



# MASTER THESIS

im Rahmen des Universitätslehrganges “Geographical Information Science & Systems” (UNIGIS MSc) am Interfakultären Fachbereich für GeoInformatik (Z\_GIS) der Paris Lodron-Universität Salzburg

zum Thema

## “Auto-generated routing instructions with landmarks for indoor navigation”

vorgelegt von

Mag. Irene Fellner

103050, UNIGIS MSc Jahrgang 2014

Zur Erlangung des Grades

“Master of Science (Geographical Information Science & Systems) – MSc(GIS)”

Gutachter:

Univ.Prof. Dr. Georg Gartner

Wien, 16. Dezember 2015

# Acknowledgement

I would like to thank Prof. Georg Gartner and Dr. Haosheng Huang from the Vienna University of Technology for the supervision and the valuable feedback during the whole process of writing this thesis.

Furthermore, I would like to thank the entire University of Salzburg UNIGIS team for their support throughout this master's program.

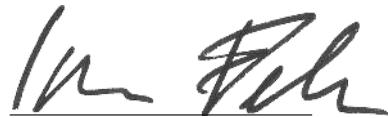
Additionally, thanks to Michael Diener, developer of the WU Campus GIS, for giving me the idea for this topic and for professional advice regarding technical aspects of the system.

Finally, I would like to acknowledge the patience, emotional support and occasional distractions of my family, my partner Andreas and my daughter Marlene.

# Declaration of Authorship

By my signature below, I certify that my thesis is entirely the result of my own work. I have cited all sources I have used in my thesis and I have always indicated their origin.

Wien, 16.12.2015

A handwritten signature in black ink, appearing to read 'Irene Fellner', written over a horizontal line.

Irene Fellner

# Abstract

This thesis deals with the question of how route instructions for indoor navigation can be generated automatically based on the information available in spatial indoor databases. Landmarks can significantly improve the quality of routing instructions. However, in particular, indoor navigation poses special challenges to the automatic creation of routing instructions with landmarks.

In order to create routing instructions including landmarks automatically, three phases are specified in this thesis: landmark identification, landmark selection and landmark integration.

This thesis aims at developing an “indoor landmark navigation model” (ILNM), which defines the processes and algorithms for these three phases. It is based on the “landmark navigation model” (LNM) by Duckham et al. (2010) (Matt Duckham et al. (2010). “Including landmarks in routing instructions”. In: *Journal of Location Based Services* 4.1, pp. 28–52). As the LNM was developed for outdoor environments and for a different kind of data source, it had to be adapted to the requirements and challenges of indoor navigation.

In order to evaluate the ILNM, it was applied to the data of the Campus GIS of the Vienna University of Economics and Business (WU). After feature types had been selected and rated for their landmark suitability, the landmark selection and integration algorithms were applied to three sample routes of the Campus WU.

The generated route instructions demonstrate that the ILNM basically produces correct route instructions including landmarks. A comparison to solely metric-based routing instructions shows that landmarks are important to increase the quality of indoor route instructions. However, the generated route instructions also disclose some gaps in the model and unresolved challenges of automatic indoor routing generation. Finally, suggestions are given for future work to overcome some of these problems.

# Contents

<b>Acknowledgement</b>	<b>I</b>
<b>Declaration of Authorship</b>	<b>II</b>
<b>Abstract</b>	<b>III</b>
<b>List of figures</b>	<b>IX</b>
<b>List of tables</b>	<b>XI</b>
<b>Abbreviations</b>	<b>XII</b>
<b>1. Introduction</b>	<b>1</b>
1.1. Motivation . . . . .	1
1.2. Objectives and research questions . . . . .	4
1.3. Methods . . . . .	5
1.4. Structure of the thesis . . . . .	8
<b>2. Landmarks in indoor route instructions</b>	<b>9</b>
2.1. Human navigation and wayfinding . . . . .	9
2.1.1. Concepts of navigation . . . . .	9
2.1.2. Cognitive aspects of wayfinding . . . . .	9
2.1.3. Communication of navigation knowledge . . . . .	10
2.2. Route instructions with landmarks . . . . .	13
2.2.1. Characteristics and categories of landmarks . . . . .	13
2.2.2. The role of landmarks in route instructions . . . . .	15
2.3. Indoor navigation and wayfinding . . . . .	17
2.3.1. Wayfinding in built environments . . . . .	17
2.3.2. Landmark-based indoor navigation systems . . . . .	19
<b>3. Development of the “Indoor Landmark Navigation Model” (ILNM)</b>	<b>23</b>
3.1. Related work . . . . .	25

## Contents

3.1.1.	Automated generation of route instructions with landmarks . . .	26
3.1.2.	“Landmark Navigation Model” . . . . .	28
3.1.3.	Identification of indoor landmarks . . . . .	34
3.1.4.	Criteria for selecting landmarks . . . . .	36
3.1.5.	Indoor route instruction generation . . . . .	38
3.2.	Landmark identification . . . . .	43
3.2.1.	Feature type selection . . . . .	44
3.2.2.	Landmark weighting . . . . .	45
3.3.	Landmark selection . . . . .	51
3.3.1.	Criteria for selecting landmarks . . . . .	52
3.3.2.	Algorithm . . . . .	56
3.4.	Landmark integration . . . . .	58
3.4.1.	Adapting outdoor to indoor route instruction generation . . . .	59
3.4.2.	Algorithm . . . . .	60
<b>4.</b>	<b>Application of the ILNM to WU Campus GIS</b>	<b>64</b>
4.1.	Fundamentals of the application process . . . . .	64
4.1.1.	WU Campus GIS . . . . .	64
4.1.2.	Sample routes . . . . .	68
4.1.3.	Application method . . . . .	72
4.2.	Landmark identification . . . . .	74
4.2.1.	Feature type selection . . . . .	74
4.2.2.	Landmark weighting . . . . .	77
4.3.	Landmark selection . . . . .	84
4.3.1.	Route 1 . . . . .	85
4.3.2.	Route 2 . . . . .	105
4.3.3.	Route 3 . . . . .	118
4.4.	Landmark integration . . . . .	135
4.4.1.	Route 1 . . . . .	136
4.4.2.	Route 2 . . . . .	139
4.4.3.	Route 3 . . . . .	140
<b>5.</b>	<b>Evaluation</b>	<b>144</b>
5.1.	Analysis of the sample route instructions . . . . .	144
5.2.	Comparison to metric-based instructions . . . . .	145
5.3.	Drawbacks and possible problems . . . . .	150

*Contents*

<b>6. Summary and Outlook</b>	<b>154</b>
<b>Bibliography</b>	<b>158</b>
<b>A. Expert Rating</b>	<b>163</b>
A.1. Results . . . . .	163

# List of Figures

1.1. Main steps of this thesis . . . . .	7
2.1. Three-stage task model for producing route descriptions or route maps (adapted from Agrawala (2002)) . . . . .	11
2.2. Categories of landmarks based on a dynamic view (from Elias (2006))	15
2.3. Example of a complex building with different floor plans: Library & Learning Center of WU . . . . .	18
2.4. Factors predicting navigation in buildings (from Carlson et al. (2010))	19
3.1. Processes of generating route instructions with landmarks . . . . .	24
3.2. Extended LNM algorithm from Duckham et al. (2010) . . . . .	34
3.3. The seven wayfinding choremes: Their conceptualization as linguistic externalization (top), the grammatical notation used (middle) and their graphical externalization (bottom) (from Klippel, Tappe, et al. (2005))	38
3.4. WhereIs compared to Coral generated route description (from Dale et al. (2005)) . . . . .	40
3.5. The process of landmark identification in the ILNM . . . . .	44
3.6. The process of landmark selection in the ILNM . . . . .	52
3.7. ILNM landmark selection algorithm . . . . .	57
3.8. The process of landmark integration in the ILNM . . . . .	58
3.9. ILNM landmark integration algorithm . . . . .	61
3.10. ILNM algorithm . . . . .	63
4.1. Panorama view of Campus WU . . . . .	65
4.2. WU Campus GIS with route displayed on the map . . . . .	65
4.3. WU Campus GIS with POIs represented by icons on the map and static map elements in the background . . . . .	68
4.4. Sample route 1 displayed in WU Campus GIS . . . . .	69
4.5. Sample route 2 displayed in WU Campus GIS . . . . .	70
4.6. Sample route 3 (ground floor) displayed in WU Campus GIS . . . . .	71



*List of Figures*

4.7. Sample route 3 (third floor) displayed in WU Campus GIS . . . . .	71
4.8. Landmark candidates of the ground floor of Campus WU displayed in ArcGIS according to their weight . . . . .	80
4.9. Landmark candidates of the ground floor in Building TC of Campus WU displayed in ArcGIS according to their weight . . . . .	81
4.10. Landmark candidates of the third floor of Campus WU displayed in ArcGIS according to their weight . . . . .	82
4.11. Landmark candidates of the third floor in Building LC of Campus WU displayed in ArcGIS according to their weight . . . . .	83
4.12. Adjustment of the landmark suitability weight in the ILNM selection process . . . . .	84
4.13. Route 1 with decision points illustrated in ArcGIS . . . . .	86
4.14. Route 1 with buffer zone and landmark candidates displayed in ArcGIS according to their weight . . . . .	88
4.15. Landmark candidates for route 1 displayed in ArcGIS according to their label weight . . . . .	90
4.16. Landmark candidates for decision points in route 1 displayed in ArcGIS according to their decision point weight 1 . . . . .	93
4.17. Landmark candidates for decision points in route 1 displayed in ArcGIS according to their decision point weight 2 . . . . .	94
4.18. Landmark candidates for decision points in route 1 displayed in ArcGIS according to their decision point weight 3 . . . . .	97
4.19. Landmark crossed by two route legs illustrated in ArcGIS . . . . .	98
4.20. In-leg landmark candidates for route leg 3 of route 1 displayed in ArcGIS according to their in-leg weight 1 . . . . .	101
4.21. In-leg landmark candidates for route leg 3 of route 1 displayed in ArcGIS according to their in-leg weight 2 . . . . .	102
4.22. Selected landmarks for route 1 displayed in ArcGIS according to their relevant weight . . . . .	104
4.23. Route 2 with decision points illustrated in ArcGIS . . . . .	106
4.24. Route 2 with buffer zone and landmark candidates displayed in ArcGIS according to their weight . . . . .	107
4.25. Landmark candidates for route 2 displayed in ArcGIS according to their label weight . . . . .	108
4.26. Landmark candidates for decision points in route 2 displayed in ArcGIS according to their decision point weight 3 . . . . .	112

*List of Figures*

4.27. Landmark candidates for leg 2 and leg 3 of route 2 displayed in ArcGIS according to their label weight 2 . . . . .	115
4.28. Selected landmarks for route 2 displayed in ArcGIS according to their relevant weight . . . . .	117
4.29. Route 3 (ground floor) with decision points illustrated in ArcGIS . . .	118
4.30. Route 3 (third floor) with decision points illustrated in ArcGIS . . . .	119
4.31. Route 3 (ground floor) with buffer zone and landmark candidates displayed in ArcGIS according to their weight . . . . .	120
4.32. Route 3 (third floor) with buffer zone and landmark candidates displayed in ArcGIS according to their weight . . . . .	121
4.33. Landmark candidates for route 3 (ground floor) displayed in ArcGIS according to their label weight . . . . .	122
4.34. Landmark candidates for route 3 (third floor) displayed in ArcGIS according to their label weight . . . . .	123
4.35. Landmark candidates for decision points of route 3 (ground floor) displayed in ArcGIS according to their decision point weight 3 . . . . .	128
4.36. Landmark candidates for decision points of route 3 (third floor) displayed in ArcGIS according to their decision point weight 3 . . . . .	129
4.37. Landmark candidates for leg 2 route 3 (ground floor) displayed in ArcGIS according to their in-leg weight 2 . . . . .	132
4.38. Selected landmarks for route 2 displayed in ArcGIS according to their relevant weight . . . . .	134
4.39. Selected landmarks for route 2 displayed in ArcGIS according to their relevant weight . . . . .	135
5.1. Open space and ambiguous possibilities for direction changes on Campus WU . . . . .	148
5.2. Stairs in a distinct room on route 1 . . . . .	151
5.3. Non-visible door at a decision point of route 2 . . . . .	151
5.4. Open doors as crossed landmarks on route 2 . . . . .	152

## List of Tables

3.1. Approaches for automated generation of route instructions with landmarks . . . . .	29
3.2. Detailed factors for scoring landmark suitability for POI categories according to Duckham et al. (2010) . . . . .	31
3.3. Expert’s rating of one category (takeaway food) from Duckham et al. (2010) . . . . .	32
3.4. Landmark scoring system based on POI categories from Duckham et al. (2010) . . . . .	32
3.5. Example for resulting context-specific route direction and its verbal externalization (from Richter (2007)) . . . . .	41
3.6. Different room labels next to (a, b, d and e) or on (c and f) the door .	47
3.7. Detailed factors for scoring landmark suitability for feature categories in the ILNM (adapted version from Duckham et al. (2010)) . . . . .	49
3.8. Example rating of two categories of WU Campus GIS: elevator and auditorium . . . . .	50
3.9. Factors for landmark selection in the LNM and ILNM . . . . .	56
4.1. Feature category selection for WU Campus GIS . . . . .	77
4.2. Scoring of all landmark categories of WU Campus GIS . . . . .	78
4.3. Landmark categories with label weights for route 1 in WU Campus GIS	89
4.4. Landmark categories with adjusted decision point weights for route 1 in WU Campus GIS . . . . .	92
4.5. Occurrence of landmark instances on each route leg of route 1 in WU Campus GIS . . . . .	95
4.6. Landmark categories with final decision point weights for route 1 in WU Campus GIS . . . . .	96
4.7. In-leg landmarks with adjusted weights for leg 3 of route 1 in WU Campus GIS . . . . .	100
4.8. Landmark categories with label weights for route 2 in WU Campus GIS	109

*List of Tables*

4.9. Landmark categories with adjusted decision point weights for route 2 in WU Campus GIS . . . . .	110
4.10. Occurrence of landmark instances on each route leg of route 2 in WU Campus GIS . . . . .	111
4.11. Landmark categories with final decision point weights for route 2 in WU Campus GIS . . . . .	111
4.12. In-leg landmarks with adjusted weights for leg 2 and leg 3 of route 2 in WU Campus GIS . . . . .	114
4.13. Landmark categories with label weights for route 3 in WU Campus GIS	124
4.14. Landmark categories with adjusted decision point weights for route 3 in WU Campus GIS . . . . .	125
4.15. Occurrence of landmark instances on each route leg of route 3 in WU Campus GIS . . . . .	126
4.16. Landmark categories with final decision point weights for route 3 in WU Campus GIS . . . . .	127
4.17. In-leg landmarks with adjusted weights for leg 3 of route 3 (ground floor) in WU Campus GIS . . . . .	131
5.1. Route instructions generated by the campus GIS of AAU and EPFL .	146
5.2. Landmark-based route instructions compared to metric-based instruction for route 1 . . . . .	147
5.3. Locations with possible ambiguous decision points on Campus WU . .	149
A.1. Rating feature categories of the WU Campus GIS . . . . .	167

# Abbreviations

**GIS** Geographic Information System

**ILNM** Indoor landmark navigation model

**LNМ** Landmark navigation model

**POI** Point of interest

**WU** Vienna University of Economics and Business

# 1. Introduction

## 1.1. Motivation

Landmarks play an important role in spatial recognition and learning new environments (Siegel and White 1975). People do not only use landmarks to orient themselves in a new environment but also to enrich route descriptions like defining points for turning actions with the help of landmarks (e.g. Lovelace et al. (1999), Tom and Denis (2003), Rehrl, Leitinger, et al. (2009)). Sorrows and Hirtle (1999) define landmarks as prominent, identifying features in an environment that can easily be recognized and memorized.

Although a study by Daniel and Denis (1998) demonstrates that around 85 percent of all elements of human route instructions refer to landmarks, there are hardly any pedestrian navigation systems that include landmarks in their route instructions. The reason for this is the absence of reliable methods to identify landmarks and integrate them automatically into routing instructions.

In particular, indoor navigation poses special challenges to the automatic creation of route instructions with landmarks: Indoor spaces are usually characterized by a very limited amount of different landmark types and a lack of highly salient landmarks. In addition, there are more open spaces which do not include clear paths to choose from (Mast, Jian, et al. 2012) and route instructions within buildings cannot refer to street names like in outdoor environments. But as it is more likely to lose orientation within a building than outside (Radoczky 2003) and changes in direction happen more frequently, textual guidance instructions (in addition to floor plans) including a high density of landmarks in indoor route instructions would be desirable (Radoczky 2007).

However, so far, no approach has been developed for the automatic generation of indoor route descriptions with landmarks from an existing spatial database. Existing approaches usually rely on hand-crafted data sources and are not designed to use data from existing GIS databases.

According to Duckham et al. (2010), the automatic integration of landmarks in routing instruction requires two intelligent mechanisms: First, spatial features have

## 1. Introduction

to be identified that are cognitively salient in an environment ("good" landmarks), and second, from these identified features landmarks have to be carefully selected for an individual route ("relevant" landmarks.). Adding the step of the generation of the route description leads to the following three main steps of automated route generation with landmarks:

1. **Landmark identification:** Identification of suitable landmark candidates,
2. **Landmark selection:** Selection of landmarks for an individual route,
3. **Landmark integration:** Generation of a route description with landmarks for a specific route.

Concerning the *identification* of landmarks, only a few studies have looked at how persons use landmarks in route descriptions (e.g. Denis (1997), Peters et al. (2010), Rehrl (2011)) and these studies are limited to outdoor environments. Exceptions are studies by Raubal and Egenhofer (1998) and Millonig and Schechtner (2007) which were conducted in a train station and at an airport. However, none of these studies defines the criteria for selecting spatial features as landmarks for indoor route descriptions.

Current approaches concerning the *selection* of landmarks and their *integration* in route descriptions are mainly limited to outdoor environments and to the extraction of landmarks based on detailed visual or geometric information about buildings (e.g. Raubal and Winter (2002), Elias (2003)). An alternate approach was proposed by Duckham et al. (2010).

They developed a "landmark navigation model" (LNM), which incorporates landmarks into route instructions and does not depend on specific instance-level data about the visual or geometric characteristics of individual features. Instead the model relies solely on class-level information about the types of landmarks, in addition to the road network and route geometry. The LNM implements cognitive salience in two ways: first, by weighting types of spatial features for their expected experiential salience; and second, for their relevance in the context of a route (Duckham et al. 2010).

Since detailed visual or geometric information about individual properties is usually not available within buildings, the LNM may serve as a good starting point for this thesis. However, as navigation within buildings disposes of special characteristics and challenges in contrast to outdoor navigation, the model has to be adapted in various aspects:

## 1. Introduction

- **Data source.** In the LNM the landmarks are selected from a public web service. As for indoor environments POIs are not provided via web services, a spatial indoor database has to be used as data source. As spatial indoor databases usually contain a lot of different information, it is necessary to define the criteria for the selection of feature types as landmark candidates, e.g. generalizing and classifying them.
- **Landmark types.** In the LNM solely points of interest (POIs) are used as landmarks. Within buildings typical POIs from outdoor environments (shops, sights) are usually not available. Therefore, different feature types have to be used as landmarks: beside indoor POIs also rooms or basic indoor objects like stairs or doors can serve as landmarks. Using different object types requires taking into consideration their particular characteristics: e.g. for rooms or stairs it has to be determined, which part is actually visible from a route.
- **Landmark characteristics.** To some extent, indoor landmarks dispose of different characteristics than outdoor landmarks, which also affects the criteria for rating their landmark suitability. For example, if rooms serve as landmarks, it is relevant if a unique label is available. On the other hand, some factors for rating outdoor landmarks are not applicable to indoor objects, for instance their nighttime salience. Thus, for the landmark suitability rating the factors have to be adjusted to the requirements of indoor landmarks.
- **Routing networks.** Routing networks in outdoor environments differ considerably from route paths in indoor environments. Therefore, the landmark selection process has to be adapted to these specific characteristics of indoor environments. For instance, a higher density of landmarks is desired within buildings, as changes in direction happen more often. In addition, it is more likely that several landmarks of the same category (e.g. of a specific room type) occur on a specific route leg, which requires a different handling of numerical chunking. Thus, the landmark selection algorithm has to be refined to consider these indoor-specific situations.
- **Routing instructions.** Routing instructions within buildings dispose of several differences compared to outdoor environments. Therefore, the algorithm for generating routing instructions has to be adjusted to the requirements of indoor environments. The most important distinction is the lack of street names, which makes indoor navigation considerably more complex. Additionally, indoor routes



## 1. Introduction

often involve changes of the floor level or lead directly through landmarks (e.g. doors, rooms), which has to be considered in the routing instruction algorithm.

To summarize, there is no approach in the literature which defines how to automatically identify and select spatial features as landmarks from an existing database for navigation within buildings. All approaches with the exception of the LNM by Duckham et al. (2010) use information about individual features rather than feature categories. In addition, almost all approaches for the identification and integration of landmarks assume that landmarks are point-like entities along a route. Exceptions to this geometric limitation of landmarks are found in the research by Duckham et al. (2010) or Richter (2007). The LNM by Duckham et al. (2010) provides a good approach for automatically selecting landmarks and integrating them into routing instructions. However, it was developed for outdoor environments and has to be adapted in various aspects to the characteristics and requirements of indoor navigation.

### 1.2. Objectives and research questions

The objective of this thesis is to develop an "indoor landmark navigation model" (ILNM) for the use within buildings and for the selection of landmarks from different existing feature types of a spatial database. The ILNM will be based on the methods and algorithm of the LNM created by Duckham et al. (2010). In order to evaluate the ILNM for its practical use, it will be applied to the data of the Geographic Information System (GIS) of the Vienna University of Economics and Business (WU), the "WU Campus GIS", for three sample routes.

Campus WU was opened in autumn 2013 and consists of seven building complexes designed by different, internationally renowned architects. Due to the various architects all buildings differ considerably both from outside but also regarding the interior design. Therefore, the application of the ILNM to its floor plans allows testing for a variety of indoor situations.

The WU Campus GIS is an online application provided to help people to find their way within the buildings of the campus. It offers calculating routes between any locations on the campus. However, the route is currently being only displayed on the floor map with no textual description. The database of the WU Campus GIS contains a lot of potential landmarks like POIs, doors, elevators, or particular room types. Therefore, the system is highly suitable to test the approach for the automatic generation of indoor route descriptions with landmarks.

## 1. Introduction

The main research question of this master thesis is:

**How can route instructions including landmarks be automatically created for indoor navigation based on category-level information about features from an existing spatial database?**

The main elements of this research question are:

- **Automatic creation.** An algorithm is developed which can be implemented into a system and which creates route instructions automatically from the underlying data base.
- **Indoor.** Route instructions are created for navigation within buildings.
- **Category-level information.** As usually in spatial databases of indoor environments no or few information is stored about the visual characteristics of the individual features, the approach has to rely on class-level information about the feature types.
- **Existing spatial database.** In contrast to existing approaches where landmarks are explicitly recorded for specific indoor routes, this thesis addresses the identification of landmark from existing spatial features within buildings.

In the course of this thesis the following sub-questions will be handled:

1. Which rules and steps are necessary for selecting feature types from spatial indoor databases as indoor landmarks?
2. Which factors are relevant for rating these features types for their indoor landmark suitability?
3. How can these features be selected as landmarks for specific indoor routes?
4. How can these landmarks be integrated into indoor route descriptions?
5. How well do route instructions created by the ILNM work for indoor navigation?

### 1.3. Methods

In the first step, a literature review on the use of landmarks in indoor route instructions, on approaches for automated generation of route instructions with landmarks as well as on special characteristics of indoor landmarks and indoor route instructions will

## 1. Introduction

be performed. Based on these findings, the ILNM will be developed. For this purpose, the LNM will be adjusted to the specific requirements of indoor route instructions and adapted to the data structure of indoor environments.

In order to evaluate the ILNM, it will be applied to the data of the WU Campus GIS in the course of a case study. In the first step, the landmark identification process, a preselection of indoor feature objects will be made according to predefined rules. The resulting features will be rated for their landmark suitability according to factors defined in the ILNM. This is done in the course of an expert rating. The result of this first process of the ILNM will be a set of rated indoor feature types which will serve as landmark candidates for the WU Campus GIS.

Next, the landmark selection process will be applied to three sample routes at Campus WU. This algorithm selects landmarks from the landmark candidates which were identified in the previous step, for specific routes. The application is done manually for each step of the ILNM landmark selection algorithm, mainly with the help of the GIS software “ArcGIS”. The step-wise application allows traceability and visualization of intermediate steps and results of the process.

Finally, the selected landmarks will be integrated into route instructions with the ILNM landmark integration algorithm. The results of this application process will be indoor route descriptions with references to landmarks for three routes.

In the course of the evaluation of the results of these ILNM application processes the generated route instructions will be analyzed and possible drawbacks of the approach as well as enhancements for future work will be given.

The main steps of this master thesis are illustrated in Figure 1.1.

## 1. Introduction

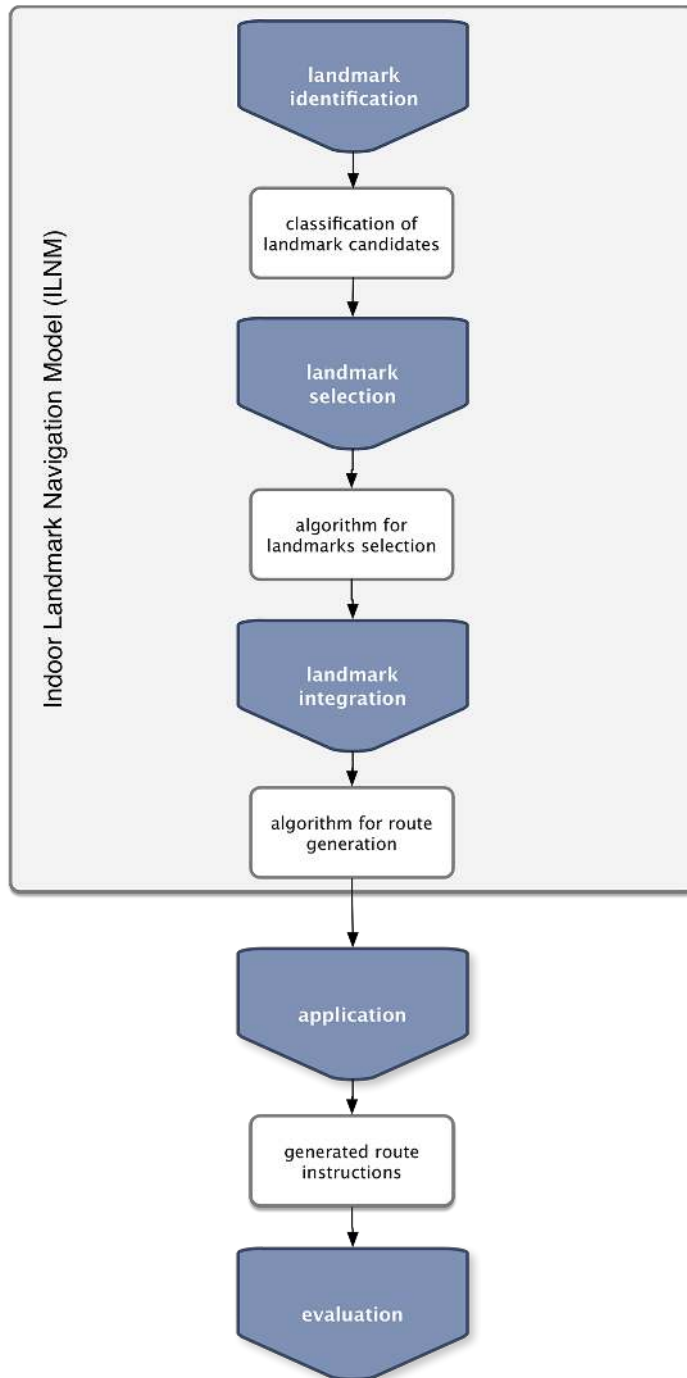


Figure 1.1.: Main steps of this thesis

## 1.4. Structure of the thesis

The thesis is divided into six chapters. After an introduction to the topic and research questions in the first chapter, chapter 2 discusses the theoretical background on landmarks and their role in indoor route instructions. First of all, the concepts of navigation and wayfinding are explained. Then, the basics on landmarks and their importance for route instructions are outlined. Finally, the particular challenges of indoor wayfinding and indoor route instructions are described and a review of existing landmark-based indoor navigation systems is given.

In chapter 3, the development of the ILNM is described. First, an overview of related work for the whole approach as well as for the three sub processes is given. Then, the basis for the ILNM, the LNM, is explained before the actual adaptation of the three sub-processes to the ILNM is performed. For each process the relevant modifications and applied rules are described.

Chapter 4 then moves on to the application of the ILNM to the WU Campus GIS. In the first subsection, the fundamentals of this process as well as the selected sample routes are outlined. The following subsections describe the application of each ILNM process step as well as the results in detail.

Chapter 5 provides an evaluation of the route instructions generated by the ILNM and a discussion of possible drawbacks and problems of the ILNM.

In the concluding section, a summary of the findings of this thesis and ideas for future work are given.

## 2. Landmarks in indoor route instructions

This chapter deals with the theoretical background on landmarks and their role in indoor route instructions. First of all the concepts of navigation and wayfinding are explained. Then the basics on landmarks and their importance for route instructions are outlined. Finally, the particular challenges of indoor wayfinding and indoor route instructions are described.

### 2.1. Human navigation and wayfinding

#### 2.1.1. Concepts of navigation

One widely used definition of navigation was created by Daniel R. Montello (2005) who defines navigation as: “coordinated and goal-directed movement through the environment by organisms or intelligent machines.” He divides navigation into the two components locomotion and wayfinding. *Locomotion* is described as “the movement of one’s body around an environment.” It requires the continuous perception and interpretation of the local surrounds. In contrast to locomotion, *wayfinding* is defined as “the goal-directed and planned movement of one’s body around an environment in an efficient way.” This means wayfinding requires a destination, which should be reached. According to Golledge (1999): “Wayfinding is the process of determining and following a path or route between an origin and destination.”

While paths are referred to the physical possibilities to get from a start to a destination point, a route refers to only one specific possibility and ignores the others (Rehrl 2011). Paths or routes are represented as one-dimensional linked segments which form a network when integrated with other paths (Golledge 1999).

#### 2.1.2. Cognitive aspects of wayfinding

Efficient wayfinding requires a set of cognitive processes. The basic cognitive processes can be found in the definition of wayfinding above: determining and following a route. According to Downs and Stea (1982), wayfinding consists of four consecutive

## 2. Landmarks in indoor route instructions

processes: orientation, planning the route, keeping on the right track, and discovering the destination. A more comprehensive explanation of wayfinding by Golledge (1999) lists the following cognitive processes required for successful wayfinding: identifying origin and destination, determining turn angles, identifying segment lengths and directions of movement, recognizing landmarks and embedding the route to be taken in some large reference frame.

Different strategies exist for individuals to optimize the wayfinding process. Usually these strategies depend on the degree of familiarity with the spatial environment. While exploring a new environment humans build different forms of spatial knowledge: landmark, route, and survey knowledge. *Landmark knowledge* is acquired first and refers to the fact that while exploring a new environment people first notice salient objects or structure at fixed locations. The second knowledge, which is acquired, is *route knowledge*. It consists of information about the order of landmarks and of the experienced paths of movement connecting them. *Survey knowledge* is derived from accumulated route knowledge and results in map-like representation of metric spatial relationships between sets of environmental features such as routes and landmarks. However, as metric configurational knowledge begins to be acquired on first exposure to a novel place, there is no stage at which only pure landmark or route knowledge exists (Daniel R Montello 1998).

The result of the process of spatial knowledge acquisition is called “cognitive map”. Cognitive maps are the internal representation of perceived environmental features (points, lines, areas, and surfaces) and the spatial relations among them (Golledge 1999). As it is unlikely that all elements and all pieces of information will be organized into a single, coherent maplike cognitive structure, cognitive maps are usually fragmented or incomplete. Therefore, Tversky (1993) introduced the term “cognitive collages”.

### 2.1.3. Communication of navigation knowledge

For conveying navigation information to the pedestrian and supporting pedestrian wayfinding in urban environments different communication forms are available, with maps and route instructions being most commonly used. Several researchers (Denis (1997), Lovelace et al. (1999), Agrawala (2002)) have defined the task of creating a route instruction or route map as a three stage process consisting of:

1. activation of a representation, the spatial knowledge, of the environment to be described,

## 2. Landmarks in indoor route instructions

2. choice of a specific route through the environment,
3. translation of the chosen route through the environment into a set of route instructions or into a route depiction.

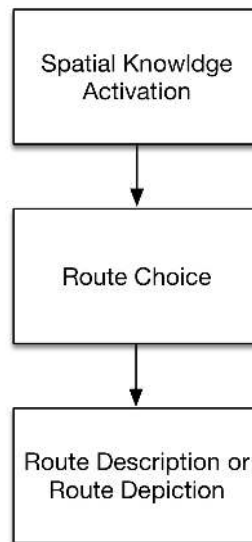


Figure 2.1.: Three-stage task model for producing route descriptions or route maps (adapted from Agrawala (2002))

This general three-stage model shown in Figure 2.1 applies to both maps or route descriptions created by human and by navigation systems.

### Maps and floor plans

Maps are the most important forms when communicating spatial information, as they provide a good overview of the local environment (Radoczky 2003). They may be seen as the attempts by humans to record the absolute and relative location of places, features, and spatial relations among phenomena. Maps used in wayfinding are usually two-dimensional planar representations of a segment of the earth's surface (Golledge 1999).

In the context of human wayfinding a specific form of maps - so-called route maps - play an important role. According to Agrawala (2002), the information that can be depicted in route maps falls into three classes: turning point information, local context and overview context. A *turning point* can be defined by a pair of roads and the turn direction between those roads. *Local context* consists of information about the route itself and the environment immediately surrounding it. *Overview context*



## 2. Landmarks in indoor route instructions

consists of large scale area landmarks and of global properties of the route. Turning point information is considered as essential, local context is seen as less important and overview context is least important.

Floor plans are map-like depictions of different building levels and a good possibility to represent complex indoor structures. Usually they are generated from CAD-plans and although they have similar properties as maps, specific generalization techniques are required for the customization to the specific nature of indoor environments.

### **Route instructions**

Route instructions represent another important way to communicate spatial information. The primary purpose of route directions is defined by Daniel and Denis (1998) as "to elicit actions, so that a mover is brought from a starting point to a destination that he/she intended to reach in an environment".

Different studies looked into what constitutes 'good route directions', which was summarized by Lovelace et al. (1999) as follows:

- priming the traveler for upcoming choice points,
- mentioning landmarks at choice points,
- giving "you've gone too far if" statements in case a choice point is missed,
- giving landmarks rather than street names,
- giving distances between choice points,
- telling the traveler which way to proceed at a choice point,
- providing information to allow recovery from errors,
- providing clearly linear information,
- providing a limited amount of redundant information.

While some of these suggestions are based on empirical evidence, others are based only on thought experiments or intuition, which have not been tested yet. However, there have been many studies confirming the importance of landmarks on the quality of route instructions, which will be discussed in detail in Section 2.2.2.

## 2.2. Route instructions with landmarks

Research on the the creation of cognitively ergonomic route instructions (i.e. how easy are the route instructions for a human to understand, remember and use), reveals that automatically generated route directions, which consist merely of street names, numerical references to distances or turning angles (as they are used for navigation of vehicles) are not suitable for human orientation and wayfinding (Duckham et al. 2010).

Findings in spatial-cognition research show that humans use salient objects - so-called landmarks - for cognitive mapping of the environmental structure (Lynch 1960), for orienting themselves in a new environment (Siegel and White 1975) and for enriching route descriptions like defining points for turning actions with the help of landmarks (e.g. Lovelace et al. (1999), Tom and Denis (2003), Ross et al. (2004), Rehrl, Leitinger, et al. (2009)). Landmarks serve as reference points in the environment, which help to structure space and support navigation by identifying choice points, where navigational decisions have to be made (Millonig and Schechtner 2007).

### 2.2.1. Characteristics and categories of landmarks

Landmarks are defined as prominent, identifying features in an environment that can easily be recognized and memorized (Sorrows and Hirtle 1999). The term was first introduced by Lynch (1960) who defined the essential characteristic of a viable landmark as its singularity and its contrast with its background.

In the literature different classifications of landmarks exist based on various criteria. One approach is to distinguish between a static (or structural) and a dynamic (or functional) view on landmarks (Klippel (2003), Richter (2013)). A static view focuses on the properties of the objects themselves, i.e., how they differ from other features in their surrounding. A dynamic view accounts for the location of landmark candidates along a route to assess their suitability as references in instructions.

#### **Categorization based on a static view**

Concerning on how an object stands out from its environment and therefore serves as a landmark, the categorization introduced by Sorrows and Hirtle (1999) is certainly the most important one. They differentiate between visual, cognitive and structural landmarks:

## 2. Landmarks in indoor route instructions

- A *visual landmark* stands out from its environment because of its visual characteristics. An example of this might be a big cathedral.
- A *cognitive landmark* is one with a typical meaning, or because it is atypical, in the environment. For example a cognitive landmark might be culturally or historically important.
- A *structural landmark* is important because of its location in the environment, like a big square or a typical downtown plaza.

These three categories are not discrete, the strongest landmarks in an environment will be landmarks that belong to all of these categories.

Another classification of landmarks, which is relevant only for mobile navigation services, is the distinction between active and passive landmarks. *Active landmarks* build up a spontaneous radio connection the moment the mobile device reaches their range and identify themselves without any intervention of the user. Beside supplying positioning data active landmarks are also able to provide system-independent additional information about their environment. Particularly for indoor environment active landmarks are a reasonable method to supplement the navigation system with positioning and landmark information (Radoczky 2007). *Passive landmarks* are conventional landmarks, which do not actively communicate with the mobile device.

### **Categorization based on a dynamic view**

According to the position of a landmark on a route, different studies (e.g. Denis (1997)) distinguish between “landmarks at a choice point” (at any point where a potential change of direction exists) and “non-choice landmarks”. Lovelace et al. (1999) refine this categorization and distinguish between four groups of landmarks:

- “*Potential choice point*” landmarks are landmarks that are located at potential turning points but are not used on the route being described.
- “*Choice point*” landmarks are those at choice points, which are used on the route described.
- “*On route*” landmarks occur along the path of travel but not at a potential or used choice point.
- “*Off route*” landmarks are not contiguous to the path followed but of some orientation value, such as mountains or out of view buildings.

## 2. Landmarks in indoor route instructions

An important outcome of the study of Lovelace et al. (1999) is that choice point and on-route landmarks are the most used ones in route directions of unfamiliar environments.

Steck and Mallot (2000) categorize landmarks according to their function in orientation into local and global landmarks. *Global landmarks* such as towers or mountain peaks are visible from a large area and define a global reference that does not change when the person moves a small distance. They therefore resemble a compass. In contrast, *local landmarks* are visible only from a small distance and they serve as a sequence of intermediate goals in route navigation.

Whether an object serves as a local or global landmark is not a unique property of this object but depends on how the human uses that object. One object serving as a global landmark in one navigation task may serve as a local landmark in another navigation process.

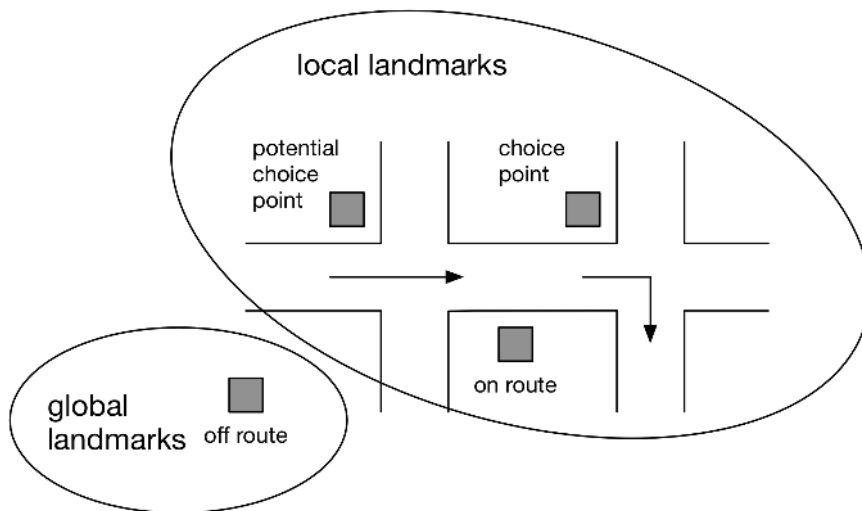


Figure 2.2.: Categories of landmarks based on a dynamic view (from Elias (2006))

### 2.2.2. The role of landmarks in route instructions

Denis (1997) developed a general framework for the analysis of route instructions. He examined route descriptions in a natural environment and established a classification of items of these descriptions, consisting of five classes:

1. prescription of actions without referring to any landmark (“Walk straight ahead.”),
2. prescription of actions with reference to a landmark (“Turn right at the church.”),

## 2. Landmarks in indoor route instructions

3. reference to landmarks without referring to any associated action (“There is a green house.”),
4. description of landmarks (“The name of the restaurant is ‘Comida’.”),
5. commentaries (“The walk requires around 15 minutes.”).

This classification was used to construct “skeletal descriptions” that reflected the essentials needed for navigation along a route. Further studies with this classification show that the sum of the elements with reference to or information about landmarks, account for around 80 percent of the overall route instruction. Another study by Daniel and Denis (1998) demonstrates that around 85 percent of all elements of human route instructions refer to landmarks.

Many studies examined the quality of route instructions and its relation to the occurrence of landmarks as well as the use of landmarks in human route instructions (e.g. Lovelace et al. (1999), Tom and Denis (2003), Rehrl, Leitinger, et al. (2009), Rehrl (2011)). All studies confirmed that landmarks are an important element of route instructions and play a crucial role for their quality.

The quality of route instructions can be measured in a number of ways: It may be a function of the absolute number of various elements included in the instruction (e.g. landmarks, turns, descriptive information). Second, it can be also measured subjectively by having the direction rated by people. Finally, the quality may be measured functionally, in terms of how well the route instruction facilitate completion of the wayfinding task (Lovelace et al. 1999).

In a study by Denis et al. (1999) verbal route instructions were collected and their quality measured subjectively and functionally. The results show, that landmarks were more frequently mentioned at points requiring reorientation or choice among alternative streets than along a route where no reorientation was needed. An experiment by Lovelace et al. (1999) investigated, which types and positions of landmarks are used in route instruction (see Chapter 2.2.1 for a description of these landmarks types). In contrast to the study by Denis et al. (1999) this experiment showed that on-route landmarks also account for a high percentage of the overall number of landmarks mentioned in the route instructions and therefore not only landmarks at choice points are important to the quality of route directions. The study also revealed that off-route landmarks are not important. One reason for the difference in the findings between Denis et al. (1999) and Lovelace et al. (1999) might be differences in the the difficulty of the routes used in the studies. While the routes used by Denis et al. (1999) were

## 2. Landmarks in indoor route instructions

rather simple with 2 to 4 segments, the route used by Lovelace et al. (1999) had 14 segments and 13 turns.

Tom and Denis (2003) investigated the differences between the use of street names or landmarks in route instructions. One experiment showed that in a wayfinding task, route directions referring to street names were much less effective than those referring to landmarks for guidance purposes. Another experiment showed that when people generate route instructions, they tend to use significantly less street names than landmarks.

### 2.3. Indoor navigation and wayfinding

Studies on wayfinding, route instructions and landmarks were mainly conducted in outdoor environments. However, these results cannot be applied directly to indoor environments, as there are some particular challenges and characteristics of wayfinding within buildings.

#### 2.3.1. Wayfinding in built environments

Different studies have looked at the factors that influence wayfinding performance within buildings. For instance, Weisman (1981) identifies four classes of environmental factors that influence wayfinding situations: visual access, the degree of architectural differentiation, the use of signs and room numbers, and floorplan configuration (Weisman (1981) quoted in Hölscher et al. (2006)). Wayfinding performance within buildings also depends on whether large parts of the building are immediately visible, whether the floorplans of different levels are identical and whether mental floorplans at transition points like staircases or elevators are properly connected (Hölscher et al. 2006).

## 2. Landmarks in indoor route instructions



Figure 2.3.: Example of a complex building with different floor plans: Library & Learning Center of WU

Carlson et al. (2010) developed a framework that encompasses the factors for successful navigation in a building. They argue that how easy it is in a building to navigate and find a way emerges as an integration of the spatial structure of the building, the cognitive map that is constructed during navigation, and the strategies and individual abilities of the user. Figure 2.4 shows these main factors and their intersections:

- *Correspondence* between the building and the cognitive map refers to the extent to which the cognitive map represents the spatial structure of the building in terms of the content and configuration of its units. For example, users expect the floor layouts in multistory buildings will be identical on every level.
- *Compatibility* between the building and the strategies of the user relates to the extent to which the spatial structure of the building impacts strategy selection. For example, it is advantageous to have unimpeded lines of sight connecting entrance spaces and other key central spaces to the means of vertical circulation, like stairs and elevators (Weisman (1981) quoted in Carlson et al. (2010)).
- *Completeness* of the cognitive map as a function of the strategies of the users, refers to the extent to which the navigation strategy dictates the features that are included in the cognitive map.
- Finally, *complexity* represents the intersection of all three factors and refers to the difficulty of the wayfinding problem in a given building for a given user using

## 2. Landmarks in indoor route instructions

specific strategies and relying on a specific cognitive map (Carlson et al. 2010).

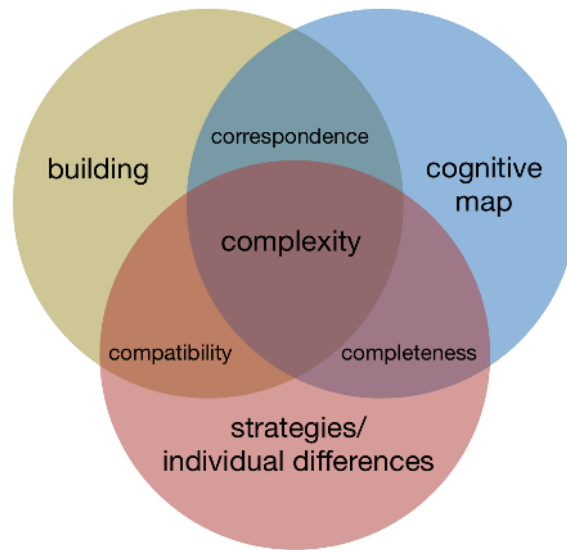


Figure 2.4.: Factors predicting navigation in buildings (from Carlson et al. (2010))

Hölscher et al. (2006) investigated, which wayfinding strategies people incorporate in multi-level buildings and propose a distinction of three strategies:

1. *Central point strategy*: sticking as much as possible to well-known parts of the building, like the main entry hall or main connecting corridors.
2. *Direction strategy*: choosing routes that head towards and lead to the horizontal position of the goal, irrespective of level-changes.
3. *Floor strategy*: first finding one's way to the floor of the goal, irrespective of the horizontal position of the destination.

Their study revealed that for unknown routes the floor strategy was most efficient.

### 2.3.2. Landmark-based indoor navigation systems

With the emerging of more and more large and complex buildings, the problem of indoor wayfinding for people who are unfamiliar with them increases. Indoor navigation systems providing verbal or textual route instructions would be a helpful form for supporting the wayfinding process for indoor environments. However, as outlined in Chapter 2.2 route instructions for pedestrians are only useful if they use landmarks for defining choice points or for describing route segments.



## 2. Landmarks in indoor route instructions

Since it is more likely to lose orientation within a building than outside (Radoczky 2003) and changes in direction happen more frequently, it is expected that the user demands a higher density of landmarks than outdoors. However, buildings usually dispose of a smaller choice of landmark categories and they might not be as remarkable as outdoor landmarks (Gartner (2007), Radoczky (2007)). Additional challenges to the creation of indoor route instructions with landmarks occur due to the fact that within buildings there are more open spaces, which do not include clear paths to chose from (Mast, Jian, et al. 2012) and indoor route instructions cannot refer to street names like in outdoor environments.

As research on indoor navigation systems is still in its infancy, few real systems to support indoor navigation exist. Krisp et al. (2015) list the the three major challenges that need to be considered when building an indoor navigation system:

- *data acquisition*: the problem of acquiring indoor data in a sufficient level of detail.
- *route computation*: the question of how to compute a route similar to the route a user would take if he/she would know the building very well.
- *visualization and communication*: the challenge of how to display the route so that the user can find the way.

For the investigation of existing indoor navigation systems Huang and Gartner (2010) propose an evaluation framework which combines the key aspects of indoor navigation:

- *indoor positioning*: signal, signal metrics, positioning algorithms,
- *route communication*: presentation forms,
- *context-aware adaptation*: context parameters, adaptivity, adaptation objects,
- *other features*: network access, client platform.

Huang and Gartner (2010) outline that the provision of landmark-based semantic enriched instructions is one of the key challenges of indoor navigation systems that require further research and development. Therefore few approaches exist so far for the creation of semantic enriched indoor route instructions. Below a selection of approaches for indoor navigation systems is described which offer textual route instructions with at least some kind of reference to landmarks.

## 2. Landmarks in indoor route instructions

Rehrl, Göll, et al. (2005) developed a combined indoor/outdoor navigation system for public transport travellers with a Bluetooth based positioning solution. Routes are communicated through maps and textual instructions. Regarding the textual instructions they focused on the creation of naturally sounding route instructions with references to objects in the scene space like gateways, signs or orientation marks. In addition, information from nearby landmarks and signs is added to the path descriptions.

The indoor navigation system “iNAV” designed by Kargl et al. (2007) uses interchangeable localization plugins that complement each other for determining the position of the user. The route is displayed on orientation maps which offer orthogonal and perspective projections. In navigation mode different textual and spoken orientation hints give a description of the current environment.

Millonig and Schechtner (2007) developed a prototype navigation system for pedestrians for a major train station. In order to identify highly frequented routes, decision points and landmarks, the station was monitored for two weeks by surveillance cameras and the people trajectories were analyzed. In addition, route descriptions given by test persons were investigated and people were asked to identify salient landmarks. Based on this data a routing table was created to define navigational instructions from each origin in the station to each possible destination.

To overcome the problem that buildings usually dispose of a smaller choice of landmark categories, Radoczky (2007) suggests the usage of active landmarks. These landmarks automatically build up a spontaneous radio connection when the mobile device reaches their range. Additionally to the supply of mere positioning data, they can also provide system-independent additional information about their environment.

Mast, Jian, et al. (2012) tried to overcome the problem of a lack of clear paths and highly distinctive landmarks in indoor environments by integrating more elaborate descriptive information into indoor route instructions. For instance, scenes, i.e. open areas without clearly identifiable nodes and edges, are described as one entity, and the location of the scene exit is described with respect to the scene. By introducing more elaborate descriptive information into the instructions configurations of landmarks can be generated that can serve as highly salient landmarks. In an experiment these route instructions were tested with an indoor route directions system called “Infokiosk” (Cuayáhuatl et al. 2010). The results clearly show that descriptive route instructions can improve wayfinding in indoor environments both on an objective and a subjective level.

## 2. Landmarks in indoor route instructions

In the information system for indoor navigation developed by Heiniz et al. (2012) users are guided through the building by using images of the surroundings and textual instructions. In this system users are involved into the navigation process and complete missing information through recognized content. Therefore positioning of the user works in any building independent from the hardware infrastructure. Information about the route is communicated through textual and graphical route instructions including relevant landmarks on the route.

To summarize, due to particular challenges of indoor navigation few real systems exist to support indoor wayfinding, and only a part of the prototypes in the literature offers route instructions with landmarks. The landmarks in these route instructions are usually not selected automatically from a database of spatial features but assigned to the routes manually in advance or the route instructions are completely hand-crafted.

This approach would not work for large buildings or building complexes like university campuses with a very long routing network as the manual effort of the data handling would be too high. In the next chapter studies on the automatic selection of indoor landmarks will be discussed and an approach for the automated creation of indoor route instructions with landmarks will be developed.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

With the establishment of the importance of landmarks in route instructions, several computational approaches for the automatic identification, selection and integration of landmarks in navigation instructions have been developed (see Section 3.1.1). Duckham et al. (2010) and Richter (2013) distinguish between two steps in the process of generating route instructions with landmarks: (1) the *identification of features* that may serve as landmarks in principle (“landmark candidates”) and (2) the *selection of some of these candidates* to be included in the instructions.

In the course of this master thesis the step of the generation of the route instructions with selected landmarks is seen as a separate process. Therefore it will be distinguished between the following three main steps of automated route generation with landmarks:

1. **Landmark identification:** Identification of suitable landmark candidates,
2. **Landmark selection:** Selection of landmarks for an individual route,
3. **Landmark integration:** Generation of a route description with landmarks for a specific route.

These processes are outlined in Figure 3.1.

### 3. Development of the "Indoor Landmark Navigation Model" (ILNM)

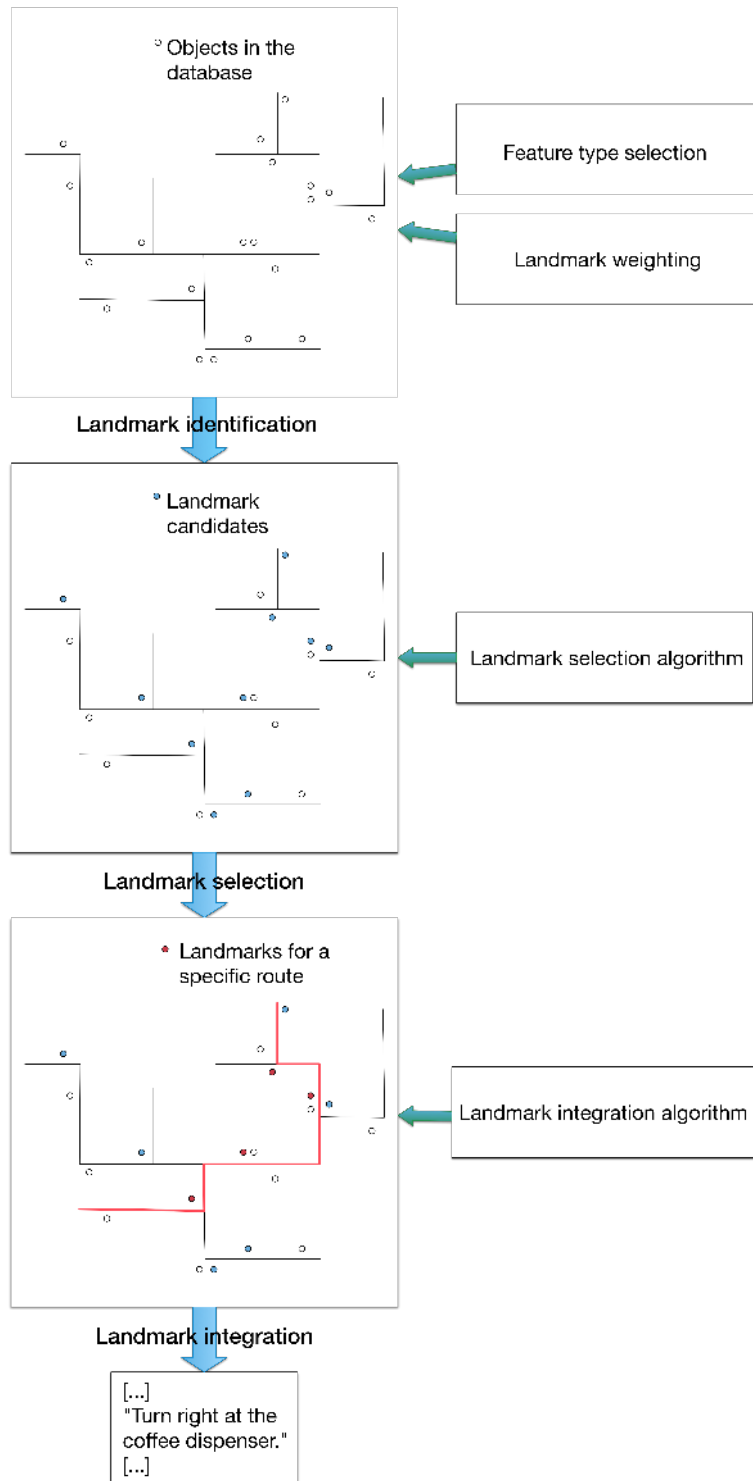


Figure 3.1.: Processes of generating route instructions with landmarks

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

Corresponding to the classification of landmarks introduced by Sorrows and Hirtle (1999) into visual, semantic and structural landmarks, the process of landmark identification takes visual and semantic attraction of spatial features into account and identifies landmark candidates independent from a route. The next step, landmark selection, is based on the structural location of a landmark candidate with reference to the actual route. In the course of landmark integration, the selected landmarks are incorporated into route instructions.

In many approaches these steps are seen as independent and they focus only on one of these processes. In addition, they partly differ considerably according to other factors, like the data source, the geometry type of the landmarks or the method they apply for identifying landmark objects. With one exception they were all developed for outdoor environments and beside one approach all are relying on the individual properties of the potential landmark objects instead of object types.

While for outdoor environments detailed visual or geometric information about individual properties may be available for example in the form of geo-referenced images or digital cadastral maps, this kind of information is usually not available for indoor objects. Using instead class-level information about the types of landmarks, as proposed in the “landmark navigation model” (LNM) by Duckham et al. (2010) (see Section 3.1.2), is a promising approach to overcome this problem. Therefore this model will serve as a starting point for the approach of this work.

The aim of this thesis is to develop an “indoor landmark navigation model” (ILNM) for the automatic creation of route instructions with landmarks for indoor environments based on the LNM by Duckham et al. (2010). In this model all three sub processes of automatic route instruction generation shall be covered: *landmark identification* (Section 3.2), *landmark selection* (Section 3.3) and *landmark integration* (Section 3.4) and only data will be used, which is usually available in *existing, spatial databases for indoor environments*. Each process from the LNM will be modified to the specific requirements of indoor route instructions and adapted to the data structure of indoor environments.

#### 3.1. Related work

In the following section approaches and studies, which are relevant to the processes of the ILNM, are outlined. First, approaches for automated generation of route instructions with landmarks are described and a classification of them in comparison to the ILNM is made. Second, the LNM by Duckham et al. (2010) which servers as a basis

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

for the development of the ILNM, is described. Then, approaches and relevant studies for the sub processes of the ILNM, i.e. landmark identification, landmark selection and landmark integration, are stated.

#### 3.1.1. Automated generation of route instructions with landmarks

The first approach was developed by Raubal and Winter (2002), which was extended later by several researchers. It is based on a set of evaluation functions to assess the visual, semantic and structural saliency of features in a data set according to the characterization of landmarks developed by Sorrows and Hirtle (1999) (see Section 2.2.1). Regarding the visual attraction four measures are included: Facade area, shape, color, and visibility. Semantic measures for the formal model of landmark saliency comprise cultural and historical importance and explicit marks. For the structural saliency nodes and boundaries are considered. These evaluation functions are combined to a global measure of landmarks saliency for each feature in a dataset.

While the structural saliency in the model by Raubal and Winter (2002) is independent from the route, the approach by Klippel and Winter (2005) uses the street network and the location of the buildings relative to the street network to compute structural saliency. In addition, they introduce advance visibility, which characterizes the visibility of the object from an approaching direction. The salience of a facade in the context of a route is then calculated from weighted visual, semantic and structural salience and advance visibility.

Elias (2003) aims at identifying the most salient features in a dataset by the use of a knowledge discovery process and data mining methods. Compared to the two previous methods, in this approach facades play only one contributing factor and no measure for relative or absolute ranking in a neighbourhood is provided. Landmarks are identified by detecting outliers, i.e. objects, which have a unique attribute in a certain environment.

Winter et al. (2008) developed a computational model for the generation of a hierarchy of landmarks by combining the approaches by Raubal and Winter (2002) and Elias (2003). Their model builds hierarchies of landmarks from salience with a ranking based on visibility and allows distinguishing between local and global landmarks. For the generation of the route directions, they modified the approach of granular route directions introduced by Tomko and Winter (2006) for the particularities of the landmark hierarchies.

Some approaches depend on landmarks being already known and do not specify

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

how to identify potential landmarks from a data set (e.g. Richter (2007), Caduff and Timpf (2005)).

The approach by Richter (2007) creates a computational process for generating context-specific route instructions that takes different types of landmarks into account. This approach exploits the circular order of a decision point’s branches as well as the order of events in route following according to the directedness of a route. Landmarks are integrated into an abstract specification of route instructions according to the location of a landmark’s coordinate points relative to a decision point.

Caduff and Timpf (2005) and Elias and Sester (2006) aimed at optimizing a route according to the presence of landmarks. In the framework developed by Caduff and Timpf (2005) the route between two points is generated as a function of the presence of highly weighted landmarks at each node. Landmarks are weighted according to their distance to the node, the orientation of the traveler with respect to the landmarks and their salience. The resulting route is presented in the form of a diagrammatic route description.

Elias and Sester (2006) introduced an approach that creates a route, which takes landmark quality and distance information into account and also considers landmark chunking rules. Landmarks are qualified according to different criteria, including permanence, visibility, perception, usefulness of location, individual appearance or uniqueness of landmarks.

While the above described approaches for the identification and selection of landmarks are based on detailed visual or geometric information about buildings, the approach by Duckham et al. (2010) represents an exception. They developed a “landmark navigation model” (LNM) which incorporates landmarks into route instructions and does not depend on specific instance-level data about the visual or geometric characteristics of individual features. Instead the model relies solely on class-level information about the types of landmarks, in addition to the road network and route geometry (see Section 3.1.2 for a more detailed description). Another difference to the other approaches is the type of data source: Each approach for landmark identification uses a specific data source, mostly spatial databases (Richter 2013), in contrast to the approach of Duckham et al. (2010), which depends only on commonly available data from a publicly available webmapping service.

There exists only one approach so far which deals with automatic landmark extraction for indoor environments. Lyu et al. (2015) developed a computational model for extracting indoor landmarks from a spatial dataset. In the first step salience is calcu-



### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

lated from weighted visual, semantic and structural attractiveness for both point-like objects (POIs) and polygons (rooms). The indicators for this calculation are taken from several relevant theories, i.e. spatial cognition, affordance theory as well as space syntax and include: *visible area*, *circularity*, *shape perceivability*, *accessibility*, *location importance* and *functional importance*. In the second step these values are compared with the attributes of surrounding objects to identify landmarks.

Table 3.1 shows a classification of the approaches discussed above as well as of the ILNM, which will be developed in this thesis, according to different criteria. This table is a modified version of the categorization introduced by Richter (2013), which was simplified in some aspects but also extended by new criteria. In this categorization a distinction is made between the processes the approaches focus on as well as between the structure and function in wayfinding. The structural (or “static”) view refers to the properties of the features themselves, whereas the functional (or “dynamic”) view accounts for the location of landmark candidates along a route to assess their suitability as references in instructions (see also Section 2.2.1). Further distinction criteria include the source of data, the conceptual geometry of landmark candidates and whether they aim to identify individual features (instances) or categories of features (types). The differentiation between indoor and outdoor environments forms the last criteria <sup>1</sup>.

#### 3.1.2. “Landmark Navigation Model”

Duckham et al. (2010) developed an approach for generating route instructions with landmarks which relies on commonly available data about categories of landmarks, rather than detailed instance level data about the visual characteristics and facades of buildings. Their process of the creation of route instructions has two phases: an offline process of landmark identification from available categories; and an online landmark selection process based on route-specific factors.

The “landmark navigation model” (LNM) relies on category-level information about *types* of landmarks, rather than instance-level information about *individual* landmarks. Category-level information about features in geographic environments is typically much more widely (e.g. geocoded business directories) available than information about individual objects. The core LNM consists of two components: the landmark weighting system (“landmark identification”) and an annotation algorithm (“landmark selection”).

---

<sup>1</sup>“x” = aspect is fully covered, “(x)” = aspect is partly covered

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

	Sub-process		View		Datasource			Geometry			Level		Environment				
	Identi- fication	Selec- tion	Integra- tion	Static	Dyna- mic	GIS	WWW	Geore- ferenced Images	Unde- fined	Point	Poly- gon	Line	Indivi- dual	Cate- gory	Indoor	Out- door	Unde- find
Raubal and Winter (2002)	x		(x)	x		x		x		x			x			x	
Elias (2003)	x			x		x				x			x			x	
Klippel and Winter (2005)		x			x			x		x			x			x	
Caduff and Timpf (2005)		x	(x)		x			x		x			x			x	
Elias and Sester (2006)		x			x					x			x				x
Winter et. al. (2008)	x			x		x				x			x			x	
Duckham et. al. (2010)	x	x	x	x	x		x			x	(x)		x	x		x	
Richter (2007)			x		x			x		x	x	x	x			x	
Lyu and Meng (2015)	x			x		x				x	x	x	x		x		
ILNM	x	x	x	x	x	x				x	x	x	x	x	x		

Table 3.1.: Approaches for automated generation of route instructions with landmarks

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

#### Landmark weighting

The weighting system of the LNM is created by a heuristic process which assigns weights based on the expected properties of the categories of POIs. There are two independent factors to consider:

1. How suitable is a typical instance of POI category as a landmark?
2. How likely is it that a particular instance of a POI category is typical?

A category is highly suitable if it consists of uniformly salient individuals. These two factors are used to weight POI categories according to how suitable they are as landmarks. A heuristic process is used in order to generate for a set of  $C$  of POI categories a normalized weighting function:  $weight : C \rightarrow [0, 1]$ . Developing this landmark weighting heuristic has two phases:

1. identifying the factors that contribute to landmark suitability and
2. designing a scoring system to convert the suitability factors into a normalized score.

In the last step the overall suitability score can be calculated.

#### 1. Suitability factors

As outlined in Section 2.2.1 landmarks can be classified according to their visual, semantic and structural characteristics. Duckham et al. (2010) developed a more detailed list of sub-characteristics, tailored to determining the landmark suitability of POI categories. Table 3.2 outlines these specific suitability factors used in the LNM.

#### 2. Scoring system

In order to calculate the landmark suitability, a heuristic scoring system was developed for the LNM. The scoring system is two-dimensional to account for the two components of category suitability defined above. It uses a five point rating for the suitability of typical landmarks of a category (from “Ideal” to “Never suitable”) as well as a five point rating for the frequency of typical landmarks in a category (from “All typical” to “Few”). Table 3.3 shows an example of an expert ranking of the POI category “takeaway food” in terms of the suitability of the category as well as the typicality of instances of the category.

These expert ratings are then combined to the overall scores defined in table 3.4.

#### 3. Overall suitability score

After ranking each landmark category against each suitability factor an overall suitability score for the landmark category can be derived. This score represents the sum

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

Character	Factor	Explanation
Visual	Physical size	Larger POIs are more easily seen, and so better candidate landmarks than smaller POIs.
	Prominence	POIs that are visually prominent are better candidate landmarks than those with few or no distinguishing markings.
	Difference from surroundings	POIs that are typically different from their surroundings are preferable landmark candidates.
	Nighttime vs. daytime salience	POIs that are highly visible both in day and night are better landmark candidates in the context of the case study.
	Proximity to road	POIs that are closer to the road are more likely to be seen by navigators, and therefore are better candidate landmarks.
Semantic	Ubiquity and familiarity	POIs that are ubiquitous and familiar represent better candidate landmarks.
	Length of description	POIs that require short or very familiar descriptions are more suitable landmarks than POIs that require longer or more complex descriptions.
Structural	Spatial extents	Point-based POIs are likely to be more suitable landmarks, as they are less ambiguous than landmarks with spatial extents.
	Permanence	POIs that are expected to change or move less frequently make better candidate landmarks.

Table 3.2.: Detailed factors for scoring landmark suitability for POI categories according to Duckham et al. (2010)

of scores for all suitability factors according to the values in Table 3.4. Finally the weighting for a particular landmark category  $c$ ,  $weight(c)$  is normalized in the range  $[0,1]$  (with 1 being most suitable and 0 being least suitable) as outlined in equation 3.1 where  $score_f(c)$  is the suitability factor from Table 3.4 for a category  $c \in C$  with respect to the suitability factor  $f$ , and  $F$  is the set of all suitability factors (Duckham et al. 2010).

$$weight(c) = \frac{\sum_{f \in F} score_f(c) - \min\left(\left\{\sum_{f \in F} score_f(c') \mid c' \in C\right\}\right)}{\max\left(\left\{\sum_{f \in F} score_f(c') \mid c' \in C\right\}\right)} \quad (3.1)$$

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

	<b>Takaway food</b>	
	Suitability	Typicality
Physical Size	suitable	most
Proximity to road	highly	most
Visibility	ideal	all
Difference from surroundings	suitable	all
Ubiquity	ideal	all
Nighttime vs. daytime salience	ideal	most
Permanence	somewhat	all
Length of description	suitable	all
Spatial extents	ideal	all

Table 3.3.: Expert’s rating of one category (takeaway food) from Duckham et al. (2010)

<b>Typical landmark</b>	<b>Frequency of typical landmarks in category</b>				
	All	Most	Many	Some	Few
Ideal	8	4	2	1	0
Highly suitable	4	4	2	1	0
Suitable	2	2	2	1	0
Somewhat suitable	1	1	1	1	0
Never suitable	0	0	0	0	0

Table 3.4.: Landmark scoring system based on POI categories from Duckham et al. (2010)

#### **Annotation algorithm**

The annotating algorithm creates route instructions with landmarks based on the weighting system. In addition to the set of categories and the category weighting function, this algorithm is based on two further data sources: the route network and a geocoded POI directory.

In the core LNM algorithm by Duckham et al. (2010) simple turn-by-turn routing instructions with references to landmarks are generated. If no landmark is available at a decision point, the algorithm reverts to a standard turn-by-turn instruction, like “⟨Perform action⟩ onto ⟨Street Name⟩ after ⟨Distance⟩”.

The core LNM was refined in a further step by additional extensions which apply both to landmark weighting and the route instructing algorithm:

**Adjusting POI category weights:** Landmark weights can be adjusted for different user groups, e.g. one set for car drivers and one set for pedestrians.

**Adjusting POI instance weights:** As wayfinders focus more on the side of the street

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

that the next turn will be made toward, the weight for a POI can also be adjusted according to its side of the road in relation to the action. Another adjustment refers to the fact that several landmarks of the same category may occur on a particular route segment. In this case the first instance of that POI category keeps its salience.

**Altering route instructions:** The generation of route instructions can be adjusted to deal with some special cases like the **absence of landmarks**, in which the road type or street name can be used in the route instruction. In addition, some minimum threshold  $s \in [0, 1]$  can be applied such that no landmark is ever selected with a suitability weighting below  $s$ .

Also **landmarks off decision** points can be used on longer route segments to provide confirmation to users that they are on the correct route and for the case, that the upcoming decision point has no suitable landmark.

Another extension of the route instruction algorithm refers to the geometry type of the selected landmarks. So called **areas of interest** (AOIs) can be used as on-route landmarks in addition to POIs. In the LNM these AOIs are used for in-leg instructions, as their spatial extent makes them unsuitable as landmarks at decision points. Dependent on the spatial relationship between the route leg and the extended region, instructions of the form “*Continue along*” or “*Continue through*” are generated.

In Figure 3.2 steps (vii) a) to (ix) represent the route generation algorithm in the LNM. The result are route directions like “*Turn left onto Spring Street, Melbourne at Imperial Hotel.*”

- 
- (i) Generate a route from origin  $o \in V$  to destination  $d \in V$  from the graph  $G = (V, E)$  using a standard shortest path algorithm.
  - (ii) Find the set of POIs  $P' \subseteq P$  that lie anywhere along the route (on decision points or along route legs).
  - (iii) Associate with each POI instance  $p \in P'$  the landmark weight,  $weight_i(c)$ , for the specific user context  $i$  and that POI’s associated category  $c \in C$  such that  $category(p) = c$ .
  - (iv) For any POI  $p \in P'$  at a decision point, increase the suitability weighting if the POI is on same side of the road as the upcoming instruction.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

- (v) Set to zero the weight of every POI which is not the first instance of its category on each route leg.
- (vi) For each decision point, select the POI that is incident with that decision point and has the highest weight. If two or more landmarks have the same weight, arbitrarily select one landmark to use.
- (vii) For each route leg that is longer than some travel time threshold  $t$ , select the in-leg landmark with the highest landmark suitability weight.
  - a) If the decision point has no selected landmark generate a new routing instruction of the form “⟨Perform action⟩ onto ⟨Street Name⟩ after ⟨Selected in-leg landmark⟩”.
  - b) Otherwise generate a new routing instruction of the form “Continue ⟨Action⟩ the ⟨Selected landmark⟩” where
    - i. If the selected landmark is point-based, then associated ⟨Action⟩ is “past”.
    - ii. Otherwise, if the selected landmark has spatial extents, determine whether the selected landmark abuts or overlaps the route, and set the upcoming ⟨Action⟩ to be “along” (abuts) or “through” (overlaps).
- (viii) For each decision point with a selected landmark, generate the routing instruction of the form “⟨Perform action⟩ onto ⟨Street Name⟩ at ⟨Selected landmark⟩”.
- (ix) For each decision point without a selected landmark and not already preceded by an in-leg routing instruction, generate a standard routing instruction of the form “⟨Perform action⟩ onto ⟨Street Name⟩ after ⟨Distance⟩”.

---

Figure 3.2.: Extended LNM algorithm from Duckham et al. (2010)

A case study, implemented within an online web-based navigation service, demonstrates practicality of the approach.

#### 3.1.3. Identification of indoor landmarks

While it is relatively easy to identify which object types may function as landmarks for outdoor environments (e.g. outstanding buildings, prominent shops), for indoor environments this is more difficult to determine. Features within buildings may vary considerably according to the function or according to the architectural style of the

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

building. For example in a hospital different features (e.g. reception desks, waiting rooms) may be cognitively salient than in a university building (computer terminals, lockers, lecture rooms). In some buildings particular door types may be outstanding (e.g. due to the color), while in other buildings all doors look the same and may not serve as landmarks. However, some features within public buildings usually will always work as landmarks as they are typically outstanding from the environment, like elevators, coffee dispensers, entries or stairways.

For outdoor environments several studies have been executed which analyze the use of landmarks in real route descriptions (e.g. Denis (1997), Peters et al. (2010), Rehrl (2011)). However, this kind of studies do not exist for indoor environments. Nevertheless, a few studies have already investigated which objects people use to orientate themselves within buildings. Millonig and Schechtner (2007) and Raubal and Egenhofer (1998) examined indoor navigation with landmarks in large public transport stations. In the master thesis of Jonchon Wun (2013) the use of indoor landmarks as navigational aids is investigated.

Millonig and Schechtner (2007) identified highly frequented routes, decision points and landmarks in a main train station by monitoring it for two weeks with surveillance cameras and analyzing the people trajectories. In addition, route descriptions given by test persons were investigated and people were asked to identify salient landmarks. Most of the identified landmarks are shops or service centers (e.g. post office, bank, travel agency). Also main entrances, ticket machines, info displays and escalators were identified as landmarks.

Raubal and Egenhofer (1998) present a computational model to compare the complexity of wayfinding tasks in built environments, where choices and clues function as complexity-measures. Clues can be seen similar to landmarks. The authors analyzed interviews where subjects had to describe their spatial experiences with two simulated airport spaces to identify the choices and clues for that simulated route. The results do not explicitly list the kind of landmarks that were identified, but shops, signs and building elements (gates, corridors, open spaces) are most often mentioned in this paper.

Jonchon Wun (2013) investigates in her master thesis which types of landmarks are used within buildings. In empirical tests people were observed while following the route in a university building. After completion of the navigation task people had to describe the route, the objects they recognized while following the route and list navigation aids they usually use within big buildings like offices, shopping centers or



### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

airports. Finally people were asked to rate the importance of color guiding systems within buildings. The most often used navigation aids of the navigation task in the university building were: signs, colors, stairways and showcases.

However, more objects were recognized during the navigation task, which may function as potential landmarks. The most often mentioned objects were: elevators, stairways, showcases, room labels, porter’s lodges, facilities (like cafeteria), different types of doors, lockboxes, main entries, signs. Concerning the navigation aids people use usually within large buildings, the most answers were: ”You-are-here-maps”, main entry, signs, wall colors, escalator, elevator, ticket or information counter, facilities (porter’s lodge, shops, etc.), stairways and art objects. Other objects, that were mentioned, like show cases, info screens, vending machines were rated both as often used and as rarely or never used.

Although her master thesis represents one of the few studies of indoor landmark identification, its results cannot be directly applied to the selection of potential landmarks for indoor route instructions. People in this study were primarily asked to rate objects they recognized or they used as navigational aids. But navigational aids may differ from objects which can be used in route route instructions as landmarks. For instance, when navigating in an unfamiliar environment without any route instructions, a coffee dispenser may not be very useful. However, in a route description the instruction ”turn right at the coffee dispenser” may be very helpful.

To summarize, so far no study exists that really reveals which features may serve as good landmarks in route descriptions for indoor environments. In addition, beside typical objects that can be found in nearly all buildings, indoor features may vary considerable among buildings and building types. Therefore, possible landmark candidates have to be selected and specified in the course of a heuristic process individually for each building, taking into consideration the definition of Sorrows and Hirtle (1999), that landmarks are salient because of their visual, semantic or structural characteristics.

#### 3.1.4. Criteria for selecting landmarks

When selecting landmarks for specific routes, different aspects have to be considered, which are listed below. Beside the role of the landmark in route instructions other factors such as visibility or side of the route are relevant.

- **Role in route instruction.** As stated in Section 2.2.1 landmarks can fulfil different functions with reference to a specific route. Various studies (e.g. Denis

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

(1997), Lovelace et al. (1999), Steck and Mallot (2000)) have developed different categorizations, which can be summarized into the following classification (Elias 2006):

- *Global landmarks or distant landmarks.* These landmarks are not on the route and primarily serve orientation purpose.
- *Local landmarks.* Local landmarks are landmarks that lie on the route. They can be further differentiated into:
  - \* *“Choice point” landmarks or landmarks at decision points (with direction change).* Decision point landmarks represent the most important category, as different studies reveal that prominent features located at a decision point on a route are more relevant than prominent features along its segments (e.g. Klippel and Winter (2005), Lovelace et al. (1999), Tom and Denis (2003)).
  - \* *“Potential choice point” landmarks or landmarks at decision points without direction change.* They are located at potential turning points but not used in the concrete route (Lovelace et al. 1999)
  - \* *“One route” landmarks.* Landmarks off decision points or “on route” landmarks can be used to provide confirmation to users that they are on the correct route.

For a detailed description of these landmark functions see Section 2.2.1.

- **Advance visibility.** Winter (2003) outlines that features which are easily and early visible from the direction of a route are more salient and reduce stress and cognitive workload for the traveller when used in route instructions.
- **Side of the road.** Maass (1996) discovered that wayfinders focus more on the side of the street the next turn will be made toward. Therefore, features on that side should be ranked more highly (Duckham et al. 2010).
- **Location at decision point.** Klippel and Winter (2005) developed a classification for the structural aspects of landmarks with a focus on their location at decision points. Landmarks at decision points can be further differentiated in relation to the action:
  - Landmarks passed before re-orientation at the decision point,
  - Landmarks not passed at the decision point, and
  - Landmarks passed after reorientation at the decision point.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

At decision points landmarks passed before re-orientation are most easily to conceptualize as the turning occurs immediately after them.

- **Multiple landmarks on same route leg.** If several landmarks of the same category occur on a particular route leg, the individual landmark salience should be adjusted: only the first instance of a particular category of landmarks on a route keeps its salience; the following ones are set to zero (Duckham et al. 2010). Another possibility would be the introduction of numerical chunking (Klippel and Winter 2005), to produce route instructions like “Turn left at the second police station”. However, this strategy should be applied only for small counts.

#### 3.1.5. Indoor route instruction generation

##### Approaches of route instruction generation

For the generation of route instructions different approaches with a different level of detail exist. One approach to model conceptual route knowledge is called “wayfinding choremes” (Klippel (2003), Klippel, Tappe, et al. (2005)). Wayfinding choremes are conceptual primitives which reflect mental conceptualizations of turning and non-turning actions at decision points. They are based on an eight-direction model in which each sector is represented by 45° increments for prototypical directions. From these eight directions one route segment is singled out as the reference direction, resulting in seven available directions for conceptualizing goal-oriented actions. Combining these seven directions with the reference direction result in seven wayfinding choremes:  $wc_{sr}$ ,  $wc_r$ ,  $wc_{hr}$ ,  $wc_s$ ,  $wc_{hl}$ ,  $w_l$  and  $wc_{sl}$  (see Figure 3.3).

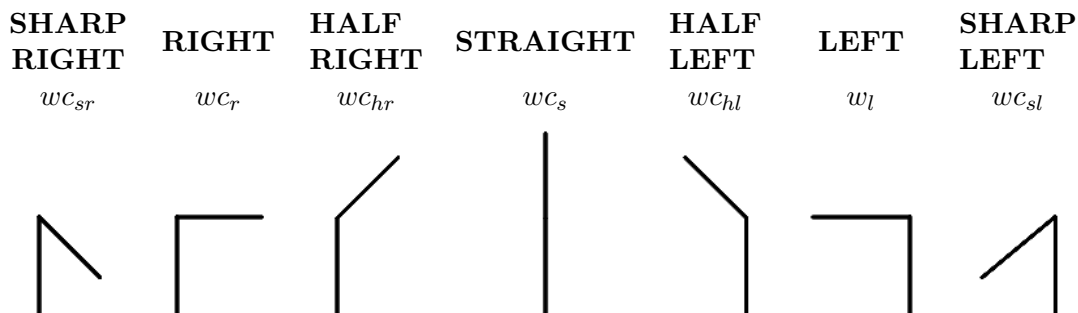


Figure 3.3.: The seven wayfinding choremes: Their conceptualization as linguistic externalization (top), the grammatical notation used (middle) and their graphical externalization (bottom) (from Klippel, Tappe, et al. (2005))

One step further these wayfinding choremes can be chunked into complex expressions by applying term rewriting rules, so called “HORDE” (Higher-Order Route Direction

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

Elements) to model further cognitive organization principles. The wayfinding choreme approach is a neutral representation formalism which supports different forms of externalization, whereas language is one possibility. Its underlying formal model can be taken as a basis for different languages or different terms within one language.

Dale et al. (2005) developed a framework for generating natural route descriptions for wayfinding systems. This framework incorporates techniques from natural language generation (NLG) research to produce more natural-sounding descriptions. They focus on three aspects of the generation process:

- **Discourse structure:** The use of discourse structure facilitates the understanding of the structure of a route. In their approach, Dale et al. (2005) segment the sequence of instructions in a meaningful way. For the segmentation two alternative strategies are introduced:
  - **Landmark-based segmentation:** Landmarks can be used to structure route descriptions as a landmark at a decision point delimits part of the route to be followed.
  - **Path-based segmentation:** This approach of segmentation is based on the investigation of characteristics of the constituent paths of the route to determine whether they belong to a meaningful higher-level entity. For this segmentation three features of paths and turns are relevant: road status hierarchy, path length and turn topology, whereas road status has been proved to be the best segmentation indicator.
- **Aggregation:** With aggregation techniques information can be combined into fluent and coherent multiclausal sentences. For this purpose two specific aggregation strategies are important: With the “path and point” strategy a description of a point is folded into the description of a path (“Continue on until you get to the next set of lights.”). The “point and direction” strategy combines a turn direction with a specification of the location where this instruction is to be executed (“...at the end of the street turn right.”)
- **Referring expression generation:** With referring expression generation techniques user-oriented descriptions of key elements in routes can be produced. The objective is to distinguish the intended referent from other entities with which it might be confused. In this approach properties and relations from a predetermined list of types are added to the content of a description until enough information to identify the referent has been collected.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

The approach was implemented into their test system “Coral”. Figure 3.4 shows a route description generated by the commercially available wayfinding system “WhereIs”, and the same route described with the approach by Dale et al. (2005) in the test system “Coral”.

	Instruction	Street Address	Suburb	Distance	Est. Time
(S)	depart	PARBURY LA	DAWES POINT	17 m	1 Min
(→)	right	LOWER FORT ST	DAWES POINT	27 m	1 Min
(←)	left	GEORGE ST	DAWES POINT	572 m	11 Mins
(F)	arrive	GEORGE ST	THE ROCKS	Total 616 m	Total 13 Mins

Click on instruction icon for detailed map

---

Start at Parbury Lane.

Follow Parbury Lane until you reach the end.

Take a right.

Follow Lower Fort Street for 30 metres.

Turn to the left at George Street.

Follow George Street until you reach your destination.

---

Figure 3.4.: WhereIs compared to Coral generated route description (from Dale et al. (2005))

Richter (2007) developed a computational process for generating context-specific route instructions that takes different types of landmarks into account. This approach exploits the circular order of a decision point’s branches as well as the order of events in route following according to the directedness of a route. The process of the automatic generation of route instructions is realized in four steps:

1. **Generating abstract turn instructions.** In the first step for every decision point of the route all possible instructions are generated. Actions to be performed at a decision point are represented as direction relations; each kind of action is denoted by a specific relational term.
2. **Spatial chunking (1).** Through spatial chunking the actions to be performed at several consecutive decision points are combined into a single action. In the

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

first step, abstract turn instructions are combined based on two simple syntactic rules: first, instructions that employ the same direction relation can be combined; second the egocentric direction relation “straight” can be combined with any other direction relation. This results in ‘do n-times’ or ‘do until’ instructions. The second rule refers to situations where going straight at a decision point does not need to be explicitly stated.

3. **Spatial chunking (2).** In the second step of spatial chunking it is verified whether the generated chunks are cognitively and structurally sensible. For example, chunks based on linear landmarks need to end with a decision point where another landmark is present.
4. **Optimization.** In the fourth step the route instructions are actually generated. From all possible abstract turn instructions for each decision point the one that is best gets selected. For this purpose two optimization approaches are implemented in the model. Local optimization proceeds through the route from origin to destination and selects for every decision point the best chunk starting with this point. Then it is checked whether this chunk improves the directions. While local optimization does not necessarily find an optimal solution, global optimization guarantees this by generating every possible combination of chunks.

Figure 3.5 shows an example chunk of a route direction generated through this approach as an XML-specification. In addition, also a verbal externalization is listed. However, this is not part of this process, but done with a natural language generation system of another study.

	<pre>&lt;Direction&gt; &lt;instruction point="1" relation="straight"&gt; &lt;/instruction&gt; &lt;instruction point="2" relation="right"&gt; landmark id="1" type="Map" relation="lm"/&gt; &lt;/instruction&gt; &lt;/Direction&gt;</pre>	“At the next junction go straight, and then turn right before a map post.”
--	--	--

Table 3.5.: Example for resulting context-specific route direction and its verbal externalization (from Richter (2007))

### Characteristics of indoor route instructions

While most approaches for the generation of route instructions refer to the structure of outdoor route instructions, studies focusing on the indoor route instructions are

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

still rare. However, as indoor environments are structurally and conceptually different from street networks, it is necessary to adapt the instruction generation process to the requirements of indoor wayfinding. While street networks usually dispose of a clear structure of decision points with only few options, indoor environments often involve a spatially complex layout including open spaces where no clear routes and decision points exist (Rüetschi (2007), Mast and Wolter (2013)).

Therefore indoor route instructions differ in some important aspects from instructions for outdoor environments:

- Street names cannot be used. Instead the type of the path (e.g. corridor, ramp, stairs) can be referred to, e.g. “*Go along the corridor until ...*”.
- Types of intersection (e.g. roundabout) cannot be used.
- Changes of floor levels have to be considered, e.g. “*Use the elevator to go to the third floor*”.
- Paths through open spaces have to be considered, e.g. “*Go through the hall*”.

Few studies exist which specify which elements indoor route instructions should contain. In the information system for indoor navigation developed by Heiniz et al. (2012) route instructions consist of the approximate length of the current route segment, walking directions, and the name of the endpoint. Walking directions are derived from angles between prior and current segments of the route. This results in instructions like “*Turn slightly left and follow the route for 20 meters*”. If available, route instructions are enriched by landmarks by denoting waypoints, like “*Next: Auditorium 3*”.

Mast and Wolter (2013) argue that good route instructions for indoor environments should provide context by relating instructions to environmental features, i.e. by describing and locating objects. As a solution, they propose a probabilistic framework for comparing and selecting object descriptions. Their approach uses vague models of features and evaluates them based on the principle of discriminatory power. Through this method object descriptions like “*The pillar in front of the door to the left of the clock*” can be generated. However, their system so far does not deal with motion instructions and therefore does not create complete route instructions.

Williams and Watson (1999) provide one of the few existing studies which analyze indoor route descriptions. They collected spontaneous speech from speakers giving instructions on how to get from the reception desk of a university building to seven

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

different destinations within the department. They divide route description elements into four distinct types:

- **path:** instruction to follow a pathway, e.g. “*Follow the corridor to the end*”;
- **turn:** instruction to make a turning movement, e.g. “*Turn left*”.
- **landmark:** drawing attention to some outstanding feature that will help with navigation, e.g. “*There is a green EXIT sign*”.
- **locate:** locating the destination, e.g. “*His office is the first on the left*”.

In Williams (1998) indoor route representations are described as a series of corridor sections and turns. Corridor sections are represented by start and end points and a list of intermediate points. Points can be either junctions between corridors or orientation points, like landmarks.

## 3.2. Landmark identification

The first step when automatically creating route instructions with landmarks is to identify features that may serve as landmarks (“landmark candidates”), independent from a concrete route. For the approach of this master thesis, where categories of indoor features will be used as landmarks, two steps are required to identify good landmark candidates:

1. define features or feature types which may be basically suitable as landmarks (“*feature type selection*”) and
2. assess their suitability as landmarks (“*landmark weighting*”).

These steps are highlighted in the overall ILNM process model in Figure 3.5.

Based on the literature review on existing studies on indoor landmark identification in section 3.1.3, aspects for the selection of feature types from a spatial indoor database will be discussed and a modified landmark weighting system of the LNM will be developed. These rules and this weighting system can be applied to an indoor GIS database to get a set of weighted landmark candidates, which can be used for the selection of landmarks for concrete routes in the next step (see Section 3.3).



### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

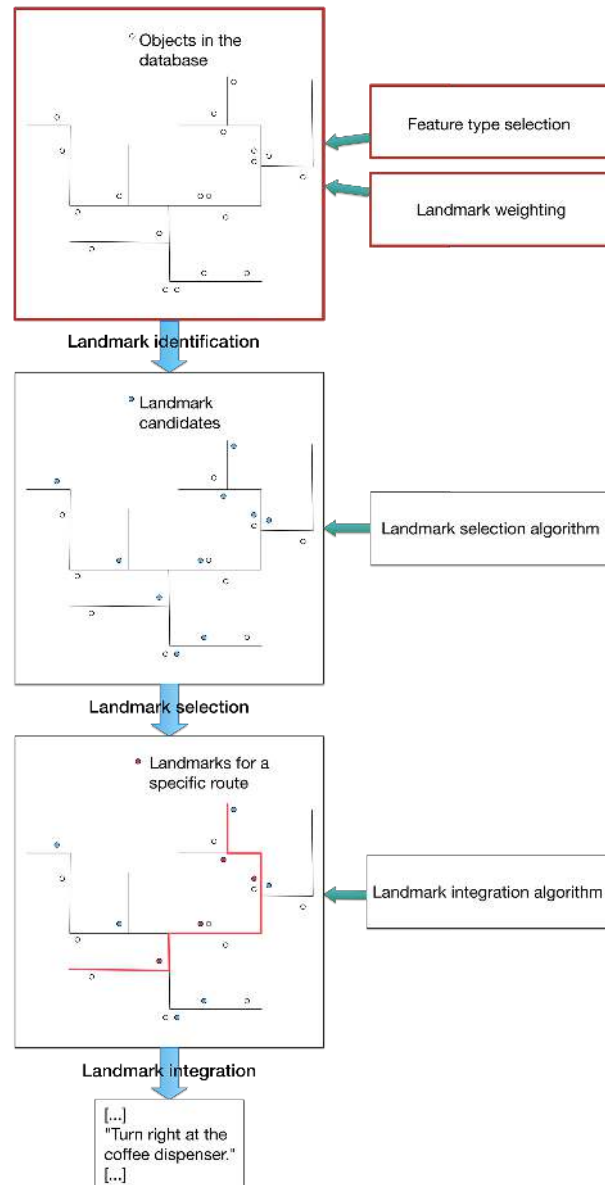


Figure 3.5.: The process of landmark identification in the ILNM

#### 3.2.1. Feature type selection

In the case study of the LNM only a small subset of the available POI categories was selected because of the very large number of categories most of which have a low salience for navigators. However, Duckham et al. (2010) do not specify how the resulting categories have been actually selected.

The ILNM is not solely based on POI categories, but also on general indoor feature types and room categories, which are usually available in indoor GIS databases. As

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

these databases usually contain a lot of different feature types, the following **preprocessing steps** are proposed to narrow down the possible landmark categories:

- **Classification.** If features are not yet assigned a classification they have to be categorized if suitable attributes are available in the database, e.g. in the WU Campus GIS for part of the rooms an attribute denoting the room category (e.g. ”seminar room”) is available.
- **Generalization.** If multiple category names exist for similar feature types, these have to be summarized into unique categories. For example, in the WU Campus GIS all rooms of the category ”student lounge” and ”staff lounge” can be summarized into the category ”lounge”. In addition, the room type ”Uncategorized” can be introduced to allow referencing to different other room types, like laboratories or archives, with the room number.
- **Preselection.** For all feature types a preselection has to be executed. Only those feature categories should be selected, which fulfil the following criteria:
  - **Recognizability:** Features need to be recognizable on the route because of their shape, their label (e.g. room label like “Toilet”), extension, or other characteristics like door or interior (if visible from the route).
  - **Widespread availability:** Features, which only occur on few, specific places (e.g. special room types) are not selected.
  - **Allowance of classification:** Only feature types which can be classified according to appropriate attributes are selected.

For the feature categories which pass these preprocessing steps the detailed landmark weighting can be calculated in the next step, which is described in Section 3.2.2.

#### 3.2.2. Landmark weighting

For the assessment of the selected feature types in the ILNM the suitability factors for landmark weighting by Duckham et al. (2010) described in Section 3.1.2 will be applied in a modified version:

- **Features instead of POIs.** Instead of using only POI categories, feature categories will be used, typically consisting of architectural indoor object categories, room categories and POI categories.
- **Removal of factors “Nighttime vs. daytime salience” and “Proximity to road”.** For assessing indoor landmarks the factors “Nighttime vs. daytime

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

salience” and “Proximity to road” do not seem to be useful, as indoor environments are usually well illuminated and proximity to road is not applicable. The proximity to a concrete route will be taken into consideration in the process of the landmark selection. Therefore these two factors will be removed for scoring landmark suitability in the ILNM.

- **New factor “Availability of a unique label”.** For the assessment of the landmark categories a new factor will be introduced: “Availability of a unique label”. This refers to the availability of an attribute of an instance of a selected feature category, which can be used in route instructions, e.g. a room label. The idea behind this is, that landmark categories, which allow a reference with a unique label (“Turn right after auditorium TC.1.002”) are more useful than those without (“Turn right after the auditorium”).
- **Modified distinction between point-like and area-like landmarks.** Duckham et al. (2010) distinguish between point-like landmark objects and areas of interest (AOIs) in the way, that AOIs can only be used as landmarks for in-leg instructions, as the spatial extents make them unsuitable as landmarks at decision points. However, within buildings features with spatial extents (e.g. rooms, ramps) are usually not as large-scale as in outdoor environments (e.g. parks, rivers) and also features with spatial extents may serve as landmarks at decision points. For instance a ramp may be an in-leg landmark, if you have to follow it, but can also be a landmark at a decision point if the route only crosses a ramp and you have to change the direction at this point. Therefore, the geometry of decision point landmarks will not be limited to point-like objects in the ILNM. However, as point-based features are likely to be more suitable landmarks within buildings too, they will be rated higher through the factor “Spatial extents”.
- **Visible part of the objects.** In indoor environments often only a part of the object is visible from the route (e.g. the door of a room). In these cases not the size, prominence, or difference from surroundings of the object itself is relevant but the characteristics of the part of the object that is visible from the route, including the label if available (see Table 3.6 for a comparison of six differently salient room labels of WU). The actual visibility of the features will be considered in all relevant factors of the landmark weighting process.

Table 3.7 is a modified version of Table 3.2 and gives an overview of the adapted factors for scoring landmark suitability for feature categories in the ILNM. New or modified criteria are marked with an asterisk (\*). The scoring system to convert the

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)



Table 3.6.: Different room labels next to (a, b, d and e) or on (c and f) the door

suitability factors into a normalized score from the LNM (see Table 3.4) will be left unchanged in the ILNM.

In Duckham et al. (2010) this scoring system was applied by a group of experts who had to agree on a ranking for each POI category. For the ILNM a similar approach is suggested. Experts have to rank each landmark category resulting from the preprocessing procedure according to the factors outlined in Table 3.7. Table 3.8 shows two example ratings for feature categories of the WU Campus GIS. For example, a typical elevator might be ranked as “Ideal” as a candidate landmark in terms of physical size (the doors of elevators are very large), “Highly suitable” in terms of prominence (the doors of elevators are usually quite prominent), and difference from surroundings (elevator doors usually differ from other doors) and “Ideal” in terms of ubiquity and familiarity (basically all people know how elevators look like), have limited spatial extents (essentially point locations), and have short, simple descriptions. Most or all elevators might be viewed as possessing these characteristics. However, elevators, might be ranked as “Never suitable” in terms of the availability of a unique label, as

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

elevator doors at WU do not have a clear labelling or number. While most characteristics can be applied to all elevators at WU, the “high prominence” and “high difference from surroundings” is applicable only to most elevators, as few are in a less prominent position or have doors which are very similar to the wall.

After all features have been rated the overall suitability score can be determined for each category according to Table 3.4 and based on these scores the normalized weight can be calculated. For the calculation of the normalized score the formula 3.1 from Duckham et al. (2010) is slightly adapted to the standard formula for calculating weighted scores:

$$weight(c) = \frac{\sum_{f \in F} score_f(c) - \min\left(\left\{\sum_{f \in F} score_f(c') \mid c' \in C\right\}\right)}{\max\left(\left\{\sum_{f \in F} score_f(c') \mid c' \in C\right\}\right) - \min\left(\left\{\sum_{f \in F} score_f(c') \mid c' \in C\right\}\right)} \quad (3.2)$$

The result of this process is a list of weighted feature categories which can be applied to the landmark selection process for concrete routes in the next step.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

Character	Factor	Explanation
Visual	Physical size*	Larger features are more easily seen, and therefore better candidate landmarks than smaller features. In indoor environments often only part of the object is visible from the route (e.g. the door of a room). In these cases not the size of the object itself is relevant but the size of its visible part.
	Prominence*	Features that are visually prominent are better candidate landmarks than those with few or no distinguishing markings. In addition, not only the prominence of the feature itself but also of the feature label is relevant.
	Difference from surroundings	Features that are typically different from their surroundings are preferable landmark candidates.
	Availability of a unique label*	Features with a unique and visible label, which can be used as a reference in routing instructions, are better landmark candidates than those without.
Semantic	Ubiquity and familiarity	Features that are ubiquitous and familiar represent better candidate landmarks.
	Length of description	Features that require short or very familiar descriptions are more suitable landmarks than features that require longer or more complex descriptions.
Structural	Spatial extents*	Point-based features are likely to be more suitable landmarks, as they are less ambiguous than landmarks with spatial extents. In this context rooms with a distinct door (e.g. offices, auditoriums) will be treated as point-based features, as the door of the room represents the distinguishing marking in contrast to rooms without an explicit door (e.g. lounges, study areas), which will be rated as landmarks with spatial extents.
	Permanence	Features that are expected to change or move less frequently make better candidate landmarks.

Table 3.7.: Detailed factors for scoring landmark suitability for feature categories in the ILNM (adapted version from Duckham et al. (2010))

3. Development of the “Indoor Landmark Navigation Model” (ILNM)

	<b>Elevator</b>		<b>Auditorium</b>	
	Suitability	Typicality	Suitability	Typicality
Physical size	Ideal	All	Highly Suitable	Most
Prominence	Highly Suitable	Most	Highly suitable	Most
Difference from surroundings	Highly suitable	Most	Suitable	All
Availability of a unique label	Never suitable	All	Ideal	All
Ubiquity and familiarity	Ideal	All	Ideal	All
Length of description	Ideal	All	Suitable	Most
Spatial extents	Highly suitable	Most	Ideal	Most
Permanence	Ideal	All	Ideal	Most

Table 3.8.: Example rating of two categories of WU Campus GIS: elevator and auditorium

### 3.3. Landmark selection

After having identified landmark candidates, these features can be used as a pool of potential landmarks to select from when generating instructions for specific routes within buildings. Therefore, in the next step the criteria and the algorithm for the landmark selection of a concrete route have to be defined. In this phase landmarks are selected according to their *structural salience*. According to Klippel and Winter (2005) objects are called structurally salient if their location is cognitively or linguistically easy to conceptualize in route directions.

The step of landmark selection is highlighted in Figure 3.6.



### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

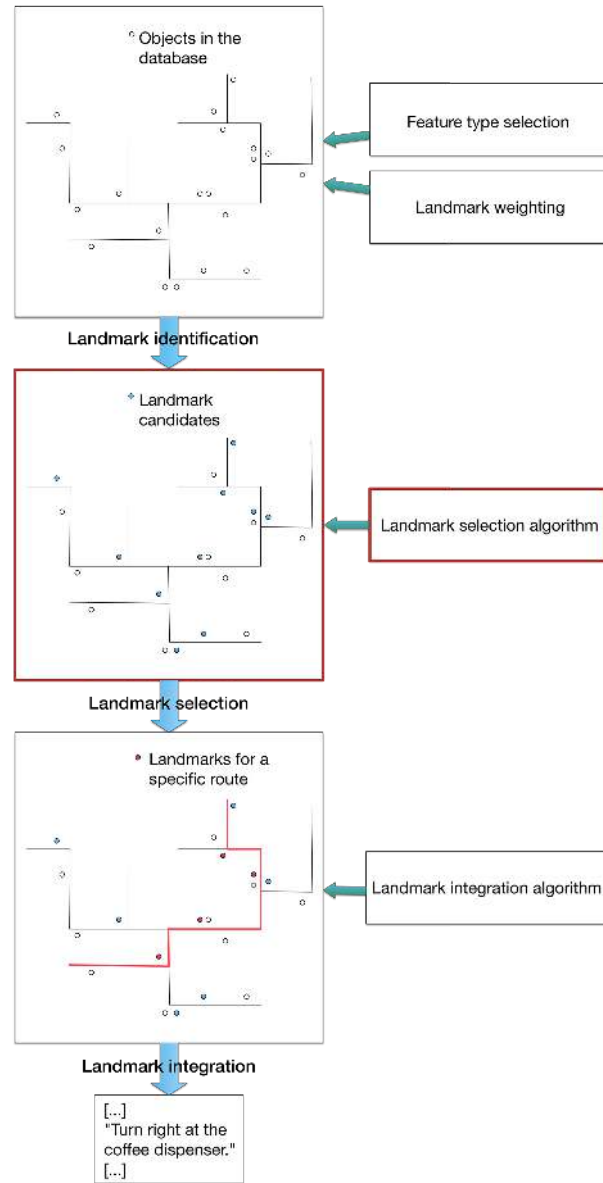


Figure 3.6.: The process of landmark selection in the ILNM

#### 3.3.1. Criteria for selecting landmarks

When selecting landmarks for specific routes, different aspects have to be considered, which are outlined in Section 3.1.4.

Duckham et al. (2010) created a basic and an extended algorithm for landmark selection and annotation in their LNM. The basic landmark selection algorithm chooses only *landmarks at decision points*. In the extended algorithm some refinements were made, taking into consideration more aspects for landmark selection. Table 3.9 lists

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

the aspects that may be relevant for landmarks selection and if and how they were considered in the extended LNM. In addition, this table describes how they will be incorporated in the ILNM. In the ILNM the factors were basically considered in the same way as in the LNM with the following exceptions:

- *Role in route instruction:* The LNM distinguishes between “landmarks at decision points” and “landmarks off decision points”. For the ILNM a new landmark category “crossed landmarks” will be introduced. This landmark category is a sub category of landmarks off decision points and usually appears only in indoor environments where a route may go directly through landmarks, e.g. a particular room type or a door. In contrast to normal “on route landmarks”, which are selected only if a threshold length  $lt$  for a route leg is exceeded, landmarks crossed by the route should be always selected due to their prominence on the route to create unambiguous route instructions.
- *Location at decision point:* This factor is not considered in the LNM. However, in the ILNM it is taken into account, as indoor landmarks are usually smaller and less salient than outdoor landmarks and therefore landmarks passed after reorientation would be hard to recognize in many cases. In addition, in case of multiple landmarks with the same weight for one decision point, the landmark which is closest to the decision point is selected, in contrast to an arbitrary selection in the LNM.
- *Location on the route leg:* In the LNM on-route landmarks are selected for route legs exceeding a threshold travel time  $t$ . The actual position of the landmark on the route leg is not considered. However, confirmation landmarks are usually most valuable in the middle part of the route. At the beginning of the route leg, a confirmation that the user is on the right way, is not necessary. At the end of the route leg, it might have already been expected. Therefore, in the ILNM in-leg landmarks that are located in the middle half of the route, will be ranked higher.
- *Multiple landmarks on same route leg:* In the LNM only the first instance keeps its salience in case of several landmarks of the same category on a particular route leg. This approach does not seem to be applicable for indoor landmarks, as some landmarks (e.g. particular room types) may occur regularly and in high numbers on the same route leg and assigning salience only to the first instance of this landmark type does not seem to be useful in these cases.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

Instead, numerical chunking might be a suitable approach for indoor route instructions. Therefore multiple landmarks on the same route leg will be considered in this way. A count limit will be set to avoid cognitive overload. Landmarks exceeding this limit will not be considered. Landmarks with an occurrence higher than one and below the count limit will be devalued according to their count.

Table 3.9 lists the factors for landmarks selection of the ILNM compared to the factors of the LNM.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

<b>Factor</b>	<b>(Extended) LNM</b>	<b>ILNM</b>
<i>Role in route instruction</i>	<p><i>Landmarks at decision points</i> represent the most important category of landmarks in the LNM.</p> <p><i>Landmarks off decision points</i> or “on route” landmarks are used to provide confirmation to users that they are on the correct route. To determine on which route legs landmarks off decision points shall be selected, a threshold travel time <math>t</math> for a route leg was defined. These in-leg landmarks are also used where an upcoming decision point has not suitable landmark.</p>	<p><i>Landmarks at decision points</i> represent the most important category of landmarks in the ILNM.</p> <p><i>Landmarks off decision points</i> or “on route” landmarks will be selected if a threshold route length <math>lt</math> for a route leg is exceeded. These in-leg landmarks are <i>not</i> used where an upcoming decision point has no suitable landmark.</p> <p><i>Landmarks crossed by the route</i> (a sub category of “on route landmarks”) are always selected to create unambiguous route instructions.</p>
<i>Advance visibility</i>	This factor is not considered.	This factor is not considered.
<i>Side of the road</i>	Features on the side the next turn will be made toward are ranked more highly.	Features on the side the next turn will be made toward are ranked more highly.
<i>Location at decision point</i>	This factor is not considered.	<p>Landmarks passed before reorientation at the decision point are ranked more highly than landmarks passed after reorientation.</p> <p>In case of multiple landmarks with the same weight for one decision point, the landmark which is closest to the decision point is selected.</p>

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

<i>Location on route leg</i>	This factor is not considered.	In-leg landmarks, that are located in the middle half of the route leg, are ranked more highly than landmarks located at the beginning or end of the route leg.
<i>Multiple landmarks on same route leg</i>	If several landmarks of the same category occur on a particular route leg, only the first instance of a particular category of landmarks on a route keeps its salience; the following ones are set to zero.	If several landmarks of the same category occur on a particular route leg, their weight will be reduced according to their count and they will be considered in the course of numerical chunking if their count does not exceed a threshold number $n$ .

Table 3.9.: Factors for landmark selection in the LNM and ILNM

#### 3.3.2. Algorithm

In the LNM of Duckham et al. (2010) both landmark selection and landmark integration, i.e. the generation of the route instructions, are combined in one algorithm (see Figure 3.2). In this algorithm (i) to (vii) correspondent to landmark selection and (vii) a) to (vii) d) to landmark integration. As in the ILNM landmark selection and landmark integration are seen as separate processes, individual algorithms are defined for them, which are combined in the last step.

For the landmark selection of the ILNM the algorithm of the LNM has to be adapted according to the modified factors for indoor landmark selection outlined in Table 3.9. The algorithm for landmark selection of the ILNM is shown in Figure 3.7.

- 
- (i) Generate a route from origin  $o \in V$  to destination  $d \in V$  from the graph  $G = (V, E)$  using a standard shortest path algorithm.
  - (ii) Find the set of landmark candidates  $L' \subseteq L$  that lie anywhere along the route (on decision points or along route legs).
  - (iii) Associate with each landmark instance  $l \in L'$  the landmark weight,  $weight_i(c)$ , for that landmark’s associated category  $c \in C$  such that  $category(l) = c$ .

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

- (iv) For any landmark  $l \in L'$ , increase the suitability weighting if a unique label is available.
- (v) For any landmark  $l \in L'$  at a decision point, determine if the landmark is located before, exactly at or after the decision point. Increase the suitability weighting if it is passed before reorientation and decrease it if the landmark is located after the decision point.
- (vi) For any landmark  $l \in L'$  at a decision point, increase the suitability weighting if the landmark is located on the same side of the path as the upcoming instruction.
- (vii) If multiple instances of the same landmark category occur on the route leg before the decision point, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their suitability weighting and determine their number of occurrence for use in the route instruction.
- (viii) For each decision point, select the landmark that is incident with that decision point and has the highest weight. If two or more landmarks have the same weight, select the landmark which is closest to the decision point. For each selected landmark determine the unique label, the position with reference to the decision point, and the number of the instance.
- (ix) For each route leg, select the landmarks that are crossed by the route. If multiple instances of the same landmark category occur on the same route leg, calculate their number.
- (x) For each route leg that is longer than some length threshold  $lt$ , determine the in-leg landmarks and increase the suitability weighting if the landmark is located in the middle half of the route leg.
- (xi) If multiple instances of the same landmark category occur on the same route leg, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their in-leg suitability weighting.
- (xii) For each route leg that is longer than some length threshold  $lt$ , select the in-leg landmark with the highest landmark suitability weight. If two or more landmarks have the same weight, select the landmark that is nearest to the midpoint of the route leg.

---

Figure 3.7.: ILNM landmark selection algorithm

### 3.4. Landmark integration

The last step in the process of automatic route description generation is the integration of the selected landmarks into advance wayfinding instructions. This step is highlighted in the overall ILNM process model in Figure 3.8.

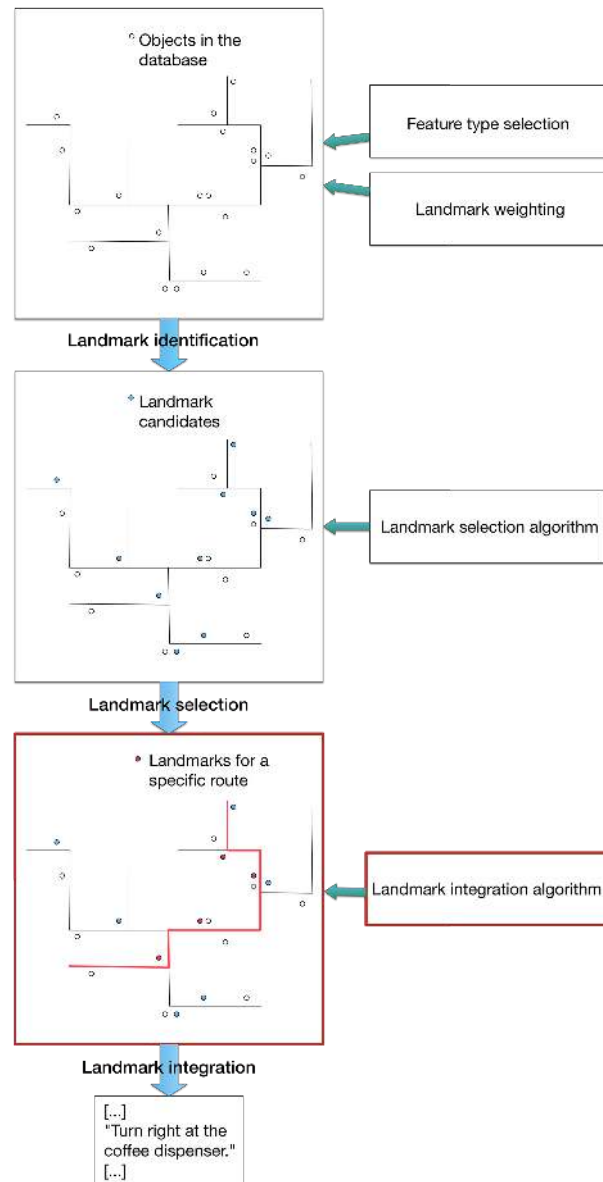


Figure 3.8.: The process of landmark integration in the ILNM

### 3.4.1. Adapting outdoor to indoor route instruction generation

The annotation algorithm for generating route instructions by Duckham et al. (2010) creates route instructions for outdoor environments. Taking into consideration the different nature of indoor route instructions discussed in 3.1.5 the route generation algorithm of the ILNM has to be adapted to the requirements of indoor navigation:

- **Usage of path type instead of street name.** As within buildings street names are not available, route instructions have to refer to the underlying type of the path to create route instructions like “*Go along the corridor.*” However, this reference is not as useful as the street name, as in indoor environments almost all paths are usually of this type and no unique identifier like the street name is available. Other typical indoor path types include stairs, ramps or elevators. In the ILNM the basic route instruction for common indoor paths will be “Go along the path.” as this covers most indoor situations.
- **Consideration of paths through open spaces.** As outlined in Mast, Jian, et al. (2012) within buildings there are more open spaces, which do not include clear paths to chose. For this case it has to be evaluated if the path segment goes through an open space, i.e. through a particular room type, and if yes, route instructions such as “*Pass trough the hall.*” will be generated.
- **Handling of in-leg landmarks as point-based objects only and consideration of paths through landmarks.** The LNM distinguishes between point-based and area-based in-leg landmarks to create instructions like “*Continue past ...*” for point-like landmarks and “*Continue along or through ...*” for landmarks with spatial extents. In the ILNM this differentiation will not be made for ordinary in-leg landmarks, as indoor landmarks usually do not have that spatial extent as outdoor landmarks (e.g. parks, rivers) and for polygon-based indoor landmarks like rooms the action “*past*” will be more appropriate. However, for landmarks crossed by the route, irrespective from their spatial extent, always the action “through” will be used.
- **Adaptation of route instructions for pedestrians and indoor scenarios.** The LNM creates route instructions in the form “⟨Perform action⟩ onto ⟨Street Name⟩ at ⟨Selected landmark⟩”. To adapt these instructions for pedestrians and indoor use, the structure will be changed to “Turn ⟨Direction⟩ ⟨Spatial preposition⟩ ⟨Number⟩ ⟨Selected landmark⟩” to create route instructions like “Turn right after the second meeting room.”



### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

- **Consideration of changes of floor levels.** As indoor routes often contain changes of floor levels, this situation is considered and an instruction of the form “Use the ⟨Path reference⟩ to go to the ⟨Destination floor number⟩ floor”.
- **Consideration of location at decision point.** The ILNM determines if the decision point landmark is passed before or after the decision point. The route instruction algorithm incorporates this by differentiating between “before” and “after” in the turn instruction.
- **No substitution of decision point landmarks by in-leg landmarks.** In case of decision points without selected landmarks in-leg landmarks may be used to create turn instructions in the LNM. This is possible as through the instruction “⟨Perform action⟩ onto ⟨Street Name⟩ after ⟨Selected in-leg landmark⟩” it is clearly stated where the turning action has to be made. However, in indoor environments instructions of this form may be ambiguous due to the lack of clear path (street) names. Therefore the ILNM uses always the default instruction “Turn ⟨Direction⟩ after ⟨Distance⟩“ for decision points without selected landmarks.

#### 3.4.2. Algorithm

In the LNM by Duckham et al. (2010) the algorithm only contains those parts of route instructions which may contain references to landmarks. Other elements, like general action instructions (e.g. “Continue on Bourke St. - head towards Market Lane.”) or the last instruction (e.g. “Arrive at Princess Theatre.”) are not included in the algorithm.

Although the route instruction generation will be kept simple too in the ILNM, it includes additional descriptive elements, e.g. changes of floor levels and references to the location of the destination, in order to create complete indoor route instructions.

Like in the LNM the route instruction algorithm of the ILNM will be kept relatively simple with distinguishing only between three different directions: left, right and straight. If this thesis proves that indoor route instructions including landmarks can be created automatically based on this algorithm, the instruction generation process can be refined in a later step. This route integration of the ILNM is illustrated in Figure 3.9.

- 
- (i) For each route leg for which crossed landmarks exist, create a route instruction of the form “Go along the ⟨Path reference⟩. You will pass through ⟨Number⟩

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

- ⟨Selected crossed landmark(s)⟩”.
- (ii) For each route leg that is longer than some length threshold  $lt$  and for which an in-leg landmark was selected create a routing instruction:
    - a) If a crossed landmark is selected, append to the previous instruction “and pass ⟨Selected in-leg landmark⟩”.
    - b) Otherwise generate a new routing instruction of the form “Go along the ⟨Path reference⟩ and pass ⟨Selected in-leg landmark⟩”.
  - (iii) For each route leg, for which neither a crossed landmark nor an in-leg landmark exists, create a routing of the form “Go along the ⟨Path reference⟩”.
  - (iv) For each route leg, which involves a change of the floor level, create a routing instruction of the form “Use the ⟨Path reference⟩ to go to the ⟨Destination floor number⟩ floor”.
  - (v) For each decision point with a selected landmark, generate a routing instruction of the form “Turn ⟨Direction⟩ ⟨Spatial preposition⟩ the ⟨Number⟩ ⟨Selected landmark⟩”.
  - (vi) For each decision point without a selected landmark generate a standard routing instruction of the form “Turn ⟨Direction⟩ after ⟨Distance⟩”.
  - (vii) In case of the last leg of the route, create a new routing instruction:
    - a) If the destination is located on the right or left side of the route, create a routing instruction of the form “Your destination, ⟨Destination⟩ is located on the ⟨Spatial preposition⟩ side of the ⟨Path reference⟩”.
    - b) Otherwise create a routing instruction of the form “The ⟨Path reference⟩ leads straight to your destination ⟨Destination⟩.”
- 

Figure 3.9.: ILNM landmark integration algorithm

Combining the landmark selection algorithm from Figure 3.7 with the landmark integration algorithm from Figure 3.9 results in the complete ILNM algorithm which is illustrated in Figure 3.10 below.

---

- (i) Generate a route from origin  $o \in V$  to destination  $d \in V$  from the graph  $G = (V, E)$  using a standard shortest path algorithm.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

- (ii) Find the set of landmark candidates  $L' \subseteq L$  that lie anywhere along the route (on decision points or along route legs).
- (iii) Associate with each landmark instance  $l \in L'$  the landmark weight,  $weight_i(c)$ , for that landmark’s associated category  $c \in C$  such that  $category(l) = c$ .
- (iv) For any landmark  $l \in L'$ , increase the suitability weighting if a unique label is available.
- (v) For any landmark  $l \in L'$  at a decision point, determine if the landmark is located before, exactly at or after the decision point. Increase the suitability weighting if it is passed before reorientation and decrease it if the landmark is located after the decision point.
- (vi) For any landmark  $l \in L'$  at a decision point, increase the suitability weighting if the landmark is located on the same side of the path as the upcoming instruction.
- (vii) If multiple instances of the same landmark category occur on the route leg before the decision point, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their suitability weighting and determine their number of occurrence for use in the route instruction.
- (viii) For each decision point, select the landmark that is incident with that decision point and has the highest weight. If two or more landmarks have the same weight, select the landmark which is closest to the decision point. For each selected landmark determine the unique label, the position with reference to the decision point, and the number of the instance.
- (ix) For each route leg, select the landmarks that are crossed by the route. If multiple instances of the same landmark category occur on the same route leg, calculate their number.
- (x) For each route leg that is longer than some length threshold  $lt$ , determine the in-leg landmarks and increase the suitability weighting if the landmark is located in the middle half of the route leg.
- (xi) If multiple instances of the same landmark category occur on the same route leg, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their in-leg suitability weighting.

### 3. Development of the “Indoor Landmark Navigation Model” (ILNM)

- (xii) For each route leg that is longer than some length threshold  $lt$ , select the in-leg landmark with the highest landmark suitability weight. If two or more landmarks have the same weight, select the landmark that is nearest to the midpoint of the route leg.
- (xiii) For each route leg for which crossed landmarks exist, create a route instruction of the form “Go along the ⟨Path reference⟩. You will pass through ⟨Number⟩ ⟨Selected crossed landmark(s)⟩”.
- (xiv) For each route leg that is longer than some length threshold  $lt$  and for which an in-leg landmark was selected create a routing instruction:
  - a) If a crossed landmark is selected, append to the previous instruction “and pass ⟨Selected in-leg landmark⟩”.
  - b) Otherwise generate a new routing instruction of the form “Go along the ⟨Path reference⟩ and pass ⟨Selected in-leg landmark⟩”.
- (xv) For each route leg, for which neither a crossed landmark nor an in-leg landmark exists, create a routing of the form “Go along the ⟨Path reference⟩”.
- (xvi) For each route leg, which involves a change of the floor level, create a routing instruction of the form “Use the ⟨Path reference⟩ to go to the ⟨Destination floor number⟩ floor”.
- (xvii) For each decision point with a selected landmark, generate a routing instruction of the form “Turn ⟨Direction⟩ ⟨Spatial preposition⟩ the ⟨Number⟩ ⟨Selected landmark⟩”.
- (xviii) For each decision point without a selected landmark generate a standard routing instruction of the form “Turn ⟨Direction⟩ after ⟨Distance⟩”.
- (xix) In case of the last leg of the route, create a new routing instruction:
  - a) If the destination is located on the right or left side of the route, create a routing instruction of the form “Your destination, ⟨Destination⟩ is located on the ⟨Spatial preposition⟩ side of the ⟨Path reference⟩”.
  - b) Otherwise create a routing instruction of the form “The ⟨Path reference⟩ leads straight to your destination ⟨Destination⟩.”

---

Figure 3.10.: ILNM algorithm

## **4. Application of the ILNM to WU Campus GIS**

In this chapter the ILNM is applied to the data of WU Campus GIS to test its applicability. In Section 4.1 a description of the system, the sample routes and the application method is given. Section 4.2 applies the rules and weighting system of Section 3.2 to the feature types of WU Campus GIS to obtain a list of weighted landmark candidates.

In the next step the selection and integration of these landmark candidates for concrete routes are tested for three sample routes of Campus WU. In Section 4.3 the landmark selection algorithm of the ILNM is applied to these routes on the base of the identified landmark candidates from Section 4.2. In the last step the landmark integration of the ILNM is applied in Section 4.4 to the sample routes to obtain route descriptions with references to landmarks.

### **4.1. Fundamentals of the application process**

#### **4.1.1. WU Campus GIS**

The newly established Campus WU was opened in autumn 2013 and consists of seven building complexes designed by different, internationally renowned architects. The central building is the Library & Learning Center (LC), which is surrounded by different building types. The Teaching Center (TC) houses most of the WU's auditoriums, the department buildings (D1 - D5) form the home of the departments and comprise learning facilities like seminar rooms or study areas. In addition, an administrative building (AD) and a building for the Executive Academy (EA) of WU exist. Due to the various architects all buildings differ considerably both from the outside but also regarding the interior design.

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.1.: Panaroma view of Campus WU<sup>1</sup>

The WU Campus GIS was developed to facilitate orientation on the new campus. It is available as an online map application which is accessible by any web browser. Users can search for rooms, people, organizations, and other interesting facilities as well as points of interest (POIs). The results are displayed on the map and for each result additional options are available, e.g. setting a destination or start point and calculating the route to the nearest entry or underground station. By defining a start and a destination point, the optimal route between these points is calculated and displayed on the map (see Figure 4.2 as an example). In addition, categories of POIs can be chosen from a list to be displayed on the map. Also typical web mapping functions like zooming and panning are available.

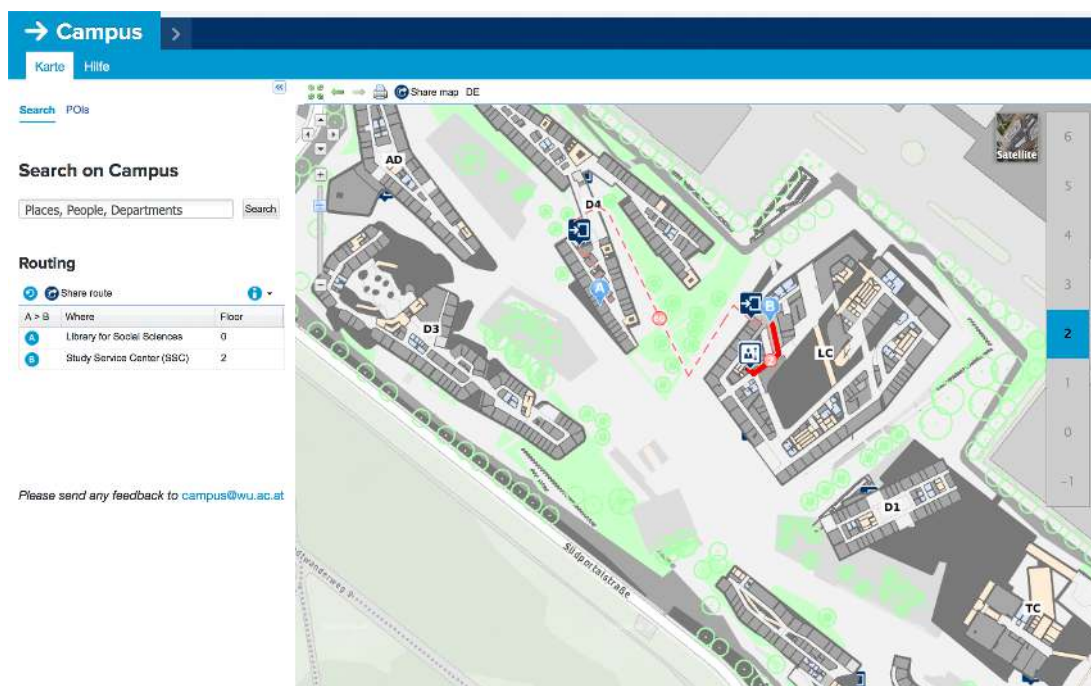


Figure 4.2.: WU Campus GIS with route displayed on the map (*WU Campus GIS 2015*)

<sup>1</sup>©Johannes Zinner, source: <http://www.wu.ac.at/campus/architecture/> accessed on September 9, 2015

#### 4. Application of the ILNM to WU Campus GIS

In WU Campus GIS both static map elements, consisting mainly of rooms, doors and furniture, as well as dynamic elements (route information, POIs, queryable rooms) are available. Static map elements form the basic map view. Dynamic map elements can be queried, highlighted or showed on request on the map.

The system is completely based on open source technologies, most important are: PostGIS, GeoServer, Python, OpenLayers, GeoExt, pgRouting. Routing between two locations is performed on the basis of the network lines using the Dijkstra shortest path algorithm.

Beside the local GIS database a central room database is used, that holds the main rooms and their attributes, and which can be queried from the GIS via a defined interface. The base of the application is a geometrical data model. Each object type is of a defined geometry type and is stored as a separate layer per floor. These feature types are described below (the geometry type is stated in brackets):

- **Rooms/Spaces (polygon):** Rooms are both static map elements and dynamic elements as they can be queried and highlighted on the map. The following attributes are important for these functions:
  - **Unique id:** All rooms have a unique id. When searching for a person, organization or room number in WU Campus GIS external interfaces are queried. The unique id is used to map the query results to the corresponding room in the GIS database, and the results are highlighted on the map.
  - **Room name:** In addition, an internal room name (assigned by the planners), which allows conclusion to the room type (e.g. “Gang 08”), is stored in the database. However, the room types are not consistently named: in total there are 900 different room names in the database. A wildcard expression for the room name is used by GeoServer to create different color schemes of the rooms, e.g. all room with names including “Treppe” or “Stiege” (German words for stairs) are colored differently on the static map than all rooms containing the word “WC” or “toilet”.
  - **Room label:** Most rooms also have an official room label, which consists of an abbreviation for the building, the floor, and the room number (e.g. “LC.3.072”). It usually corresponds to the room label which can be found on or next to the door, except that the building abbreviation is usually omitted there. Some rooms also have an additional room name (e.g. “TC.0.01 ERSTE”). These room labels are not stored in the GIS database

#### 4. Application of the ILNM to WU Campus GIS

but in the central room database of WU and linked to the corresponding room via the unique ID in WU Campus GIS.

- **Room category:** About 14 percent of all main rooms in the room database are assigned a specific room category.
- **Doors (linestring):** Doors are only used as static map elements for visualization purposes and no information about the type of the door is stored in the database.
- **Furniture (linestring):** Furniture only represents static map elements for visualization purposes.
- **POIs (point):** POIs form dynamic map elements and represent important locations which might be relevant for students and visitors of the campus. They are organized in different categories (e.g. access, education, facilities, public infrastructure), from which the user can select to be displayed on the map (see Figure 4.3). In addition, WU Campus GIS also allows searching for their names and displays the results on the map.
- **Library shelves (polygon):** Library shelves, which have been digitized for two floors of the library, form both static and dynamic map elements. They have a unique left and right label stored in the database and can also be highlighted if linked directly from the library online directory.
- **Network lines (linestring):** Network lines have been created manually and form the base for routing queries between two locations. Each network line segment has a specific type (e.g. “indoor way”, “stairs” or “ramp”) and a cost value associated.
- **Network line nodes (point):** Network line nodes are located at key network intersections to identify and connect the routing network lines with specific route features. Examples of network node types are: private, public and main entry.
- **Additional visualization information (polygon and linestring):** Additional information is available which serves only visualization purposes, like building outlines, representations of stairs, elevators and ramps, outlines of parking areas and bike paths.

All data except for navigational lines, network lines and network line nodes was extracted from AutoCAD plans.



## 4. Application of the ILNM to WU Campus GIS

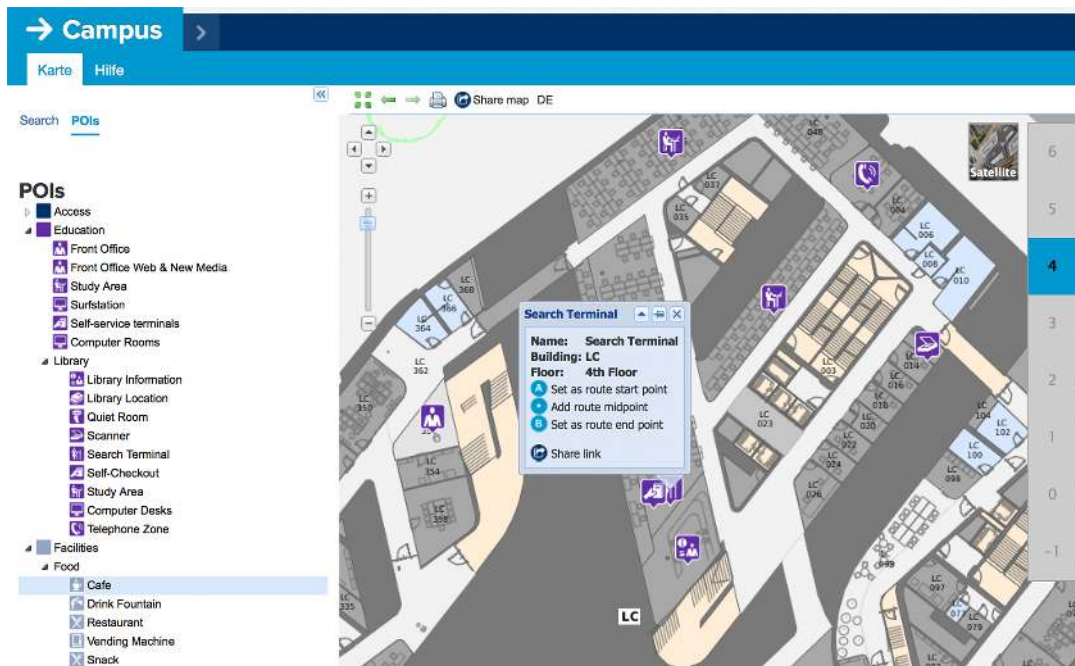


Figure 4.3.: WU Campus GIS with POIs represented by icons on the map and static map elements in the background (*WU Campus GIS 2015*)

### 4.1.2. Sample routes

The landmark selection and integration process will be tested with the help of three sample routes at Campus WU. To test the ILNM for different scenarios, these routes will be selected from different area types of the buildings:

- Public area, classical corridor and open space situation.
- Closed department area, split corridor situation.

These routes were selected as they differ both according to their area type and path type. Public areas usually contain other types of landmarks (e.g. seminar rooms, study areas) than areas in closed department areas.

The sample routes also have different corridor situations. The first sample route shows a classical corridor situation for the main part of the route and leads through an open space in the last section. In contrast, the second sample route in the closed department area leads through a split corridor, where small rooms like toilets or kitchens are located in the middle of the corridor. The third sample route combines the different area types as it leads from a public area to a closed department area. Comparing these route types should give a good overview about the quality of the route instructions generated by the ILNM for different areas of Campus WU.

#### 4. Application of the ILNM to WU Campus GIS

As this thesis focuses on the integration of landmarks into route instructions, the instructions shall be kept simple. Therefore the sample routes are relatively short and do not contain any changes of the building.

##### **Route 1: Public area**

The first sample route is in Building TC on the third floor and leads from one elevator of the third floor to the room TC.3.20. Most of the auditoriums, seminar and project rooms are located in this building and all floors have public access. This route was chosen as it represents a typical building area designated for students with different room categories and features like lockers or vending machines. It is illustrated in Figure 4.4.

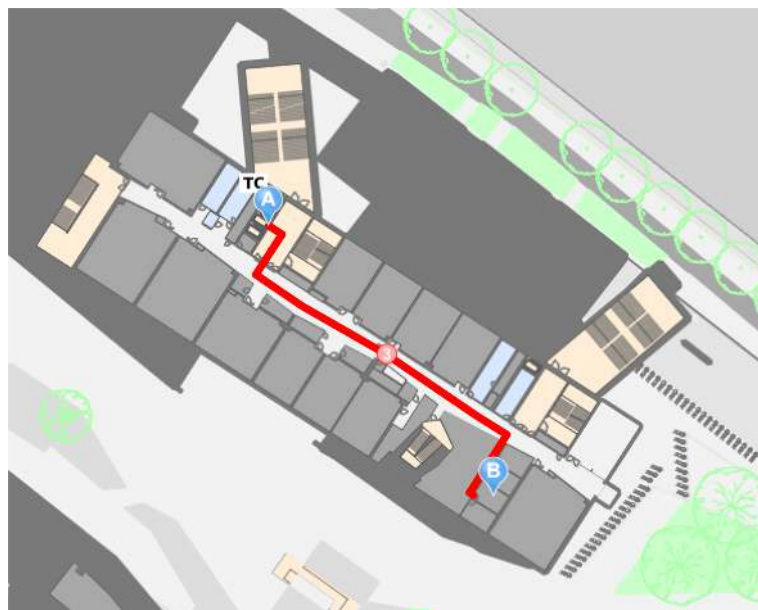


Figure 4.4.: Sample route 1 displayed in WU Campus GIS

##### **Route 2: Department area**

The second sample route is located at the fourth floor of Building D4 and leads from room D4.4.234 to room D4.4.144. It represents a typical department section with mainly offices and few outstanding features and is illustrated in Figure 4.5. However, the route is special as it does not lead through a typical corridor situation with rooms on the left and right side. Instead, on parts of the route the corridor is divided into two corridor sections by small rooms located in the middle of the corridor.

#### 4. Application of the ILNM to WU Campus GIS

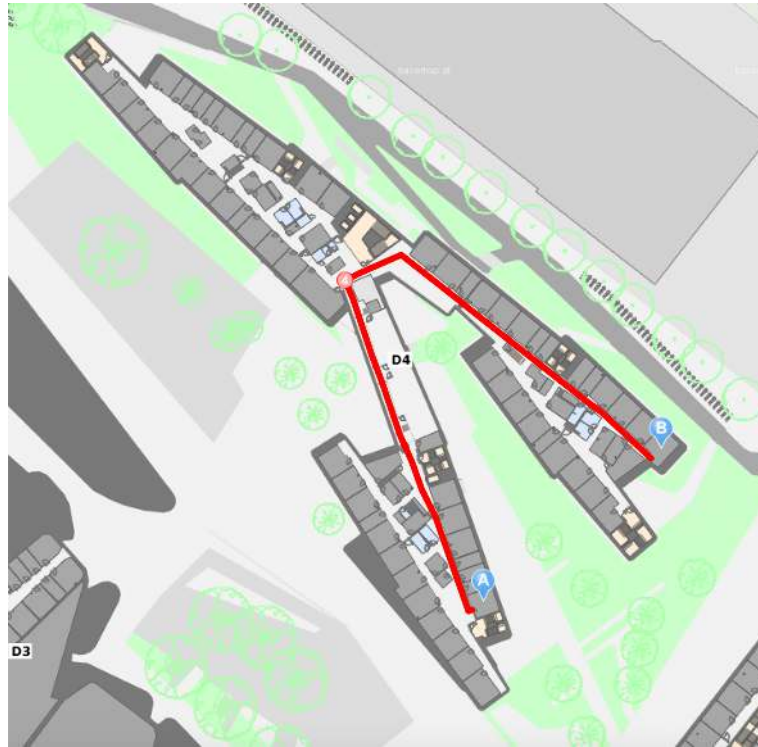


Figure 4.5.: Sample route 2 displayed in WU Campus GIS

#### **Route 3: Public area and department area**

The third sample route is located in Building D2 and leads from the seminar room D2.0.038 on the ground floor to the office D2.3.088 on the third floor. This route involves a change of the floor level and combines the two route types of the other sample routes. The ground floor represents a typical public area designated for students with different room categories. The third floor is a typical department section with mainly offices. The route is illustrated in Figure 4.6 and 4.7.

#### 4. Application of the ILNM to WU Campus GIS

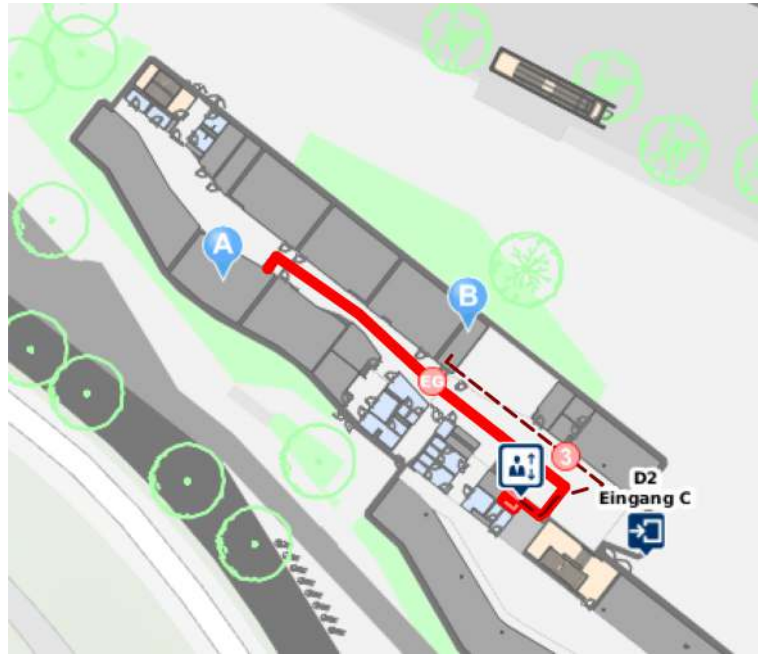


Figure 4.6.: Sample route 3 (ground floor) displayed in WU Campus GIS

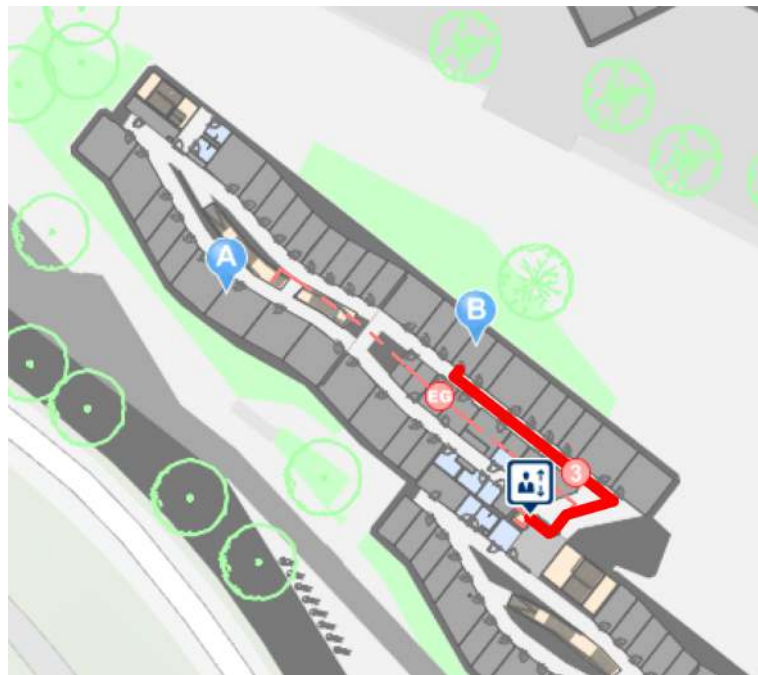


Figure 4.7.: Sample route 3 (third floor) displayed in WU Campus GIS

### 4.1.3. Application method

The application of the ILNM to the WU Campus GIS will be not be demonstrated by actually implementing the approach through hard-coding it into the system, but by applying the rules and algorithms stepwise manually, partly with the help of the GIS software “ArcGIS 10.3”. ArcGIS is chosen because of the availability and existing knowledge with the software.

Applying the algorithm step by step with a GIS application offers some advantages in contrast to the actual hard-coded implementation:

- It allows the **visualization of intermediate steps and results**.
- It allows **better traceability of the individual steps** of the landmark selection and integration process.
- It allows **better control of new results** in case of changed algorithm parameters; so the ILNM algorithm can be iteratively adapted if the results are not satisfactory.

The final results will be the same as if the approach would have been actually implemented: Route descriptions with references to landmarks, which can be further analyzed and evaluated.

The ILNM will be applied to a local copy of the productive system of the WU Campus GIS. This allows experimenting with the data of the system. Before the algorithms of the ILNM can be applied to specific routes in the system, the data has to be prepared in ArcGIS:

- **Local storage of remote information:** The remote information from the central room database is stored locally and joined with the room layers, so that the category information about a room is directly available.
- **Creation of landmark category layers:** Each landmark category is stored as a separate layer and assigned the landmark weight from the landmark weighting process of Section 4.2.2. Except for the landmark category “Stairs” all landmark categories can be extracted directly from the feature types stored in the database, mainly with the help of attribute queries. Stairs have to be extracted from the route network lines. The start and end point of each route segment of the type “stairs” is transformed into a point object. In addition, toilets are stored as POIs in the database. this information was used to create room. However, as they are

#### 4. Application of the ILNM to WU Campus GIS

actually room categories, the rooms which contain toilet POIs are assigned the appropriate room category and toilet type.

- **Creation of sample route layers:** Each sample route is stored as a separate layer by selecting the corresponding route segments from the network lines layer. These layers form the basis for the landmark selection process.

## 4.2. Landmark identification

In this section landmark candidates will be identified from the features of the spatial database of the WU Campus GIS. As stated in Section 3.2 this identification requires two steps:

1. *Feature type selection*: Based on the preprocessing steps suggested in Section 3.2.1 a selection of feature type categories of the database of the WU Campus GIS will be performed.
2. *Landmark weighting*: Based on the adapted ILNM weighting system outlined in Section 3.2.2 the selected feature categories will be rated according to their landmark suitability.

The result of this process will be a set of weighted landmark candidates, which can be applied to the selection of landmarks for specific routes (see Section 4.3).

### 4.2.1. Feature type selection

The first step when selecting features for the landmark weighting process is to examine which information is available for each feature category in the data source. From the features of the WU Campus GIS described in Section 4.1.1, POIs are probably the most important source for landmark candidates. In addition, also static map elements like doors or rooms, can serve as landmarks if they are salient in some context.

Most features of the WU Campus GIS and their associated attributes were taken primarily from AutoCAD plans of the buildings' architects. Examining the information stored in the database reveals the following **problems concerning the data quality**:

#### 1. Inconsistent information:

- Different names were used for the same information, e.g. "Aufzug" and "Lift" (German words for "elevator").
- Different names were used for the same room type, e.g. "Front Office", "Frontoffice" and "Front Desk".

#### 2. Missing information:

- Door types might be a good landmark category (e.g. glass door, fireproof door), however there is no information stored in the database which allows a conclusion to be drawn to the type of the door.

#### 4. Application of the ILNM to WU Campus GIS

- Some attributes are not set for all instances of a feature type, e.g. the room number or the room category.
- As mentioned in the literature review above, signs are an important source for indoor landmarks. Although many orientation signs are available in all buildings of the campus, these objects are not registered in the database of the WU Campus GIS.

#### 3. Obsolete information:

- Most information was extracted automatically from the AutoCAD plans, which represent the status of two years prior to the opening of the campus. In the meantime, some information may have changed, e.g. room types that have been assigned a different usage may have been not updated in the database.

To narrow down the landmark candidates, the preprocessing steps as suggested in Section 3.2.1 were applied to all feature types of the WU Campus GIS. This means the features have been *classified*, *generalized* and only those feature categories have been *preselected* whose instances are *recognizable* on the route and *widespread available* in the buildings.

These classified, generalized and selected feature types can be categorized into three main feature type classes:

- **Basic indoor objects** like doors or elevators. This information is taken from the GIS database.
- **Room categories** like auditoriums or meeting rooms. This information is taken from the central room database of WU.
- **POI categories** like vending machines or lockers. This information is taken from the GIS database.

If the same information is stored in different databases or tables, the data source which is more accurate and which is usually kept up to date is preferred. E.g. room categories are both available from the GIS database and from the central room database. The central room database holds categories only for around 14 percent of all rooms, but they are usually always kept up to date, as it is the base for other applications. In contrast to the GIS database, where room categories could only be inferred from the room name. As this attribute is not used for GIS functions, it is never updated. Therefore the central rooms database is the first choice for room types.



#### 4. Application of the ILNM to WU Campus GIS

Room categories, which are not assigned a category are mainly offices and secondary rooms like operations rooms. These rooms will be summarized into the category "Uncategorized".

For all feature categories it is determined if a unique label is available, which can be used in route instructions for references. Room numbers correspond to the information which can be found on most room labels on or next to the door. POIs can also have more descriptive names (e.g. "Front Office IT-SERVICES"). If this unique label is available only for a part of the features of this category, the word "partly" is added.

In total 21 feature categories have passed this first preprocessing step. They are listed in Table 4.1. For these objects the detailed landmark weighting will be calculated in the next step in Section 4.2.2.

#### 4. Application of the ILNM to WU Campus GIS

	<b>Feature category</b>	<b>Unique label</b>
<b>Basic indoor objects</b>		
	Bridge	-
	Door	-
	Elevator	-
	Stairs	-
<b>Room categories</b>		
	Auditorium	Room number/Room name
	Lounge	Room number (partly)
	Meeting room	Room number
	PC room	Room number
	Project room	Room number
	Seminar room	Room number
	Study area	Room number (partly)
	Toilet	Name (type)
	Other	Room number (partly)
<b>POIs</b>		
	Computer terminal	-
	Entrance/Exit	Name
	Front office	Name
	Library search terminal	-
	Library self-checkout	-
	Locker	-
	Scanner	-
	Vending machine	-

Table 4.1.: Feature category selection for WU Campus GIS

#### 4.2.2. Landmark weighting

Table 3.7 on page 49 gives an overview of factors for scoring landmark suitability of pre-selected features categories. In Duckham et al. (2010) the scoring system was applied by a group of experts who had to agree on a ranking for each POI category. For this master thesis the same approach is used. The rating is performed by four experts (two female, two male) who are employees of WU and therefore know the

#### 4. Application of the ILNM to WU Campus GIS

features in the buildings very well. In an expert rating discussion they agreed on a ranking for each landmark category listed in Table 4.1 according to the factors outlined in Table 3.7 on page 49. Table 3.8 shows two example ratings, a full list of all 21 rated categories can be found in the appendix in Section A.1.

After all feature categories were rated, the overall suitability score was determined for each category according to Table 3.4 and based on these scores the normalized weight was calculated according to formula 3.2. In Table 4.2 an overview of all rated categories and their average scores as well as their normalized weights is given.

	Overall suitability score	Weight normalized with respect to all 21 categories assessed
Stairs	52	1.00
Entrance/Exit	46	0.81
Locker	46	0.81
Elevator	44	0.74
Toilet	44	0.74
Vending machine	40	0.61
Auditorium	36	0.48
Computer terminal	36	0.48
Meeting room	32	0.35
Seminar room	32	0.35
Bridge	30	0.29
Door	30	0.29
PC room	29	0.26
Project room	29	0.26
Lounge	28	0.23
Front office	26	0.16
Library self-checkout	25	0.13
Scanner	25	0.13
Study area	23	0.06
Uncategorized room	22	0.03
Library search terminal	21	0.00

Table 4.2.: Scoring of all landmark categories of WU Campus GIS

#### 4. Application of the ILNM to WU Campus GIS

To visualize the results of the landmark weighting, the feature categories and their weights are illustrated in ArcGIS for two floors of the campus. For this purpose each feature category was extracted as an individual layer, mainly with the help of attribute queries. In the next step the feature categories were assigned the appropriate value for their weight and on the base of this value a graduated color visualization was performed.

Figures 4.8 to 4.11 show the results of this visualization. As the feature category “uncategorized room” comprises all rooms which do not fall into the specified room types, all rooms are potential landmark candidates and therefore all rooms are colored. In contrast, POI categories, which have not been selected in the course of the feature type selection process, are colored in gray. POIs are represented by circle symbols. Doors and elevators are line feature types. For stairs, the start and end points were extracted, as usually only one of these points represents the actual location of the landmark on the route. They are represented by a square symbol. The green lines show the network lines, i.e. the possible routes on the campus.

The visualization shows that the dark red colored objects are basic indoor objects and POIs, i.e. these feature types are usually better landmark candidates than room categories.

A comparison between the visualization of the ground floor (Figure 4.8) and the third floor (Figure 4.10) shows that the ground floor disposes about more and better landmark candidates than the fourth floor. The reason behind this is that ground floors usually are most frequented and therefore the most important rooms (e.g. auditoriums) and other specific objects (e.g. computer terminals) are generally located there.

Figure 4.9 shows the landmark candidates of the ground floor of Building TC (teaching center) with the big auditoriums as highly rated landmark candidates. In Figure 4.11 the differences between mainly office areas (upper right section) and areas accessible by students (library, upper left and lower right section) can be seen. In general, closed department areas with offices contain fewer landmark candidates than public areas for students or visitors. This differences are also visible in Figure 4.10, where the teaching center in the lower right section of the figure disposes about considerably higher ranked landmark candidates than for instance the department building D4 (left to the library center in the upper left section of the figure).

#### 4. Application of the ILNM to WU Campus GIS

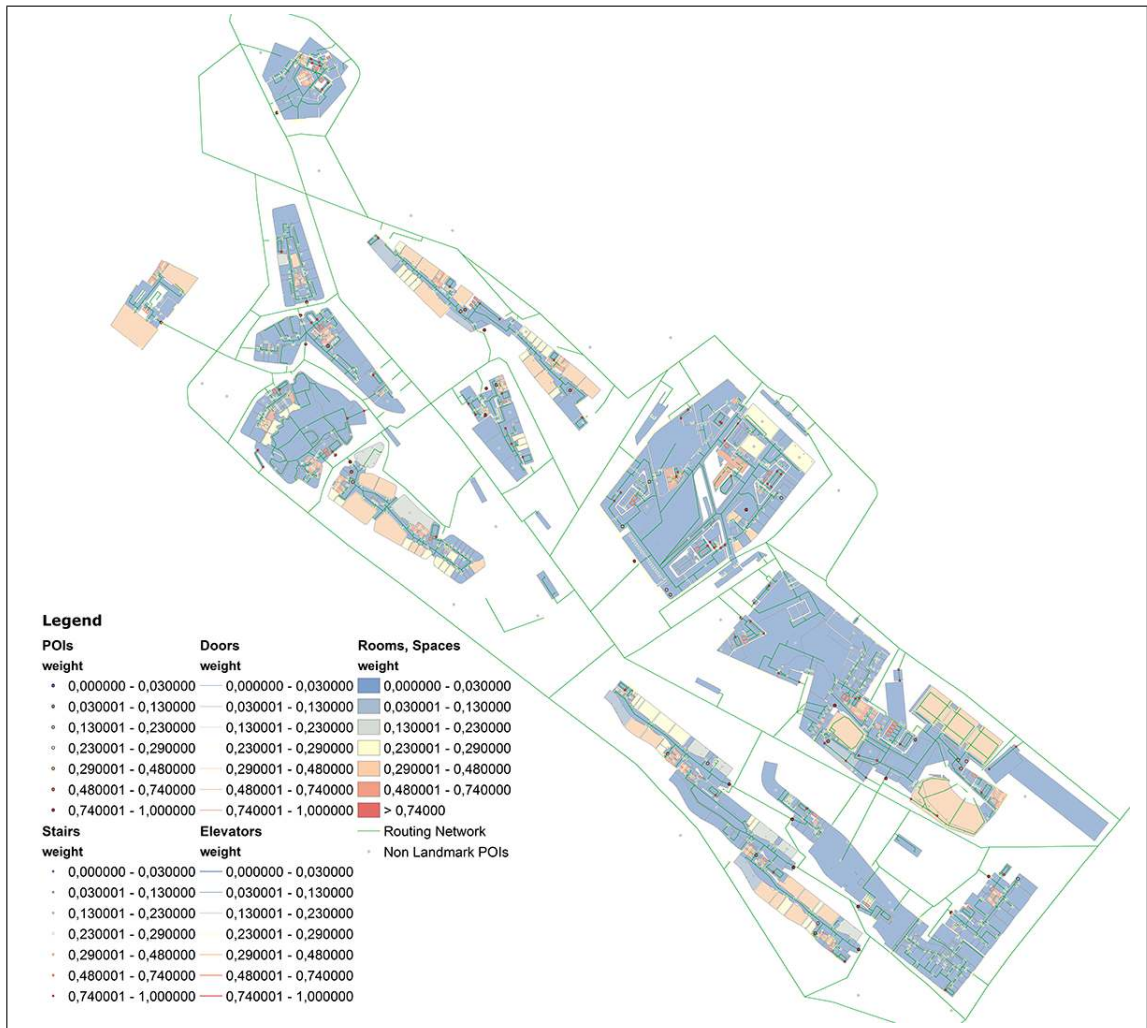


Figure 4.8.: Landmark candidates of the ground floor of Campus WU displayed in ArcGIS according to their weight

4. Application of the ILNM to WU Campus GIS



Figure 4.9.: Landmark candidates of the ground floor in Building TC of Campus WU displayed in ArcGIS according to their weight

#### 4. Application of the ILNM to WU Campus GIS

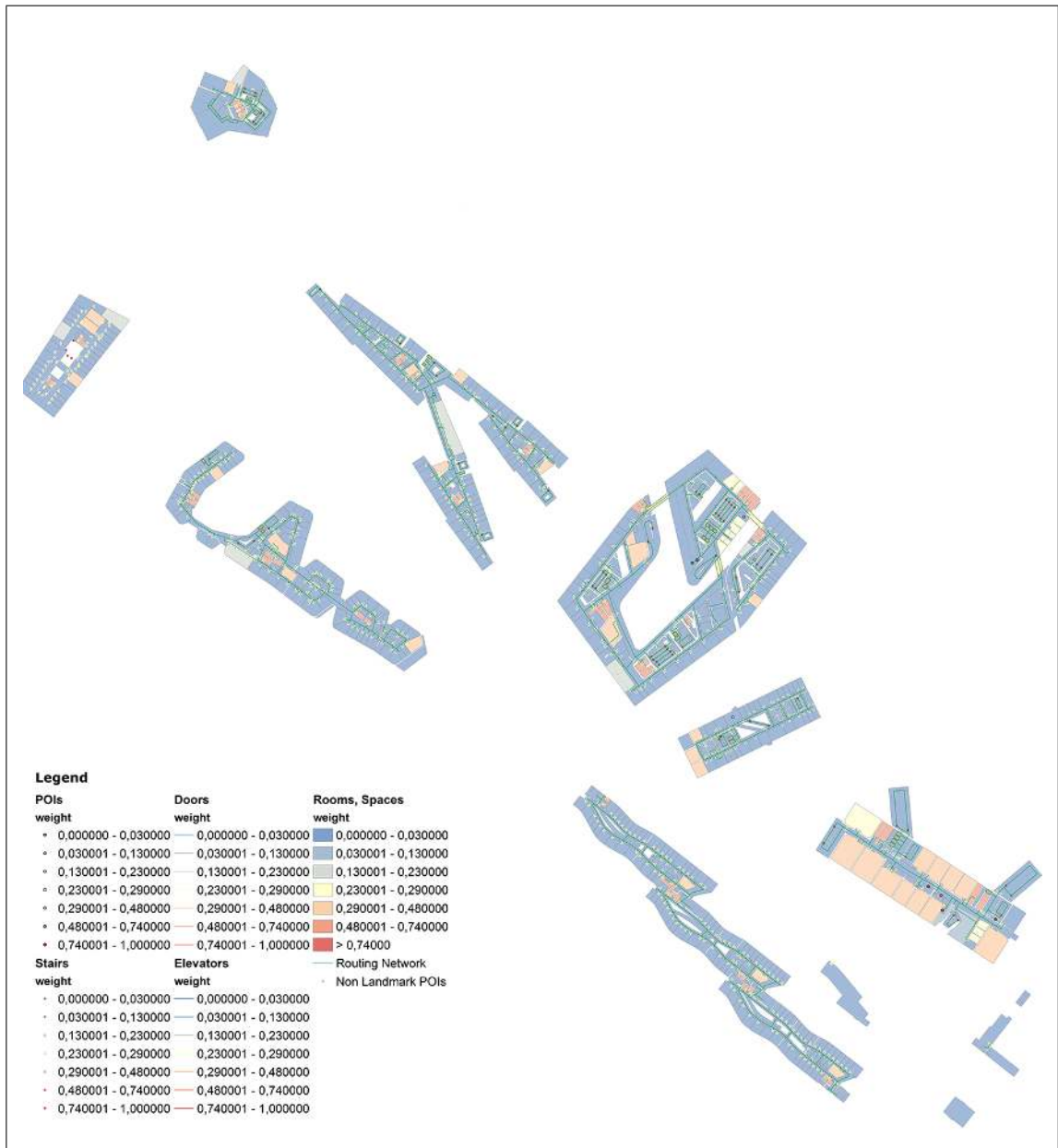


Figure 4.10.: Landmark candidates of the third floor of Campus WU displayed in ArcGIS according to their weight

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.11.: Landmark candidates of the third floor in Building LC of Campus WU displayed in ArcGIS according to their weight



### 4.3. Landmark selection

In this section the steps and heuristics are described to select landmarks for the sample routes and to adjust their landmark suitability weighting according to the algorithm in Figure 3.3.2. Although the steps of the algorithm were not implemented and therefore not executed completely automatically, the logic behind each step is described to create a basis for a possible implementation in a later step.

For route 1 each step of the selection process is described in detail. For route 2 and route 3 the same application processes were applied and therefore only the results of each step are stated. Figure 4.12 illustrates the adjustment of the landmark suitability weights in the steps of the selection process. In the left box the number of the relevant algorithm step is stated, the term in bold refers to the appropriate weight name, below the criteria for the weight adjustment is given.

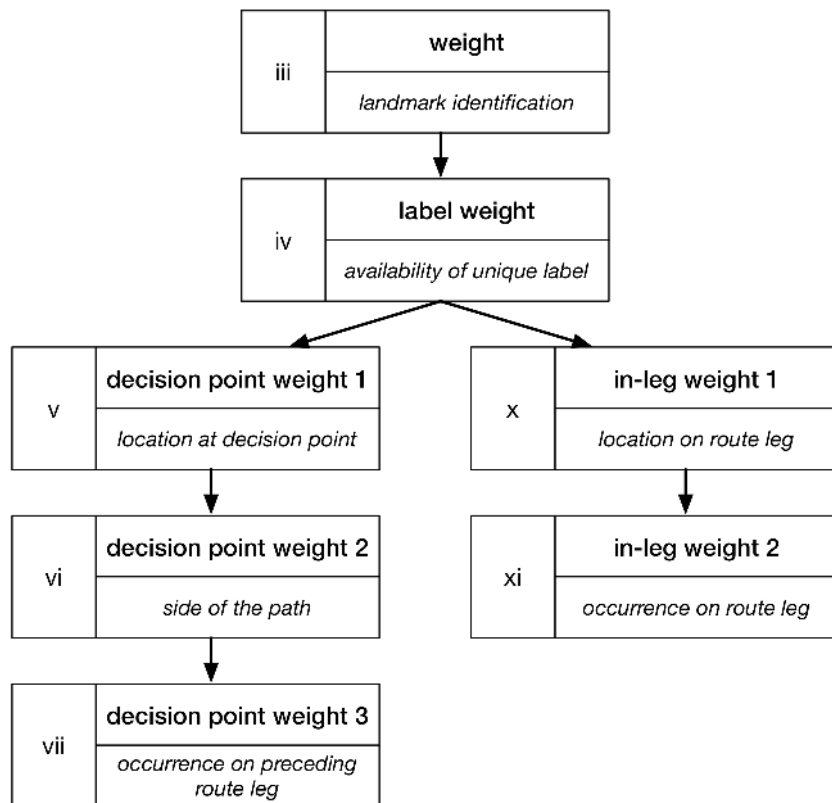


Figure 4.12.: Adjustment of the landmark suitability weight in the ILNM selection process

## 4. Application of the ILNM to WU Campus GIS

### 4.3.1. Route 1

(i) Generate a route from origin  $o \in V$  to destination  $d \in V$  from the graph  $G = (V, E)$  using a standard shortest path algorithm.

The shortest route between start and destination point is generated in the WU Campus GIS using the Dijkstra shortest path algorithm. In ArcGIS the appropriate route segments are selected and stored as a separate feature class. In addition, the decision points of the route are identified and stored separately. Decision points are defined as points where a change of direction as well as a choice between at least two route segments is necessary.

The shortest route between the second elevator of the third floor in the TC and the project room TC.3.18 was generated in the WU Campus GIS and extracted in ArcGIS manually. The route as well as the decision points are illustrated in red in Figure 4.13.

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.13.: Route 1 with decision points illustrated in ArcGIS

(ii) Find the set of landmark candidates  $L' \subseteq L$  that lie anywhere along the route (on decision points or along route legs).

In order to identify all landmark candidates for the route, the following steps have to be performed:

- **Definition of visibility zone:** In the first step a buffer zone around the route path is created with a distance of 4 meters on each site of the route. The value of 4 meters on each site represents the assumed visible area and is a simplified method to determine which features are visible from the route.
- **Selection of landmark features:** In the next step all landmarks that lie anywhere within or intersect this buffer zone can be selected. As the actual

#### 4. Application of the ILNM to WU Campus GIS

visibility varies across different feature types, the actual selection process has to be adjusted for each feature category:

- **Rooms:** For rooms it is necessary to determine if the door of the room is visible from the route, i.e. if the room is also within the buffer zone. Therefore only rooms that have a door which also lies within the buffer zone and rooms that do not have a door at all (e.g. lounges, corridor areas) and which intersect the buffer zone are selected.
- **Elevators, Doors, Bridges:** These basic indoor objects can be determined by selecting all objects that intersect the buffer zone of the route.
- **POIs:** POIs are stored as simple point objects in the database but are usually considerably larger objects. Therefore a buffer of 1 meter will be created for all POIs to calculate if they fall into the buffer zone with their average, estimated size. Then, all features are selected from this buffered POI layer which lie within or intersect the buffer zone.

In the next step it has to be determined if they are visible from the route. For POIs it is assumed that they are either visible if they are within the buffer zone and within the same room as the route path or within an adjacent room without door (e.g. an open lounge or adjacent corridor space). In this way, those POIs are eliminated which are within the buffer zone but are located in closed rooms and may not be seen from the route.

- **Stairs:** For stairs it also has to be determined if they are visible from the route, as stairs within staircases are usually not or only poorly visible from the route. This is done by first selecting all end or start points of stairs, that lie within the buffer zone, and in the next step the same procedure as for POIs for selecting only features that are either in the same room as the route path or in an adjacent room without door is applied.

The landmark candidates for route 1 and the buffer zone are illustrated in Figure 4.14.

(iii) Associate with each landmark instance  $l \in L'$  the landmark  $weight_i(c)$ , for that landmark's associated category  $c \in C$  such that  $category(l) = c$ .

For each landmark instance within the buffer zone the associated weight as well as its number of instances is determined.

#### 4. Application of the ILNM to WU Campus GIS

For each landmark instance within the buffer zone of route 1 the associated weight as well as its number of occurrence is shown in Table 4.3. Figure 4.14 illustrates the landmark candidates with their associated weight.



Figure 4.14.: Route 1 with buffer zone and landmark candidates displayed in ArcGIS according to their weight

(iv) For any landmark  $l \in L'$ , increase the suitability weighting if a unique label is available.

For each landmark instance of the route a new attribute “label weight” is added and the weight value is increased by 0.2 if a unique label or unique name is available for the landmark instance. For rooms it is assumed that they are labelled if a room name

#### 4. Application of the ILNM to WU Campus GIS

is available in the database, for POIs a description name in the database represents a unique label.

An increase of 0.2 represents a fifth of the maximum initial weight from the landmark weighting process and should provide a reasonable effect on the weight while keeping the influence of the initial weight sufficiently high. This value is also used for the weight adjustments in the successive algorithm rules. Although it would be also possible to use different values according to the relevance of the rule, for this thesis always the same value is used.

The new landmark weights can be seen in Table 4.3. Figure 4.15 illustrates the landmark candidates for route 1 according to their label weight.

Landmark category	Number of instances	Weight	Unique label	Label weight
Locker	1	0.81	no	0.81
Toilet	2	0.74	yes	0.94
Elevator	4	0.74	no	0.74
Auditorium	1	0.48	yes	0.68
Vending machine	1	0.61	no	0.61
Seminar room	5	0.35	yes	0.55
Project room	4	0.26	yes	0.46
Door	23	0.29	no	0.29
Uncategorized room	4	0.03	yes	0.23
Study area	1	0.06	yes	0.26
Study area	1	0.06	no	0.06
Uncategorized room	17	0.03	no	0.03

Table 4.3.: Landmark categories with label weights for route 1 in WU Campus GIS

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.15.: Landmark candidates for route 1 displayed in ArcGIS according to their label weight

(v) For any landmark  $l \in L'$  at a decision point, determine if the landmark is located before, exactly at or after the decision point. Increase the suitability weighting if it is passed before reorientation and decrease it if the landmark is located after the decision point.

To select all landmarks at decision points in the first step the area of a decision point has to be determined. For this purpose a buffer is created around each decision point, with a distance of 4 meters which corresponds with the assumed visibility zone.

In the next step all landmarks that are located within this decision point area are selected and their location with reference to the decision point is determined. For

#### 4. Application of the ILNM to WU Campus GIS

rooms with doors it has to be verified that the door of the room is within the buffer zone. Rooms with doors outside the decision point buffer have to be removed, as doors usually represent the visible part of a room. If the route leads through the room or space, it is not suitable as a landmark at a decision point and is therefore removed.

If the landmark is passed before reorientation, the suitability weighting is increased by 0.2 and if it is located after reorientation the weighting is decreased by 0.2. If the landmark is located exactly at the decision point, the weight is not adjusted. The new weight is stored in a new attribute “decision point weight 1”.

The landmarks around decision points for route 1 and their adjusted decision point weights are listed in Table 4.4.

(vi) For any landmark  $l \in L'$  at a decision point, increase the suitability weighting if the landmark is located on the same side of the path as the upcoming instruction.

If the landmark is on the same side as the upcoming instruction, the adjusted decision point suitability weighting is increased by 0.2. The new weighting is stored as “decision point weight 2” and listed in Table 4.4.



4. Application of the ILNM to WU Campus GIS

Landmark category	Count	Before, at, or after decision point	Decision point weight 1	Same/other side	Decision point weight 2
<b>Decision point 1</b>					
Door	1	after	0.09	other	-0.11
Elevator	2	before	0.94	same	1.14
Elevator	1	before	0.94	other	0.74
Uncategorized room (without label)	2	before	0.23	same	0.43
Uncategorized room (without label)	1	before	0.23	other	0.03
Uncategorized room (without label)	3	after	-0.17	other	-0.37
<b>Decision point 2</b>					
Door	2	before	0.49	same	0.69
Door	1	after	0.09	other	-0.11
Uncategorized room (with label)	2	after	0.03	other	-0.17
Uncategorized room (without label)	1	after	-0.17	same	0.03
<b>Decision point 3</b>					
Door	2	before	0.49	other	0.29
Door	1	after	0.09	other	-0.11
Toilet	1	before	1.14	other	0.94
Project room	1	after	0.26	other	0.06
Uncategorized room (without label)	1	after	-0.17	other	-0.37

Table 4.4.: Landmark categories with adjusted decision point weights for route 1 in WU Campus GIS

Figure 4.16 shows the landmark candidates at decision points of route 1 according to decision point weight 1, in Figure 4.17 they are displayed according to decision point weight 2.

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.16.: Landmark candidates for decision points in route 1 displayed in ArcGIS according to their decision point weight 1

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.17.: Landmark candidates for decision points in route 1 displayed in ArcGIS according to their decision point weight 2

(vii) If multiple instances of the same landmark category occur on the route leg before the decision point, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their suitability weighting and determine their number of occurrence for use in the route instruction.

The route is divided into singular route legs at the decision points. For each route leg a new buffer is created. For the creation of the visibility buffers of the entire route

#### 4. Application of the ILNM to WU Campus GIS

and the decision points the end type “round” was used. In contrast, for the leg buffers the end type “flat” is used, as it determines what actually is passed on a route leg and not what is visible.

In the next step the occurrence of each landmark category in each route leg buffer is counted. The threshold number  $n$  is set to 5. Although basically the maximum value for numerical chunking is defined as three (see Duckham et al. (2010)), for indoor routing it is set higher for two reasons:

1. First, the travelling time on one route leg in buildings is usually considerably shorter than in outdoor environments. Therefore the cognitive workload for counting to a higher number is not that high as in outdoor environments.
2. Second, in indoor environments the chance of the occurrence of multiple landmarks of the same category on route legs is higher than in outdoor environments. In order to preserve a sufficient number of landmark candidates within buildings, the numerical chunking threshold is set to a higher number.

For landmarks exceeding this number, their suitability weighting for in-leg landmarks is set to zero. For multiple landmarks with an occurrence below or of 5, the suitability weighting is reduced by 0.05 for each occurrence higher than 1. This means, in case of two instances of the same category, their weight is reduced by 0.05, in case of three it is reduced by 0.1, in case of four it is reduced by 0.15 and in case of five it is reduced by 0.2.

The occurrence of the instances of each landmark category are listed in Table 4.5. Table 4.6 shows the decision point landmarks of route 1 with their final weights.

Landmark category	Leg 1 count	Leg 2 count	Leg 3 count	Leg 4 count
Locker	0	0	1	0
Elevator	4	3	0	0
Toilet	0	0	2	0
Vending machine	0	0	1	0
Auditorium	0	0	1	0
Seminar room	0	0	5	0
Door	0	2	19	3
Project room	0	0	0	3
Study area	0	0	2	0
Uncategorized room	0	5	15	0

Table 4.5.: Occurrence of landmark instances on each route leg of route 1 in WU Campus GIS

4. Application of the ILNM to WU Campus GIS

Landmark category	Count	Preceding leg count	Decision point weight 3
<b>Decision point 1</b>			
<b>Elevator</b>	2	4	<b>0.99</b>
Elevator	1	4	0.59
Uncategorized room (without label)	2	6	0
Uncategorized room (without label)	1	6	0
Uncategorized room (without label)	3	6	0
Door	1	0	-0.11
<b>Decision point 2</b>			
<b>Door</b>	2	2	<b>0.64</b>
Door	1	2	-0.16
Uncategorized room (with label)	2	5	-0.37
Uncategorized room (without label)	1	5	-0.17
<b>Decision point 3</b>			
Door	2	19	0
Door	1	19	0
<b>Toilet</b>	1	2	<b>0.89</b>
Project room	1	0	0.06
Uncategorized room (without label)	1	15	0

Table 4.6.: Landmark categories with final decision point weights for route 1 in WU Campus GIS

In Figure 4.18 the landmarks at decision points are illustrated according to their final decision point weight.

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.18.: Landmark candidates for decision points in route 1 displayed in ArcGIS according to their decision point weight 3

(viii) For each decision point, select the landmark that is incident with that decision point and has the highest weight. If two or more landmarks have the same weight, select the landmark which is closest to the decision point. For each selected landmark determine the unique label, the position with reference to the decision point, and the number of the instance.

For each decision point the landmark instances with the highest adjusted decision point weights are selected. For use in route instructions also the unique label (if available), the number of the occurrence of the instance on the preceding route leg, as well as the information if the landmark is located before, at or after the decision point is relevant.

#### 4. Application of the ILNM to WU Campus GIS

For route 1 the following decision point landmarks are selected:

1. **Decision point 1:** Elevator, before, 1
2. **Decision point 2:** Door, before, 2
3. **Decision point 3:** Toilet room “Mens WC, TC.3.54”, before, 2

(ix) For each route leg, select the landmarks that are crossed by the route. If multiple instances of the same landmark category occur on the same route leg, calculate their number.

All crossed landmarks are identified. Only those rooms, that are of a particular category, i.e. that do not belong to the category “Uncategorized room” are selected, as in most cases only those rooms are useful in instructions for passing through a room or open space. In addition, landmarks that are at the beginning and at the end of the route leg (i.e. the start and destination points) are removed.

If one landmark is crossed by more than one route leg, it is not used as a crossed landmark, as the generated instruction may be not correct. In particular, doors may be crossed by more than one route leg due to their kind of representation in the database. In the example in Figure 4.19 the door is crossed by the blue and red route leg, however in reality it is only crossed by the blue leg.

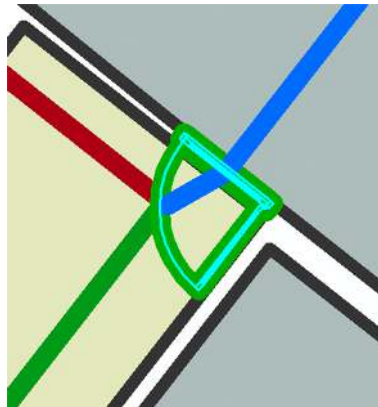


Figure 4.19.: Landmark crossed by two route legs illustrated in ArcGIS

For route 1 the following crossed landmarks are identified:

1. **Route leg 1:** None
2. **Route leg 2:** 1 Door

#### 4. Application of the ILNM to WU Campus GIS

3. **Route leg 3:** None

4. **Route leg 4:** 1 Self study area

(x) For each route leg that is longer than some length threshold  $lt$ , determine the in-leg landmarks and increase the suitability weighting if the landmark is located in the middle half of the route leg.

Particular in indoor environments, where direction changes happen more frequently, a high density of in-leg landmarks is necessary. Therefore a confirmation that the user is on the right way should be provided for all route segments that take longer than around 30 seconds to walk. Assuming an average travel speed of 4 km/h for pedestrians, confirmation landmarks should be selected for all route legs longer than 33 metres.

To determine if the landmarks are located in the middle half of the route segment, the mid point of the route leg is determined and a buffer of one fourth of the overall route segment length is created around this mid point. In the next step all landmarks that are within this buffer are selected. For rooms with doors it is determined if the door of the room is also located in the middle half of the route leg. Crossed landmarks are removed from this selection as they have already been selected in step (ix).

For in-leg landmarks that are located within the middle half of the route leg the suitability weight is increased by 0.2 and stored in a new attribute “in-leg suitability weight 1”.

In route 1 route leg 1 is 2.7 meters, route leg 2 is 7.4 meters, route leg 3 is 45.7 meters, and route leg 4 is 11.3 meters long. Therefore only for the third route segment the in-leg landmarks will be determined. The adjusted values are listed as “in-leg suitability weight 1” in Table4.7.

(xi) If multiple instances of the same landmark category occur on the same route leg, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their in-leg suitability weighting.

The threshold number  $n$  is again set to 5. For landmarks exceeding this number, their suitability weighting for in-leg landmarks is set to zero. For multiple landmarks with an occurrence below or of 5, the suitability weighting is reduced by 0.05 per instance number higher than 1.

Table 4.7 gives an overview of all landmarks of leg 3 of route 1 with their adjusted weights according to their location and their total number of occurrence.



#### 4. Application of the ILNM to WU Campus GIS

<b>Route segment 3</b>					
Landmark category	Count	Middle half	In-leg weight 1	Leg Count	In-leg weight 2
<b>Locker</b>	1	yes	1.01	1	<b>1.01</b>
Toilet	2	no	0.94	2	0.89
Vending machine	1	yes	0.81	1	0.81
Auditorium	1	no	0.68	1	0.68
Seminar room	4	yes	0.75	5	0.55
Study area (with label)	1	yes	0.46	2	0.41
Seminar room	1	no	0.55	5	0.35
Study area (without label)	1	no	0.06	2	0.01
Door	9	yes	0.49	9	0
Door	10	no	0.29	10	0
Uncategorized room (with label)	2	yes	0.46	15	0
Uncategorized room (without label)	2	yes	0.23	15	0
Uncategorized room (with label)	4	no	0.23	15	0
Uncategorized room (without label)	7	no	0.03	15	0

Table 4.7.: In-leg landmarks with adjusted weights for leg 3 of route 1 in WU Campus GIS

Figure 4.20 illustrates the in-leg landmark candidates of the route leg 3 according to their in-leg weight 1. In Figure 4.21 they are displayed according to their in-leg weight 2.

4. Application of the ILNM to WU Campus GIS



Figure 4.20.: In-leg landmark candidates for route leg 3 of route 1 displayed in ArcGIS according to their in-leg weight 1

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.21.: In-leg landmark candidates for route leg 3 of route 1 displayed in ArcGIS according to their in-leg weight 2

(xii) For each route leg that is longer than some length threshold  $lt$ , select the in-leg landmark with the highest landmark suitability weight. If two or more landmarks have the same weight, select the landmark that is nearest to the midpoint of the route leg.

For all relevant route legs the landmarks with the highest in-leg suitability weights are selected. In case of multiple landmarks with the same in-leg weight the landmark which is closest to the midpoint of the route leg is selected.

For route 1 the in-leg landmark with the highest suitability weight for leg 3 are the lockers with a suitability weight of 1.01.

#### 4. Application of the ILNM to WU Campus GIS

##### Summary

The following landmarks are selected for route 1:

##### 1. Route leg 1

- a) **Landmark crossed by the route:** -
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** Elevator, before, 1

##### 2. Route leg 2

- a) **Landmark crossed by the route:** Door, 1
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** Door, before, 2

##### 3. Route leg 3

- a) **Landmark crossed by the route:** -
- b) **In-Leg-landmark:** Locker, 1
- c) **Decision point landmark:** Toilet “Men’s WC, TC.3.54”, before, 2

##### 4. Route leg 4

- a) **Landmark crossed by the route:** Study area, 1
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** -

All selected landmarks are illustrated in Figure 4.22 according to their relevant weight.

#### 4. Application of the ILNM to WU Campus GIS

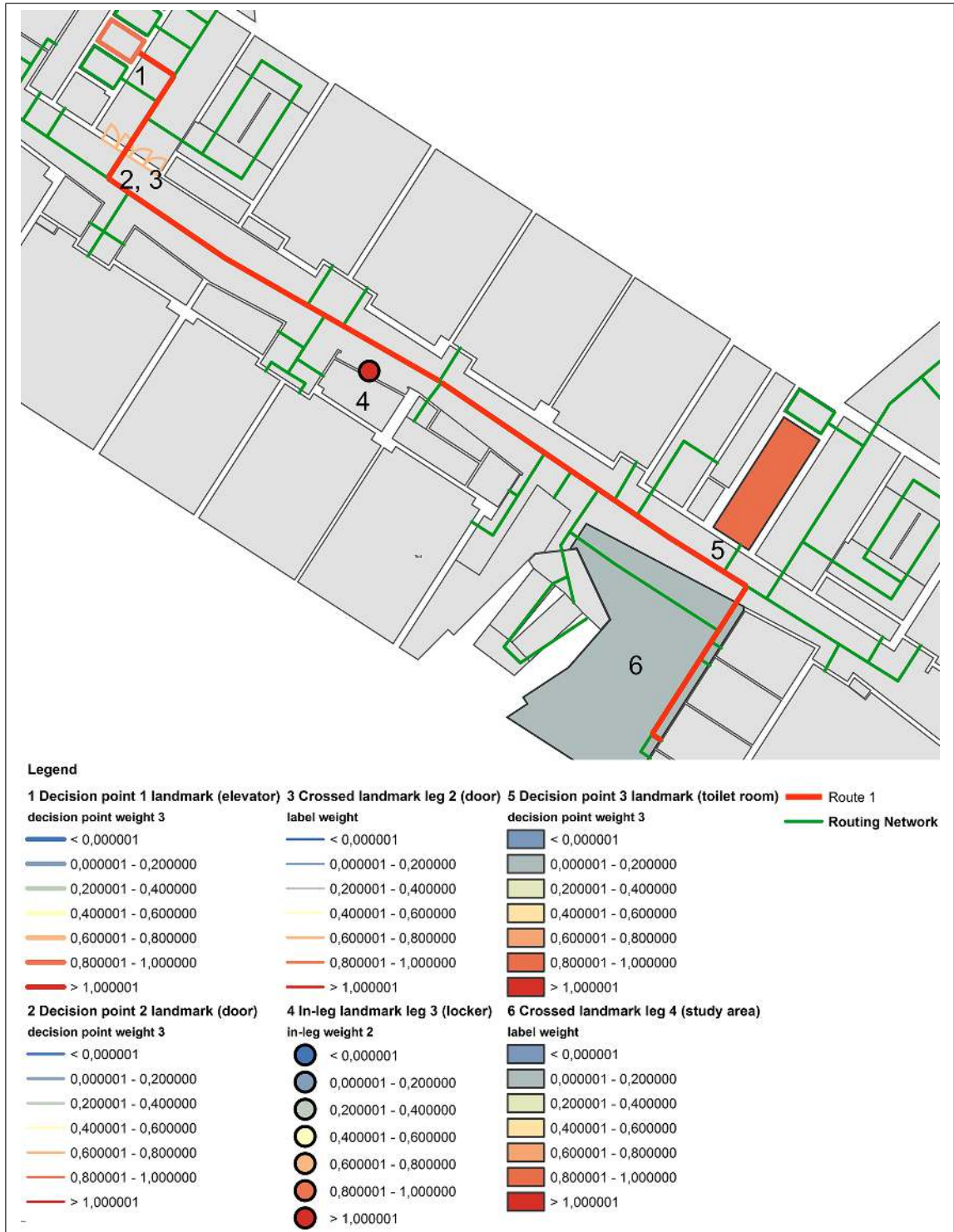


Figure 4.22.: Selected landmarks for route 1 displayed in ArcGIS according to their relevant weight

#### 4. Application of the ILNM to WU Campus GIS

##### 4.3.2. Route 2

(i) Generate a route from origin  $o \in V$  to destination  $d \in V$  from the graph  $G = (V, E)$  using a standard shortest path algorithm.

The shortest route between room D4.4.234 and D4.4.144 was generated in WU Campus GIS and extracted in ArcGIS manually. The route as well as the decision points are illustrated in Figure 4.23.

#### 4. Application of the ILNM to WU Campus GIS

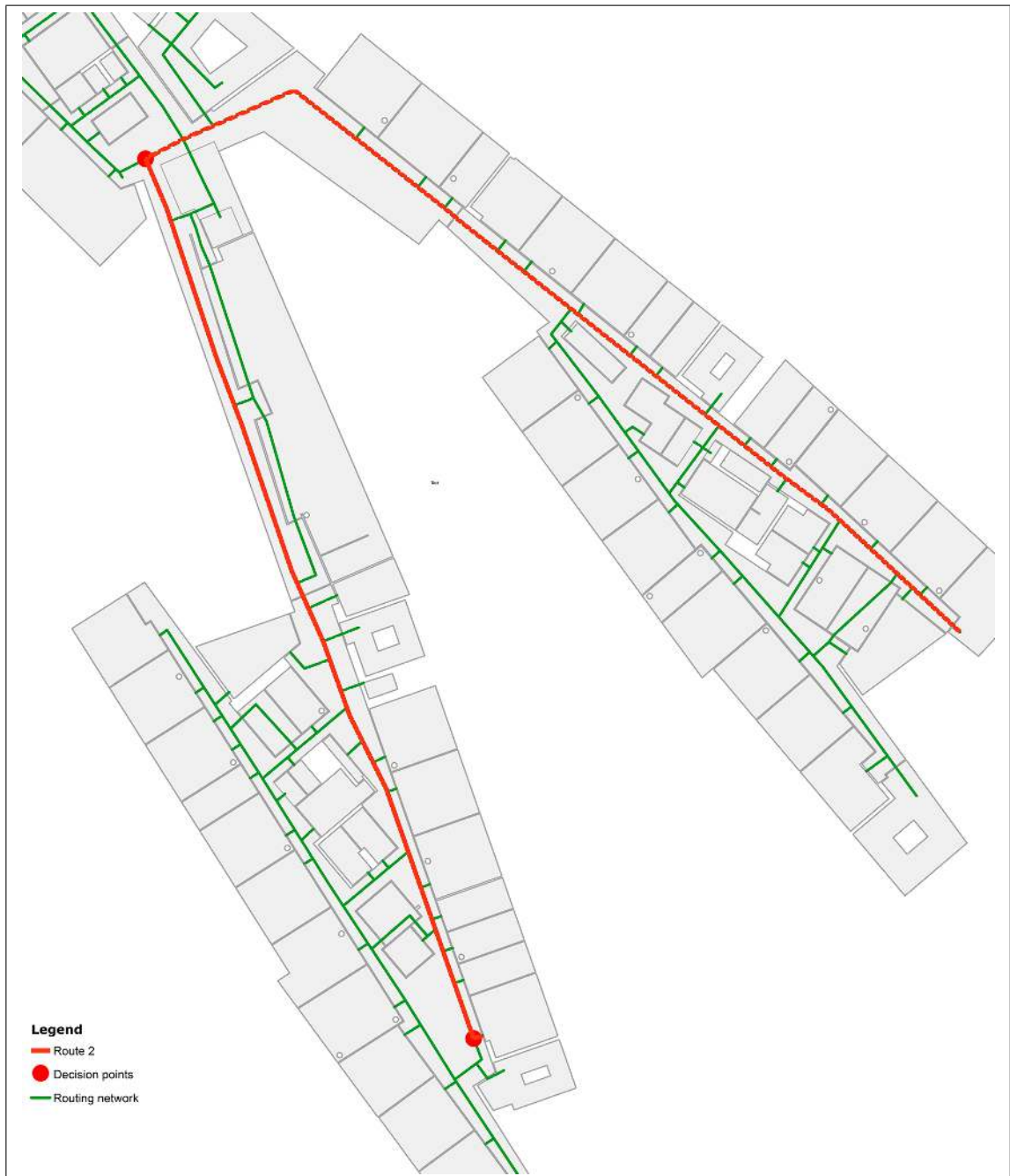


Figure 4.23.: Route 2 with decision points illustrated in ArcGIS

(ii) Find the set of landmark candidates  $L' \subseteq L$  that lie anywhere along the route (on decision points or along route legs).

The result of this algorithm step is a set of landmark candidates for route 2 and is illustrated in Figure 4.24.

#### 4. Application of the ILNM to WU Campus GIS

(iii) Associate with each landmark instance  $l \in L'$  the landmark  $weight_i(c)$ , for that landmark's associated category  $c \in C$  such that  $category(l) = c$ .

For each landmark instance within the buffer zone of route 2 the associated weight as well as its number of occurrence is shown in Table 4.8. Figure 4.24 illustrates the landmark candidates according to their initial weight.

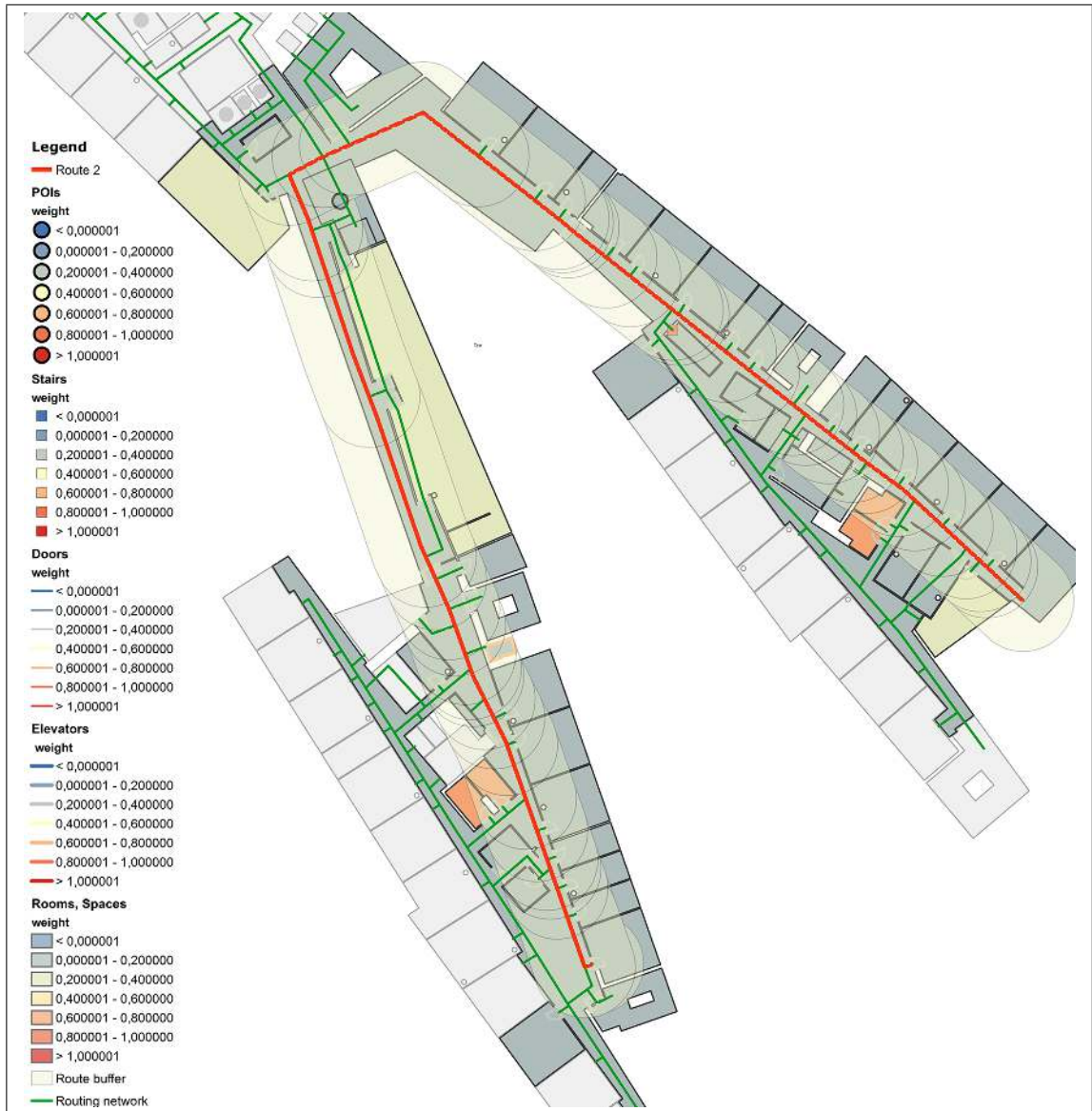


Figure 4.24.: Route 2 with buffer zone and landmark candidates displayed in ArcGIS according to their weight



#### 4. Application of the ILNM to WU Campus GIS

(iv) For any landmark  $l \in L'$ , increase the suitability weighting if a unique label is available.

The adjusted landmark weights can be seen in Table 4.8 and are illustrated in Figure 4.25.



Figure 4.25.: Landmark candidates for route 2 displayed in ArcGIS according to their label weight

#### 4. Application of the ILNM to WU Campus GIS

Landmark category	Number of instances	Weight	Unique label	Label weight
Stairs	1	1.00	no	1.00
Elevator	1	0.74	no	0.74
Toilet	4	0.74	yes	0.94
Meeting room	2	0.35	yes	0.55
Door	51	0.29	no	0.29
Lounge	1	0.23	yes	0.43
Front office	1	0.16	yes	0.36
Uncategorized room	31	0.03	yes	0.23
Uncategorized room	17	0.03	no	0.03

Table 4.8.: Landmark categories with label weights for route 2 in WU Campus GIS

(v) For any landmark  $l \in L'$  at a decision point, determine if the landmark is located before, exactly at or after the decision point. Increase the suitability weighting if it is passed before reorientation and decrease it if the landmark is located after the decision point.

The landmarks around decision points and their adjusted decision point weights are listed in Table4.9.

(vi) For any landmark  $l \in L'$  at a decision point, increase the suitability weighting if the landmark is located on the same side of the path as the upcoming instruction.

The landmarks around decision points and their adjusted decision point weights are listed in Table4.9.

4. Application of the ILNM to WU Campus GIS

Landmark	Count	Before, at, or after decision point	Decision point weight 1	Same/other side	Decision point weight 2
<b>Decision point 1</b>					
Door	1	before	0.59	same	0.89
Door	1	after	-0.01	same	0.29
Door	1	after	0.09	other	-0.11
Uncategorized room (with label)	1	before	0.43	same	0.63
Uncategorized room (with label)	1	after	0.03	same	0.23
Uncategorized room (with label)	1	after	0.03	other	-0.17
Uncategorized room (without label)	1	after	-0.17	other	-0.37
<b>Decision point 2</b>					
Door	1	before	0.49	other	0.29
Door	1	after	0.09	other	-0.11
Front Office	1	before	0.56	same	0.76
Meeting room (with label)	1	before	0.75	other	0.55
Uncategorized room (with label)	1	before	0.23	same	0.43
Uncategorized room (with label)	1	after	0.03	other	-0.17

Table 4.9.: Landmark categories with adjusted decision point weights for route 2 in WU Campus GIS

(vii) If multiple instances of the same landmark category occur on the route leg before the decision point, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their suitability weighting and determine their number of occurrence for use in the route instruction.

The occurrence of instances of each landmark category are listed in Table 4.10. Table 4.11 shows the decision point landmarks of route 2 with their final weights.

#### 4. Application of the ILNM to WU Campus GIS

Landmark category	Leg 1 count	Leg 2 count	Leg 3 count
Stairs	0	0	1
Elevator	0	1	0
Toilet	0	2	2
Meeting room	0	1	1
Door	2	23	26
Lounge	0	1	0
Front office	0	1	1
Uncategorized room	1	17	28

Table 4.10.: Occurrence of landmark instances on each route leg of route 2 in WU Campus GIS

Landmark category	Count	Preceding leg count	Decision point weight 3
<b>Decision point 1</b>			
<b>Uncategorized room</b>	1	1	<b>0.63</b>
Uncategorized room	1	1	0.23
Uncategorized room	1	1	-0.17
Uncategorized room	1	1	-0.37
Door	1	2	0.64
Door	1	2	0.24
Door	1	2	-0.16
<b>Decision point 2</b>			
<b>Front Office</b>	1	1	<b>0.76</b>
Meeting room	1	1	0.55
Door	1	23	0
Door	1	23	0
Uncategorized room (with label)	1	16	0
Uncategorized room (without label)	1	16	0

Table 4.11.: Landmark categories with final decision point weights for route 2 in WU Campus GIS

Figure 4.26 illustrates the decision points of route 2 with their landmark candidates according to their final decision point weights 3.

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.26.: Landmark candidates for decision points in route 2 displayed in ArcGIS according to their decision point weight 3

(viii) For each decision point, select the landmark that is incident with that decision point and has the highest weight. If two or more landmarks have the same weight, select the landmark which is closest to the decision point. For each selected landmark determine the unique label, the position with reference to the decision point, and the number of the instance.

The following landmarks are selected as landmarks at decision points for route 2:

1. **Decision point 1:** Uncategorized Room “D4.4.234”, before, 1

#### 4. Application of the ILNM to WU Campus GIS

2. **Decision point 2:** Front Office “Front Office Finance, Accounting and Statistics”, before, 1

(ix) For each route leg, select the landmarks that are crossed by the route. If multiple instances of the same landmark category occur on the same route leg, calculate their number.

For route 2 the following landmarks are selected as crossed landmarks:

1. **Route leg 1:** None
2. **Route leg 2:** 2 doors
3. **Route leg 3:** 2 doors

(x) For each route leg that is longer than some length threshold  $lt$ , determine the in-leg landmarks and increase the suitability weighting if the landmark is located in the middle half of the route leg.

Route leg 1 is 0.7 metres, route leg 2 is 66.7 metres, route leg 3 is 72.7 metres long. Therefore for the second and third route segment the in-leg landmarks will be determined.

The in-leg suitability weighting is increased by 0.2 if the landmark is located within the middle half of the route leg. These adjusted values are listed as “in-leg weight 1” in Table4.12.

(xi) If multiple instances of the same landmark category occur on the same route leg, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their in-leg suitability weight.

Table 4.12 gives an overview of all landmarks of leg 2 and leg 3 with their adjusted weights according to their location and their total count of occurrence.

4. Application of the ILNM to WU Campus GIS

Landmark category	Count	Middle half	In-leg weight 1	Leg count	In-leg weight 2
<b>Route leg 2</b>					
<b>Elevator</b>	1	yes	0.94	1	<b>0.94</b>
Toilet	2	no	0.94	2	0.94
Meeting room	1	no	0.55	1	0.55
Lounge	1	yes	0.63	1	0.63
Front office	1	no	0.36	1	0.36
Door	10	yes	0.49	23	0
Door	13	no	0.29	23	0
Uncategorized room (with label)	3	yes	0.43	16	0
Uncategorized room (without label)	2	yes	0.23	16	0
Uncategorized room (with label)	7	no	0.23	16	0
Uncategorized room (without label)	4	no	0.03	16	0
<b>Route leg 3</b>					
<b>Stairs</b>	1	yes	1.2	1	<b>1.2</b>
Toilet	2	no	0.94	2	0.89
Meeting room	1	no	0.55	1	0.55
Front office	1	no	0.36	1	0.36
Door	14	yes	0.49	26	0
Door	12	no	0.29	26	0
Uncategorized room (with label)	11	yes	0.43	28	0
Uncategorized room (without label)	2	yes	0.23	28	0
Uncategorized room (with label)	9	no	0.23	28	0
Uncategorized room (without label)	6	no	0.03	28	0

Table 4.12.: In-leg landmarks with adjusted weights for leg 2 and leg 3 of route 2 in WU Campus GIS

Figure 4.27 illustrates the in-leg landmarks for leg 2 and leg 3 of route 2 according to their final in-leg weight.

#### 4. Application of the ILNM to WU Campus GIS

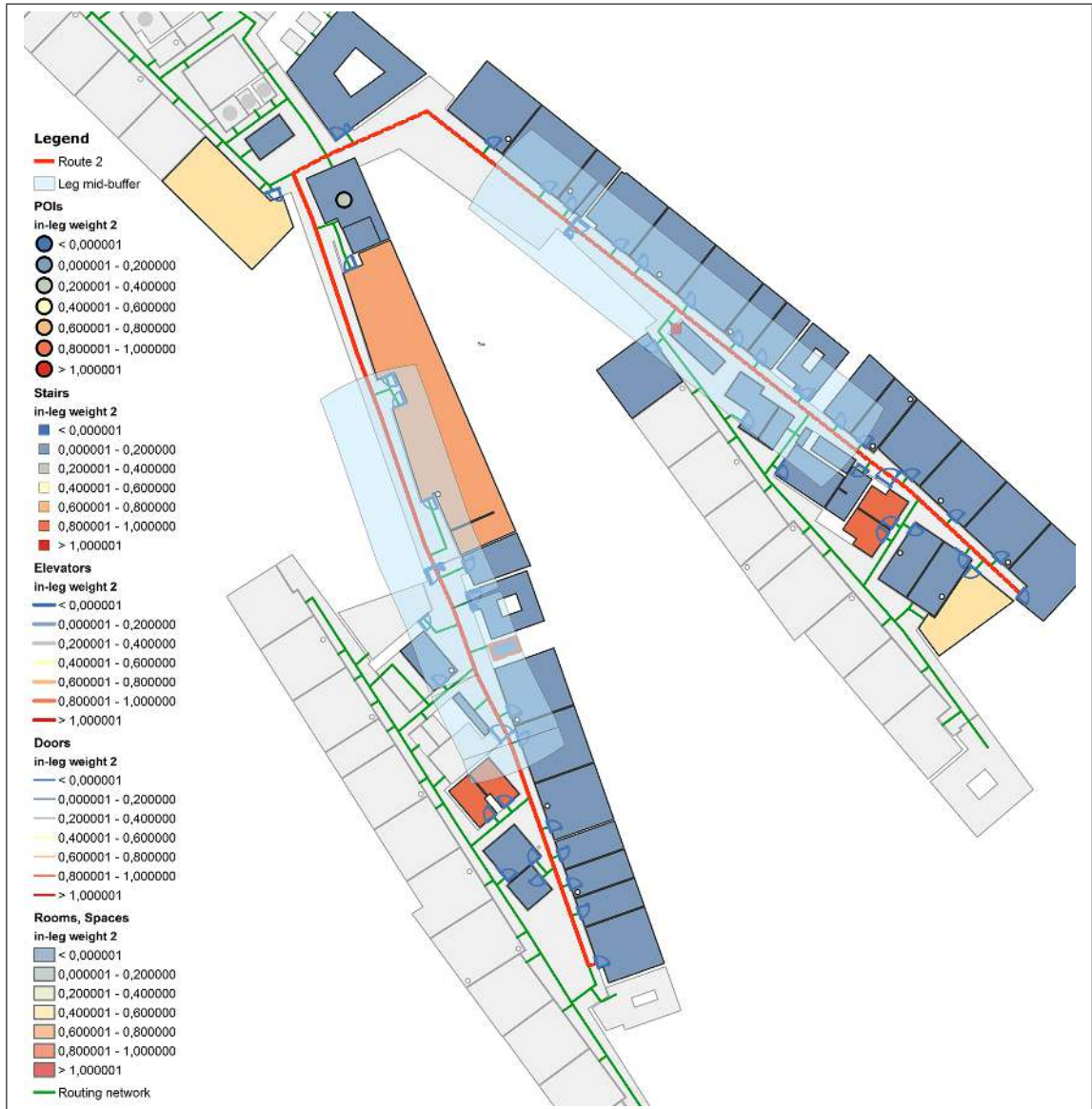


Figure 4.27.: Landmark candidates for leg 2 and leg 3 of route 2 displayed in ArcGIS according to their label weight 2

(xii) For each route leg that is longer than some length threshold  $lt$ , select the in-leg landmark with the highest in-leg landmark suitability weight. If two or more landmarks have the same weight, select the landmark that is nearest to the midpoint of the route leg.

For route leg 2 the landmark with the highest in-leg suitability weight is the elevator with a value of 0.94. For route leg 3 the landmark with the highest in-leg suitability



#### 4. Application of the ILNM to WU Campus GIS

weight are the stairs with a value of 1.2.

##### **Summary**

The following landmarks have been selected for route two:

##### **1. Route leg 1**

- a) **Landmark crossed by the route:** -
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** Uncategorized room "D4.4.234", before, 2

##### **2. Route leg 2**

- a) **Landmark crossed by the route:** Door, 2
- b) **In-Leg-landmark:** Elevator, 1
- c) **Decision point landmark:** Front Office "Front Office Finance, Accounting and Statistics", before, 1

##### **3. Route leg 3**

- a) **Landmark crossed by the route:** Door, 2
- b) **In-Leg-landmark:** Stairs, 1
- c) **Decision point landmark:** -

All selected landmarks of route 2 are illustrated in Figure 4.28 according to their relevant weight.

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.28.: Selected landmarks for route 2 displayed in ArcGIS according to their relevant weight

### 4.3.3. Route 3

(i) Generate a route from origin  $o \in V$  to destination  $d \in V$  from the graph  $G = (V, E)$  using a standard shortest path algorithm.

The shortest route between the seminar room D2.0.038 and the office room D2.3.088 was generated in the WU Campus GIS and extracted in ArcGIS manually.

The route as well as the decision points are illustrated in Figure 4.29 for the part of the route on the ground floor and in Figure 4.30 for the part of the route on the third floor.



Figure 4.29.: Route 3 (ground floor) with decision points illustrated in ArcGIS

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.30.: Route 3 (third floor) with decision points illustrated in ArcGIS

(ii) Find the set of landmark candidates  $L' \subseteq L$  that lie anywhere along the route (on decision points or along route legs).

The result of this algorithm step is a set of landmark candidates for route 3 and is illustrated in Figure 4.31 for the part of the route on the ground floor and in Figure 4.32 for the part of the route on the third floor.

(iii) Associate with each landmark instance  $l \in L'$  the landmark  $weight_i(c)$ , for that landmark's associated category  $c \in C$  such that  $category(l) = c$ .

For each landmark instance within the buffer zone of route 3 the associated weight as well as its number of occurrence is shown in Table 4.13. Figures 4.31 and Figure 4.32 illustrate the landmark candidates according to their initial weight.

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.31.: Route 3 (ground floor) with buffer zone and landmark candidates displayed in ArcGIS according to their weight

#### 4. Application of the ILNM to WU Campus GIS

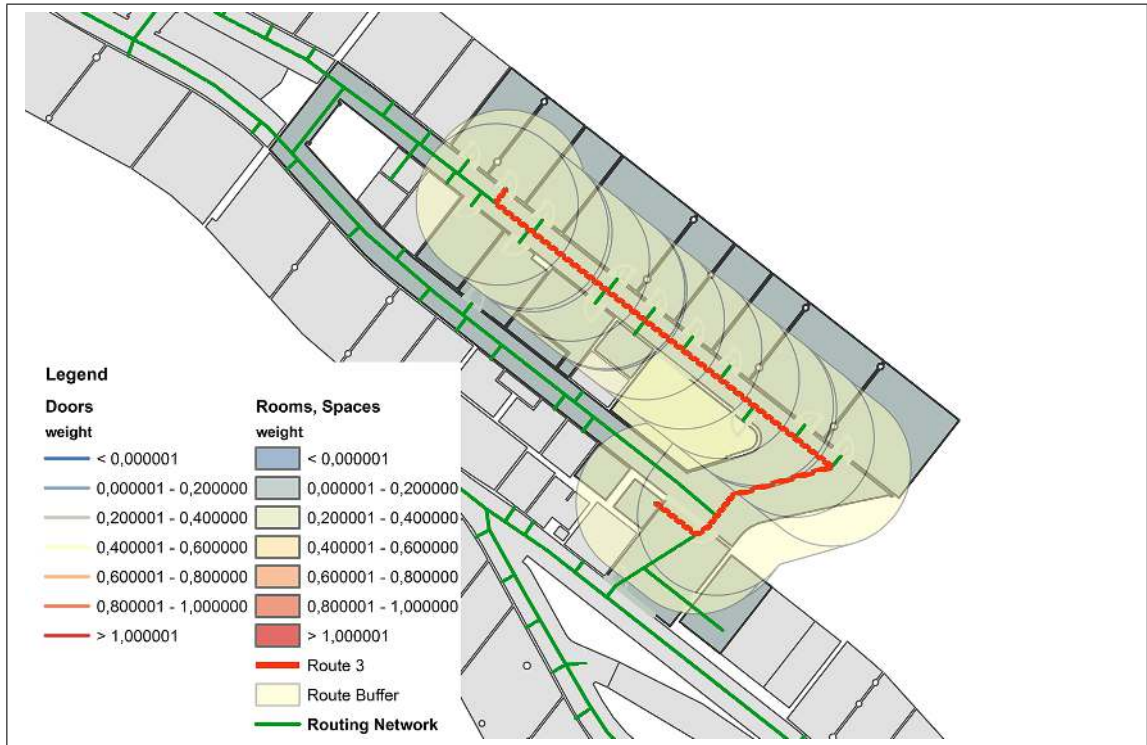


Figure 4.32.: Route 3 (third floor) with buffer zone and landmark candidates displayed in ArcGIS according to their weight

(iv) For any landmark  $l \in L'$ , increase the suitability weighting if a unique label is available.

The adjusted landmark weights can be seen in Table 4.13 and are illustrated in Figure 4.33 for the ground floor and in Figure 4.34 for the third floor.

4. Application of the ILNM to WU Campus GIS

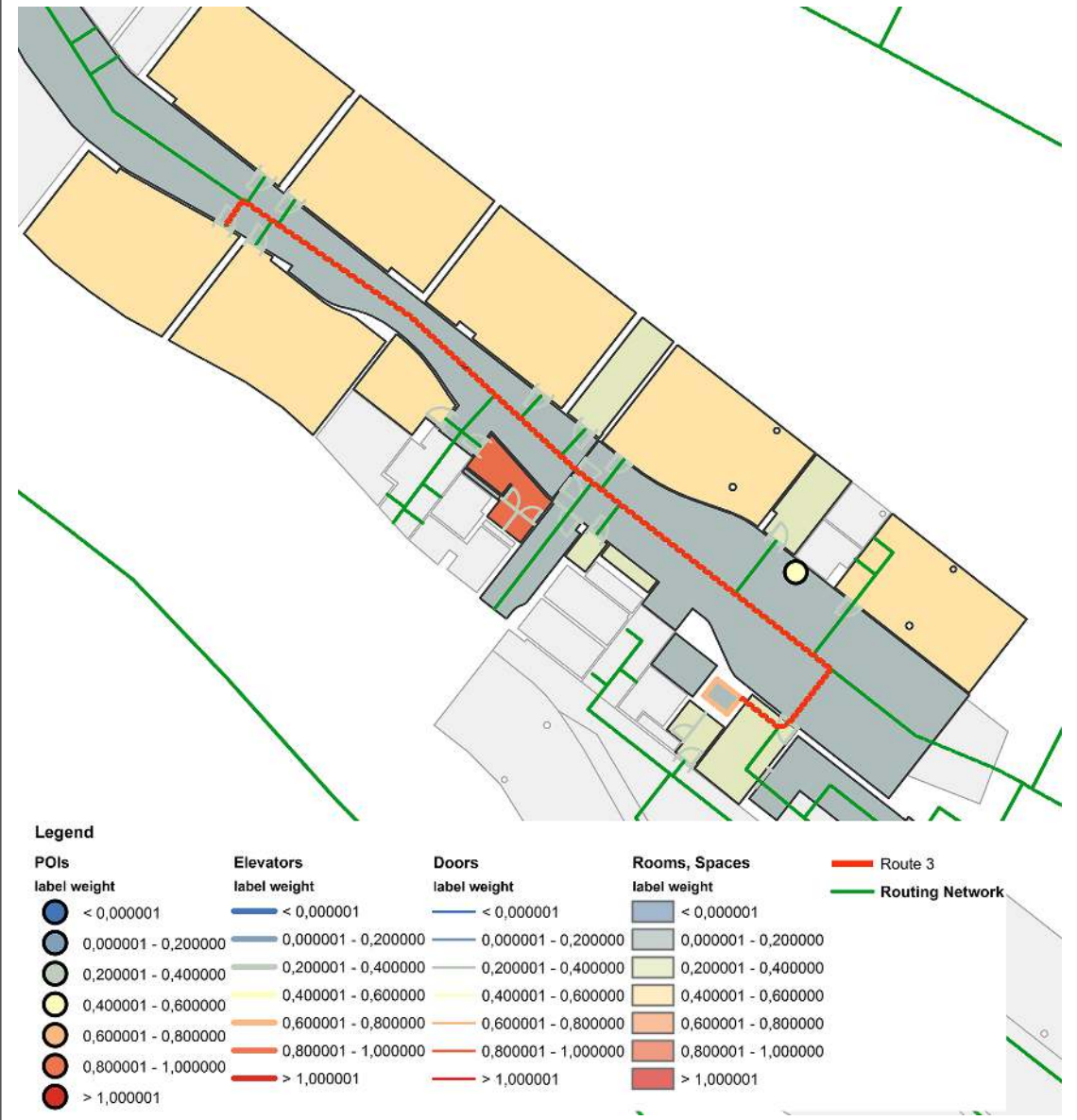


Figure 4.33.: Landmark candidates for route 3 (ground floor) displayed in ArcGIS according to their label weight

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.34.: Landmark candidates for route 3 (third floor) displayed in ArcGIS according to their label weight

(v) For any landmark  $l \in L'$  at a decision point, determine if the landmark is located before, exactly at or after the decision point. Increase the suitability weighting if it is passed before reorientation and decrease it if the landmark is located after the decision point.

The landmarks around decision points and their adjusted decision point weights are listed in Table 4.14.

(vi) For any landmark  $l \in L'$  at a decision point, increase the suitability weighting if the landmark is located on the same side of the path as the upcoming instruction.

The landmarks around decision points and their adjusted decision point weights are listed in Table 4.14.



#### 4. Application of the ILNM to WU Campus GIS

Landmark category	Number of instances	Weight	Unique label	Label weight
<b>Ground floor</b>				
Toilet	1	0.74	yes	0.94
Elevator	1	0.74	no	0.74
Seminar room	2	0.35	yes	0.55
Computer terminal	1	0.48	no	0.48
Project room	1	0.26	yes	0.46
PC room	3	0.26	yes	0.46
Lounge	2	0.23	yes	0.43
Door	19	0.29	no	0.29
Uncategorized room	31	0.03	yes	0.23
Uncategorized room	4	0.03	no	0.03
<b>Third floor</b>				
Meeting room	1	0.35	yes	0.55
Door	18	0.29	no	0.29
Uncategorized room	13	0.03	yes	0.23
Uncategorized room	6	0.03	no	0.03

Table 4.13.: Landmark categories with label weights for route 3 in WU Campus GIS

4. Application of the ILNM to WU Campus GIS

Landmark	Count	Before, at, or after decision point	Decision point weight 1	Same/other side	Decision point weight 2
<b>Ground floor</b>					
<b>Decision point 1</b>					
Seminar room	2	before	0.75	same	0.95
Door	2	before	0.49	same	0.69
PC room	2	after	0.26	same	0.46
Door	2	after	0.09	same	0.29
<b>Decision point 2</b>					
Door	1	before	0.49	same	0.69
Lounge	1	before	0.63	other	0.43
Door	1	before	0.49	other	0.29
<b>Decision point 3</b>					
Elevator	1	at	0.74	same	0.94
Door	1	before	0.49	same	0.69
Door	1	after	0.09	other	-0.11
Uncategorized room (without label)	1	after	-0.17	other	-0.37
<b>Third floor</b>					
<b>Decision point 1</b>					
Door	1	at	0.29	same	0.49
Door	1	after	0.09	other	-0.11
Uncategorized room (without label)	1	after	-0.17	other	-0.37

Table 4.14.: Landmark categories with adjusted decision point weights for route 3 in WU Campus GIS

#### 4. Application of the ILNM to WU Campus GIS

(vii) If multiple instances of the same landmark category occur on the route leg before the decision point, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their suitability weighting and determine their number of occurrence for use in the route instruction.

The occurrence of instances of each landmark category are listed in Table 4.15. Table 4.16 shows the decision point landmarks of route 3 with their final weights.

Landmark category	Leg 1 count	Leg 2 count	Leg 3 count	Leg 4 count
<b>Ground floor</b>				
Elevator	0	0	0	0
Toilet	0	1	0	0
Computer terminal	0	1	0	0
Seminar room	1	2	0	0
Door	2	16	1	2
PC room	0	3	0	0
Project room	0	1	0	0
Lounge	0	2	0	0
Uncategorized room	0	9	0	1
<b>Third floor</b>				
Meeting room	0	1		
Door	2	13		
Uncategorized room	0	12		

Table 4.15.: Occurrence of landmark instances on each route leg of route 3 in WU Campus GIS

#### 4. Application of the ILNM to WU Campus GIS

Landmark	Count	Preceding leg count	Decision point weight 3
<b>Ground floor</b>			
<b>Decision point 1</b>			
<b>Seminar room</b>	2	1	<b>0.95</b>
Door	2	2	0.65
PC room	2	0	0.46
Door	2	2	0.24
<b>Decision point 2</b>			
<b>Lounge</b>	1	2	<b>0.38</b>
Door	1	16	0
Door	1	16	0
<b>Decision point 3</b>			
<b>Elevator</b>	1	0	<b>0.94</b>
Door	1	1	0.69
Door	1	1	-0.11
Uncategorized room (without label)	1	0	-0.37
<b>Third floor</b>			
<b>Decision point 1</b>			
<b>Door</b>	1	2	<b>0.44</b>
Door	1	2	-0.16
Uncategorized room (without label)	1	0	-0.37

Table 4.16.: Landmark categories with final decision point weights for route 3 in WU Campus GIS

Figure 4.35 and Figure 4.36 illustrate the decision points of route 3 with their landmark candidates according to their final decision point weight 3.

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.35.: Landmark candidates for decision points of route 3 (ground floor) displayed in ArcGIS according to their decision point weight 3

#### 4. Application of the ILNM to WU Campus GIS



Figure 4.36.: Landmark candidates for decision points of route 3 (third floor) displayed in ArcGIS according to their decision point weight 3

(viii) For each decision point, select the landmark that is incident with that decision point and has the highest weight. If two or more landmarks have the same weight, select the landmark which is closest to the decision point. For each selected landmark determine the unique label, the position with reference to the decision point, and the number of the instance.

The following landmarks are selected as landmarks at decision points for route 3:

- **Ground floor**

1. **Decision point 1:** Seminar room, before, 2, "D2.0.038"
2. **Decision point 2:** Lounge, before, 2, "D2.0.005"
3. **Decision point 3:** Elevator, at, 1

- **Third floor**

1. **Decision point 1:** Door, at, 2

#### 4. Application of the ILNM to WU Campus GIS

(ix) For each route leg, select the landmarks that are crossed by the route. If multiple instances of the same landmark category occur on the same route leg, calculate their number.

For route 3 the following landmarks are selected as crossed landmarks:

- **Ground floor**

1. **Route leg 1:** None
2. **Route leg 2:** 1 door
3. **Route leg 3:** None
4. **Route leg 4:** None

- **Third floor**

1. **Route leg 1:** None
2. **Route leg 2:** None

Route leg 3 on the ground floor and route leg 2 on the third floor cross one door each. However, due to the inaccurate representation of doors in the database, these doors would also be crossed by another route leg according to the spatial query in ArcGIS, which is not correct in reality. According to the rule, that landmarks, which are crossed by more than one route leg, will be eliminated, these doors will not be selected as crossed landmarks for this route.

(x) For each route leg that is longer than some length threshold  $lt$ , determine the in-leg landmarks and increase the suitability weighting if the landmark is located in the middle half of the route leg.

On the ground floor, route leg 1 is 1.6 metres, route leg 2 is 40 metres, route leg 3 is 4.2 metres, and route leg 4 is 2.6 metres long. On the third floor, route leg 1 is 2.6 metres, and route leg 2 is 30.4 metres long. Therefore for the second route segment of the route on the ground floor the in-leg landmark will be determined.

The in-leg suitability weighting is increased by 0.2 if the landmark is located within the middle half of the route leg. These adjusted values are listed as “in-leg weight 1” in Table4.17.

(xi) If multiple instances of the same landmark category occur on the same route leg, set their weight to zero if their count exceeds some number threshold  $n$ , otherwise only decrease their in-leg suitability weight.

#### 4. Application of the ILNM to WU Campus GIS

Table 4.17 gives an overview of all landmarks of leg 3 with their adjusted weights according to their location and their total count of occurrence.

Landmark category	Count	Middle half	In-leg weight 1	Leg count	In-leg weight 2
<b>Route leg 2 (ground floor)</b>					
<b>Toilet</b>	1	yes	1.14	1	<b>1.14</b>
Meeting room	1	no	0.55	1	0.55
Lounge	1	yes	0.63	2	0.68
Lounge	1	no	0.43	2	0.38
Computer terminal	1	no	0.48	1	0.48
Seminar room	2	no	0.55	2	0.50
PC room	1	yes	0.66	3	0.56
PC room	2	no	0.46	3	0.26
Project room	1	yes	0.66	1	0.66
Door	8	yes	0.49	16	0
Door	7	no	0.29	16	0
Uncategorized room (with label)	3	yes	0.43	9	0
Uncategorized room (without label)	3	yes	0.23	9	0
Uncategorized room (with label)	2	no	0.23	9	0
Uncategorized room (without label)	1	no	0.03	9	0

Table 4.17.: In-leg landmarks with adjusted weights for leg 3 of route 3 (ground floor) in WU Campus GIS

Figure 4.37 illustrates the in-leg landmarks for leg 3 of route 3 according to their final in-leg weight.



#### 4. Application of the ILNM to WU Campus GIS

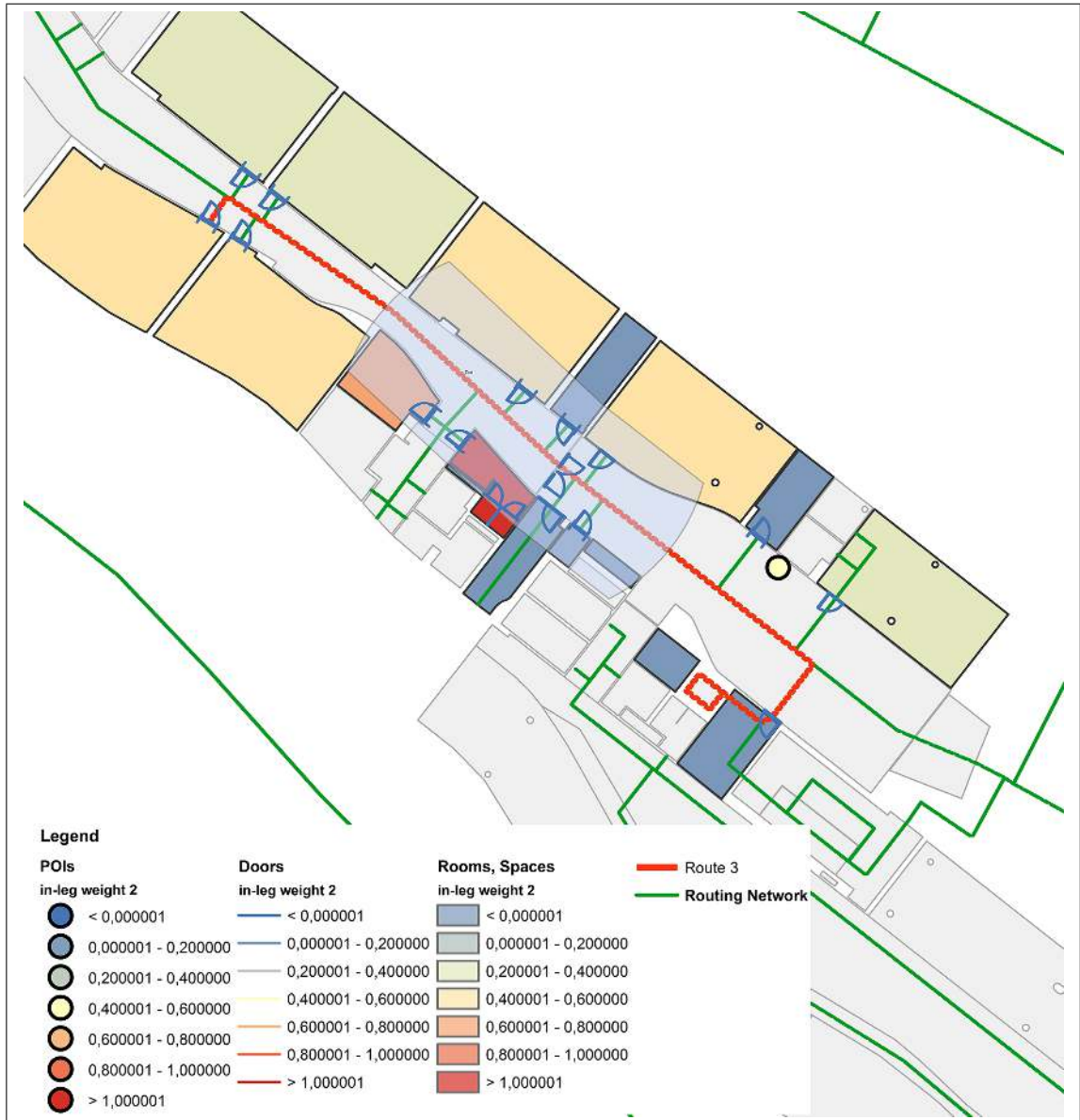


Figure 4.37.: Landmark candidates for leg 2 route 3 (ground floor) displayed in ArcGIS according to their in-leg weight 2

(xii) For each route leg that is longer than some length threshold  $lt$ , select the in-leg landmark with the highest in-leg landmark suitability weight. If two or more landmarks have the same weight, select the landmark that is nearest to the midpoint of the route leg.

For route leg 2 the landmark with the highest in-leg suitability weight is the toilet room (“D2.0.012”) with a value of 1.14.

## Summary

The following landmarks have been selected for route 3:

- **Ground floor**

1. **Route leg 1**

- a) **Landmark crossed by the route:** -
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** Seminar room “D2.0.038”, before, 2

2. **Route leg 2**

- a) **Landmark crossed by the route:** Door, 1
- b) **In-Leg-landmark:** Toilet “D2.0.012”, 1
- c) **Decision point landmark:** Lounge “D2.0.005”, before, 2,

3. **Route leg 3**

- a) **Landmark crossed by the route:** Door, 1
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** Elevator, at, 1

4. **Route leg 3**

- a) **Landmark crossed by the route:** -
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** -

- **Third floor**

1. **Route leg 1**

- a) **Landmark crossed by the route:** -
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** Door, at, 2

2. **Route leg 2**

- a) **Landmark crossed by the route:** -
- b) **In-Leg-landmark:** -
- c) **Decision point landmark:** -

#### 4. Application of the ILNM to WU Campus GIS

All selected landmarks of route 3 are illustrated in Figure 4.38 and Figure 4.39 according to their relevant weight.

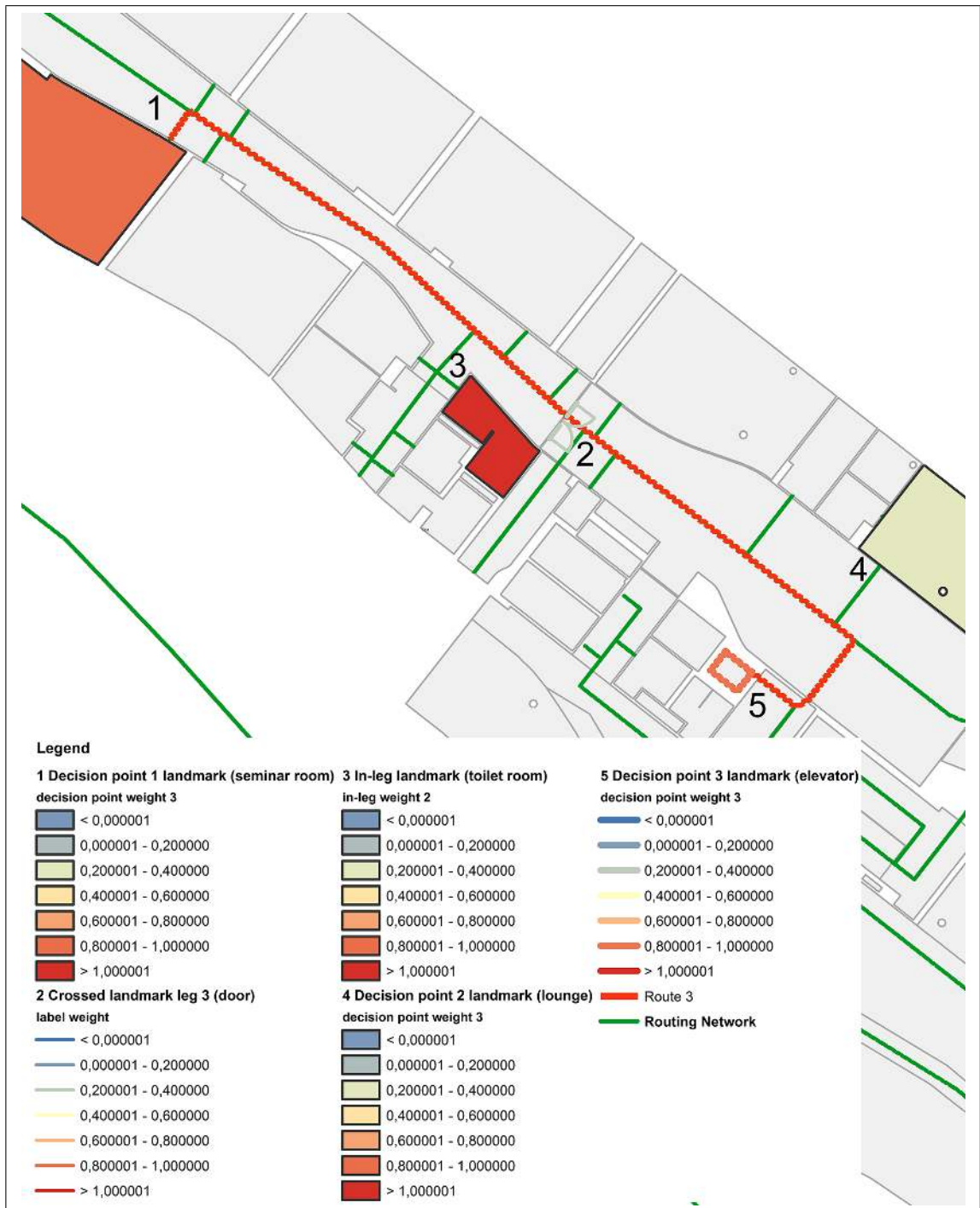


Figure 4.38.: Selected landmarks for route 2 displayed in ArcGIS according to their relevant weight



Figure 4.39.: Selected landmarks for route 2 displayed in ArcGIS according to their relevant weight

#### 4.4. Landmark integration

In this section the ILNM landmark integration algorithm is applied to the selected landmark of the previous process. For each route leg of the sample routes the steps (i) to (vii) are applied. A “–” indicates, that the relevant step does not result into a route instruction

The variables in the route instructions are applied according to the following rules:

- **Path reference:** For the path reference the type of the route segment is determined. The most important types in the database are: “way inside”, “ramp”, “elevator”, “stairs”. All route segments of the type “way inside” are referred as “path”.
- **Number:** To determine the number of occurrence for use in route instructions, the following rules are applied:
  - For *landmarks crossed by the route* the total count of occurrence on the

#### 4. Application of the ILNM to WU Campus GIS

relevant route leg is used.

- For *decision point landmarks* the number is determined according to the following logic:
  - \* Basically the number of the instance’s occurrence on the preceding route leg is used.
  - \* If the number is one, no number is used in the route instruction.
  - \* If the decision point landmark has a unique label, also no number is used in the route instruction, as the unique label clearly identifies the landmark.
  - \* If the decision point landmark is located after the decision point, the occurrence number is increased by one, as the occurrence is always calculated for the preceding route leg, but a landmark after a decision point is located on the successive route leg.

- **Spatial preposition:** If the decision point landmark is located before the decision point, the preposition *after* is used in the route instruction. For landmarks located after the decision point, the preposition *before* is applied.

For referring to the location of the destination, it is distinguished between the prepositions *left* and *right* according to the position of the destination point in relation to the route leg.

For the first route leg of route 1 the algorithm steps are specified, for the successive route legs only the results of each algorithm step are stated.

##### 4.4.1. Route 1

###### Application of the ILNM landmark integration algorithm

###### Route leg 1:

- (i) For each route leg for which crossed landmarks exist, create a route instruction of the form “Go along the ⟨Path reference⟩. You will pass through ⟨Number⟩ ⟨Selected crossed landmark(s)⟩”.

Result: –

- (ii) For each route leg that is longer than some length threshold  $lt$  and for which an in-leg landmark was selected create a routing instruction:

#### 4. Application of the ILNM to WU Campus GIS

- a) If a crossed landmark is selected, append to the previous instruction “and pass ⟨Selected in-leg landmark⟩”.
- b) Otherwise generate a new routing instruction of the form “Go along the ⟨Path reference⟩ and pass ⟨Selected in-leg landmark⟩”.

Result: –

- (iii) For each route leg, for which neither a crossed landmark nor an in-leg landmark exists, create a routing of the form “Go along the ⟨Path reference⟩”.

Result: “Go along the path.”

- (iv) For each route leg which involves a change of the floor level, create a routing instruction of the form “Use the ⟨Path reference⟩ to go to the ⟨Destination floor number⟩ floor”.

Result: –

- (v) For each decision point with a selected landmark, generate a routing instruction of the form “Turn ⟨Direction⟩ ⟨Spatial preposition⟩ the ⟨Number⟩ ⟨Selected landmark⟩”.

Result: “Turn right after the elevator.”

- (vi) For each decision point without a selected landmark generate a standard routing instruction of the form “Turn ⟨Direction⟩ after ⟨Distance⟩”.

Result: –

- (vii) In case of the last leg of the route, create a new routing instruction:

- a) If the destination is located on the right or left side of the route, create a routing instruction of the form “Your destination, ⟨Destination⟩ is located on the ⟨Spatial preposition⟩ side of the ⟨Path reference⟩”.
- b) Otherwise create a routing instruction of the form “The ⟨Path reference⟩ leads straight to your destination ⟨Destination⟩.”

Result: –

#### **Route leg 2:**

- (i) Go along the path. You will pass through one door.
- (ii) –
- (iii) –

#### 4. Application of the ILNM to WU Campus GIS

(iv) –

(v) Turn left after the second door.

(vi) –

(vii) –

##### **Route leg 3:**

(i) –

(ii) Go along the path and pass the lockers.

(iii) –

(iv) –

(v) Turn right after the toilet room: “Men’s WC, TC.3.54”.

(vi) –

(vii) –

##### **Route leg 4:**

(i) Go along the path. You will pass through the study area.

(ii) –

(iii) –

(iv) –

(v) –

(vi) –

(vii) Your destination is located on the left side of the path.

##### **Complete route instruction**

1. Go along the path.
2. Turn right after the elevator.
3. Go along the path. You will pass through one door.

#### 4. Application of the ILNM to WU Campus GIS

4. Turn left after the second door.
5. Go along the path and pass the lockers.
6. Turn right after the toilet: “Men’s WC, TC.3.54”.
7. Go along the path. You will pass through the study area.
8. Your destination is located on the left side of the path.

#### 4.4.2. Route 2

##### Application of the ILNM landmark integration algorithm

##### Route leg 1:

- (i) –
- (ii) –
- (iii) Go along the path.
- (iv) –
- (v) Turn right after the room “D4.4.234”.
- (vi) –
- (vii) –

##### Route leg 2:

- (i) Go along the path. You will pass through 2 doors
- (ii) and pass the elevator.
- (iii) Turn right after the front office “Front Office Finance, Accounting and Statistics”.
- (iv) –
- (v) –

##### Route leg 3:

- (i) Go along the path. You will pass through 2 doors
- (ii) and pass the stairs.



#### 4. Application of the ILNM to WU Campus GIS

- (iii) –
- (iv) –
- (v) –
- (vi) The path leads straight to your destination “Room D4.4.144”.

##### **Complete route instruction**

1. Go along the path.
2. Turn right after the room “D4.4.234”.
3. Go along the path. You will pass through 2 doors and pass the elevator.
4. Turn right after the front office ”Front Office Finance, Accounting and Statistics”.
5. Go along the path. You will pass through 2 doors and pass the stairs.
6. The path leads straight to your destination “Room D4.4.144”.

##### **4.4.3. Route 3**

##### **Application of the ILNM landmark integration algorithm**

##### **Route leg 1, ground floor:**

- (i) –
- (ii) –
- (iii) Go along the path.
- (iv) –
- (v) Turn right after the seminar room “D2.0.038”.
- (vi) –
- (vii) –

##### **Route leg 2, ground floor:**

- (i) Go along the path. You will pass through 1 door

#### 4. Application of the ILNM to WU Campus GIS

- (ii) and pass the toilet room “D2.0.012”.
- (iii) –
- (iv) –
- (v) Turn right after the lounge “D2.0.005”.
- (vi) –
- (vii) –

##### **Route leg 3, ground floor:**

- (i) –
- (ii) –
- (iii) Go along the path.
- (iv) –
- (v) Turn right at the elevator.
- (vi) –
- (vii) –

##### **Route leg 4, ground floor:**

- (i) –
- (ii) –
- (iii) Go along the path.
- (iv) –
- (v) Use the elevator to go to the third floor.
- (vi) –
- (vii) –

##### **Route leg 1, third floor:**

- (i) –

#### 4. Application of the ILNM to WU Campus GIS

- (ii) –
- (iii) Go along the path.
- (iv) –
- (v) Turn left at the second door.
- (vi) –
- (vii) –

#### **Route leg 2, third floor:**

- (i) –
- (ii) –
- (iii) Go along the path.
- (iv) –
- (v) –
- (vi) –
- (vii) Your destination “Room D2.3.088” is located on the right side of the path.

#### **Complete route instruction**

1. Go along the path.
2. Turn right after the seminar room “D2.0.038”.
3. Go along the path. You will pass through 1 door and pass the toilet room “D2.0.012”.
4. Turn right after the lounge “D2.0.005”.
5. Go along the path.
6. Turn right at the elevator.
7. Go along the path.
8. Use the elevator to go to the third floor.

#### *4. Application of the ILNM to WU Campus GIS*

9. Go along the path.
10. Turn left at the second door.
11. Go along the path.
12. Your destination “Room D2.3.088” is located on the right side of the path.

## 5. Evaluation

### 5.1. Analysis of the sample route instructions

The generated route instructions for the three sample routes demonstrate that the ILNM algorithm basically produces correct route instructions including landmarks, although they also show some gaps in the model.

For *route 1*, the landmark selection algorithm extracted landmarks for each decision point and one route leg exceeding the threshold length. In addition, two crossed landmarks were selected. One problem might be the fact that the crossed landmark of the second route leg is the same as the landmark at the second decision point. The instruction “You will pass through one door. Turn left after the second door.” might be confusing to users. The other elements of the instruction seem to be clear. The selected lockers represent a highly salient in-leg landmark and the instruction “Turn right after the second toilet: ‘Men’s WC, TC.3.54’” is very precise.

The instructions for *route 2* also contain landmarks for all decision points and for both route legs exceeding the threshold length. The crossed landmarks are doors for both route legs and may be confusing to some users as they are usually open and therefore not immediately recognizable when walking along the route. The first in-leg landmark is a toilet room, which is slightly harder to recognize in advance than for instance the lockers on the first route. The instruction ‘Turn right after the front office “Front office Finance, Accounting and Statistics”’ should be clear to all persons who are familiar with the appearance of front offices. As in-leg landmark of the second route leg stairs were selected, which are relatively good to identify in advance. However, as they only lead downstairs and not upstairs, they do not represent a typical instance of this landmark category.

For *route 3* landmarks for all decision points, one in-leg landmark, and one crossed landmark were selected. Two additional crossed landmarks (doors) exist in reality for this route. However, due to the representation of doors in the database, these doors would also be crossed by another route leg according to the spatial query in ArcGIS, but this is not correct in reality. According to the rule that landmarks which are

## 5. Evaluation

crossed by more than one route leg will be completely eliminated, these doors were not selected as crossed landmarks for this route. Nevertheless, users might miss this information in the route instruction.

On the third floor, the first decision point is located immediately after the elevator and the instruction “Turn left after the elevator” would be clearer than the instruction generated by the algorithm “Turn left at the second door”. However, elevators are extracted from the route path type in the database of the WU Campus GIS. Due to the routing logic in the WU Campus GIS, the route paths for floor changes are always defined for the floors of the underneath floor. As the third floor is the last floor in Building D2, route paths of the type “elevator” or “stairs” do not exist.

In addition, for this decision point, on the preceding route leg 2 doors are within the visibility zone. However, the first door is located on the other side of the route leg within a distance and may not be immediately visible to all persons. Therefore, the generated instruction “Turn left at the second door” may be not completely clear to all persons.

### 5.2. Comparison to metric-based instructions

The usefulness of the generated route instructions can be evaluated by comparing them to indoor routing instructions of related navigation services and metric-based instructions. As stated in Section 2.3.2, few real systems exist to support indoor wayfinding and as far as is known no real system exists which generates routing instructions including landmarks automatically.

Two systems which are similar to the WU Campus GIS are the indoor orientation tools of the Alpen-Adria University of Klagenfurt (AAU) and of the Ecole Polytechnique Fédérale de Lausanne (EPFL). They offer indoor maps, displaying POIs, routing between two points and searching for locations within the buildings. Both systems generate metric-based route instructions. While the system of the EPFL generates instructions that only indicate the places of changes of the floor level, the system of the AAU generates full metric-based route instructions, which indicate each change of direction (see Table 5.1 for examples).

As stated in Section 2.2, automatically generated route directions which consist merely of street names, numerical references to distances or turning angles (as they are used for navigation of vehicles) are not suitable for human orientation and wayfinding (Duckham et al. 2010). In order to illustrate the difference between metric-based route

## 5. Evaluation

AAU	EPFL
Sie befinden sich bei Z.0.30 auf Ebene 0.	<b>A</b> Departure from level 2
1m, danach nach links.	1 Down the ramp to level 1 165 m
7m, danach nach rechts.	2 Down the ramp to level 0 196 m
Nach 10m:	3 Up the stairs to level 1 249 m
Stiege nach oben.Sie befinden Sich nun auf Ebene 1.	4 Up the stairs to level 2 267 m
1m, danach nach links.	5 Down the stairs to level 1 726 m
49m, danach nach rechts.	<b>B</b> Arrival to level 1 884 m
Sie haben HS 4 erreicht.	

Table 5.1.: Route instructions generated by the campus GIS of AAU (*Alpen Adria Universität Klagenfurt - Campus-GIS 2015*) and EPFL (*EPFL - Orientation Tool 2015*)

descriptions and instructions including landmarks, the instructions for the sample route 1 of Section 4.4.1 will be converted into instructions containing only distances. Table 5.2 contains a comparison to the landmark-based route description.

## 5. Evaluation

<b>Landmark-based instructions</b>	<b>Metric-based instructions</b>
Go along the path.	Go along the path.
Turn right after the elevator.	Turn right after 2.7 meters.
Go along the path. You will pass through one door.	Go along the path.
Turn left after the second door.	Turn left after 7.4 meters.
Go along the path and pass the lockers.	Go along the path.
Turn right after the toilet: ‘‘Men’s WC, TC.3.54’’.	Turn right after 45.7 meters.
Go along the path. You will pass through the Study area.	Go along the path.
Your destination is located on the left side of the path.	Your destination is located on the left side of the path.

Table 5.2.: Landmark-based route instructions compared to metric-based instruction for route 1

The comparison shows that beside the metric-based indication of the point for a change of direction, no confirmation clues for route legs are provided by non-landmark based instructions. In particular, for decision points with preceding long route legs where multiple changes in direction are possible the metric-based instructions could lead to wrong navigation decisions.

Decision point 3 of the first sample route provides an example of this case. With 45.7 meters the preceding route leg is relatively long and there are several possibilities for direction changes immediately before decision point 3 (see Figure 5.1). Therefore, the route instruction ‘‘Turn right after 45.7 meters.’’ could lead to wrong navigation actions, whereas the instruction ‘‘Turn right after the second toilet: ’’Men’s WC, TC.3.54’’ unambiguously identifies the correct decision point.



## 5. Evaluation



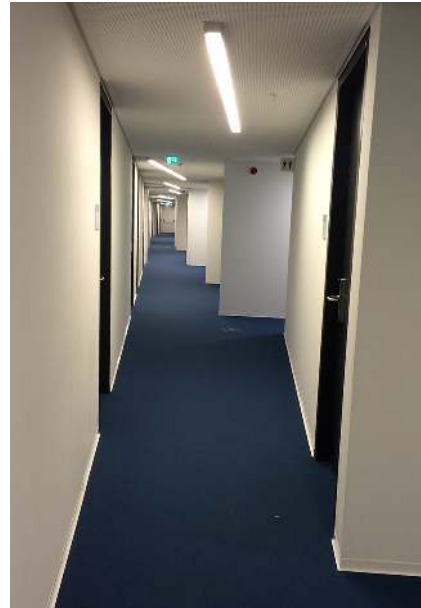
Figure 5.1.: Open space and ambiguous possibilities for direction changes on Campus WU

Table 5.3 shows two further examples of potentially difficult to identify decision points if only metric distances are used to specify them. The examples are characterized by multiple turning possibilities within a short distance and possibly long preceding route legs.

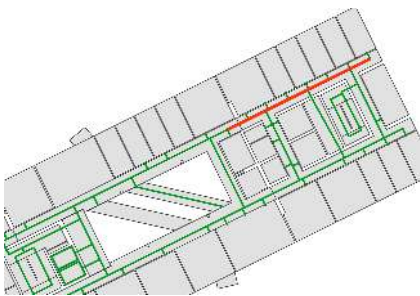
## 5. Evaluation



Building D4, floor 4, floor plan (ArcGIS)



View into the red marked part of the corridor



Building T1, floor 3, floor plan (ArcGIS)



View into the red marked part of the corridor

Table 5.3.: Locations with possible ambiguous decision points on Campus WU

Landmark-based instructions not only help to reduce navigation errors, but also have additional positive effects on the navigation experience. As for instance Rehr (2011) verified through empirical studies, landmark-based instructions can increase the feeling of security being on the right way. In addition, landmark-based instructions were generally rated considerably higher than metric-based instructions in terms of clarity, comprehensibility, effectiveness, assistance and attractiveness. Although these studies were conducted with outdoor routes, their results may be conveyed to indoor navigation.

### 5.3. Drawbacks and possible problems

As stated, landmark-based instructions can considerably increase the quality of indoor route instructions. However, the route evaluations show that there might be a lack of clarity in the produced route instructions in some cases. In particular, the following possible problems or drawbacks have been identified in the course of the ILNM application process:

- **Difficult determination of visibility of landmarks.** Determining which landmark types can actually be seen from a route is difficult in indoor environments. In contrast to outdoor navigation, there are often no clear paths available for a route within buildings. In addition, not all landmark objects are aligned to the route path, like buildings along a street in outdoor environments. Furthermore, calculating the actual visibility of landmarks is not possible due to the lack of geometric information about the individual objects.

Therefore, a heuristic visibility buffer was defined and combined with additional rules, like checking if the landmark POI is located in the same room as the route path or in an adjacent room without door. However, this might not always lead to completely correct selections. In some cases, this process may select landmarks that are not or hardly visible from the route or exclude landmarks, that would be visible on the route.

For instance, two small rooms may be arranged behind each other but fall both into the buffer zone, although only the first room is actually visible. Or stairs may be located in another room and are therefore excluded, but they would be actually visible as they are behind an (always) open glass door (see Figure 5.2 as an example).

## 5. Evaluation

In addition, the visibility buffer was calculated on the base of hand-drawn network lines in the WU Campus GIS which are assumed to be the path the user takes (usually the middle of a corridor). But in some areas the actual user path may differ considerably from this assumed path, in particular, in cases of traversing open spaces.



Figure 5.2.: Stairs in a distinct room on route 1

In addition, also the angle of view should be considered in the selection of landmarks. For instance, at the second decision point of route 2, a room with a door represents a landmark candidate, although the door might actually not to be seen due to its alignment away from the decision point (see Figure 5.3).

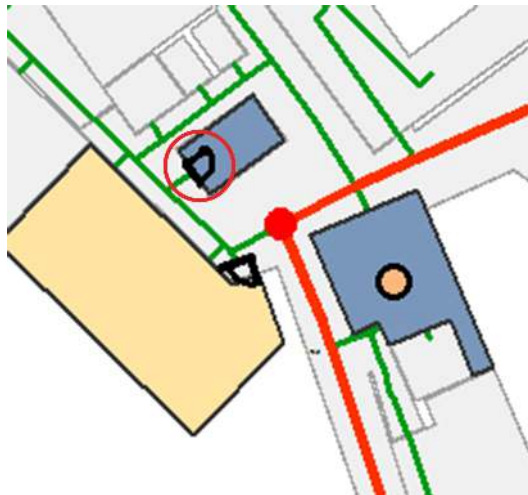


Figure 5.3.: Non-visible door at a decision point of route 2

## 5. Evaluation

- **Complexity of numerical chunking.** Numerical chunking requires that features are easily recognizable in a clear order on the route. However, in particular, in complex buildings, landmarks are not always aligned in parallel to the route or may be difficult to recognize from the route. In these cases, counting them may be ambiguous.
- **Different perception of open and closed doors.** If the route leads through a door, this is stated in the route instruction. However, it makes a difference in the perception of the door if it is closed or open. Open doors may not be that easy to recognize as closed doors. Route 2 leads through open doors on two route legs which are always open and therefore, the instruction “You will pass through two doors” may be confusing to the user. In Figure 5.4, two open doors of the first route leg are shown. In particular, the first door in the front may be difficult to recognize.



Figure 5.4.: Open doors as crossed landmarks on route 2

- **Difficult determination of exact landmark position.** Some landmark types require the calculation of the exact position of their visible part. For instance, for rooms it is necessary to determine the position of the appropriate door to determine the exact position of the room’s visible part. The automatic determination of this information is complicated in some cases. In WU Campus GIS, some doors are drawn with a distance to the room polygon and some not. In addition, some rooms may not have a door, but the door of an adjacent room might touch the boundary of the room polygon, which would lead to false spatial analysis.

## 5. Evaluation

- **Insufficient data accuracy.** In some cases, the accuracy of the spatial data is not sufficient to create exact route instructions. In particular, POIs are always stored as point objects, but in some cases vary considerably in their extension from these points. For instance, lockers are sometimes distributed over an area, which makes it difficult to exactly determine, if the turn instruction has to be performed before or after them.

The ramp in route 1 (visible in Figure 5.4 in the background) represents another example of missing information. It is not saved as a separate network line type in the WU Campus GIS database, as no floor change is connected with the ramp and therefore, it is not relevant for route generation. However, in a route instruction the inclusion of the ramp might be expected. In addition to the spatial data, also the information about characteristics of individual features (e.g. label, category) may not always be correct.

## 6. Summary and Outlook

The objective of this thesis was the development of an “indoor landmark navigation model” (ILNM), based on the “landmark navigation model” (LNM) introduced by Duckham et al. (2010). The ILNM provides rules and algorithms for the automatic creation of indoor route instructions including landmarks from an existing spatial database. As indoor databases usually do not contain information about the visual characteristics of the individual features, the model is based on category-level information about feature types. The ILNM consists of three consecutive phases: *landmark identification*, *landmark selection*, and *landmark integration*.

Indoor navigation disposes about special challenges in comparison to outdoor navigation. Among them are more frequent changes in direction, a smaller choice of landmarks, more open spaces without clear paths to choose from and the lack of street names for references in route instructions.

Therefore, the LNM had to be modified in all phases to the specific requirements of indoor route instructions and adapted to the data structure of indoor environments:

The *landmark identification* process consists of two steps: *feature type selection* and *landmark weighting*.

For the *feature type selection* step, the rules were defined, how to preselect features from spatial indoor databases, which can be rated for their landmark suitability in the next step.

Then, the factors of the *landmark weighting* process were adjusted. For instance, while in the LNM only POIs are used as landmarks, in the ILNM both POIs and other feature types like rooms, elevators or stairs, can serve as landmarks. In addition, the factor “nighttime vs. daytime salience” was removed, as it is not applicable to indoor environments. Instead, a new factor “availability of a unique label” was introduced, as landmarks with a unique label (i.e. a room number) are more useful in route instructions. Other modifications include the consideration of the visible part of a feature, for instance the door of a particular room type, and the removal of a distinction between point-like and area-like landmarks.

## 6. Summary and Outlook

For the *landmark selection* process, the selection algorithm was adjusted to the characteristics of indoor environments. For example, a distinction if the landmark is passed before or after the decision point was introduced, as well as the new landmark category “crossed landmark”, as in indoor environments routes often lead directly through landmarks like doors or particular room types. Further new elements in the route selection algorithm include the check of the landmark location on route legs and the consideration of spatial chunking.

The algorithm for *landmark integration* was adapted to the needs of pedestrians and indoor scenarios. For example, instead of the street name the actual path type has to be used, and an instruction in case of a change of the floor level was added. In addition, the location at the decision point has to be mentioned in the turning instruction, and in contrast to the LNM in-leg landmarks are not suitable to replace decision point landmarks within buildings due to the lack of clear street names.

The application of the ILNM to the data of WU Campus GIS in the course of a field study showed that basically valid route instructions can be generated with the ILNM, although some gaps in the model could be revealed. In the course of the preselection process 21 feature types have been identified, which were assessed through an expert rating in the next step. The normalized weights of this landmark identification process formed the basis for the landmark selection step. It was performed for three sample routes at Campus WU. The results show that for all decision points and relevant route legs appropriate landmarks could be selected.

These landmarks were integrated into route instructions through the landmark integration algorithm in the last step of the application process. Finally, valid route instructions for all routes could be generated.

A comparison of the generated route instructions to metric-based indoor route descriptions showed that landmark-based route instructions generally increase the quality of route instructions and are particularly important in cases where multiple turning possibilities are located within a short distance.

However, the generated route instructions also show some drawbacks and problems. They are mainly concerned with the *main challenges of automatic indoor routing generation* that were revealed in the course of the ILNM application process:

1. **Dependency on high data accuracy.** In contrast to outdoor environments, for navigation within buildings a deviation of only a few meters can lead to completely wrong navigation instructions. Therefore, high data accuracy is required,



## 6. Summary and Outlook

both for the routing network and the landmark size and position. In addition to the geometric accuracy, also the descriptive characteristics of the individual landmark instances (category, label) need to be correctly defined for all features, as this information is used for selecting landmarks and referring to them in the route instructions.

2. **Determination of the actual visibility of landmarks.** Calculating which features are actually visible from an indoor route is difficult without exact geometric information about the individual features. While for outdoor environments all features that are located along a street can be selected, indoor environments usually do not dispose about a clear structure of routing paths and adjacent features. In fact, an exact 3D-model of the building would be necessary to accurately calculate the visibility of potential landmarks along a route.
3. **Complexity of indoor environments.** In comparison to outdoor environments, routing instructions within buildings have to consider more complex navigation situations. For instance, features are often not aligned in parallel to the route, which makes numerical chunking more difficult. In addition, routes may lead through open spaces, include changes of floor levels, and there are no street names to refer to.

To overcome some of these problems, the following enhancements and algorithm refinements are suggested for future work:

- **Improvement of selection parameters through empirical studies.** The landmark selection process depends mostly on heuristics. Empirical user studies could improve parameters like the route leg threshold length for in-leg landmarks and the relative weighting changes. In particular, different increasing and decreasing values for adjusting the suitability weight might improve the overall selection process.
- **Application to a larger number of sample routes.** To validate the findings of the three routes, the application of the ILNM could be applied to a larger set of sample routes on Campus WU to reveal possible additional enhancements of the model.
- **Definition of different, appropriate buffer zones.** Instead of using one value for the generation of all buffer zones different values could be used to increase the accuracy in the landmark selection process. For example, beside a

## 6. Summary and Outlook

default buffer size a specific value could be stored as an attribute of the route leg for areas with special conditions.

- **Multiple in-leg landmarks on longer route legs.** In the LNM and the ILNM for route legs exceeding some travel or length threshold, an in-leg landmark is selected. The restriction of selecting only one landmark may be unsuitable in some cases. For instance, on very long route legs or on route legs with multiple in-leg landmarks with a very high suitability weighting, it might be appropriate to integrate more than one landmark into the route instruction.
- **Verification of previous selections of landmarks.** As sample route 1 demonstrates, the same landmark can be selected for different functions. However, this might be confusing in some situations. Therefore, a verification if a specific landmark has already been selected in a previous step of the selection process and if yes, adjusting its landmark weight in some way, or merging two instruction elements to refer to the same landmark, could improve the results.
- **Verification of the order of selected landmarks.** It is possible that different information is available for one route leg, for instance if a crossed landmark and an in-leg landmark are selected for the same leg or the route leg also contains a change of the floor level. In the current route generation algorithm of the ILNM, a predefined order is given to include this information into the instructions. However, it might be more advantageous if the real order of these occurrences is checked for each route leg and the route instructions are generated in this order.
- **Determination of a suitability threshold.** In the ILNM selection algorithm always the landmark with the highest suitability weighting is chosen. However, it might be useful to define some minimum suitability threshold, which prevents selecting landmarks with a weighting value below this threshold weight.
- **More complex route instructions.** Route instruction generation in the ILNM is kept relatively simple. However, for real indoor route instructions more situations have to be considered. For instance, instructions could be dependent on the length of the route leg and the instruction “Go along the path.” could only be used for legs exceeding a defined length. In addition, if a change of the building is required, the algorithm also has to integrate outdoor landmarks.

# Bibliography

- Agrawala, Maneesh (2002). “Visualizing Route Maps”. PhD thesis. Stanford, CA, USA: Stanford University.
- Alpen Adria Universität Klagenfurt - Campus-GIS (2015). URL: <https://campus-gis.aau.at/> (visited on 11/29/2015).
- Caduff, David and Sabine Timpf (2005). “The Landmark Spider: Representing Landmark Knowledge for Wayfinding Tasks.” In: *AAAI Spring Symposium: Reasoning with Mental and External Diagrams: Computational Modeling and Spatial Assistance*, pp. 30–35.
- Carlson, Laura A, Christoph Hölscher, Thomas F Shipley, and Ruth Conroy Dalton (2010). “Getting lost in buildings”. In: *Current Directions in Psychological Science* 19.5, pp. 284–289.
- Cuayáhuitl, Heriberto, Nina Dethlefs, Kai-Florian Richter, Thora Tenbrink, and John Bateman (2010). “A dialogue system for indoor wayfinding using text-based natural language”. In: *International Journal of Computational Linguistics and Applications, ISSN 0976 962*, pp. 285–304.
- Dale, Robert, Sabine Geldof, and Oean-Philippe Prost (2005). “Using natural language generation in automatic route description.” In: *Journal of Research & Practice in Information Technology* 37.1.
- Daniel, Marie-Paule and Michel Denis (1998). “Spatial descriptions as navigational aids: A cognitive analysis of route directions”. In: *Kognitionswissenschaft* 7.1, pp. 45–52.
- Denis, Michel (1997). “The description of routes: a cognitive approach to the production of spatial discourse”. In: *Cahiers de Psychologie Cognitive* 16, pp. 409–458.
- Denis, Michel, Francesca Pazzaglia, Cesare Cornoldi, and Laura Bertolo (1999). “Spatial discourse and navigation: An analysis of route directions in the city of Venice”. In: *Applied cognitive psychology* 13.2, pp. 145–174.
- Downs, R.M. and D. Stea (1982). *Kognitive Karten: die Welt in unseren Köpfen*. UTB für Wissenschaft: Uni-Taschenbücher. Harper & Row.

## Bibliography

- Duckham, Matt, Stephan Winter, and Michelle Robinson (2010). “Including landmarks in routing instructions”. In: *Journal of Location Based Services* 4.1, pp. 28–52.
- Elias, Birgit (2003). “Extracting landmarks with data mining methods”. In: *Spatial Information Theory. Foundations of Geographic Information Science*. Springer, pp. 375–389.
- (2006). “Extraktion von Landmarken für die Navigation”. PhD thesis. Hannover: Hannover.
- Elias, Birgit and Monika Sester (2006). “Incorporating landmarks with quality measures in routing procedures”. In: *Geographic Information Science*. Springer, pp. 65–80.
- EPFL - Orientation Tool* (2015). URL: <http://plan.epfl.ch/> (visited on 11/29/2015).
- Gartner, Georg (2007). “Semantic Wayfinding with Ubiquitous Cartography”. In: *Proc. of the XXIII International Cartographic Conference*, pp. 4–10.
- Golledge, Reginald G. (1999). “Human wayfinding and cognitive maps”. In: *Wayfinding behavior: Cognitive mapping and other spatial processes*, pp. 5–45.
- Heiniz, Paul, Karl-Heinz Krempels, Christoph Terwelp, and Stefan Wuller (2012). “Landmark-based navigation in complex buildings”. In: *Indoor Positioning and Indoor Navigation (IPIN), 2012 International Conference on*, pp. 1–9.
- Hölscher, Christoph, Tobias Meilinger, Georg Vrachliotis, Martin Brösamle, and Markus Knauff (2006). “Up the down staircase: Wayfinding strategies in multi-level buildings”. In: *Journal of Environmental Psychology* 26.4, pp. 284–299.
- Huang, Haosheng and Georg Gartner (2010). “A Survey of Mobile Indoor Navigation Systems”. In: *Cartography in Central and Eastern Europe*. Ed. by Georg Gartner and Felix Ortog. Lecture Notes in Geoinformation and Cartography. Springer Berlin Heidelberg, pp. 305–319.
- Jonchon Wun, Denise (2013). *Spezifikation von Indoor Landmarks*. Diplomarbeit an der Technischen Universität Wien.
- Kargl, Frank, Sascha Geßler, and Florian Flerlage (2007). “The iNAV indoor navigation system”. In: *Ubiquitous Computing Systems*. Springer, pp. 110–117.
- Klippel, Alexander (2003). “Wayfinding choremes”. In: *Spatial Information Theory. Foundations of Geographic Information Science*. Springer, pp. 301–315.
- Klippel, Alexander, Heike Tappe, Lars Kulik, and Paul U. Lee (2005). “Wayfinding choremes - a language for modeling conceptual route knowledge”. In: *Journal of Visual Languages & Computing* 16.4, pp. 311–329.

## Bibliography

- Klippel, Alexander and Stephan Winter (2005). “Structural salience of landmarks for route directions”. In: *Spatial information theory*. Springer, pp. 347–362.
- Krisp, Jukka M, Mathias Jahnke, Hao Lyu, and Florian Fackler (2015). “Visualization and Communication of Indoor Routing Information”. In: *Progress in Location-Based Services 2014*. Springer, pp. 33–44.
- Lovelace, Kristin L., Mary Hegarty, and Daniel R. Montello (1999). “Elements of good route directions in familiar and unfamiliar environments”. In: *Spatial information theory. Cognitive and computational foundations of geographic information science*. Springer, pp. 65–82.
- Lynch, Kevin (1960). *The image of the city*. Vol. 11. MIT press.
- Lyu, Hao, Zhonghai Yu, and Liqiu Meng (2015). “A Computational Method for Indoor Landmark Extraction”. In: *Progress in Location-Based Services 2014*. Springer, pp. 45–59.
- Maass, Wolfgang (1996). “Von visuellen Daten zu inkrementellen Wegbeschreibungen in dreidimensionalen Umgebungen: Das Modell eines kognitiven Agenten”. PhD thesis. Saarbrücken: Technische Fakultät der Universität des Saarlandes.
- Mast, Vivien, Cui Jian, and Desislava Zhekova (2012). “Elaborate Descriptive Information in Indoor Route Instructions”. In: *Proceedings of the 34th Annual Conference of the Cognitive Science Society*. Cognitive Science Society. Austin, pp. 1972–1977.
- Mast, Vivien and Diedrich Wolter (2013). “A probabilistic framework for object descriptions in indoor route instructions”. In: *Spatial Information Theory*. Springer, pp. 185–204.
- Millonig, Alexandra and Katja Schechtner (2007). “Developing Landmark-Based Pedestrian-Navigation Systems”. In: *IEEE Transactions on Intelligent Transportation Systems* 8.1, pp. 43–49.
- Montello, Daniel R (1998). “A new framework for understanding the acquisition of spatial knowledge in large-scale environments”. In: *Spatial and temporal reasoning in geographic information systems*, pp. 143–154.
- Montello, Daniel R. (2005). “Navigation”. In: *The Cambridge Handbook of visuospatial thinking*. Ed. by P. Sha and A. Miyake. New York: Cambridge University Press, pp. 257–294.
- Peters, Denise, Yunhui Wu, and Stephan Winter (2010). “Testing landmark identification theories in virtual environments”. In: *Spatial cognition VII*. Springer, pp. 54–69.

## Bibliography

- Radoczky, Verena (2003). *Kartographische Unterstützungsmöglichkeiten zur Routenbeschreibung von Fußgängernavigationssystemen im In- und Outdoorbereich*. Diplomarbeit an der Technischen Universität Wien.
- (2007). “How to design a pedestrian navigation system for indoor and outdoor environments”. In: *Location Based Services and TeleCartography*. Berlin: Springer.
- Raubal, Martin and Max J Egenhofer (1998). “Comparing the complexity of wayfinding tasks in built environments”. In: *Environment and planning B* 25, pp. 895–914.
- Raubal, Martin and Stephan Winter (2002). “Enriching Wayfinding Instructions with Local Landmarks”. In: *Geographic Information Science*. Ed. by Max J. Egenhofer and David M. Mark. Vol. 2478. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 243–259.
- Rehrl, Karl (2011). “Kognitiv-ergonomische Sprachanweisungen als elektronische Navigationsunterstützung für Fußgängerinnen und Fußgänger”. PhD thesis. Wien: Technische Universität Wien.
- Rehrl, Karl, Nicolas Göll, Sven Leitinger, and Stefan Bruntsch (2005). “Combined indoor/outdoor Smartphone navigation for public transport travellers”. In: *Proceedings of the 3rd Symposium on LBS & TeleCartography*. Vol. 2005. Citeseer, pp. 235–239.
- Rehrl, Karl, Sven Leitinger, Georg Gartner, and Felix Ortag (2009). “An Analysis of Direction and Motion Concepts in Verbal Descriptions of Route Choices”. In: *Spatial Information Theory*. Ed. by Kathleen Stewart Hornsby, Christophe Claramunt, Michel Denis, and Gérard Ligozat. Vol. 5756. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 471–488.
- Richter, Kai-Florian (2007). “A uniform handling of different landmark types in route directions”. In: *Spatial information theory*. Springer, pp. 373–389.
- (2013). “Prospects and Challenges of Landmarks in Navigation Services”. In: *Cognitive and Linguistic Aspects of Geographic Space*. Ed. by Martin Raubal, David M. Mark, and Andrew U. Frank. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 83–97.
- Ross, Tracy, Andrew May, and Simon Thompson (2004). “The Use of Landmarks in Pedestrian Navigation Instructions and the Effects of Context”. In: *Mobile Human-Computer Interaction - MobileHCI 2004*. Ed. by Stephen Brewster and Mark Dunlop. Vol. 3160. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 300–304.

## Bibliography

- Rüetschi, Urs-Jakob (2007). “Wayfinding in scene space modelling transfers in public transport”. PhD thesis. Universität Zürich.
- Siegel, Alexander W. and Sheldon H. White (1975). “The development of spatial representations of large-scale environments.” In: *Advances in child development and behavior* 10, pp. 9–55.
- Sorrows, Molly E. and Stephen C. Hirtle (1999). “The nature of landmarks for real and electronic spaces”. In: *Spatial information theory. Cognitive and computational foundations of geographic information science*. Springer, pp. 37–50.
- Steck, Sibylle D and Hanspeter A Mallot (2000). “The role of global and local landmarks in virtual environment navigation”. In: *Presence: Teleoperators and Virtual Environments* 9.1, pp. 69–83.
- Tom, Ariane and Michel Denis (2003). “Referring to landmark or street information in route directions: What difference does it make?” In: *Spatial information theory. Foundations of geographic information science*. Springer, pp. 362–374.
- Tomko, Martin and Stephan Winter (2006). “Recursive construction of granular route directions”. In: *Journal of Spatial Science* 51.1, pp. 101–115.
- Tversky, Barbara (1993). “Cognitive maps, cognitive collages, and spatial mental models”. In: *Spatial Information Theory A Theoretical Basis for GIS*. Springer, pp. 14–24.
- Weisman, Jerry (1981). “Evaluating Architectural Legibility Way-Finding in the Built Environment”. In: *Environment and behavior* 13.2, pp. 189–204.
- Williams, Sandra (1998). “Generating pitch accents in a concept-to-speech system using a knowledge base”. In: *ICSLP*.
- Williams, Sandra and Catherine I Watson (1999). “A profile of the discourse and intonational structures of route descriptions”. In: *EUROSPEECH*.
- Winter, Stephan (2003). “Route Adaptive Selection of Salient Features”. In: *Spatial Information Theory. Foundations of Geographic Information Science*. Ed. by Walter Kuhn, Michael F. Worboys, and Sabine Timpf. Vol. 2825. Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 349–361.
- Winter, Stephan, Martin Tomko, Birgit Elias, and Monika Sester (2008). “Landmark hierarchies in context”. In: *Environment and Planning B* 35.3, p. 381.
- WU Campus GIS (2015). URL: <http://campus.wu.ac.at/> (visited on 07/22/2015).

# A. Expert Rating

## A.1. Results

- **Suitability:** ideal - highly suitable - suitable - somewhat suitable - never suitable
- **Typicality:** all - most - many - some - few

	Basic indoor objects			
	Bridge		Door	
	Suitability	Typicality	Suitability	Typicality
Physical size	highly	all	highly	all
Prominence	highly	most	somewhat	most
Difference from surroundings	suitable	all	somewhat	most
Availability of a unique label	never	all	never	all
Ubiquity and familiarity	suitable	all	ideal	all
Length of description	ideal	all	ideal	all
Spatial extents	suitable	all	ideal	most
Permanence	ideal	all	highly	most
	Elevator		Stairs	
	Suitability	Typicality	Suitability	Typicality
Physical size	ideal	all	ideal	all
Prominence	highly	most	ideal	all
Difference from surroundings	highly	most	ideal	all
Availability of a unique label	never	all	never	all
Ubiquity and familiarity	ideal	all	ideal	all
Length of description	ideal	all	ideal	all
Spatial extents	highly	most	highly	most
Permanence	ideal	all	ideal	all



A. Expert Rating

	<b>Room categories</b>			
	<b>Auditorium</b>		<b>Lounge</b>	
	Suitability	Typicality	Suitability	Typicality
Physical size	highly	most	ideal	all
Prominence	highly	most	ideal	most
Difference from surroundings	suitable	all	ideal	most
Availability of a unique label	ideal	all	ideal	some
Ubiquity and familiarity	ideal	all	somewhat	all
Length of description	suitable	most	highly	most
Spatial extents	ideal	most	suitable	most
Permanence	ideal	most	ideal	most
	<b>Meeting room</b>		<b>PC room</b>	
	Suitability	Typicality	Suitability	Typicality
	Physical size	highly	many	suitable
Prominence	highly	many	suitable	all
Difference from surroundings	highly	many	suitable	all
Availability of a unique label	ideal	all	ideal	all
Ubiquity and familiarity	highly	all	somewhat	all
Length of description	suitable	all	suitable	all
Spatial extents	ideal	all	ideal	all
Permanence	ideal	most	ideal	most
	<b>Project room</b>		<b>Seminar room</b>	
	Suitability	Typicality	Suitability	Typicality
	Physical size	highly	many	suitable
Prominence	suitable	all	suitable	all
Difference from surroundings	suitable	all	suitable	all
Availability of a unique label	ideal	all	ideal	all
Ubiquity and familiarity	somewhat	all	highly	all
Length of description	suitable	all	suitable	all
Spatial extents	ideal	all	ideal	all
Permanence	ideal	most	ideal	most

A. Expert Rating

	<b>Study area</b>		<b>Toilet</b>	
	Suitability	Typicality	Suitability	Typicality
Physical size	ideal	most	suitable	all
Prominence	ideal	most	ideal	all
Difference from surroundings	ideal	most	highly	all
Availability of a unique label	ideal	few	suitable	all
Ubiquity and familiarity	somewhat	all	ideal	all
Length of description	highly	most	highly	all
Spatial extents	suitable	most	ideal	all
Permanence	ideal	most	ideal	all
	<b>Uncategorized</b>			
	Suitability	Typicality		
Physical size	suitable	most		
Prominence	suitable	most		
Difference from surroundings	suitable	most		
Availability of a unique label	ideal	many		
Ubiquity and familiarity	ideal	most		
Length of description	highly	most		
Spatial extents most	highly	most		
Permanence	ideal	many		

A. Expert Rating

	<b>POIs</b>			
	<b>Computer terminal</b>		<b>Entrance/Exit</b>	
	Suitability	Typicality	Suitability	Typicality
Physical size	highly	all	ideal	most
Prominence	highly	most	ideal	all
Difference from surroundings	highly	all	ideal	all
Availability of a unique label	never	all	ideal	many
Ubiquity and familiarity	highly	all	ideal	all
Length of description	highly	all	highly	all
Spatial extents	ideal	all	highly	most
Permanence	ideal	all	ideal	all
	<b>Front office</b>		<b>Library search terminal</b>	
	Suitability	Typicality	Suitability	Typicality
	Physical size	ideal	most	somewhat
Prominence	ideal	most	suitable	many
Difference from surroundings	ideal	most	somewhat	all
Availability of a unique label	suitable	most	never	all
Ubiquity and familiarity	highly	all	somewhat	all
Length of description	suitable	all	highly	all
Spatial extents	suitable	most	ideal	all
Permanence	highly	most	ideal	most
	<b>Library self-checkout</b>		<b>Locker</b>	
	Suitability	Typicality	Suitability	Typicality
	Physical size	suitable	all	ideal
Prominence	suitable	many	ideal	all
Difference from surroundings	highly	most	ideal	all
Availability of a unique label	never	all	never	all
Ubiquity and familiarity	somewhat	all	ideal	all
Length of description	highly	all	ideal	all
Spatial extents	ideal	all	suitable	most
Permanence	ideal	most	highly	most

A. Expert Rating

	<b>Scanner</b>		<b>Vending machine</b>	
	Suitability	Typicality	Suitability	Typicality
Physical size	never	all	ideal	all
Prominence	suitable	most	ideal	many
Difference from surroundings	somewhat	all	ideal	many
Availability of a unique label	never	all	never	all
Ubiquity and familiarity	highly	all	ideal	all
Length of description	ideal	all	ideal	all
Spatial extents	ideal	all	ideal	all
Permanence	suitable	all	ideal	most

Table A.1.: Rating feature categories of the WU Campus GIS