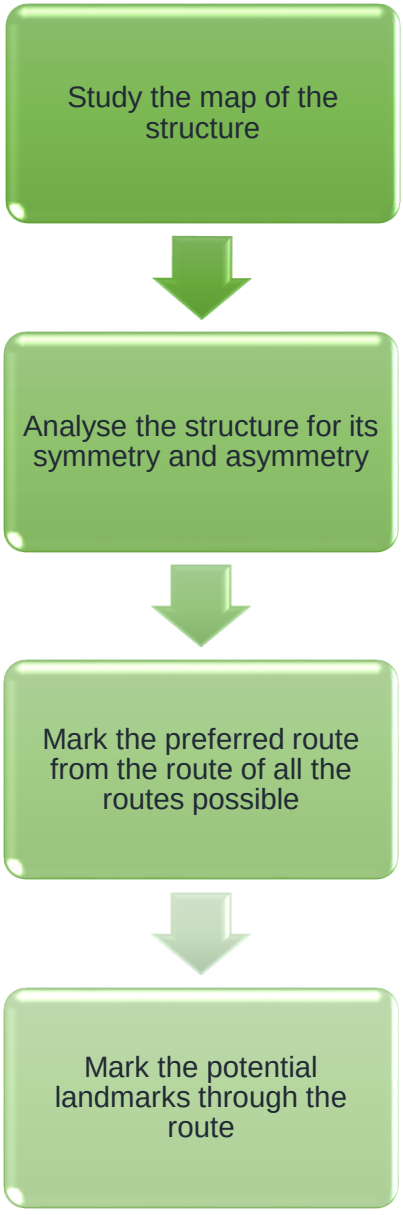


Figure 33: Flowchart to derive an indoor landmark

5.2.7 Figural Level, Vista Level and Environmental Level Landmarks

Previously in this thesis, it was discussed that indoor objects can be mapped on three levels out of the four levels of a taxonomy proposed by Montello, DR. (1993).

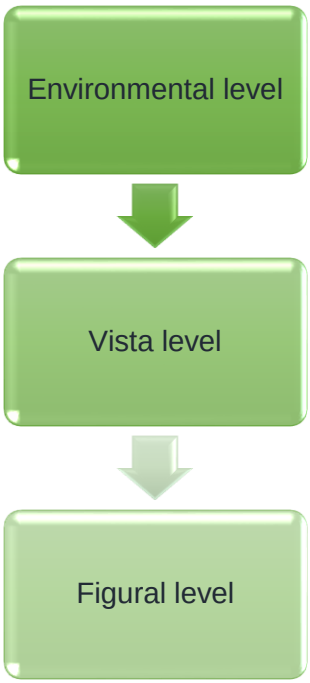


Figure 34: Level of marking the indoor landmarks in descending order of selection

In the user test performed for this thesis, all of these three level landmarks were used. While on the second round of the user test, a fire extinguisher, which belonged to the figural level indoor objects was removed from its place where it was identified and marked as a landmark during the first round of the user test.

Therefore, to avoid such a situation, marking of figural level objects as landmarks should be avoided unless there is no other potential landmark in the surroundings. Strongest indoor landmark fall under the categories of vista level and environmental level objects. Therefore, the selection of landmarks should be done in the order as described in the figure 34.

6 Conclusions and Further Research

In the introduction of this thesis (chapter 1), various research questions were proposed and the answers to those questions are given in the results chapter 5. In this chapter, the conclusions are derived from the results and also further research ideas are presented.

6.1 Conclusions

In this thesis, several conclusions are drawn based on the literature review performed and also the user test conducted. From the user test results, it is seen that an indoor landmark is an entity that is visually, spatially dominant and informative for spatial orientation in the inside of a structure. This entity could be a route maintenance point, an external point of reference or a route decision point that can either help the person to navigate and explore inside an indoor structure or that helps to reach the desired point of interest.

Also, these indoor objects are categorized into three: figural level, vista level and environmental level. Based on the user test analysis, figural level objects do not fit to be marked as landmarks as they are replaceable. So, a figural level object should be taken into consideration only in the absence of vista and environmental level objects. An indoor landmark varies significantly from an outdoor landmark based on shape, size, features and functionality.

The characteristics derived for an indoor landmark include uniqueness, contrast, spatial prominence and cognition of an object. The derived landmarks in the pre-user test and user test possessed these characteristics and thus, were selected as landmarks. The indicators that helped in deriving these landmarks were the size, colour, shape and texture of the object.

The landmarks derived were visually dominant, informative and also spatially dominant. Some of these landmarks were route maintenance points, some were route decision points and a few were external points of reference. This proves that the derived landmarks justify the developed definition of indoor landmark.

The goals and research questions of this thesis as mentioned in chapter 1.3 and sub-chapter 1.4.2 are determined in chapter 5.2 which proves that the goals of this thesis are achieved.

6.2 Further Research

In order to prove the wholeness of the developed definition of indoor landmark, a similar user test can be conducted in different scenarios. For example, a user test can be performed in an airport, a shopping mall and/or a hospital with audience from different backgrounds like students of cartography and related fields, students from entirely different field of education, general audience and with experts in the field of cartography. The results of these user tests can be used to verify the wholeness of the definition.

In the previous chapters, it was seen that the reasons for poor navigation in indoors are unconventional architectural design, poorly designed sign system and numbering system. These can be improved by bringing betterment in the designing of the structures by implementing conventional architectural designs, designing of efficient sign systems and finding out methods to design easier indoor plans that will help in making navigation an easier task in indoors.

7 Bibliography

Allen, G. (1999). Spatial Abilities, Cognitive Maps, and Wayfinding - Bases for Individual Differences in Spatial Cognition and Behavior. In: Golledge, R. (Ed.), Wayfinding Behavior - Cognitive Mapping and Other Spatial Processes (pp. 46-80). Baltimore; Johns Hopkins University Press.

Arthur, P. and Passini, R. (1990). 1-2-3 Evaluation and Design Guide to Wayfinding. Technical Report. Public Works Canada.

Brunner-Friedrich, B. and Radoczky, V. (2006). Active landmarks in indoor environments. In: Visual Information and Information Systems. pp 203-215. Springer.

Burnett, GE. (1998). 'Turn Right at the King's Head': drivers' requirements for route guidance information, Loughborough University.

Car, A. (1996). Hierarchical Spatial Reasoning: Theoretical Consideration and its Application to Modeling Wayfinding.

Ohm, C., Muller, M., Ludwig, B. and Bienk, S. (2014). Where is the Landmark? Eye Tracking Studies in Large-Scale Indoor Environments.

Deakin, A. (1996). Landmarks as Navigational Aids on Street Maps. In: Cartography and Geographic Information Systems, pp 21-36. www.tandfonline.com.

Denis, M. and Loomis, JM. (2007). Perspectives on Human Spatial Cognition: Memory, Navigation, and Environmental Learning. Psychological Research, Springer.

Downs, R. and Stea, D. (1977). Maps in Minds: Reflections on Cognitive Mapping. Harper and Row, New York.

Gärling, T., Lindberg, E., and Mäntylä, T. (1983). Orientation in buildings: Effects of familiarity, visual access, and orientation aids. In: Journal of Applied Psychology 68. pp 177-186.

Gluck, M. (1991). Making Sense of Human Wayfinding: Review of Cognitive and Linguistic Knowledge for Personal Navigation with a New Research Direction. In Mark, D. and Frank, A. (Ed.), Cognitive and Linguistic Aspects of Geographic Space. Series D: Behavioural and Social Sciences 63. pp 117-135. Dordrecht, The Netherlands, Kluwer Academic Publishers.

Golledge, RG. (1999). Human wayfinding and cognitive maps. Wayfinding behavior: cognitive mapping and other spatial processes. pp 5-45. Baltimore, JHU Press.

Habel, C. (1988). Prozedurale Aspekte der Wegplanung und Wegbeschreibung. In: Schnelle, H. and Rickheit, G. (Eds.), Sprache in Mensch und Computer. pp. 107-133. Westdeutscher

Verlag, Opladen,

Hölscher ,C., Meilinger, T., Vrachliotis, G., Brösamle, M. and Knauff, M. (2006). Up the down staircase: wayfinding strategies in multi-level buildings. In: J Environ Psychol 26 (4). pp 284-299.

Lakoff, G. (1987). Women, Fire, and Dangerous Things: What Categories Reveal About the Mind. Chicago; The University of Chicago Press.

Lovelace, KL., Hegarty, M. and Montello, DR. (1999). Elements of good route directions in familiar and unfamiliar environments. In: Spatial information theory. Cognitive and computational foundations of geographic information science. pp 65–82. Springer.

Lynch, K. (1960). The Image of the City. Cambridge, Massachusetts, MIT Press.

Lyu, H., Yu, Z., Meng, L. (2014). A Computational Method for Indoor Landmark extraction. In: Progress in Location Based Services. pp 45-59. Springer.

Maaß, W. and Schmauks, D., (1998). MOSES: Ein Beispiel für die Modellierung räumlicher Leistungen durch ein Wegebeschreibungssystem. Zeitschrift für Semiotik. pp 105-118.

Mark, D. (1997). Cognitive Perspectives on Spatial and Spatio - temporal Reasoning. In Craglia, M. and Couclelis, H. (Eds.), Geographic Information Research, Bridging the Atlantic pp. 308-319. London, UK, Taylor & Francis.

Mark, D., Freksa, C., Hirtle, S., Lloyd, R. and Tversky, B. (1999). Cognitive models of geographical space.

May, A.J., Ross, T., Bayer, S.H. and Tarkiainen, M.J. (2003). Pedestrian navigation aids: information requirements and design implications. Personal and Ubiquitous Computing 7(6). pp 331-338.

Merriam, G. and Webster, N. (2001). Merriam-Webster's Collegiate Dictionary. Merriam-Webster, Inc.

Metzger, W. (1936). Gesetze des Sehens. Kramer & Co., Frankfurt am Main.

Michon, P.E. and Denis, M. (2001). When and Why are Visual Landmarks Used in Giving Directions? In: Montello, D. (Ed.), Spatial Information Theory. Lecture Notes in Computer Science. pp 292-305. Springer.

Millonig, A., and Schechtner, K. (2007). Developing landmark-based pedestrian-navigation systems. IEEE Trans Intell Transp Syst. pp 43-49.

Moeser, S. (1988). Cognitive mapping in a complex building. Environment and Behavior 20. pp 21-49.

Montello, DR. (1993). Scale and multiple psychologies of space. In: Spatial information theory a theoretical basis for gis. pp 312–321. Springer.

Norman, D. (1988). The design of everyday things. Donald A. Norman Doubleday, New York.

Nothegger, C., Winter, S., Raubal M. (2004a). Computation of the salience of features. In: Spatial Cognition Computing, 4. pp 113-136.

Osherson, D. and Lasnik, H. (Eds.) (1990). Language: An Invitation to Cognitive Science. Cambridge, Massachusetts, MIT Press.

Presson, CC. and Montello, DR. (1988). Points of reference in spatial cognition: stalking the elusive landmark. Br J Dev Psychol. pp 378-381.

Radoczky, V. (2007). How to design a pedestrian navigation system for indoor and outdoor environments. In: Location based services and telecartography, pp. 301-316. Springer.

Raubal, M. and Egenhofer, M. (1998). Comparing the complexity of wayfinding tasks in built environments. In: Journal of Environment & Planning B 25 (6). pp 895-913.

Raubal, M. and Winter, S. (2002). Enriching wayfinding instructions with local landmarks. In: Geographic Information Science. pp 243-259 Springer.

Sorrows, ME. and Hirtle, SC. (1999). The nature of landmarks for real and electronic spaces. In: Spatial information theory. Cognitive and computational foundations of geographic information science. pp 37-50. Springer.

Timpf, S. and Frank, A. (1997): Using Hierarchical Spatial Data Structures for Hierarchical Spatial Reasoning. In: Hirtle, S. and Frank, A. (Eds.), Spatial Information Theory. Lecture Notes in Computer Science. pp 69-83. Springer.

Tversky, B. and Lee, P. (1999). Pictorial and Verbal Tools for Conveying Routes, In: Freksa, C. and Mark, D. (Eds.), 'Spatial Information Theory: Cognitive and Computational Foundations of Geographic Information Science'. pp 51-64. Springer

Wang, RF. and Brockmole, JR. (2003). Simultaneous spatial updating in nested environments. Psychon Bull Rev. pp 981-986.

Werner, S., Krieg-Brückner, B., Mallot, H., Schweizer, K. and Freksa, C. (1997). Spatial Cognition: The Role of Landmark, Route, and Survey Knowledge in Human and Robot Navigation. In: Jarke, M., Pasedach, K. and Pohl, K. (Eds.), Informatik '97. pp 41-50. Springer.

Winter, S. (2003). Route adaptive selection of salient features. In: Spatial Information Theory. Foundations of Geographic Information Science. pp 349-361. Springer.

Figure 1: Technical University of Munich. Digital image, Openbuildings.com, URL: http://c1038.r38.cf3.rackcdn.com/group2/building15103/media/featured/029phz1.jpg. (Access: July 5, 2017).

Figure 2: Office Building of Fisheries Department, Hyderabad, India. Digital image, Raveender, N., Wikimedia Commons, URL: https://upload.wikimedia.org/wikipedia/commons/thumb/e/e2/Fish_shaped_building.jpg/800px-Fish_shaped_building.jpg. (Access: July 5, 2017).

Figure 3: Colorful Buildings. Digital image, Wikimedia Commons, URL: https://upload.wikimedia.org/wikipedia/commons/thumb/9/91/Colorful_buildings_Bo-kaap_12.jpg/800px-Colorful_buildings_Bo-kaap_12.jpg. (Access: July 6, 2017).

Figure 4: The Rathaus and Marienplatz from Peterskirche in Munich, Germany. Digital image, Iliff, D., Wikimedia Commons, URL: https://upload.wikimedia.org/wikipedia/commons/thumb/7/73/Rathaus_and_Marienplatz_from_Peterskirche_-_August_2006.jpg/696px-Rathaus_and_Marienplatz_from_Peterskirche_-_August_2006.jpg. (Access: July 5, 2017).

Figure 5: Glass Facade of a Building. Digital image, pexels.com, URL: https://images.pexels.com/photos/273675/pexels-photo-273675.jpeg?w=940&h=650&auto=compress&cs=tinysrgb. (Access: July 5, 2017).

Figure 6: An Old Farm Building. Digital image, Nicol, K., Geograph.org, URL: http://s0.geograph.org.uk/geophotos/01/72/30/1723087_20e09ee9.jpg. (Access: July 5, 2017).

Figure 17: Terminal Gate. Digital image, Wikimedia Commons, URL: https://upload.wikimedia.org/wikipedia/commons/3/37/LGW_North_Terminal_gates.JPG. (Access: July 6, 2017).

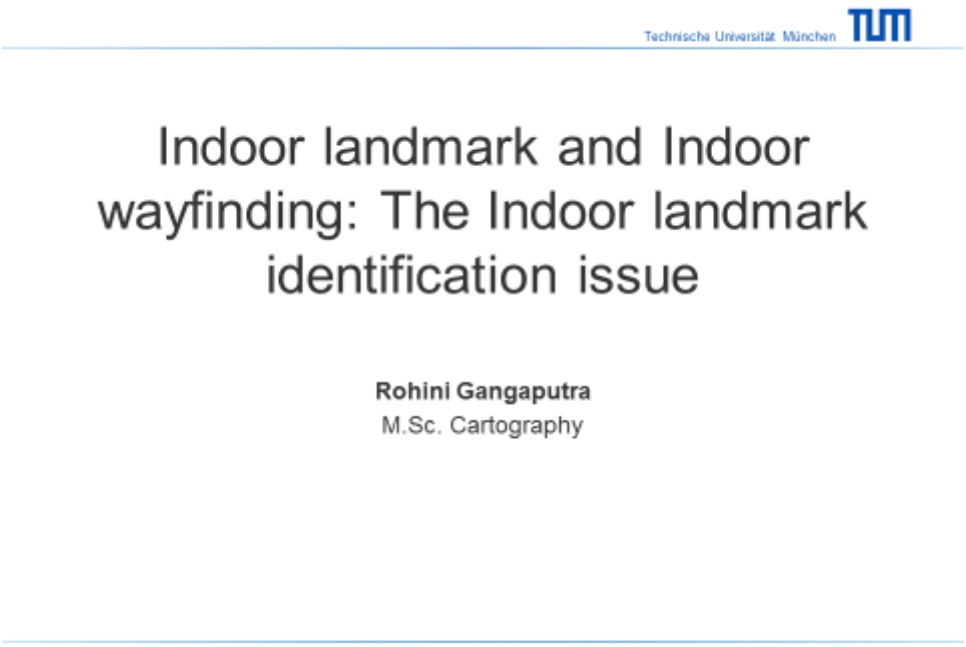
Figure 14: Emergency ward. Digital image, rotkreuzklinikum-muenchen.de, URL: https://rotkreuzklinikum-muenchen.de/_thumbnails_/3322_5_Notfallmedizin_tb_stationen_rk_032.jpg?m=1487172138. (Access: July 6, 2017).

Figure 15: Food court. Digital Image, Wikimedia Commons, URL: https://upload.wikimedia.org/wikipedia/commons/4/4b/Canal-Walk-Food-Court.jpg. (Access: July 6, 2017)

Figure 16: Tress inside Changi Airport, Terminal 3. Digital Image, Wikimedia Commons, URL: https://upload.wikimedia.org/wikipedia/commons/thumb/c/c7/SINT3.JPG/800px-SINT3.JPG. (Access: July 6, 2017)

8 Appendix User Test Material

8.1 Presentation



What is a landmark?

A landmark may be **any object** in the environment that is **easily recognizable** (e.g., buildings, rivers, specific districts) or even **idiosyncratic objects** (e.g., a celebrities mansion, my workplace), as long as its primary property is that of a **point of reference** (Couclelis et al. 1995; Presson and Montello 1988).

Idea of this user test

- To develop a more vivid definition of indoor landmark
- To diffrentiate between an indoor and an outdoor landmark
- To develop a flowchart that describes the procedure of driving a landmark
- To determine the characteristics of an indoor landmark

Ride through the Idea

- Location of the user test - TUM Main campus
- Two routes to be tested
- Two groups
- Each group- one tested route
  and one new route
- Pictures and Credits
- Fill in the questionnaire based on the user test

Routes to be tested

Route 1

Main entrance to room no. 0714 via Library

Route 2

Administrative Office to Terrace Cafeteria via Carl von Linde Hörsaal

Execution

- Walk through the given routes to identify the landmarks along the routes
- Duration for each test route – 15-20 minutes
- Mark the landmarks along the routes by drawing a route map
- Analyse why the entity contributes to a landmark
- Fill in the questionnaire given

	Route 1	Route 2
Group 1 (7 students)	Given: Pre-tested landmarks table	Task: New route: 12-15 landmarks
Group 2 (7 students)	Task: New route: 12-15 landmarks	Given: Pre-tested landmarks table

- 15-20 minutes per route
- Interchange of tasks within the routes
- Fill in the questionnaire

8.2 Questionnaire

Hello,

This questionnaire would help me to analyze your knowledge on indoor landmark and navigation and to study the behavior exhibited during wayfinding. Your answers to the questions below would be summarized and will be included in my thesis presentation (giving you the credits).

Thank you for your participation!

General information

1. Gender

☐Female ☐Male

2. Age

☐20-25 ☐26-30 ☐31-35

3. Country of Origin-

4. Bachelor's degree in-

Questions

Directions: Please indicate your answer for each of these statements with an "X" mark in the box of your answer.

1. Previously, have you performed any such task in an indoor environment as the user test given to you?

☐Yes ☐No

2. What was the difficulty level you experienced while locating landmarks in an indoor structure?

☐High ☐Moderate ☐Low

3. In a typical day, how often does navigating indoors make you feel inconvenient?

☐Always ☐Very often ☐Sometimes ☐Rarely ☐Never

4. How often do you use printed maps to navigate in indoor environment?

☐Always ☐Very often ☐Sometimes ☐Rarely ☐Never

5. How often do you use navigating tools (GPS, smartphone, and other electronic gadgets) in indoor environment?

☐Always ☐Very often ☐Sometimes ☐Rarely ☐Never

6. Navigating in an outdoor environment is easier when compared to navigating in an Indoor environment.

☐Strongly Agree ☐Agree ☐Undecided ☐Disagree ☐Strongly Disagree

7. How easy was it to locate landmarks of a new route after having a look at the landmarks list of a pre-tested route?

☐Very easy ☐Easy ☐Moderate ☐Somewhat hard ☐Hard ☐Very hard

8. Through this user test, did you gain new knowledge about indoor navigation and indoor landmarks?

☐Yes ☐No

9. If you were asked to define an indoor landmark, what would your definition be?

10. Do you think there is a difference between an indoor landmark and an outdoor landmark?

☐Yes ☐No

11. If your answer for the above question is ‘yes’, what is the difference?

12. If you were asked to volunteer for an indoor navigation project, would you do it?

8.3 Route Map Representations Drawn by the Participants of the User Test

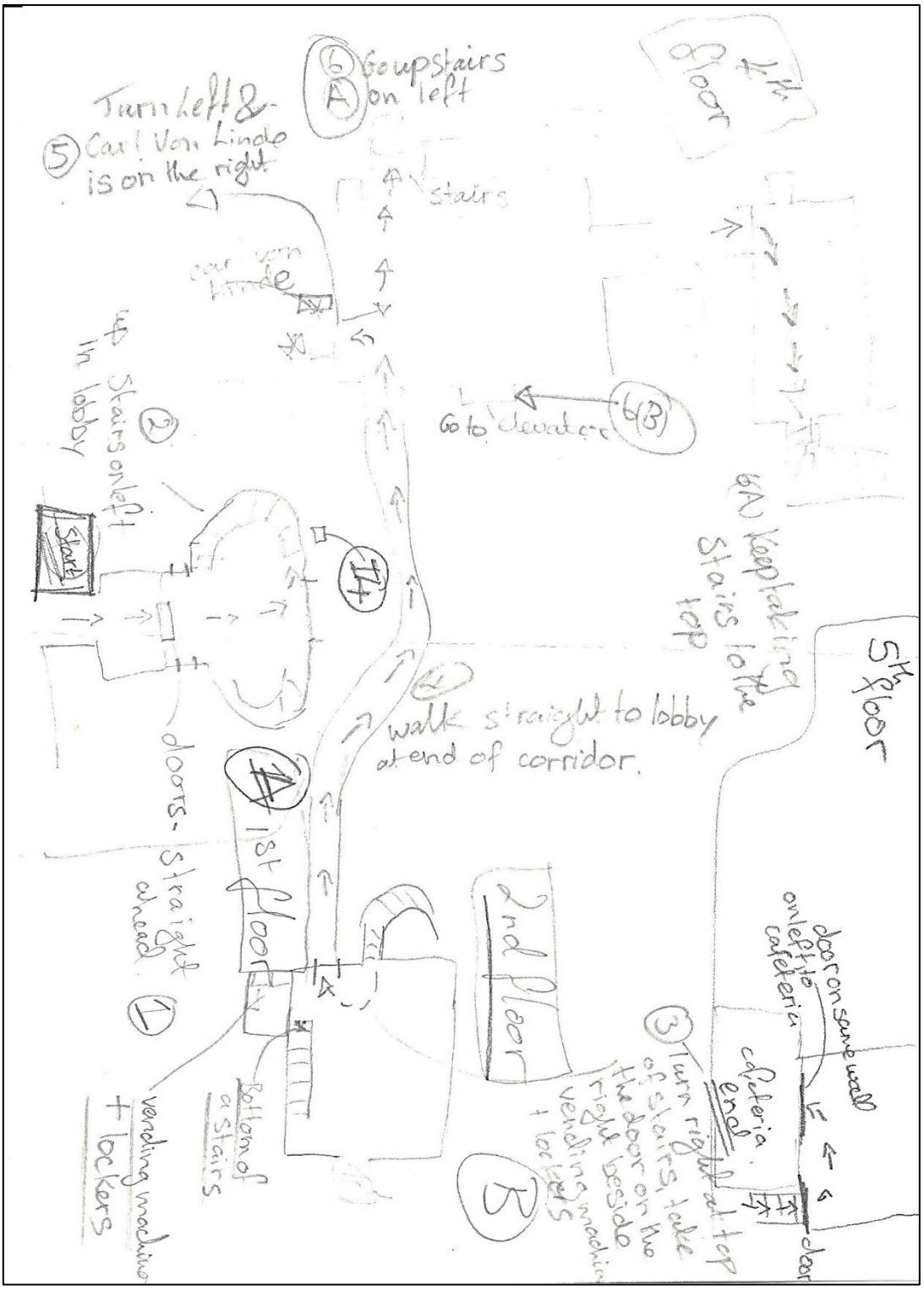


Figure 35: Map representing route from Main entrance to Cafeteria via Carl von Linde Hörsaal

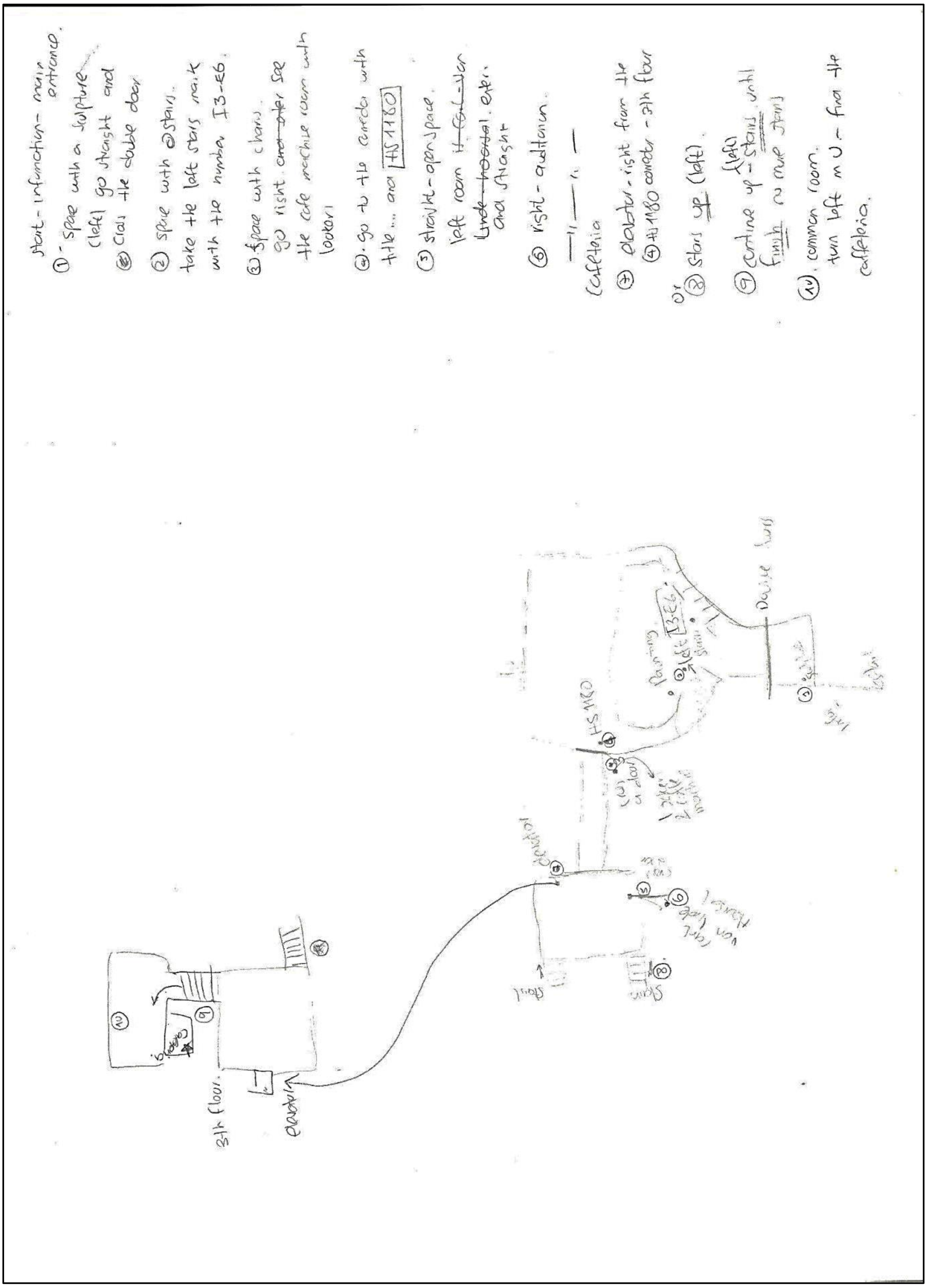


Figure 36: Map representing route from Main entrance to Cafeteria via Carl von Linde Hörsaal

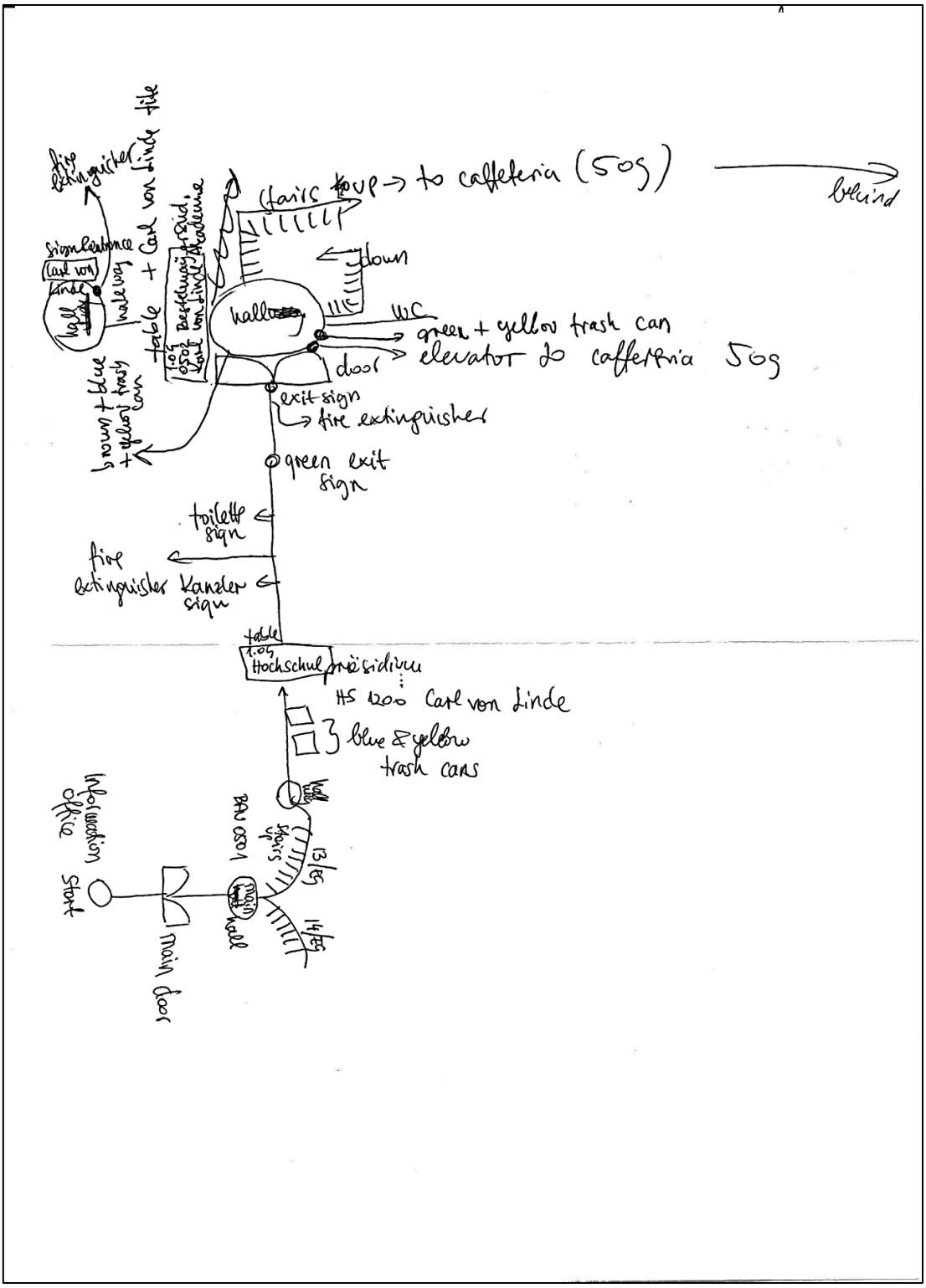


Figure 37: Map depicting the route from main entrance to Cafeteria via Carl von Linde Hörsaal

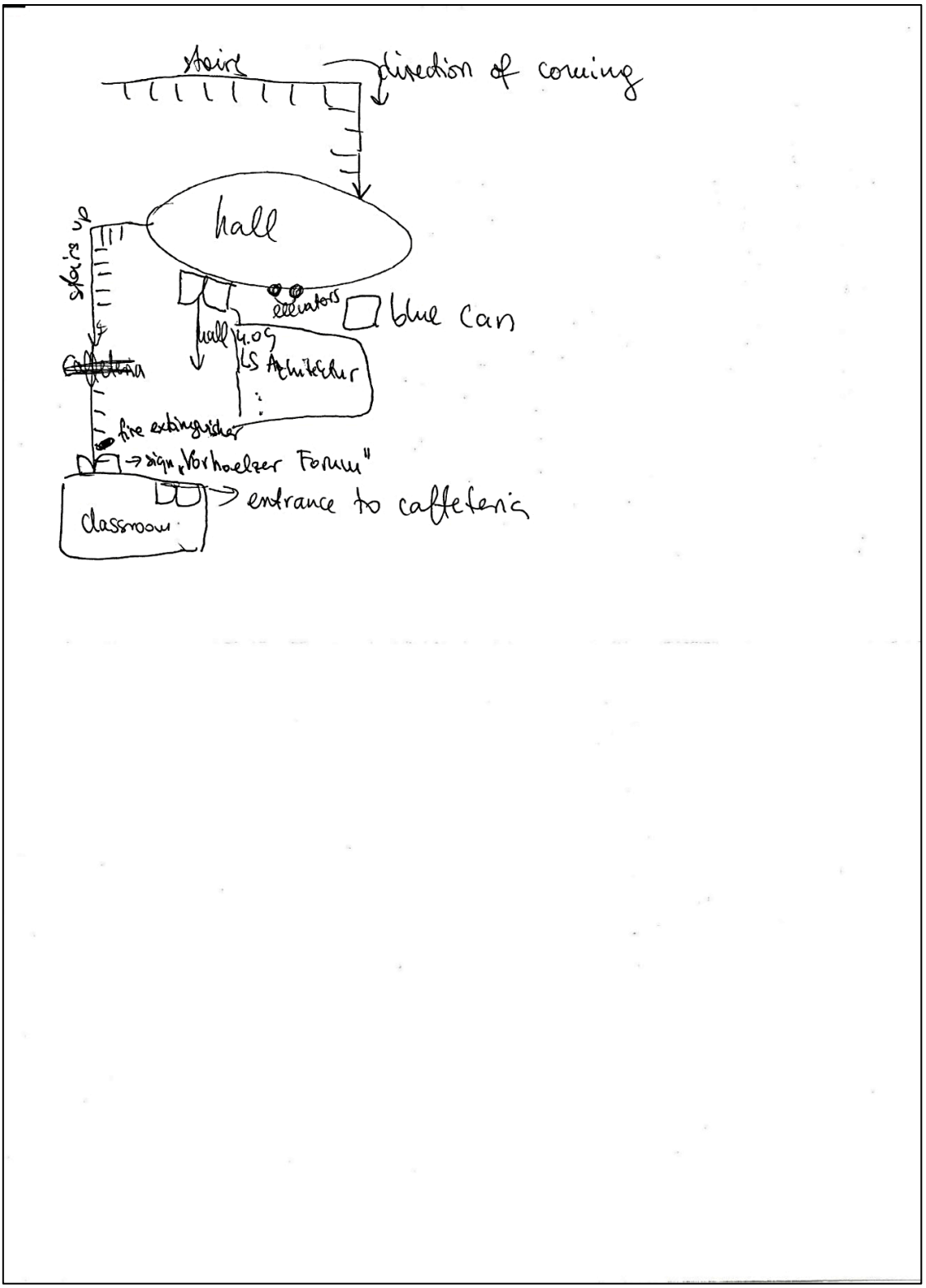


Figure 38: Continuation of figure 37

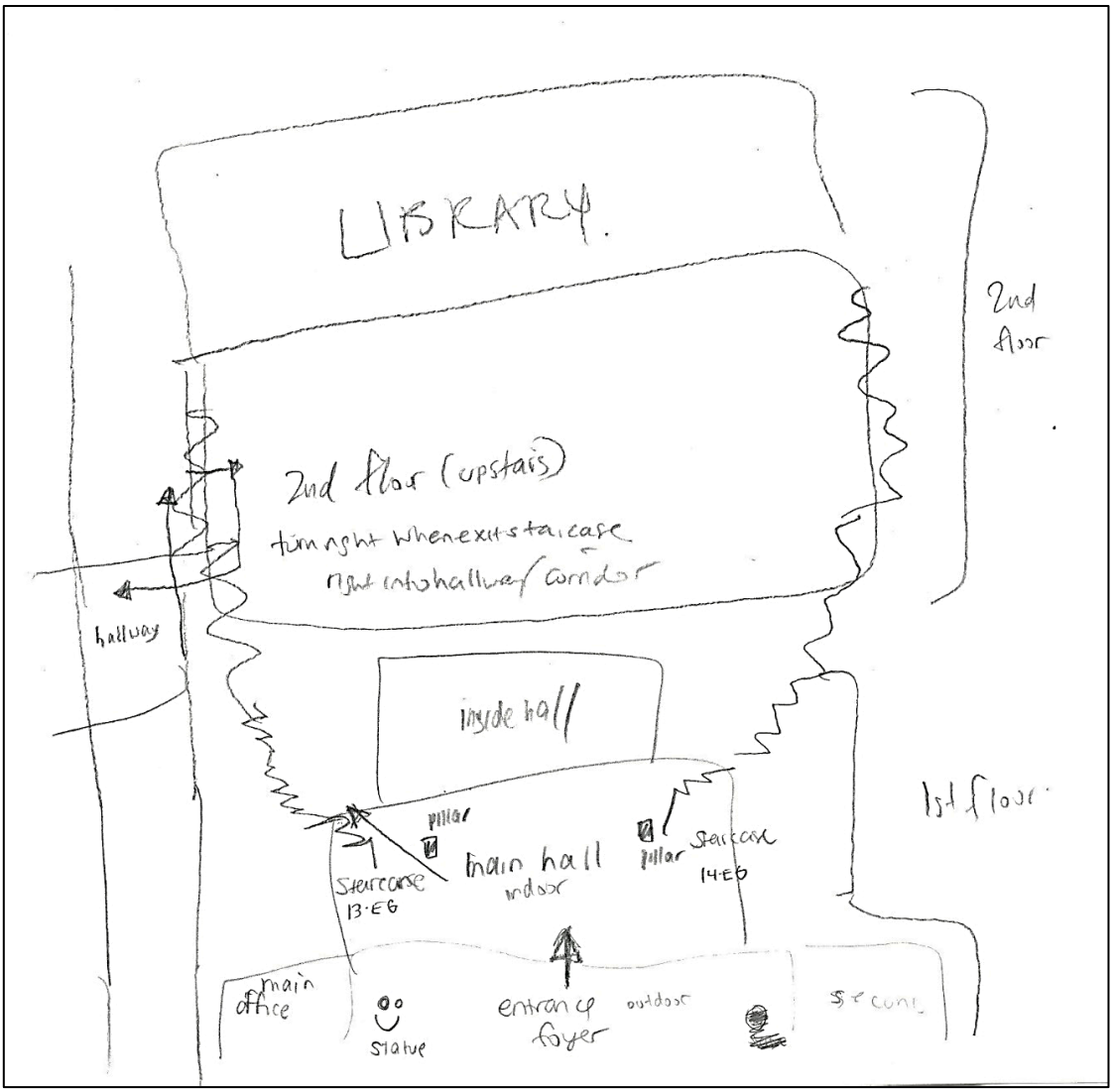


Figure 39: Route map of Main entrance to room no. 0714 via Library