THE RELATIONSHIP BETWEEN WAYFINDING PERFORMANCE, SPATIAL LAYOUT AND LANDMARKS IN VIRTUAL ENVIRONMENTS

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THE RELATIONSHIP BETWEEN WAYFINDING PERFORMANCE, SPATIAL LAYOUT AND LANDMARKS IN VIRTUAL ENVIRONMENTS

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Declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that this work fully acknowledges opinions, ideas and contributions from the work of others.

Any ethical clearance for the research presented in this thesis has been approved. Approval has been sought and granted by the University Ethics Committee on March 14 2019.

I declare that the Word Count of this thesis is 57,691 words.

Name: Demet Yesiltepe

Signature: 

Date: 29/01/2021

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"There's an art of attending to weather, to the route you take, to the landmarks along the way, to how if you turn around you can see how different the journey back looks from the journey out, to reading the sun and moon and stars to orient yourself, to the direction of running water, to the thousand things that make the wild a text that can be read by the literate. The lost are often illiterate in this language that is the language of the earth itself, or don't stop to read it. And there's another art of being at home in the unknown, so that being in its midst isn't cause for panic or suffering, of being at home with being lost" (Solnit, 2006 Page 10).

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ABSTRACT

Environmental factors, including landmarks that affect people's wayfinding performance in unfamiliar environments have been discussed in a great number of studies. However, there is still no consensus on the factors that shape people's performance or what makes a landmark preferable during wayfinding. Hence, this study aims to understand the impact of different spatial layouts, environmental conditions and landmarks on people's wayfinding performance, and the factors that make landmarks salient.

Sea Hero Quest (SHQ), an online game that has been played by more than 4.3 million people from 2016 to date, is selected as a case study to investigate the impact of different environments and other factors, in particular landmarks. Forty-five wayfinding levels of SHQ are analysed and compared using Geographic Information System (GIS) and Space syntax axial, segment and visibility graph analyses. A cluster analysis is conducted to examine the relationship between levels. Varying conditions associated with landmarks, weather and maps were taken into consideration. In order to investigate the process of selecting landmarks, visual, structural (whether landmarks are global or local) and cognitive saliency are analysed using web-based surveys, saliency algorithms and the visibility of landmarks.

Results of this study show that the complexity of layouts plays a major role in wayfinding; as the complexity of layout increases, so does the time taken to complete the wayfinding task. Similarly, the weather condition has an effect; as the weather becomes foggy and visibility decreases, the time taken to complete the wayfinding task increases. It is discovered that landmarks that are visible for more than 25% of a journey can be defined as global landmarks whereas the rest can be defined as local landmarks. Findings also show that landmarks that are visually salient (objects with a unique colour and size) and structurally salient (objects that are closer to people) are registered more by people in unfamiliar environments.

This study contributes to the existing literature by exploring the factors that affect people's wayfinding performance by using the largest dataset in the field (so providing more accurate results), focusing on 45 different layouts (while current research studies mostly focus on one or two different layouts), by proposing a threshold to distinguish global and local landmarks, and analysing visual, structural and cognitive saliency through various measures.

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PUBLICATIONS

Some of the material in this thesis has been, or is in the process of being, presented or published in the form of the following papers:

1. Yesiltepe, D., Torun, A. O., Coutrot, A., Hornberger, M., Spiers, H. J. & Conroy Dalton, R. Analysing and understanding a game environment designed for spatial navigation: A study on Sea Hero Quest (SHQ). Under review by *PLOS One*.
2. Yesiltepe, D., Conroy Dalton, R., & Torun, A. O. Landmarks in wayfinding: a review of the existing literature. *Cognitive Processing*. https://doi.org/10.1007/s10339-021-01012-x
3. Yesiltepe, D., Torun, A. O., Coutrot, A., Hornberger, M., Spiers, H. J. & Conroy Dalton, R. (2020). Computer models of saliency alone fail to predict subjective visual attention to landmarks during observed navigation. *Journal of Spatial Cognition and Computation* (pp. 39-66). https://doi.org/10.1080/13875868.2020.1830993
4. Yesiltepe, D., Conroy Dalton, R., Ozbil Torun, A. O., Hornberger, M. & Spiers, H. J. (2020). Understanding cognitive saliency by using an online game. In *German Conference on Spatial Cognition* (pp. 76-87). Springer, Cham. https://doi.org/10.1007/978-3-030-57983-8_6
5. Yesiltepe, D., Conroy Dalton, R., Ozbil Torun, A., Noble, S., Dalton, N., Hornberger, M., & Spiers, H. (2020). Redefining global and local landmarks: when does a landmark stop being local and become a global one? In *German Conference on Spatial Cognition* (pp. 111-121). Springer, Cham. https://doi.org/10.1007/978-3-030-57983-8_9
6. Yesiltepe, D., Conroy Dalton, R., Ozbil Torun, A., Coutrot, A., Hornberger, M., & Spiers, H. (2020). A study on visual and structural characteristics of landmarks and experts' and non-experts' evaluations. In *German Conference on Spatial Cognition* (pp. 95-107). Springer, Cham. https://doi.org/10.1007/978-3-030-57983-8_8
7. Yesiltepe, D., Conroy Dalton, R., Ozbil Torun, A., Dalton, N., Noble, S., Coutrot, A., Hornberger, M., & Spiers, H. (2019). A Wayfinding Research in Virtual Environments: The effect of spatial structure and different conditions on movement. *Proceedings of the 12th International Space Syntax Symposium*. http://www.12sssbeijing.com/upload/file/1562664531.pdf
8. Yesiltepe, D., Conroy Dalton, R., Ozbil Torun, A., Dalton, N., Noble, S., Coutrot, A., Hornberger, M., & Spiers, H. (2019). Usage of Landmarks in Virtual Environments

for Wayfinding: Research on the influence of global landmarks. *Proceedings of the 12th International Space Syntax Symposium*. http://www.12sssbeijing.com/upload/file/1562661388.pdf

9. Yesiltepe D., Dalton R., Ozbil A. (2018). Understanding the effect of global and local landmarks through the use of mobile technology/a mobile-based game. *XXVth International Seminar on Urban Form: ISUF*.

In particular, material from 1 is used in Chapter 5, 2 is used in part of Chapter 3, part of 3 and 6 are used in part of Chapter 6, part of 4 and 5 are used in Chapter 7.

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LIST OF EQUATIONS

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GLOSSARY

GLOSSARY

Axial map: a map that is created by using the fewest number of lines and the longest lines based on “the line of sight”.

Choice: the possibility for each segment to be selected as a part of the shortest route.

Circular environment: street segments with a circular shape. An increase in the number might make it easier for people to recover their wrong turns.

Cognitive saliency: cultural or historical characteristics of objects that make them noticeable.

Connectivity: measures the numbers of lines intersecting with a line.

Dead end: end of a street segment where there are no possible exits (i.e. cul-de-sac).

Decision point: the points in an environment where people should decide which way to go.

Checkpoints (destination): the locations a wayfinder should reach to complete a wayfinding task successfully.

Directional reach: measures how far someone can go from a segment by using specific turns (10°, 0 etc.).

Eye tracking: recording and studying eye movements in order to detect visual attention.

Fixation: maintaining the gaze on specific locations.

Gaze behaviour: eye movements that might include both saccades and fixations.

Global landmark: landmarks that can be seen from a great number of vantage points.

Global value: shows the relationship between all systems.

Integration: the accessibility of each segment from the rest of the system within a specific number of steps or direction changes.

Intelligibility: the correlation between connectivity and integration: shows how easily one can understand an environment while located at a specific point.

Isovist: a set of points visible from a defined point.

Landmark: any salient object that is personal, communicable and visible either from a distance or close up in an environment such that it can be used in the wayfinding process for various tasks (e.g. route definition, orientation etc.).

Local landmark: landmarks that can be seen from nearby.

Local value: shows the relationship between lines or grids by using specific number of turns or changes (e.g. three or five changes and how far someone can go).

Metric reach: measures how much of a system can be covered by using a specific distance from each point.

Saliency: noticeability of an object based on its visual, structural or cognitive characteristics.

Segment: a line between two intersections.

Segment length: the length of each segment (a line was used to define the space between two intersections).

Segment map: a map drawn with lines where the distance between two intersections is represented by one line.

Shortest route: minimum path length that should be covered to reach a specific point.

Street network entropy: unpredictability of a street network. When the value is low, it is easy to predict the system.

Structural saliency: location-based characteristics of an object that make it more noticeable (e.g. landmarks at decision points).

Visual attention: a cognitive process in which a subset of visual scenes is selected from all available sources.

Visual connectivity: grids/cells that are connected to each other (similar to connectivity; here the relationship between grids is explored).

Visual integration: accessibility of each grid from the rest of the system within a specific number of steps (here the relationship between grids is explored).

Visual intelligibility: the easiness of understanding an environment from any point at which a wayfinder stands (correlation between visual connectivity and integration).

Visual saliency: visual characteristics of an object that make it more noticeable, such as size, shape or colour.

Wayfinding: a process in which there is an interaction between people and the environment: the environment gives cues to the observers, and thanks to these cues, observers develop strategies and tactics to find their destination from an origin.

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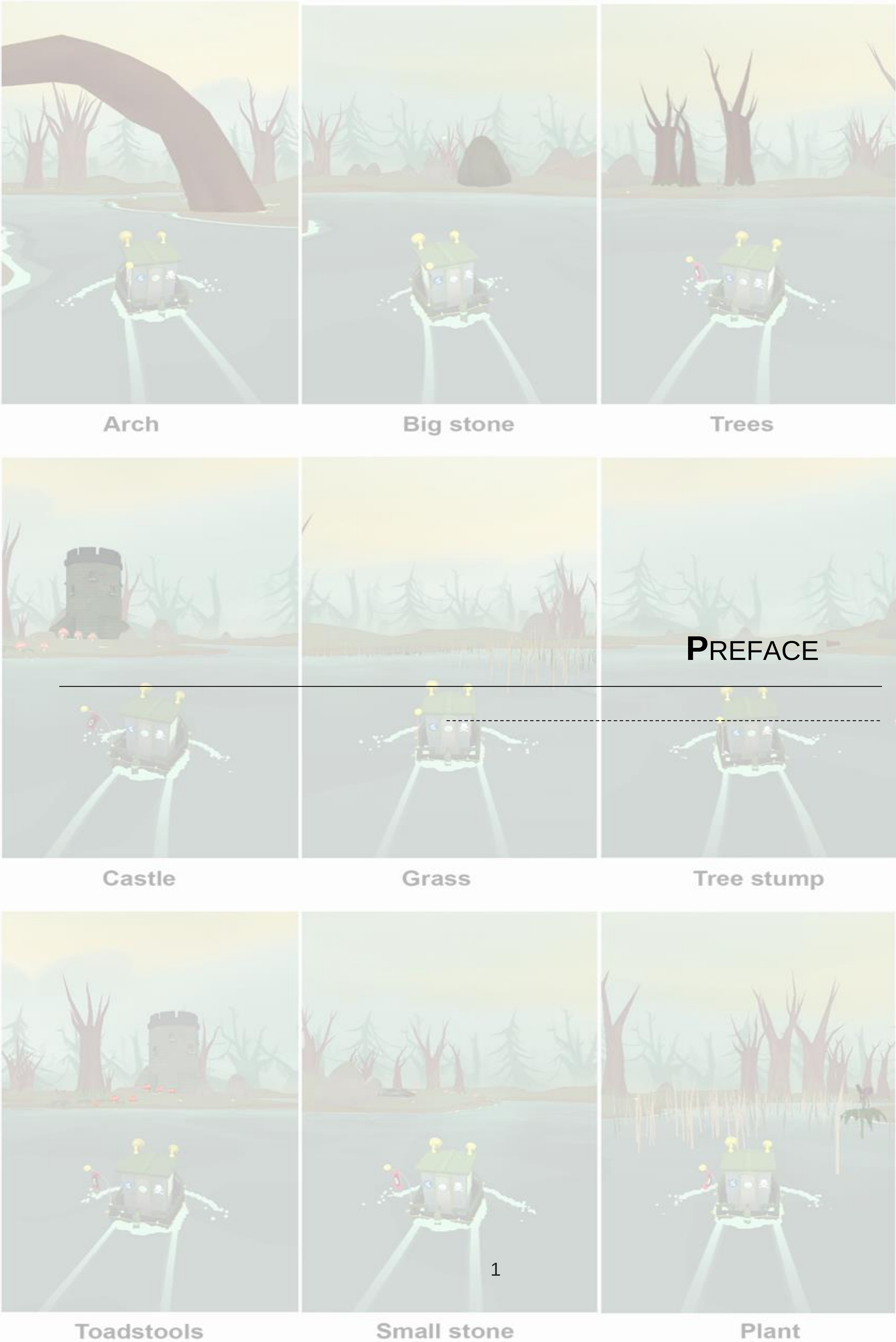
PREFACE


Arch
Big stone
Trees
Castle
Grass
Tree stump
Toadstools
Small stone
Plant

PREFACE

Around 50 million people around the world have dementia, and every year there are approximately 10 million new cases (World Health Organization, 2019). Dementia affects people in different ways, including but not limited to memory loss, thinking speed, understanding, movement or mood.[1] One of the important consequences of the disease is its effect on the region of the brain called the hippocampus, which is responsible for long-term memory storage and is also responsible for wayfinding. Hence, one of the early signs of the disease is problems in wayfinding. This is why it is thought that by checking people's wayfinding abilities, it may be possible to predict the likelihood of them developing dementia (Porter, 2016). Even though the disease and its effects are mostly known, there are still no treatments to heal the disease or to stop its progression. However, it is known that early diagnosis can be significant on the course of the disease. Thus, by using people's navigational abilities it might be possible to detect the disease earlier as the performance of people with dementia differs from that of others.

But we need to understand how people move within environments in general so that we can compare their behaviours with those of people with dementia. What has significant effects on behaviour and what makes a wayfinding task easier or more challenging? Although there are a great number of studies on wayfinding, healthy wayfinding behaviour on a mass population level is still not defined, which makes it hard to understand the difficulties faced by people with dementia (Spiers et al., 2017). Research in the last decades has pointed to different environmental factors, such as complexity, accessibility or linearity. Yet no benchmark has been defined for use in research on people with dementia. Hence, it is quite important to understand the factors that shape people's wayfinding performance, not only from an architectural or urban planning point of view, but also from a cognitive or health-related point of view.

Sea Hero Quest (SHQ), an online game that was introduced to the public in 2016 by app development company Glitchers Ltd., was developed to contribute to different aspects of research on dementia. The game was designed through collaboration between researchers and practitioners. Researchers from different universities including University College London, University of East Anglia, McGill University,

[1] For more information, please check https://www.nhs.uk/conditions/dementia/about/ .

Northumbria University, ETH Zurich, University of Cambridge and Bournemouth University partnered with Glitchers, Alzheimer's Research UK and Deutsche Telekom to tackle dementia. Researchers designed 75 levels in the game with different conditions, including landmarks that are known to affect wayfinding, and a questionnaire. Since the game was released in 2016 to date, more than 4.3 million people have played it and contributed to the research. Hence, the game now has the potential to create a benchmark of how people normally find their way and, therefore, it has the potential to be used by researchers to detect if someone is susceptible to developing dementia, based on their wayfinding performance.

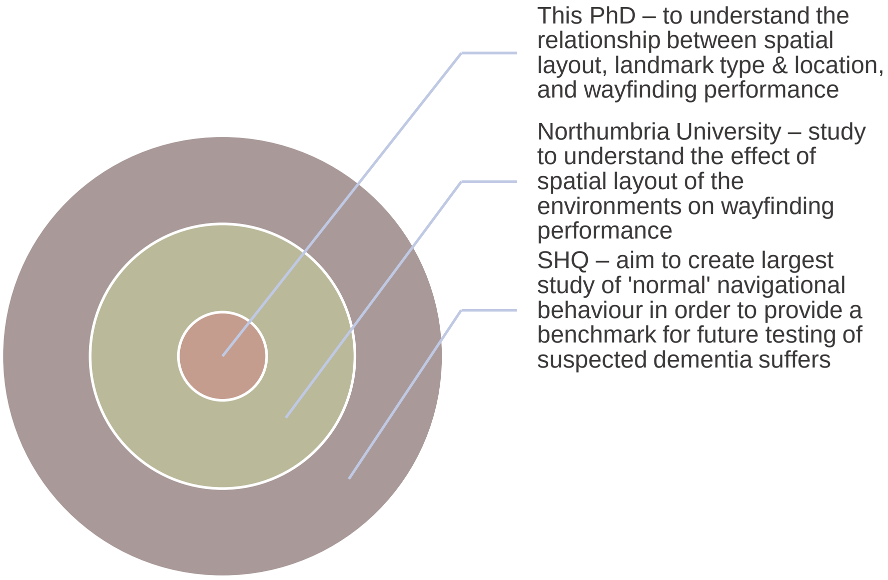


Figure 1. The contribution of the thesis to SHQ research

The data is now being analysed by all the universities mentioned above and researchers from different disciplines (architecture, neuroscience, medicine and cognitive science) aim to better understand movement decisions and the reasons lying behind decisions. As a part of this collaborative work, researchers from Northumbria University aimed to work on the spatial structure and understand how spatial layout shapes people's wayfinding performance. This thesis gives insights into the built environment and explains how spatial layout and different types of landmarks at different locations shape people's wayfinding performance (Figure 1). Using the largest dataset in the field will allow researchers to obtain accurate results as well as enable practitioners and academics to design easily navigable environments. Furthermore, the results of this study are expected to be used in studies on wayfinding abilities of people with dementia.

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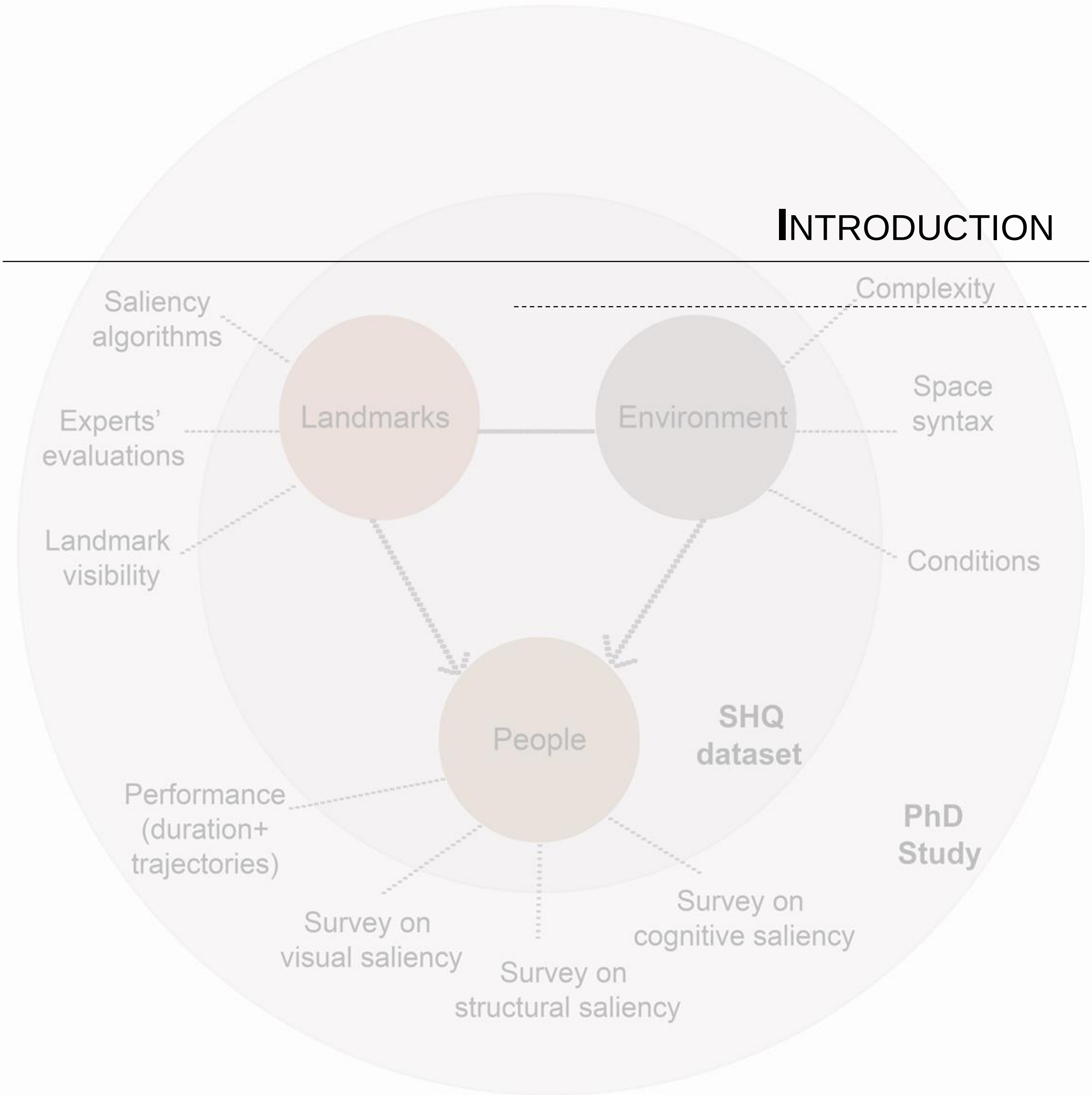
INTRODUCTION



1 INTRODUCTION

What helps us to find our way, whether or not we are familiar with the environment? Is it a building or a tree that helps us to recognise our position and find our way, or is it about the simplicity of an environment? Or is it something else, other than these two options? Is there another condition that makes wayfinding easier or harder for us? Or is it about the harmony of all of the different components?

Each day, we deal with a wayfinding task, or maybe more than one. We start the task from a specific point, an origin, and complete it by reaching a destination, or a series of destinations. In this wayfinding task, let's say we go from home to work, we can complete the process by using a route that we already know, or we can use another route that we do not know (for example, an exploratory walk in our neighbourhood – still in a familiar environment), or we can try to find a way to our destination in an unfamiliar environment (goal-oriented movement in an unfamiliar environment). In all cases, we use cues from our surroundings. In a well-known environment, we may not use the cues often because we already know where to go and the route we should follow. If we would like to change our route in a familiar environment, we might use environmental cues more than in the former situation, since our decision would depend on the cues. Hence, for instance, if we use an alternative path to reach an address near a train station, we can follow paths where we can see the clock tower of the station to reach the address. In addition, other familiar features in the environment can help us maintain orientation. In an unknown, unfamiliar environment, however, we tend to use environmental cues even more to orient ourselves (Allen, 1999; Gärling, Böök, et al., 1986). To complete the wayfinding task successfully in an unfamiliar environment, we tend to use the cues around us and try to remember the objects we see. Or we can ask for route directions from someone familiar with the environment. In this case, the instructions may be as follows: "turn right at the first traffic lights and go straight on until you see an Italian restaurant". By using these instructions, which include environmental cues, we might find our way and complete the task in an unfamiliar environment without getting lost. Hence, to better understand the impact of environmental factors on people's wayfinding performance, it might be more meaningful to focus on unfamiliar environments.

At this point, it is important to know which environmental factors help people to find their way. There are various factors that shape wayfinding performance, including spatial structure (Carlson et al., 2010) or landmark knowledge (Siegel & White, 1975).

Accordingly, spatial structure can make a wayfinding task easier if, for instance, the layouts are simple. When we look at a map to find our way, we might need to look at it only once if we see that we need to take the first right (and the only right) on a street. However, if there are alternative paths we might need to check the map again to see which turn we should choose. Hence, the simplicity of the task, for example, can be an important factor in wayfinding. Previous research suggested various measures (e.g. intelligibility, decision points) to analyse and understand environments better, and discovered the impact of these factors on movement (for example, Ozbil et al., 2015, 2016; Emo et al., 2012; Conroy Dalton, 2003; Kim, 1999; Haq & Zimring, 2003; O'Neill, 1991a; Slone et al., 2015). However, different factors have been mentioned by researchers as significant for understanding people's movement. For instance, the number of decision points (intersections in an environment) and the number of dead ends can be used to understand an environment. However, the factors that shape people's performance are still under debate.

In addition to environmental factors, other circumstances can affect our wayfinding performance and make it harder for us to find our way. For example, let's imagine that we are in a city for the first time and we would like to see specific locations with the help of a map. In this case, the information and the details that we can learn from the map affect our performance. Or imagine that we walk two quite similar paths on different days. On the first day, the weather is clear and we can see our surroundings easily. On the second day, however, the weather is foggy so we cannot see some of the signs or cues that might help us. In this situation, the number of cues we can see are affected by these conditions and so it might be harder for us to find our way. Thus, it is also important to explore these criteria in addition to the spatial structure.

On the other hand, landmarks can also be analysed to better understand their contribution to wayfinding. An object in an environment can help us to complete a wayfinding task as we can orient ourselves based on this object. Any object in an environment can be used as a landmark, since any object can be chosen for route descriptions or any object might help us to find our way in an environment. But we may choose some specific objects more than others. Again, imagine that we are in a city that we have never been to before and we explore our surroundings. Depending on where we are, we might focus on landmarks such as skyscrapers, bridges, towers, churches or mosques that can be seen from further away; or we may focus on landmarks with a specific colour, shape or material (e.g. The Louvre or The Guggenheim); or at a specific location (e.g. a landmark that is located at an intersection of major roads). We might see a landmark with a historical meaning (e.g. Charles Dickens' house in London) so that we can remember it. Or we may remember a landmark better because of its visual, structural or historical meaning. If landmarks are one of the key components of wayfinding, it is essential to understand what makes them more noticeable or, as stated in the literature, salient.

Landmarks are analysed based on their location, visibility or saliency. When we consider the location of landmarks during wayfinding, we can check whether they are along the route (when they are close), or whether they are at decision points. If they are at a decision point where we need to make a turn, for instance, we might remember them more easily. The location of a landmark can be a significant factor for that landmark being seen or remembered.

Considering visibility, on the other hand, landmarks can be categorised as global or local landmarks. If we can see an object from many points in an environment, like the tower of the train station, that might help us globally orient ourselves, and we can consider it as a global landmark. If a landmark can only be seen locally, from a limited number of vantage points, we can consider it local (Lynch, 1960). Hence, we can describe, for instance, a mountain or a tower as a global landmark, as it can be seen from many angles and a great number of vantage points. A traffic light or a sign can be described as local, as it can be seen from a limited number of points. When we think about a settlement, we can find a great number of local landmarks and many global landmarks. However, there is no clear distinction between global and local landmarks; where a local landmark stops being local and becomes a global one. The definition of global and local landmarks helps us to understand the difference between the two; however, it is not sufficient to describe all objects around us as global or local landmarks. A local landmark can be significant in finding specific destinations (e.g. turn right at *the bank*, turn left at *the second set of traffic lights*). Alternatively, global landmarks can also shape our wayfinding performance, as discussed in several research studies (Li et al., 2016; Lin et al., 2012; Li, Korda, et al., 2014), while other studies mentioned only the impact of local landmarks on wayfinding (Lynch, 1960; Ruddle et al., 2011; Castelli et al., 2008; Meilinger et al., 2014). The findings of the current studies are different in this respect. To clarify the impact of different types of landmarks, it is important to first define a threshold to distinguish objects as global and local ones. Once we can do this, then we can also see whether global landmarks are effective in wayfinding.

Finally, what makes an object preferable during a wayfinding task can be analysed by focusing on visual, structural or cognitive characteristics of landmarks – different aspects of their saliency (Sorrows & Hirtle, 1999). Visual saliency depends on visual characteristics of objects such as colour (the contrast with the background or difference from the surroundings), size, shape or material. Structural characteristics are related to the location of landmarks, such that by using the specific location of a landmark we can orient ourselves. Cognitive landmarks are those that can be remembered and used during a wayfinding task because of their historical or cultural meaning. It is possible to state that if a landmark is visually, structurally and cognitively salient, it may be more noticeable (salient) than other objects that have just one of these criteria. Different characteristics of landmarks, such as structural (Stankiewicz & Kalia, 2007) or visual (Winter et al., 2005) characteristics, were mentioned in studies as more significant for the landmarks to become salient. However, the characteristics that make certain landmarks more salient than others are still being debated. In addition, it is important to understand how to measure these characteristics of landmarks objectively to make a comparison between them. If all of the characteristics of landmarks described above can be analysed using particular measures, then a saliency score can be developed for them and a comparison between objects can be made.

1.1 Hypotheses

In the light of the earlier discussion, it is hypothesised that people's wayfinding performance is affected by spatial layout and other conditions, in particular conditions associated with landmarks. More specifically, it is hypothesised that landmarks play an important role in wayfinding and salient landmarks that have a unique colour, size, spatial location and that can be seen from many angles are expected to be preferred by a higher number of people as salient landmarks. It is also hypothesised that the complexity of layouts is key in wayfinding, and the factors that reduce the availability of information about the environment, for example, conditions associated with the weather or map readability, can also make wayfinding more challenging.

1.2 Research questions and objectives

The aim of this study is to understand the impact of spatial layouts, conditions associated with weather and maps, and landmarks on people's wayfinding performance and to explore the factors that make a landmark likely to be selected by more people. Research questions raised in this study are:

- Which environmental factors or conditions make wayfinding easier?
- How do we select landmarks in unfamiliar environments?

The objectives of this thesis are:

- To better understand how the spatial structure shapes movement,
- To explain the effect of different conditions (weather, map) on wayfinding,
- To define global and local landmarks (to make the distinction between the two clearer),

- To investigate the impact of global landmarks and salient landmarks on wayfinding,
- To explore visually, structurally and cognitively salient landmarks.

1.3 Contribution to knowledge

This thesis, therefore, aims to contribute to knowledge in several ways. First, a definition of landmarks, global and local landmarks is proposed to clarify the usage of the terms in this study. The second and perhaps more important contribution of this thesis is to identify accurate results about environmental factors that shape people's wayfinding performance through the use of the largest dataset, that of SHQ, within the wayfinding and landmark fields. This will include accurate results about the impact of different weather, map and landmark conditions. The third contribution of this thesis is to expand the literature on global landmarks and salient landmarks by analysing their impact during a wayfinding task and by defining an objective threshold between global landmarks and local landmark terms (the initial definition is qualitative, and this second objective definition is quantitative). By finding a threshold, it might be possible for the future studies to classify any object in an environment as "local", or "global" and analyse them. The final contribution of this thesis is that it gives insights to the landmark literature by analysing visual, structural and cognitive saliency using several measures.

1.4 Outline of the research

The thesis begins by reviewing the wayfinding literature to find suitable definitions of wayfinding and wayfinding in virtual environments. Changes in behaviour in familiar and unfamiliar environments are also identified. This is followed by the definition of "successful wayfinding". This definition is analysed under two headings: "People and behaviour" and "Environmental factors that affect wayfinding". First, the reasons for successful or unsuccessful completion of a wayfinding task are explained briefly by considering possible human-related issues under the former heading and then the environmental factors that might affect the process are described in the latter section. Complexity measures and Space syntax measures are introduced as environmental factors. This first literature review chapter, therefore, describes wayfinding under different conditions, and the factors that can be analysed to understand wayfinding behaviour and performance.

The second literature review chapter focuses on landmarks. First the impacts of landmarks during wayfinding are discussed, then the characteristics of landmarks that make them preferable to people are described under three headings associated with the location, visibility and saliency of landmarks. Different methods used to measure these three characteristics are identified in this chapter.

The method chapter explains how the research questions raised in the introduction are analysed. First, the case study used in this research is introduced and the measures used to analyse the environment are listed. Then the different conditions under consideration are introduced, including landmarks. In this chapter, levels in the game with the same layout and different conditions, and levels with similar layouts (determined using cluster analysis) are defined. In addition, an overall methodology is introduced for visual, structural and cognitive saliency analyses.

The first analysis chapter, “Analysing the levels of SHQ”, is designed to answer the first research question: “Which environmental factors or conditions make wayfinding easier?” Here, complexity measures, Space syntax measures and different conditions are used and analysed with the big dataset of SHQ game-playing results. The second and third study in this chapter focus on the impact of the conditions on people’s wayfinding performance by using the game-playing results again. This chapter is significant as it provides accurate results, since big data is analysed here.

Chapters 6 and 7 present the analysis of the landmarks of the game in detail. The data analysed in these chapters was obtained from the same game environment; however, additional experiments were conducted to understand people’s evaluations. Hence, rather than using the full dataset, specific groups participated via surveys that are described and analysed in these chapters. This analysis is conducted to answer the second research question specifically: “How do we select landmarks in unfamiliar environments?”

In the visual saliency analysis chapter, people are asked to evaluate visual characteristics of landmarks, and saliency algorithms are also used to make a comparison. Experts’ saliency evaluations are also taken into consideration and compared with non-experts’ evaluations.

The “Structural and cognitive saliency” chapter discusses the two characteristics of saliency using various measures and methods. An overall saliency evaluation is presented where the landmarks of the selected levels are evaluated, and salient and less salient landmarks are listed.

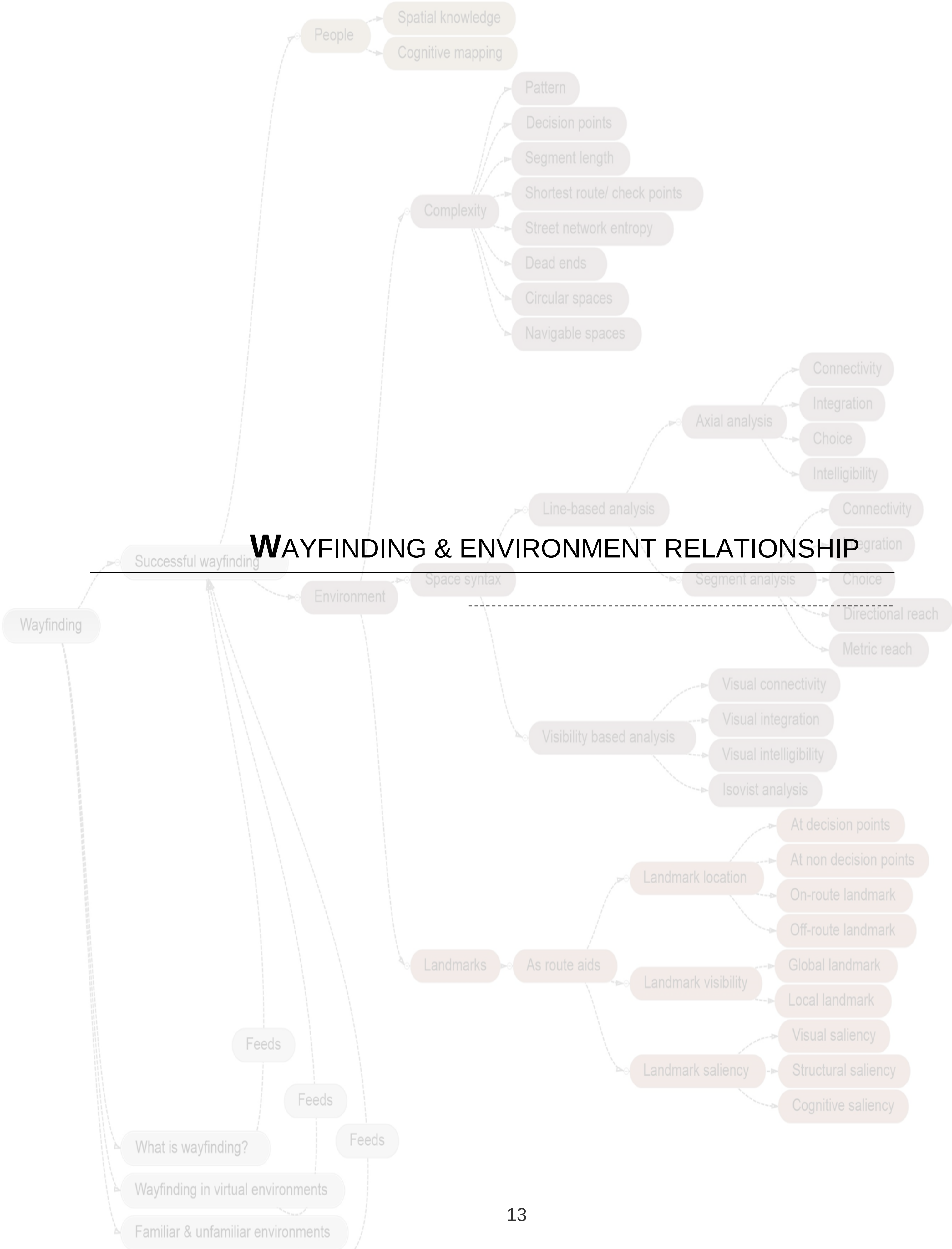
Finally, in the Discussion & conclusion, the findings and their relationship with the existing literature are highlighted and future research directions are presented.

1.5 Summary of the chapter

In this study, the factors that shape our wayfinding performance are examined by using the largest dataset in the field and the effect of different conditions is tested. Landmarks, global and local landmarks are defined. Then, global and local landmarks are explored and a distinction is identified. The saliency of landmarks is also analysed. In this chapter, more specifically, the underlying reasons for the research questions are listed, hypotheses, aims, contributions and the outline of the thesis are explained.

In order to answer the questions arising in this chapter, the existing literature is first analysed in detail to develop a methodology, as can be seen in the following chapters.

WAYFINDING & ENVIRONMENT RELATIONSHIP



2 WAYFINDING & ENVIRONMENT RELATIONSHIP

2.1 Introduction

This chapter focuses on wayfinding studies in the literature in order to understand the definitions in the literature and find the gaps (Figure 2). The chapter begins by discussing wayfinding definitions, wayfinding in virtual environments, and in familiar and unfamiliar environments to explore the impact of different conditions. Next, the criteria that make wayfinding successful are examined under two sections: people and behaviour and environmental factors. The challenges that these two groups might cause during wayfinding are investigated. The definitions as well as the findings of previous studies are explained. To conclude the wayfinding literature review, visual summary diagrams are used; the methodologies used in these studies and the gaps in the existing literature are visualised.

There are two main sections: first, wayfinding as an overall idea, in which the definition of wayfinding, wayfinding in virtual environments and wayfinding in unfamiliar and familiar environments are discussed; second, successful wayfinding is described by discussing people-related factors and environmental factors.

Once the term wayfinding has been defined and wayfinding in virtual environments is discussed, the differences between wayfinding in familiar and unfamiliar environments are explored. In addition, wayfinding in virtual environments is explained in this section. Since it is stated that real environments can be simulated and tested in virtual environments, the results of studies on virtual environments can be adapted to real environments. Some of the studies on Space syntax (a technique used to analyse environments quantitatively, see Section 2.3.2.5 for more information) and pattern analysis are investigated separately for real and virtual environments. In the rest of the thesis, there is no separation of studies on real and virtual environments.

The criteria for successful wayfinding are discussed in two sections: factors related to humans and factors related to environments. Environmental factors are analysed under two areas: complexity and Space syntax measures. Here, all measures that are used in this study are identified.

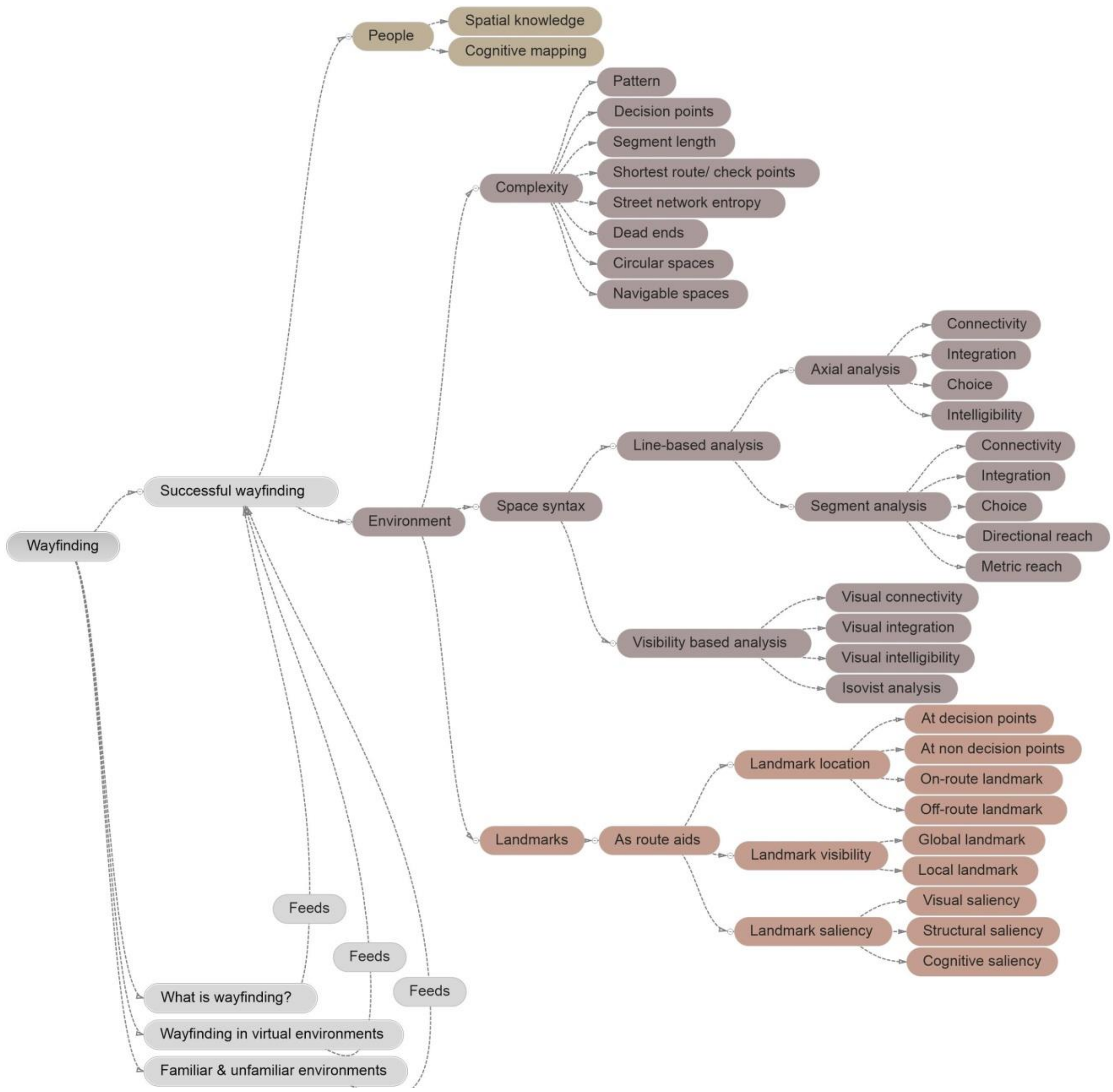


Figure 2: The pathway used in exploring the relevant literature

Articles used in this chapter were collected from Google Scholar using the search term "wayfinding". The majority of the search was conducted between April 2018 and November 2018, and more than 30,000 articles were found. Papers related to more specific topics (e.g. diseases, animal-related research, brain-related research, research on specific age groups, etc.) were excluded from the research. To make the search more effective, search strings composed of specific words such as "wayfinding" and "virtual environments", "wayfinding" and "cognitive maps", or "wayfinding" and "shortest route" were used. Finally, more than 150 papers were selected and analysed for this chapter.

2.2 Wayfinding

2.2.1 ***What is wayfinding?***

In this section, the concept of wayfinding is defined according to existing research (Montello, 2005; Montello & Sas, 2006; Golledge et al., 2000). Golledge et al. (2000)

describe two concepts that govern the processes behind human movement. One of them is “navigation”, in which spatial information is processed based on the rate of travel along a course between an origin and a destination. The other concept is “wayfinding”, which refers to selecting paths that link an origin and a destination. Montello (2005) and Montello and Sas (2006), on the other hand, subcategorise navigation into “locomotion” and “wayfinding”. Accordingly, locomotion is a traveller’s movement depending on their surroundings. It is about the directly accessible area – the surroundings of the traveller – that might have sensory effects. In contrast, wayfinding is defined as a goal-directed movement in which people have a goal destination that is not directly sensed. Because the term wayfinding as defined in these papers agrees with the nature of the current study, this term “wayfinding” is used in the rest of the thesis.

Bond (2020) stated that wayfinding is essential to our success as a species, since it allows us to cultivate social networking. Thanks to our wayfinding abilities, we contact other groups, know where to find resources or where to go for different purposes. Humans complete wayfinding tasks every day. We all go out – start a journey from a specific position – and meet our friends at a café, go to a library, go shopping or go to our school or offices to work – so end the journey as soon as we reach the goal location. Everyone might have at least one daily wayfinding task that could be in a familiar environment or a new, unfamiliar environment. Thus, this activity is a part of our everyday life. One of the earliest uses of the term wayfinding was made by Lynch (1960). He defined “way-finding” and the factors that affect the wayfinding process, mentioning related components such as environmental image or orientation[2] and disorientation. According to him, wayfinding is about *using sensory cues* from the external environment in order to survive from free-moving life. Wayfinding has multiple descriptions in the literature. Harniss et al. (2014) identified wayfinding as the *ability of people to find their way*. Similarly, Passini (1984b) defined wayfinding as a *cognitive and behavioural ability* of people to find spatial destinations. Peponis et al. (1990) discussed that it is about *finding a way to a specific destination without any delays*. Similarly, Golledge (1999) stated that *following a path between a start point and a*

[2] Spatial orientation is related to sense of direction. It is defined as “a person’s ability to mentally determine his position within a representation of the environment made possible by cognitive maps” (Passini, 1984 Page 35). A similar definition is given by Arthur and Passini (1992 Page 23) as: “the process of devising an adequate cognitive map of setting along with the ability to situate oneself within that representation”. Alternatively, it is possible to say that it is the traveller’s awareness of their current location (Montello, 2001) and their awareness of other places or objects (Hunt & Waller, 1999; Montello & Sas, 2006). Hence, orientation is about knowing where we are, knowing the places and objects around us and knowing our place in the “cognitive map” we develop.

destination is called wayfinding. Furthermore, he suggested that three components are necessary for wayfinding: *to have an origin*, *to be able to remember the destination*, and *to make the right decisions* between these two locations in order to reach the destination (Golledge, 1992). A number of studies have also argued that wayfinding is about moving through space to reach a destination (Casakin et al., 2007; Gärling, Böök, et al., 1986; Kaplan, 1976). According to Raubal, "Wayfinding behavior is the *purposeful, directed, and motivated movement* from an origin to a specific distant destination *that cannot be directly perceived by the traveller*. It involves *interaction between the wayfinder and the environment*" (2008 Page 1243). Thus, he stressed the significance of the interaction between the environment and the wayfinder, as well as taking into account the size of environments. Based on this definition, it can be said that wayfinding can only be done in large-scale environments[3] where wayfinders are not able to see the target points (destinations). These definitions make some significant points about wayfinding: it is about finding our way to a specific point, where we are not able to view this point from the origin and where we complete the task without delays – without getting lost – by using environmental cues.

Lynch (1960) discussed the need for structuring and identifying environments and suggested that many different kinds of cues, namely landmarks, that can easily be recognised because of their shape, or size (visual cues) or any other characteristics, might be useful for defining environments. Furthermore, he claimed that if someone has to find her way to a specific point, she uses the generalised mental picture of the environment and moves accordingly. This environmental image may consist of specific objects and/or locations, or it can be of objects that are linked to each other in our minds (e.g. two objects and one of the important streets that connects these two objects to each other). In the latter case (objects and a path to follow), it would be easier to find our way. Hence, Lynch stated the importance of environmental cues on environmental image and so on wayfinding. As environmental components affect

[3] It is important here to define a large-scale environment. Raubal points to Montello's (1993) definition in which Montello gave four types of scale: figural space (smaller than the human body and can be seen fully), vista space (as large as the human body or maybe larger than it, and can be seen from a single place), environmental space (larger than the human body, cannot be seen from one point) and geographical space (much larger than the human body, it also cannot be seen fully). A common classification of environments is based on the scale and it includes two components: large-scale and small-scale environments (Kuipers, 1982). According to this classification, environments that can be seen from one vantage point are called small-scale environments, while environments where people cannot see all points from one specific location and they make observations and learn about the environment to develop a cognitive map over time, are called large-scale environments. This definition then evolved to small-, medium- and large-scale environments (Mandler, 1998) and a very large-scale environment is also identified (Ruddle et al., 1999). Additionally, definitions such as spatial scenes, spatial surroundings, neighbourhoods and graphic regions (different scales) are used (Hunt & Waller, 1999). However, no consensus is observed for the definitions.

wayfinding, he also clarified the criteria that make an environment easily recognisable. In his book, legible and distinctive environments are considered to be better environments. As environmental factors affect wayfinding and they are essential for the image of an environment, which helps people to way-find, he defined an easy way of imaging the city and suggested five components of cities: edges, districts, paths, nodes and landmarks.

Allen (1999) claimed that wayfinding is about the *interaction between attributes of the traveller and the environment*. According to Golledge (2003), on the other hand, wayfinding is the ability to learn a route and retrace it. He added that for successful wayfinding, environmental knowledge is vital and it can be gained in two different ways: incidentally or intentionally. While we explore an environment, we can learn or notice things, which is gaining knowledge incidentally. In contrast, we can intentionally learn about the environment; for example, by reading about it or taking classes. Darken and Peterson (2001), on the other hand, proposed that wayfinding is a tactical and strategic process rather than movement only. Moreover, they stated the importance of a cognitive map (see Section 2.3.1.2) that is developed by the observer. According to Passini (1984), wayfinding can be defined simply as *spatial problem solving*. Hence, to solve a problem, people should use their cognitive and behavioural abilities (Arthur & Passini, 1992). In this sense, it is possible to state that not only the environment, but also the observer and her strategies, tactics and the image she creates of the environment also affect wayfinding.

According to Arthur and Passini (1992), while people try to find their way in an environment, they use three steps to solve the "*spatial problem*":

- Decision making,
- Decision executing,
- Information processing.

Decision making is about planning what to do in the environment and decision executing is about implementing the plan. Information processing, on the other hand, is about the senses that one would use (hearing, seeing etc.) depending on the environmental cues. Hence, both decision making and decision execution are supported by information processing. During the wayfinding process, if people can situate themselves in the environment and develop a plan to reach a specific goal location and they can use the environmental cues effectively, then they might feel *oriented*. In a contrary situation, people might feel *disoriented*. Thus, it can be stated that all of these terms are related to the wayfinding process.

Garling et al. (1986), on the other hand, defined four decisions someone should take to complete a wayfinding task. According to them, one should decide the destination, find the way to go to the destination by localising the destination (plan the route), find the route between the origin and destination and choose a travel mode. Downs and Stea (1973) also proposed four categories for wayfinding: orientation, route selection, route control and recognition of destination. Here, orientation is about locating oneself with respect to cues around; route selection is related to finding a route to reach a destination using minimum effort; route control is related to verifying that the followed route and the decisions taken are constantly true; and finally, recognition of destination is related to being aware of the destination so that it can be known when the wayfinding task is completed. In comparison to Arthur and Passini's three-step model (1992), in Downs and Stea's four-step model "route selection" and "route control" can be mapped onto "decision making" and "decision executing" respectively, as defined by the former, while "route control" is also closely related to "information processing". Route control can be related to the last two steps defined by Arthur and Passini, since one needs to execute his/her decision and follow the environmental cues in order to be able to understand that the followed path is correct. Therefore, route control is also related to orientation, since orientation is also about locating oneself in the environment and making sure that the followed direction is correct. Hence, the steps to complete a wayfinding task, as defined in these two studies, are quite similar; however, Down and Stea's description also highlights the significance of recognising the destination.

All of these papers point to the importance of similar ideas in wayfinding. Based on them, it is possible to say that one should first decide where to go, find a way to go to this point, and then execute the decision by observing the environment in order to not get lost. Thus, within this thesis, the *wayfinding process is thought of as an interaction between people and the environment: the environment gives cues to the observers; and thanks to these cues, observers develop strategies and tactics to find their destination from an origin.*

2.2.2 *Wayfinding in virtual environments*

Witmer et al. (1996) described virtual environments (VEs) as computer-generated simulated spaces where people can interact. Wayfinding and related topics have been discussed for VEs in addition to real environments in different studies (Conroy, 2001; Yang & Diez-Roux, 2012; Wang et al., 2005; Meilinger et al., 2015; Jansen-Osmann & Fuchs, 2006). A great number of studies on VEs have been designed to understand whether or not it is possible to use VEs in order to better understand real environments and develop solutions for the problems of the real environments.

Aga Skorupka (2008, 2009) compared real and virtual environments by using a complex office building and asking participants to find a specific location. Half of the participants experienced the virtual office while the rest experienced the real office building. She first discovered that it took more time for participants in the virtual office to complete the task. In addition, she could not find any correlation between patterns of wayfinding used in the real and virtual environments. Kort et al. (2003) considered the comparability of real and virtual environments by asking 101 participants to explore either real or computer-simulated environments. The results, however, were mixed: behaviour in VEs had similarities to that within real environments, but there were also important differences. The researchers argued that integrating spatial information with configurational knowledge was one of the problems of VEs. However, they also discovered that VEs were better for approximating perception and interaction with spatial and architectural features.

On the other hand, the differences between real and virtual environments have been defined by different studies. Ruddle and et al. (1997) clarified the differences as follows:

1. Limitation in eye, head and body movement in virtual environments: in real environments, movement is controlled and shaped by the feedback on rotational movement. However, this rotational feedback can be more limited in virtual environments as movement is controlled with a mouse or a keyboard.

It can be said that this has recently changed, and VEs have become more real-like with the development of tools like virtual reality (VR) headsets, which allow people to move to see different parts of the environment.

2. Restricted field of view in virtual environments: the field of view in virtual environments can be more limited than a human’s field of view. In virtual environments, the field of view can vary from 60° to 100° whereas human’s field of view is 180° (Mazuryk & Gervautz, 1999).

As with the changes to the first factor, it is also possible to say that the field of view has now increased in VEs to become more similar to that in real environments. Hence, nowadays the designed environments can be seen from an extended field of view (e.g. panoramic views).

3. Limitation in landmarks and nonvisual cues: virtual environments can contain fewer landmark types than real environments. Furthermore, senses used (e.g. hearing) can be also limited as senses other than sight are mostly excluded in virtual environments (see Montello et al., 2004), which can be thought of as another barrier.

This has also changed recently as sound has been added to virtual environments.

4. Finally, spatial knowledge can be different in VEs compared to real ones.

Again, it can be said that using a realistic training environment is a key factor in obtaining similar results from studies in virtual and real environments. In addition, it is also key to give participants some time to adapt to the VEs and the tools that they should use in practice sessions (Marín-Morales et al., 2019). An interesting study was performed by Wallet et al. (2011) to understand the effect of the visual fidelity of VEs on wayfinding. To do this, they used VEs that were undetailed (with no colour or texture) and detailed (with colour and texture), and which were then controlled using the results from the real environments. Researchers found that detail within VEs had a significant effect. Better performance was observed while the participants were moving within the detailed VEs. These important results demonstrate that VEs are helpful in understanding real environments as long as the VE includes many details that can be found in real environments.

As well as listing the differences between real and virtual environments in their research, Ruddle et al. (1997) compared real and virtual environments with experiments. They observed that people could develop route-finding abilities in VEs easily as they gained spatial knowledge, and these abilities were just as accurate as in real environments. Moreover, Witmer et al. (1996) aimed to understand whether a virtual model of a building could be used to navigate actual buildings. They observed that through a virtual model of a building, one could learn a route to follow in the real one. Hence, they concluded that VEs that represent the real world can be effective for learning complex routes.

Another essential contribution to the research into the relationship between real and virtual environments was made by Conroy (2001). In her study, Conroy discovered that it is possible to observe people's behaviour in real environments by using virtual environments. Within her thesis, she focused on the Tate Gallery (London), and made real-gallery observations and prepared a virtual dataset to compare with the results of the real environment. Finally, she discovered that using VEs is not only beneficial for gaining data about real environments, but they also have some advantages such as providing a rapid and accurate way of obtaining data. It has also been stated that VEs can be used to test theoretical worlds.

In their paper about spatial knowledge, Richardson et al. (1999) prepared a simple VE and a complex building. Participants first learnt the environment, completed a task and they learnt the building in three different ways: by viewing it from a map, by experiencing it and by traversing through a virtual rendition of it. As a result of this study, researchers noted that learning an initial simple VE was highly predictive of people's ability to learn a real environment. The results were similar for people who learnt the environment from a virtual layout and a real one. Similarly, Waller et al. (1998) stated that VEs allow people to develop useful representations of large spaces. Morales et al. (2019) compared navigation patterns in real and virtual environments. They used head-mounted display devices and asked participants to observe both real and virtual museums. Results of this study also showed similar navigation patterns for virtual and physical museums.

Recent cognitive studies have also expressed similar results for real and virtual environments, stating that the use of a VE provides a reliable assessment of people's navigation abilities (Claessen et al., 2016; Cushman et al., 2008; Sorita et al., 2013). More importantly, Coutrot, Schmidt et al. (2018) conducted research using the mobile app Sea Hero Quest, which is also used within this study, and they compared people's performances in real and virtual environments. Researchers discovered a significant correlation between real and virtual environment performance.

Based on all of the studies discussed here, it is possible to say that even though virtual environments might have limitations compared to real ones, one can test real environments by using the virtual ones. Moreover, the factors with the greatest effect on people's navigational abilities can be detected. These factors can form a basis for creating easily navigable environments in urban design and at urban planning scales. Hence, the rest of the review of the wayfinding and landmark literature uses explanations and examples from both real and virtual environments.

2.2.3 *Wayfinding in familiar and unfamiliar environments*

Even though real and virtual environments have some differences, the literature mostly suggests that it is possible to test real environments by using virtual environments. Another question appears after this: do people behave differently in environments they know and they do not know? As a part of their research, Garling et al. (1986) focused on the differences between the behaviour of newcomers and people who are familiar with an environment. They argued that newcomers should have some clues to find their way. This clue can be a map, which can be used to find a destination. Alternatively, people can pay attention to the environment in order to see landmarks (e.g. signs) to complete a wayfinding task. For people who are familiar with the environment, a map will not really be necessary as they already have a map in their minds. Lovelace et al. (1999) hypothesised that as familiarity increases, spatial tasks become easier, and as familiarity decreases, spatial representations[4] become distorted and people have difficulties with completing the wayfinding task. In order to test the hypothesis, they asked people to describe both familiar and unfamiliar environments. They concluded that a higher level of spatial knowledge correlated with more accurate route directions.

According to Allen (1999), there are three different wayfinding tasks: finding a destination in a familiar environment, finding a destination in a familiar environment by exploratory travelling, and finding a destination in an unfamiliar environment. Finding a destination in a familiar environment is quite common as people may go to work or back home every day. Similarly, finding a destination by an exploratory travel is also common as people can walk around and "explore" their surroundings when they go to a new place (a new destination). Wayfinding in an unfamiliar environment, as Allen (1999) and Garling et al. (1986) proposed, relies more on spatial information. This information could be a map, verbal directions or environmental cues. Unfamiliar environments have been used by researchers in VEs in order to better understand the factors shaping wayfinding performance (Darken & Sibert, 1996; Han et al., 2008; Steck & Mallot, 2000; Miller & Carlson, 2011), since people pay more attention to the cues when they are in unfamiliar environments.

To summarise, people already have a spatial representation in their minds for familiar environments and they use this while they are moving in that environment, in addition to using some environmental cues. However, in an unfamiliar environment, there are no spatial representations. In order to produce this information, people use verbal directions or environmental cues such as landmarks. Thus, thanks to these cues, wayfinding tasks can be completed successfully. But what is important and really necessary for someone to be able to find his or her way in an unfamiliar environment? In the next section, all factors that shape wayfinding performance are examined.

2.3 What is successful wayfinding?

According to Allen (1999 Page 47), "successful wayfinding is reflected in the traveller's ability to achieve a specific destination within the confines of pertinent spatial or temporal constraints and despite the uncertainty that exists". When experiencing wayfinding difficulties, people might lose time, they might feel uncomfortable, unsafe or stressed (Dogu & Erkip, 2000). In contrast, successful wayfinding increases satisfaction and safety and decreases time spent on reaching the destination. Thus, it

[4] Spatial representations are products of information processing and thus, if someone would like to stay oriented in an environment he/she should have an accurate representation (Passini, 1984a). It can be considered to be the way a space is represented in the brain.

is critical to understand the factors that lead to the successful conclusion of a wayfinding task. For success in wayfinding, Golledge (1999) stated the necessity of having an origin and a destination, as well as determining turns, defining the length of segments and recognising landmarks. Furthermore, he described four key factors for a successful wayfinding task: path integration (homing), piloting, chunking and using a schema developed from knowledge (Golledge, 2003). Path integration refers to the ability of a traveller to point at the origin of the journey in a straight line at any moment of his/her journey. Piloting refers to finding a way by using landmarks as environmental cues. Thus, by using the landmarks, people can find their destination by following paths from landmark to landmark. Chunking refers to dividing a route into pieces that can be completed sequentially until the wayfinding task is finished. While chunking a route, one can still use landmarks, for instance, as environmental cues. Finally, the schema, which is developed by the traveller, also affects wayfinding performance. Passini (1984) stated that for successful wayfinding a solution is required for the spatial problem; this reflects the way he defined wayfinding as spatial problem solving. He added that three components are essential in the wayfinding process: environmental information (a descriptive component, locational component and time component), decisions and behavioural actions.

In contrast, wayfinding can also be unsuccessful. As Arthur and Passini (1992) proposed, if a wayfinding task is unsuccessful there are two components that can be blamed: people or the environment. In their book *Wayfinding: people, signs, and architecture*, they claimed that people may pay no attention to the objects they see. Alternatively, even if they pay attention, they might still forget the objects leading to the wayfinding task being unsuccessful. Alternatively, the environment can be blamed if it is poorly designed. Both of these components can be the reason for people to lose their way or become disoriented. Thus, in this chapter the factors related to people (their observations and behaviours) and the environment will be discussed to examine how they affect the process. Owing to the motivation of the current study, the focus is on the effect of environmental factors on wayfinding, rather than on the factors related to people. However, cognitive effects are also explained in related chapters and in the analyses, since these two components cannot be thought of independently from the process.

2.3.1 ***People and behaviour***

The first component to consider in wayfinding is people. During the wayfinding process, if people observe the environment well and pay attention to their surroundings, the wayfinding process can be successful. Even though people look at objects, if they do not pay attention then they will not be able to recall or recognise[5] the objects, and it will be challenging for them to find their way.

During a typical wayfinding task, there are some steps that people follow consciously or unconsciously, such as orienting themselves, finding some clues, relating these clues to places, etc. These processes are explained under two subsections: spatial knowledge and cognitive mapping.

2.3.1.1 Spatial knowledge

Spatial knowledge is gained as people move within an environment. It can be acquired directly by experiencing environments; or viewing maps, images or 3D models (Montello, 2001; Richardson et al., 1999); or by watching a presentation; or by using virtual environments.

It is argued that when building representations of places, most people rely on senses and proprioceptive experiences to identify, encode and store the environmental knowledge. Therefore, environmental knowledge is gained during the wayfinding process (MacEachren, 1992). In addition, spatial knowledge might change over time and with experience. Sholl (1996) suggested two key processes for spatial knowledge: object-to-person and object-to-object relations. Object-to-object relations are stable; however, person-to-object relations can be shaped depending on the changes in a person's location. Environmental knowledge depends on different factors such as the way that the knowledge is acquired, or the way it is organised and stored in our memory (Leiser & Zilbershatz, 1989).

Siegel and White (1975) suggested that knowledge begins with noticing and remembering objects, namely landmarks. Furthermore, they argued that three types of knowledge are required in order to develop spatial knowledge: landmark knowledge, route (or procedural) knowledge and survey (or configural) knowledge. Landmark knowledge refers to remembering or learning the salient objects in an environment. The authors suggest that landmark knowledge is important as all learning is organised around landmarks. Route knowledge comes from serial learning that consists of a series of decisions. These decisions are always aimed at linking one point to another. Then routes between landmarks are learned and, finally, these routes are integrated into configural representations, which provide survey knowledge. Therefore, one can choose different paths and follow a route between two points depending on different conditions. For example, the effect of traffic on a very busy day may cause us to use

[5] Here, Arthur and Passini's (1992) definition gains importance. They stated that if we can remember an object even in the absence of it, then this is called *recall*, whereas it is called *recognition* in case the object is present and we see and remember it.

another route. Even though some similar definitions have been developed for spatial knowledge, such as landmark learning, route learning and region learning (MacEachren, 1992), the definitions of Siegel and White can still be considered the most effective in the literature. A more recent opinion, however, was developed by Montello (1998), who asserted that there is no stage at which only pure landmark or route knowledge exists. According to him, as familiarity increases, the quantity and completeness of spatial knowledge increase. Hence, Montello proposed that most of the steps occur in parallel, rather than in a sequential order. In another study, researchers also found that people can acquire route or survey knowledge as soon as they explore an environment (Ishikawa & Montello, 2006). Thus, we learn an unfamiliar environment by knowing the names or locations of landmarks, the routes that contain some of the landmarks and their topological relationships as we learn more about them (Ekstrom et al., 2018).

Another type of spatial knowledge identifies two terms: active and passive learning. Chrastil and Warren (2012) stated passive learning is provided by visual information given to an observer via videos or series of slides. Active learning, in contrast, is mainly derived through physical movement within the environment. Additionally, active learning may include different cognitive processes, such as using landmark information in order to update the location for the purpose of orientation (Gaunet et al., 2001). Appleyard (1970) gave an example about drivers and passengers to explain this concept. Accordingly, car passengers, undergoing passive learning, tend to learn less about the layout of a route than the drivers do. Other studies have compared active and passive learning and provided different findings. Some studies have found that active learning is more effective for route learning (Peruch et al., 1995; Farrell et al., 2003; Appleyard, 1970), while others have emphasised the impact of passive learning or found the effects of the two learning types to be similar (Wilson et al., 1997; Gaunet et al., 2001). Chrastil and Warren (2012) pointed to five key points in active learning that contribute to spatial knowledge: (1) motor commands that define the path locomotion, (2) vestibular information about self-motion, (3) allocation of attention to relevant spatial properties, (4) cognitive decisions about the selected route and (5) mental manipulation of spatial information. They then defined an additional point: (6) proprioceptive information about displacement with respect to the substrate (Chrastil & Warren, 2013).

The research on spatial knowledge points to two key ideas mostly: (1) active learning, where people explore the environment by themselves rather than seeing a video or slide, is more effective for learning the environment, (2) landmarks are key in understanding the environment.

2.3.1.2 Cognitive map/mapping

Arthur and Passini defined a cognitive map as "an overall mental image or representation of the spaces and the layout of a setting" (1992 Page 23). The mental image is created using different vista points in an environment. Hence, the process is that of mental structuring as our mind gathers all information that has been observed and links the images to each other. Golledge (2003) defined the cognitive map as one's internal representation of the spaces that have been seen. Correspondingly, it has been defined as an internal representation of an external environment, including the relationships between features (Golledge et al., 2000). Similarly, Kaplan (1976) discussed the relationship between places when he defined cognitive maps. Cognitive maps include landmark knowledge, route connections, and the distance and direction relationships as well as non-spatial attributes or emotional information (Montello, 2001). According to Downs and Stea (1973), in order to understand how cognitive – or mental – maps are formed, someone should ask three questions: (1) what do we need to know, (2) what do we know and (3) how do we gain the knowledge? They pointed to two things that people need to know: the locations and their attributes (what is there – at the location – and why should people go there). Then we should focus on what is known to understand how to arrive a destination. The authors asserted that cognitive maps, compared to base maps (a map that provides location references for features that do not change often like boundaries, rivers, lakes, roads etc.), are more abstract, highly selective and generalised. Hence, they are likely to be incomplete, schematised and augmented. Although the cognitive map is simpler than the environment, it has an order (Kitchin, 1994). People move around an environment according to the way they see it, as their cognitive maps let them. Using clues in the environment and our senses, we can build a map while we are moving within the environment.[6]

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[6] The cognitive map developed by the users of environments can also be categorised based on the way users view the environment. Here we can talk about two different options: egocentric and allocentric formats (Münzer & Stahl, 2007; Thorndyke & Hayes-Roth, 1982). According to this categorisation, the egocentric format is the view-based visual instruction format in which people learn the environment by moving within it, and allocentric is a map-based format in which people learn the environment by using maps. The allocentric perspective can be thought of as a representation with reference to objects other than the navigator (Ekstrom et al., 2018).

The allocentric perspective represents a more stable reference frame and it can involve using the locations of landmarks relative to each other, for instance. Therefore, the allocentric format is two-dimensional and egocentric format is four-dimensional. Thorndyke and Hayes-Roth (1982) aimed to understand the differences between two different groups: people who learn the environment through maps and people who learn the environment through navigation. They concluded their study by saying that navigation subjects were more accurate than map-learning subjects were.

Cognitive maps, as mentioned previously are abstract and schematised. As people move within the same environment this map tends to develop and the objects in the environment and the links between them become clearer. Hence, the base map and the maps in our minds become more similar. Therefore, it becomes easier to find a specific destination in these increasingly familiar environments over time. This process can be defined as cognitive mapping. Using the definition of Golledge et al. (2000), cognitive mapping involves storing, encoding and manipulating the experienced information.

Cognitive mapping plays an important role in spatial behaviour, decision making, learning and adapting the information to the real world (e.g. planning and teaching) (Kitchin, 1994). Moreover, as cognitive maps are used to recall information, they are also used for wayfinding tasks (Golledge, 2003). Hence, it is possible to say that spatial knowledge and cognitive maps produced with this knowledge are predictive in a successful task.

There are various additional behavioural factors that may affect people's wayfinding performance, such as cultural differences, differences in vocabulary or terminology or gender differences. Moreover, diseases that can affect memory such as Alzheimer's (Monacelli et al., 2003; Uc et al., 2004; Davis et al., 2017) or other forms of dementia (Passini et al., 1998, 1995; Marquardt & Schmieg, 2009; Marquardt, 2011) can have an effect on the success of wayfinding tasks; however, these topics will not be discussed in this thesis as these concepts are beyond the scope of this study. Only one factor, the effect of age, which was discussed in different papers (Bryden et al., 2013; Taillade et al., 2013; Harris & Wolbers, 2014; Head & Isom, 2010), will also be considered in this study since a significant relationship was found between age and performance in Sea Hero Quest (Coutrot, Silva, et al., 2018). Hence, in this study, the results from a specific age group are analysed. The next subsection discusses the environmental factors that might shape the wayfinding process.

2.3.2 ***Environmental factors that affect wayfinding***

The reasons for people being responsible for an unsuccessful wayfinding task are discussed in the previous subsection. The other important reason for failure in a wayfinding task is related to the structure of the environment. People use cognitive maps in order to complete wayfinding tasks and if the environment is new to them, then they develop a cognitive map by moving within the environment. Nevertheless, the length of time it takes for someone to build a cognitive map depends on people's abilities, as mentioned earlier. However, there is also another important factor: environment. How easy it is to walk or move within the new environment? How well can we see our environment from where we stand? Are the objects around us helpful enough? All of these questions are directly related to the environment or its conditions.

2.3.2.1 The impact of various conditions on wayfinding

One of the first factors that might affect navigational abilities is related to the conditions within the environment. There are a great number of studies about spatial navigation in virtual environments; however, the number of studies focusing on the effect of weather and map conditions is limited. Hurlebaus et al. (2008) tested two different conditions in a virtual environment by asking participants to learn a path between two locations. In the first experiment, they added no local objects (landmarks). In the second experiment, they added fog into the environment, decreasing participants' visibility such that they would not be able to see global landmarks. The researchers observed that participants who had a high variability in their route choices were affected by the fog. Similarly, Ruddle and Peruch (2004) investigated the impacts of fog and global landmark conditions in virtual environments. They discovered that removing the fog caused a reduction in the distance participants travelled to reach their destination, and the results clarified the importance of the line of sight in Space syntax. However, they could not observe any significant effects of global landmarks. Moreover, Burns (1998) discussed how poor visibility due to bad weather can obscure environmental information and cause people to get lost. Burns also described how people can experience wayfinding problems due to information being limited when signs are obscured. Hence, these criteria can also be added to the analyses in order to compare all possible variables that may shape people's wayfinding performance.

Different map conditions, such as differing levels of detail (e.g. one map with only simple geometry, another with more complex geometry or with text on it) were also compared to understand their impact on wayfinding tasks (Soh & Smith-Jackson, 2004; Devlin & Bernstein, 1997; Lobben et al., 2014). The results of these studies suggested that maps with more visual or textual detail could help people to find their way more easily. Hence, these factors should be considered to understand people's wayfinding performance.

2.3.2.2 The impact of the layout

Passini (1984b) examined the problem of disorientation by first focusing on mazes. He argued that even though we continually use our mental maps, which are automatically executed most of the time, we cannot do this in a new environment. Mazes can be enjoyable for children and adults. However, this changes when we consider everyday life. In cities, people would like to go from one location to another easily and they prefer not to feel disoriented. In a maze, because of the complexity[7] of the environment, people tend to feel disoriented or confused about their position. These feelings then might evoke the fear of being lost and in danger. If the maze walls around us are higher than eye level such that it is not possible to see the other parts of the maze, it is even harder to complete the task and the feeling of fear may increase further. Additionally, other research has shown that as the complexity of layouts increases, wayfinding performance decreases (O'Neill, 1991a, 1991b). Therefore, it is important to understand the factors that make an environment easily navigable.

Literature on cognitive science and wayfinding has introduced some terms that are key in wayfinding. Accordingly, for successful wayfinding, environments should embody relatively higher legibility[8] (Golledge, 2003; Arthur & Passini, 1992; Passini, 1984b; Lynch, 1960), readability[9] (Arthur & Passini, 1992), and imageability[10] (Arthur & Passini, 1992; Lynch, 1960; Passini, 1984b). Weisman (1981), for instance, focused on simplicity (the complexity of the environment), describability (the ease with which the environment can be described), memorability (the ease with which one could remember the environment) and legibility (the judged ease of wayfinding) of environments. Weisman discovered that there is a clear relationship between environmental legibility and wayfinding. He also discovered that people's simplicity judgements were an important predictor of wayfinding behaviour. Garling, Böök et al. (1986), on the other hand, stated that the degree of differentiation, degree of visual access and complexity of spatial layouts are key factors for wayfinding. Degree of differentiation refers to whether different parts of the environment look similar or not, and it is expected that as the degree of differentiation increases, the environments

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[7] Complex systems are defined as large nonlinear systems of interacting components, which may allow a self-organised structure (Boeing, 2018). They refer to a system that has many connections and interacting subcomponents (Batty, 2005). The complexity of layouts can be defined by different components such as the size of an environment, the number of possible destinations and routes, and the angles of intersecting routes (Li & Klippel, 2012).

[8] Legibility: "Architectural legibility is the degree to which the designed features of the environment aid people in creating an effective mental image, or 'cognitive map' of the spatial relationships within a building, and the subsequent ease of wayfinding within the environment." (O'Neill, 1991b Page 259), or as Arthur and Passini (1992) defined, it is about the ease with which an environment can be perceived and the information collected.

[9] Readability: measures the ease with which information about the environment can be understood (Arthur & Passini, 1992).

[10] Imageability: Lynch described imageability as having the same meaning as legibility, which is the quality of an object that allows it to evoke an image in an observer's mind (Lynch, 1960). Arthur and Passini (1992), on the other hand, gave different definitions for these terms. According to them, imageability is the ease with which the spatial layout can be understood and mapped.

become more differentiated. In this situation, legibility of environments tends to increase as they become more memorable. Visual access refers to the extent to which parts of the environment can be seen from other parts. Finally, for complexity, researchers focused on the importance of the size of the environment and the number of possible destinations and routes. Thus, according to this perspective, if an environment has a higher degree of differentiation, and accessibility, and low complexity then it would be easier to way-find within it. Li and Klippel (2010) stated that salient landmarks can be used in order to understand the degree of differentiation. Researchers stated that landmarks are necessary if the legibility of environments is to be fully analysed. Urban planners, designers and architects discuss not only these factors but also additional factors to understand the environmental components shaping wayfinding. These discussions are analysed under two headings: complexity and Space syntax analysis.

2.3.2.3 Complexity of environments

As mentioned, complexity is a key term in wayfinding. A complex object or place is hard to distinguish (Gershenson & Fernández, 2012) or as proposed by Batty "complexity is a characteristic of systems that are intrinsically unpredictable" (2005 Page 64). Therefore, in a complex system or layout it is hard to predict where to go. Complex systems may include simple parts and yet it may still be difficult to understand and sense the whole system. Batty stated that "a complex system in this context is based on simple rules or interactions that give rise to unanticipated spatial outcomes" (2005 Page 64). Hence, in a complex system, even if we have simple parts, it is still hard to understand the whole. But then how can the complexity of layouts be measured and understood? Lloyd (2001) defined three questions to quantify complexity: "how hard is it to describe?", "how hard is it to create?" and "what is the degree of organisation?". Based on these questions, if an object or place is hard to describe or create, then it can be thought of as complex, and in contrast, if it is easy to describe or create, then it can be thought of as simple. In addition, one can understand the closely related quantities (objects and environments that are complex to a similar degree).

Boeing (2018) defined five dimensions of complexity: temporal, visual, spatial, scaling and connectivity. The temporal dimension is described as the processes and behaviours that change over time. The visual dimension is described as humans' perception of the details of the built environment. The spatial dimension is related to land patterns and granularity, whereas scaling is related to the similarity of structures across multiple scales. Finally, connectivity is related to cities' and citizens' network organisation. Various measures are defined here by the author including entropy, which is related to the temporal and spatial dimensions; average street length, which is related to the connectivity dimension; intersection density, which is a measure of connectivity; and betweenness and closeness centrality (see Section 2.3.2.5 to read about these terminologies), which again relate to connectivity.

As previous studies have shown that complexity is a key term in wayfinding, the following subsections identify different measures that can be used to describe the complexity of layouts. In addition, the positive or negative impacts of these measures are also discussed.

Pattern

Lynch (1960) listed the five key components in cities that make them imageable: nodes, paths, districts, edges and landmarks. Accordingly, by using these five points one can understand a city system better and find one's way easier. The pattern of cities, their streets, can also be an important factor as different types of patterns may have different levels of complexity. Lynch (1981) suggested seven types of patterns:

1. Star (radial)
2. Satellite
3. Linear
4. Rectangular grid
5. Other grid
6. Baroque network
7. Lacework.

As Marshall (2004) also claimed, the relationship between these systems might be different, and hence, the complexity will vary, as will the behaviour of people. This idea points to one of the criteria defined by Lynch: paths, and their effect. In addition, it was also observed that different layouts affect people's wayfinding strategies. For instance, it was argued that in a grid network, as seen in North American street networks, with numbered streets and blocks, people might use street names in their route descriptions, whereas in Asian cities with relatively organic street layouts, people might rely on landmarks (Duckham et al., 2010). It was also suggested that different layouts could improve route learning (Evans et al., 1984). Furthermore, in a linear environment people could rely on one strategy, for example, one type of landmark may be preferred (Meilinger et al., 2015). Hence, the layout can also affect our strategies.

Decision points

The complexity of a system is not usually related to a single path, but is a combination of the circulation systems using different paths. The main distinguishing features of composite circulation systems are intersections (or nodes, as referred to by Lynch

(1960)), where people can follow alternative possible routes. Or, as argued by Arthur and Passini (1992), decision points are the intersections of corridors.

As Raubal and Egenhofer (1998) stated, decision points are directly related to choices and they are the points at which people have an opportunity to select one path from others. Decision points are the places where people should make decisions to find their way, thus these can be the points where wayfinding errors occur (Richter, 2009). Hence, it has been stated in previous studies that the number of decision points has a strong influence on wayfinding performance (Raubal & Egenhofer, 1998; Arthur & Passini, 1992).

Segment length

Segment length can be related to the decision points in an environment. If the number of decision points increases in an environment, this means that the length of segments decreases. Thus, there can be fewer possibilities of making wayfinding errors if the length of streets increases, and in turn the number of decision points decreases. Thus, longer segments indicate areas that are less complex (Richter, 2009).

Shortest route and destinations (checkpoints)

Shortest route refers to the route between two specific points that can be thought of as the best option to follow in order to finish a wayfinding task quickly and easily. There are different ways to measure the shortest route, such as that based on the distance; based on the time, that is the fastest route (Bovy & Stern, 1990); or based on the simplicity of a route, or how easy it is to explain and remember. It is expected that as the length of the shortest route decreases, the wayfinding task can be completed in a shorter time period.

Similarly, in wayfinding tasks there can be more than one destination, such that wayfinding requires finding a series of checkpoints. In comparative studies, it is essential to keep the numbers of checkpoints the same (or as similar as possible) to maximise the possibility of keeping the length of the route the same. This would also enable controlling the memory and spatial planning challenge. If the number of checkpoints varies, it is expected that it would take more time for a participant to complete the wayfinding task in an environment in which the length of the route is constant. The shortest route can also be measured with respect to the order of the checkpoints.

Dead ends

In the *Cambridge Dictionary Online* (2020), a dead end (or a cul-de-sac) is defined as “a road that is closed at one end, and does not lead anywhere”, or “a road or path that has no way out at one end”. If people want to reach a specific destination and accidentally turn in to a dead end, they can only recover this by going back to the decision point. Therefore, dead ends might make the wayfinding process more complicated as they block users’ exploration and make it harder to develop a cognitive map (Hölscher et al., 2006, 2012).

Street network entropy

Previous research stated that street network entropy (SNE) has theoretical connections with complexity (Batty, 2005; Batty et al., 2014). Entropy is explained as the state of orderliness or disorderliness (Pagkalinawan, 2019), and it can be used to quantify the complexity of street orientations and length variations (Gudmundsson & Mohajeri, 2013). Shannon’s entropy description is based on the formula:

$$\mathrm{H(X)} = -\sum_{i=1}^{m} p_{\mathrm{i}} \log_2 (p_{\mathrm{i}})$$

Equation 1. Shannon's entropy formula

Here, entropy is shown as H, m is the number of subsets in the system X, and p_{i} is the proportion of agents in the i^{th} subset (Shannon, 1948). The entropy value is low when the system is highly ordered and, hence, predictable. The value is high when the system is disordered and, hence, hardly predictable (Boeing, 2018).

2.3.2.4 The relationship between the measures and wayfinding: brief results

O’Neill (1991a) described interconnection density as a way of measuring the complexity of environments, based on the average number of directional choices at each decision point. Moreover, he hypothesised that environments with more alternatives or connections at decision points are more complex. In another study, (O’Neill, 1991b) discovered that people took more time to find a destination and they made a higher number of wrong turns when the environment had higher interconnection density. Hence, his findings supported the previous study, which stated that complexity affects wayfinding performance.

Studies about virtual environments also found similar results, as would be expected. Slone et al. (2015), for instance, developed a study based on the work of O’Neill (1991a, 1991b). They discovered that people’s abilities to find their way in an unfamiliar environment is influenced by the complexity of the layout of that environment.

As discussed previously, it is believed that longer segments indicate a less complex environment since the density of decision points will be lower (Richter, 2009). Lovelace et al. (1999) asked participants to score the quality of route directions. Researchers discovered that longer segments were more frequently mentioned than shorter ones.

Moreover, in another study, researchers stated that people found it useful to have longer segments with landmarks (Michon & Denis, 2001).

The number of dead ends and SNE have also been discussed in various studies. Researchers discovered that when people reach a dead end, or look around corners that lead them to a dead end, they make more errors (Jansen-Osmann & Wiedenbauer, 2004; Wiedenbauer & Jansen-Osmann, 2006). In another study, findings highlighted that the lower the SNE (in simpler layouts), the worse the spatial ability of the people (Coutrot et al., 2020). This study shows the comparative results from different countries and abilities of people from those countries.

Borst et al. (2009) discovered that not only the shortest route but also additional characteristics of environments influence people's behaviour. They discovered that the existence of different features, for example, shops, parks, slopes or stairs, can shape people's behaviour. Similarly, Troffa (2010) also aimed to understand whether people choose the shortest routes or highly visible routes or routes with the fewest angular changes. Results of this study showed that people tend to choose the longest route characterised by the highest visibility and by the smallest angular incidence. In addition, other studies also confirmed that minimal angular changes may attract more pedestrians than the shortest routes (Shatu et al., 2019; Turner, 2009). Thus, it is important to add all the different factors that may shape people's wayfinding choices and try to understand which are more effective. This idea leads us to the next section of the thesis, namely Space syntax.

2.3.2.5 Space syntax

In order to understand the impact of the built environment on wayfinding, to measure it quantitatively and understand the relationship between societies and the space (Hillier & Hanson, 1984) better, a set of techniques, namely "Space syntax", is used. Space syntax was developed in the early 1970s at University College London by a group of researchers led by Bill Hillier. As they discussed in *The Social Logic of Space*, "Different types of social formation, it would appear, require a characteristic spatial order, just as different types of spatial order require a particular social formation to sustain them" (Hillier & Hanson, 1984 Page 27). Hence, a social group can create an environment based on their needs and habits, while spatial structure also influences people's actions and behaviours.

Hillier and Hanson (1984) discovered that cities have some problems based on the diversity of movement. In order to better understand the problems and the possible solutions, they suggested a new way of understanding spaces: not the buildings, but the space between buildings should be analysed to understand the relations as these are the places where public activity takes place and most movement occurs (Hillier, Hanson, et al., 1987). However, another gap arose here: how could the spaces between buildings be analysed? Which methodology could be used? In Space syntax, there are two ways of analysing spaces: using lines (which can include convex spaces- see second following sub section for the definition-) or points (grids). In these two different ways, all open spaces – or spaces where people can interact – are represented with lines or points and then the relationships between these representations are analysed. The details of the method are explained in the following subsection, but first it is useful to discuss the relationship between cognition and Space syntax.

Previous studies explained that spatial configuration has an impact on spatial cognition (Tzamir, 1975; Lynch, 1960, 1981; cited in Long et al., 2007). Space syntax, however, provides an opportunity to quantitatively measure spatial configuration so that it can be related to spatial cognition. Montello (2007) analysed characteristics of environments that might affect psychology by considering the degree of differentiation and visual access that environments provide, and the complexity of layouts. These three criteria related to environment are important in order to understand people's behaviour and changes in that behaviour. Hence, Montello stated that Space syntax helps to quantitatively characterise the layout of places. Other studies indicated the need to use spatial configuration in spatial cognition, and use both objective and subjective analyses (Kim & Penn, 2004; Kim, 2001). The lack of analytical methods for describing configurational characteristics and cognitive dimensions was underlined in studies and a new approach was needed. Hence, again, Space syntax was thought of as an alternative in this sense.

In the following subsections, the terms used in Space syntax and their role in explaining behaviour and cognition are discussed.

Line-based analysis

Line-based analyses include both axial and segment-based analyses. These maps are drawn based on different principles, which are explained in the following subsections.

Axial and convex maps

Axial lines are drawn based on convex spaces. Since humans make decisions or explore environments based on the things they see, convex spaces are produced from visible/accessible spaces. In a convex space, therefore, we can observe an area from any point we are located. While producing a convex map, it is essential to draw the least number of largest spaces and to cover the environment totally (Hillier & Hanson, 1984). For instance, if we have a rectangular room with no columns or other details that would affect visibility, then this room can be represented with one convex space. Once all navigable spaces are defined with the least number of largest convex spaces, the convex map is completed. The differences in convex spaces in different urban spaces can show us the differences of systems and relationships. However, it is also possible to read the differences with axial lines, which are produced using similar criteria. Again, axial lines are drawn based on visibility. For axial lines, it is important to define all spaces with the smallest number of straight lines and with the longest set of lines (Hillier & Hanson, 1984). Whether using an axial line or a convex space, it is important to define the longest line or the largest convex space first. Next, the second longest line is drawn, and that is followed by the others. As with convex spaces, with axial lines it is important to understand the visibility within spaces. If we have a straight boulevard, for instance, with no buildings blocking our road, so our visibility, then this boulevard can be represented with only one line. If there are other roads that are connected to this boulevard and that are not completely visible from the boulevard, they are shown with additional axial lines.

Even though axial lines have been used in different studies, they have been criticised by some researchers. Ratti (2004) described several problems with Space syntax and the use of axial lines. He stated that axial maps discard components such as metric information, building height, land use or edge effect. The defined problems have been discussed in various papers: studies have been made on metric analysis (Hillier & Iida, 2005; Peponis et al., 2008, 2007), and different conditions, such as land use (Matthews & Turnbull, 2007; Ozbil et al., 2015), and alternative solutions have been developed for topographical problems (Asami et al., 2003) and for the edge effect (Turner et al., 2001). Maybe one of the most significant issues with axial maps relates to the length of axial lines and the spaces axial lines represent. For example, a long street can be represented by just one line even if the characteristics of the street change. A street with commercial buildings can consist of residential buildings after a certain point, for instance. Hence, people may not use each part of the street with the same frequency as the character of the street changes, or the street may have different cognitive effects (e.g. cultural/historical meanings). Hence, one axial line may not always be sufficient to represent the environment, and so an alternative to axial lines is needed. Hillier and Iida (2005) provided an alternative for axial maps, called “segment-based maps”.

Segment analysis

As axial maps are not effective for detecting semi-continuous lines in a system, segment maps are suggested for detecting angular relations and semi-continuous lines (Hillier & Iida, 2005; Al-Sayed et al., 2014). In segment maps, the space between two junctions is represented by a line. Hence, rather than using one long line to represent a boulevard, for instance, where the whole boulevard is visible from each corner to all others, different lines are used between intersections. This is why segment lines are defined as axial lines that are broken into pieces (Al-Sayed et al., 2014). Segment maps can be obtained in different ways. Road-centre lines, which can be collected from the municipalities, can be used as segment maps, or axial lines in an axial map can be broken into pieces to produce a segment map.

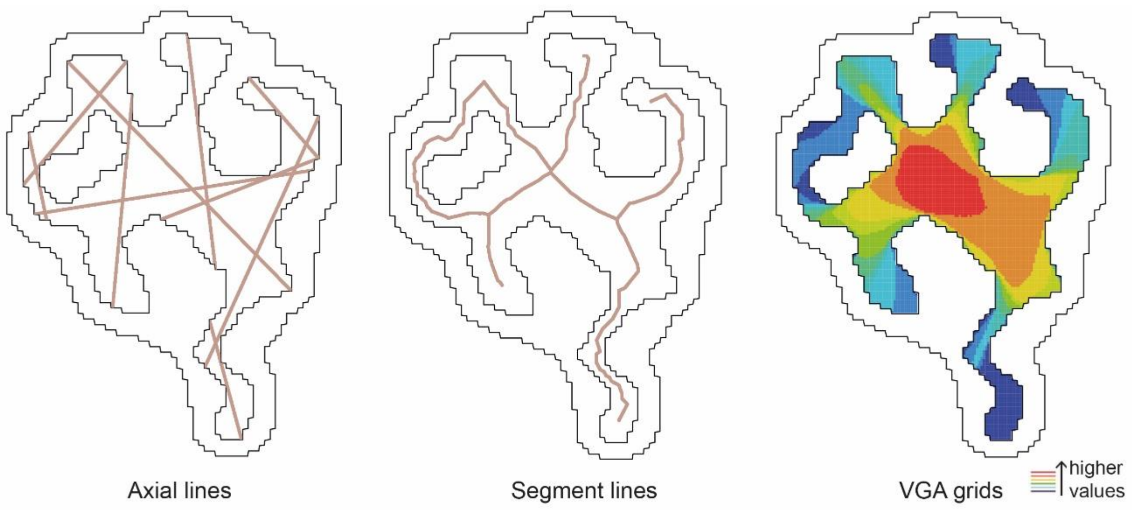


Figure 3: Three different methods (two line-based and one grid-based) to analyse navigable spaces (image shows level 46 of SHQ)

If a space is represented by lines, and the lines show the spaces that people can see or can move within, then which criteria influence people to move from one line to another? Which criteria can help us better to understand people's choices? In order to better explain the relationship between lines or spaces (Figure 3), a set of measures that are used in Space syntax are identified as follows.

Connectivity

The first measure, connectivity, measures the number of immediate lines that a line is directly connected to (Al-Sayed et al., 2014; Hillier & Hanson, 1984). Hence, this measure is about the lines that are connected to a line, and that are visible from that line no matter where we stand (Hillier, 1996b).

It is expected that the more a line is connected to others, the more it will be preferred by people as the number of alternative paths increases.

Integration

Integration shows the accessibility of a system. Imagine that we focus on one line and we would like to see how far we can reach or how much of the whole system we can cover (Hillier & Hanson, 1984), for instance, by making three direction changes. Each line, or each angular change (depending on the map we use), means a "change" and this calculation is done for all lines, so for whole system. The number of changes is called the “radius” and shown as r. The radius can be “local” values (such as 2, 3, 5 turns, for example) or it can be “global” (n) so that the relationship between each segment and all others are analysed with no limitations. If one can reach more spaces in one system compared to another, then this system is the more integrated or more accessible one.

This measure is essential as it helps us to understand movement in a different perspective. If a line or a region in a system is more accessible, then it will attract movement as well as other functions (Hillier, 1996a). People are consciously or unconsciously attracted to more integrated lines, so movement increases in these spaces. As movement increases in these spaces, commercial use tends to be located along these integrated lines. Hence integration is indicative of how many people are likely to use a space (Al-Sayed et al., 2014). However, in a neighbourhood or in a city, it is necessary to have both integrated and segregated spaces, as people in residential areas may prefer less movement and a lower number of commercial buildings.

Integration is defined as:

$$C_c\,(P_i) = (\sum\nolimits_k d_{ik})^{-1}$$

Equation 2. Integration formula

Here, C_c is closeness centrality (integration), i is the origin, and k is the destination (Law et al., 2012) as this formula measures the sum of the shortest paths between every origin and every destination.

Choice

Choice measures the movement flows (Al-Sayed et al., 2014). The more potential that lines or spaces have to be chosen as shortest routes, the higher choice values they have (Al-Sayed et al., 2014; Hillier & Hanson, 1984). According to Hillier and Stonor (2010 Page 7): “In the main forms of syntactic analysis we use for cities, the spatial element is the street segment between junctions, and the key measures are of two kinds of movement potential: *to-movement* potential, or how easy is it to get to a segment from all others (measured by mathematical ‘closeness’ normalised as syntactic integration); and *through-movement* potential, or how likely are you to pass through as space on routes between all other pairs of segments (measured by mathematical betweenness and called choice in Space syntax).” Choice is an important measure to estimate pedestrian movement potential. However, choice can be a more effective measure of the performance of people who are familiar with the environment than those who are not (Hillier, Burdett, et al., 1987), as people’s ability to find the shortest route in an environment is related to their familiarity with it. Angular choice can be measured using the following formula:

$$B_{\theta}(x) = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\sigma\,(\mathrm{i}, x, \mathrm{j})}{(n-1)(n-2)}$$

Equation 3. Choice formula

In this formula $i \neq x \neq j$, where $\sigma(i,x,j) = 1$ if the shortest route from i (start point) to j (end) passes through x, and $\sigma(i,x,j) = 0$ otherwise (Turner, 2007). In order to compare environments of different sizes, however, normalised angular choice (NACH) can also be used (Hillier et al., 2012) using this formula:

$$\mathrm{NACH} = \log(\mathrm{value}(\text{"T1024 Choice"}) + 1)/\log(\mathrm{value}(\text{"T1024 Total Depth"}) + 3)$$

Equation 4. Normalised choice formula

Hence, normalised choice is measured by counting the number of times each street segment falls on the shortest path between all pairs of segments.

Intelligibility

It has previously been stated that complexity is an important measure to test environments. Passini (1984b) argued that complexity is desirable as long as the design of the setting allows efficient information processing. However, if an environment has high complexity then it will be hard for people to find their way, to produce cognitive maps and so to complete wayfinding tasks. Therefore, a measure to control complexity is needed.

Intelligibility, as defined by Hillier (1996a Page 171), is "the degree to which what can be seen and experienced locally in the system allows the large-scale system to be learnt without conscious effort." Hence, this measure is useful in order to understand an urban environment. If an environment is intelligible, then it is not too complex for people to complete a wayfinding task. If, however, the environment is not intelligible then this means that the complexity is high. Therefore, this measure allows researchers to control the complexity of the environment.

Intelligibility can also be defined as the correlation between connectivity and global integration. Hence, if well-connected lines are also well-integrated, then the correlation in an environment is high and the system can be described as intelligible (Hillier, Burdett, et al., 1987). If the regression line for the correlation between connectivity and integration is at an angle of 45°, then spaces that are more connected are also more integrated, which is the optimal scenario, and the system is perfectly intelligible. As the line gets further away from 45° then the intelligibility decreases, which means that the connections and the integration do not change in the same way. This kind of an environment can cause people to lose orientation and get lost frequently.

Metric reach

Peponis et al. (2008) stated that the density of streets affects the potential of different types of movement. As the street network density increases, the number of destinations that can be reached also increases and more opportunities arise to discover new places. Hence, it is argued that street density is an important component for understanding movement. In order to measure this potential, researchers aim to understand the total street length that can be covered by using a certain distance threshold. For cities, 1 kilometre (Peponis et al., 2008) can be used as that is thought to be the approximate distance someone can reach in 10 minutes; depending on the sample group and the scale of the environment, the distance can vary (e.g. 400, 800 or 1600 metres).

Metric reach can be shown using this algorithm:

$$\text{Metric reach} = \mathrm{R_v}(\mathrm{P_i}, \mu)$$

Equation 5. Metric reach algorithm

Here, s is aggregate length and metric reach "of a point $\mathrm{P_i}$ according to a metric threshold μ as the length of the road segments and fractions of road segments covered by the union of all paths for which s ≤ μ" (Peponis et al., 2008 Page 883).

Directional reach

Peponis et al. discussed the impacts of direction changes on configurational complexity as well as environmental psychology and wayfinding tasks (Moeser, 1988; O'Neill, 1991a, cited in Peponis et al., 2008). They stated that the number of turns causes an increase in the cognitive load in memory, and so people tend to use paths with fewer turns (Bailenson et al., 2000, cited in Peponis et al., 2008).

Since direction changes affect people's behaviour, it is necessary to make measurements. Directional distance is defined as the number of direction changes necessary to reach a destination from a specific point (Peponis et al., 2007, 2008). In order to calculate directional reach, road segments are used, and midpoints of road segments are defined. Then the total segment length that is accessed within a defined number of direction changes is measured. Different numbers of direction changes can be used for the analysis. Usually, 10° and 20° and 0, 1 and 2 changes are preferred to understand how far one can go by using minimum angular changes or by using a minimum number of turns. This can be done for all segments or, more commonly, it can be stopped when a specified number of turns is completed.

Directional reach can be explained as follows:

$$\text{Directional reach} = R_u(P_i, \delta, \alpha, r)$$

Equation 6. Directional reach algorithm

Hence, "directional reach $R_u(P_i, \delta, \alpha, r)$ of a point P_i, according to a directional threshold δ as the aggregate length of the road segments and fractions of road segments that are no more than two direction changes away, subject to a direction change threshold angle α and a very small line segment threshold set to a fraction r of the average road segment length. When δ is set to 0, $R_u(P_i, 0, \alpha, r)$ expresses the length of the directional element which comprises P_i . When δ is set to 2, $R_u(P_i, 2, \alpha, r)$ expresses the total length of streets that are up to 2 direction changes away from a given point." (Peponis et al., 2008 Page 893).

Visibility-based analysis

Visibility-based analyses are also important measures that can be used, as they provide mathematical descriptions of experiences. These analyses can also be used to understand how people can move or how they interact within spaces. Because of the practical and cognitive limitations that axial-based analysis may have, visibility-based analysis may be preferred. Jiang and Claramunt (2002) suggested that while wayfinding in an urban environment, when people reach a specific point where they need to decide whether they will turn left, right or walk straight on, directly visible points, which can be represented by grids/cells, are essential for decision making.

In order to produce a similar representation to that of Hillier and Hanson (1984), Turner et al. (2001) constructed a graph connecting all visible points in a grid system. Visibility analysis has been performed by different researchers in different studies (Batty, 2001; Benedikt, 1979; Turner et al., 2001). An important explanation was proposed by Conroy (2001), as she discovered that people tend to slow down at intersections while they are moving within an environment. Hence, questions arose from this experiment: how do we decide which way to go? How does visibility affect movement, and how can we measure it? An isovist, or viewshed, is defined as the area in an environment that is directly visible from one location (Turner et al., 2001). A visibility graph consists of linked locations that can be seen from a specific point or points (O'Sullivan & Turner, 2001). Hence, as with line graphs, in visibility graph analysis the relationship between points is analysed and if this relationship is direct (if from one point, another point is visible or accessible), then this relationship is shown in graphs.

Visual connectivity

One of the first results that we are able to see from visibility graph analysis is visual connectivity. Visual connectivity refers to the points (or grids) that a surface is directly related to (Peponis et al., 1998). An increase in visibility may help people to find their way more easily as it may be a reason for people to be slower if a decision has to be made (Conroy, 2001). In a visually highly connected environment, people can view the alternative paths (or the environment itself) well and decide where to go.

Visual integration

Visual integration can be defined as the number of grids that must be considered to link grids to all others (Peponis et al., 1998). Hence, if we imagine that all navigable spaces are represented by grids, the integration analysis of these grids will lead us to visual integration, which also shows how many visual fields we should to pass to see the whole layout (Hillier & Tzortzi, 2006). Visual integration shows the potential core area in a system where one can see much of the spatial layout (Al-Sayed et al., 2014).

Isovist analysis

An isovist generates all locations visible from one point (Turner et al., 2001). As an isovist or viewshed measures the visible spaces, it is helpful to understand the possibilities of a potential movement. An isovist analysis can be conducted for the whole visible surroundings from a specific point (360°), it can also be conducted for specific values such as 90° or 180° to make predictions based on the observer's field of view.

2.3.2.6 The relationship between Space syntax measures and wayfinding: brief results

One of the first attempts to understand the relationship between Space syntax and human behaviour was made by Hillier et al. (1987). They aimed to see if it is possible to understand the occupation density of spaces with Space syntax measures. They observed selected points in different areas to see the number of people using the spaces. Results of correlation analysis showed a significant relationship between the number of people and the accessibility measure, integration. Peponis et al. (1990) used axial integration and asked 15 subjects to explore an environment. They also discovered that people's movement correlated with integration. Similarly, Emo et al. (2012), discovered that both local integration and global choice offered a strong correlation with people's route choices. Haq and Zimring (2003) asked 128 people to perform wayfinding tasks in three hospitals and get to know the environment. They observed that participants first used local clues, such as decision points that they could see from a given point, and as the familiarity increased, they used global clues, such as integration. Researchers argued that less intelligible settings are harder for people to understand. In the same period, Haq and Girotto (2003) conducted experiments in two hospital buildings in which they asked volunteers to explore these unfamiliar buildings. One of the most significant findings of this study is that researchers discovered that intelligibility settings are predictive for wayfinding. In another study, Kubat et al. (2012) analysed the historical peninsula of Istanbul and asked people who were unfamiliar with the area to find their way. Researchers discovered that visual connectivity as well as street connectivity (both metric and directional reach) were positively associated with the frequency of routes being selected during wayfinding. Many other studies also discussed the effectiveness of the measures: integration (Hillier et al., 1993; Kim and Penn, 2004; Ozbil et al., 2015), choice (Ozbil et al., 2015), intelligibility (Kim, 1999), metric reach (Ozbil et al., 2016, 2015), directional reach (Ozbil et al., 2016) and visibility graph analysis (Hölscher et al., 2012).

The number of studies about virtual environments is limited compared to the studies in real environments. However, it can be asserted that studies in virtual environments found similar results. Haq et al. (2005), for example, discovered that integration (local, r:3) was helpful for predicting the distribution of people in both real and virtual environments. Another study showed that intelligibility helps us to understand movement paths in virtual environments (Conroy, 2001). Studies about virtual environments also stated that people choose the straightest routes in unfamiliar environments (Conroy Dalton, 2003). This is a significant finding as it supports Hillier and Hanson’s idea (Hillier & Hanson, 1984), where they underlined the significance of the line of sight: the longest lines that can be drawn based on the visibility. This can also be explained with complexity, as more turns can create confusion.

2.3.3 ***Visual summary diagrams for wayfinding studies and conclusion***

This chapter of the thesis is about the wayfinding process and various factors that may affect it. Visual summary diagrams are used to compare the existing literature easily and to better understand the methods that have been used. With the help of the diagrams, it is possible to illustrate the content of a paper, and visualise the categories that were used and discarded. Moreover, it is also possible to compare different studies easily using this method (Simpson et al., 2017). To summarise the studies visually, papers in the literature were chosen based on their relevance to this study as well as the originality of the results.

As this thesis is concerned with landmarks and wayfinding, the main categories were defined as people (the observer), environment (the area that the observer experiences) and landmarks (the bridge between the observer and the place – the cue). Figure 4 provides a visual representation of the themes covered in the literature on the role of landmarks in wayfinding. By using the image and colours, methods used in the papers can be visually compared. The literature review associated with landmarks is discussed in full in the next chapter and the images are prepared so that the visual summary diagrams for each chapter are easily comparable. Therefore, the following description of the diagram is applicable for its use in both Chapter 2 and Chapter 3.

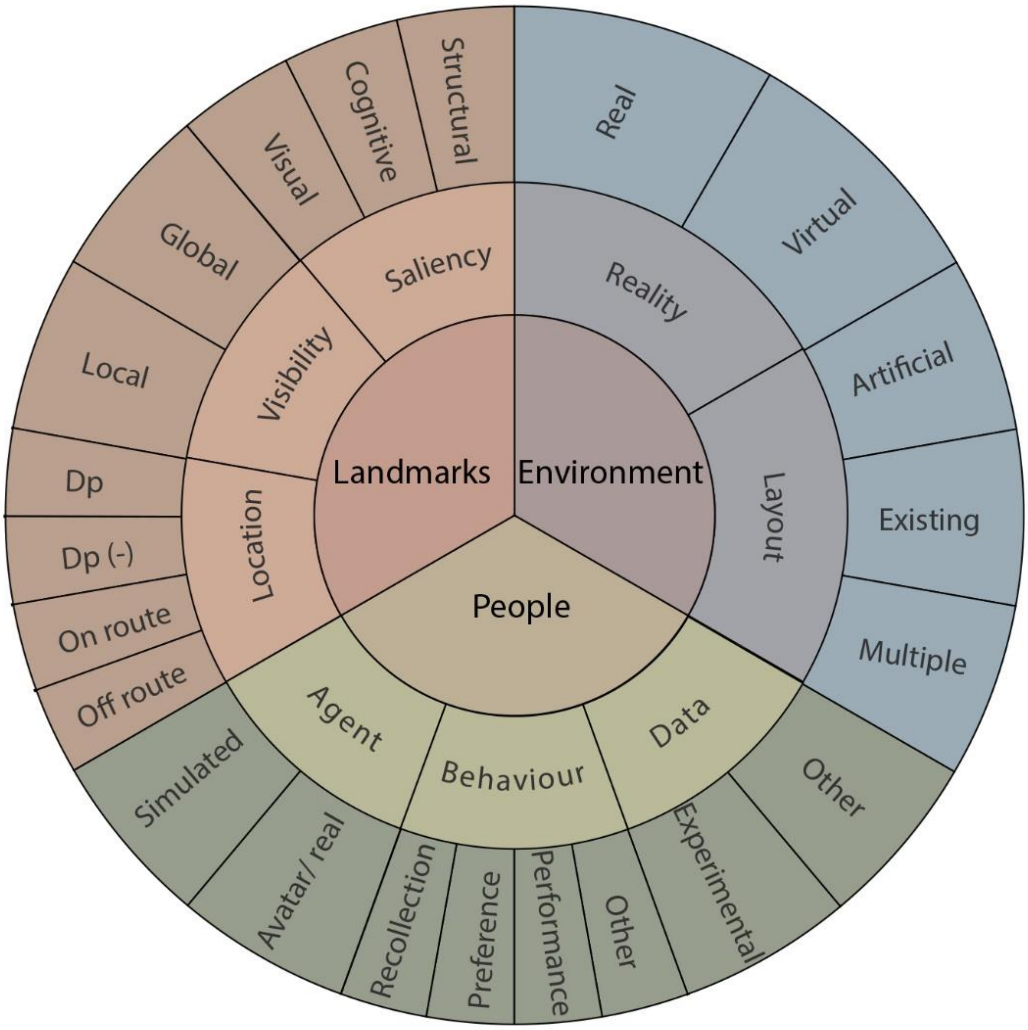


Figure 4: Visual summary diagram for wayfinding and landmark studies in the literature. The graph is an interpretation of Simpson et al.'s (2017) graph.

The *landmarks* section of the graph was further divided into three categories: location, visibility and saliency of landmarks. Based on the literature examined in the next chapter, the location of landmarks was grouped into four categories: landmarks at decision points with a turn dp and without a turn dp (-) and landmarks that are on route and off route. Thus, for example, if a paper mentioned on-route landmarks with a turn, both decision point dp and on-route options were coloured in. If, however, no turns were mentioned and only the concept of landmarks at decision points was used, then the dp (-) option was highlighted in the diagram. The visibility of landmarks was categorised as global and local, similar to the categorisation in the literature. Finally, the saliency of landmarks was further split into three categories: visual, cognitive and structural.

The *environment* was divided into two categories: mode of reality and layout. Real and virtual environments were compared under the heading reality whereas artificial, existing, and/or multiple layouts were considered under layout heading. For papers that did not use any layouts and worked with basic graphics, both real and virtual environment were coloured as the results of these studies can be used for both groups. Existing layout was used for the layouts that are based on real layouts while artificial was used for imaginary/hypothetical layouts. If a paper used multiple layouts, this fell into the multiple category.

Finally, considering the observer, the *people* segment was divided into three categories: agent (simulated or avatar/real), behaviour (recollection, preference, performance data and other observations), and data (experimental or other). The avatar/real and simulated options were coloured in depending on whether the observer was human or not. If a study included experiments with people, then the experimental segment was coloured in; otherwise, the 'other' option was used. If participants were asked to remember the experiment they participated in and then draw or note the objects they recalled, post hoc, then the recollection segment was used. Preference was used for any experimental conditions in which the subjects chose one or more alternatives from others. Performance was used to visualise any study in which participants performed a task (e.g. they needed to way-find) and that was recorded by the researchers. The 'other' option was used for any other experimental condition (e.g. questionnaires about experiences, ranking of landmarks, etc.). Therefore, this visualisation aimed to cover all existing definitions and methodologies in the literature.

Hence, to better understand the literature on wayfinding and make comparisons easily, visual summary diagrams are shown in Figure 5. Twelve papers were selected based on their relevance to this study as well as the originality of the findings. This was considered to be a sufficient number to cover all segments of the diagram with the examples. It was also thought that this number would provide a sufficient range of examples for the reader while not being so many that the reader might became overwhelmed with information. The diagram visualises and compares papers in three categories: in column a, papers about wayfinding and behaviour; in column b, papers about complexity analyses and wayfinding; in column c, papers about Space syntax and wayfinding.

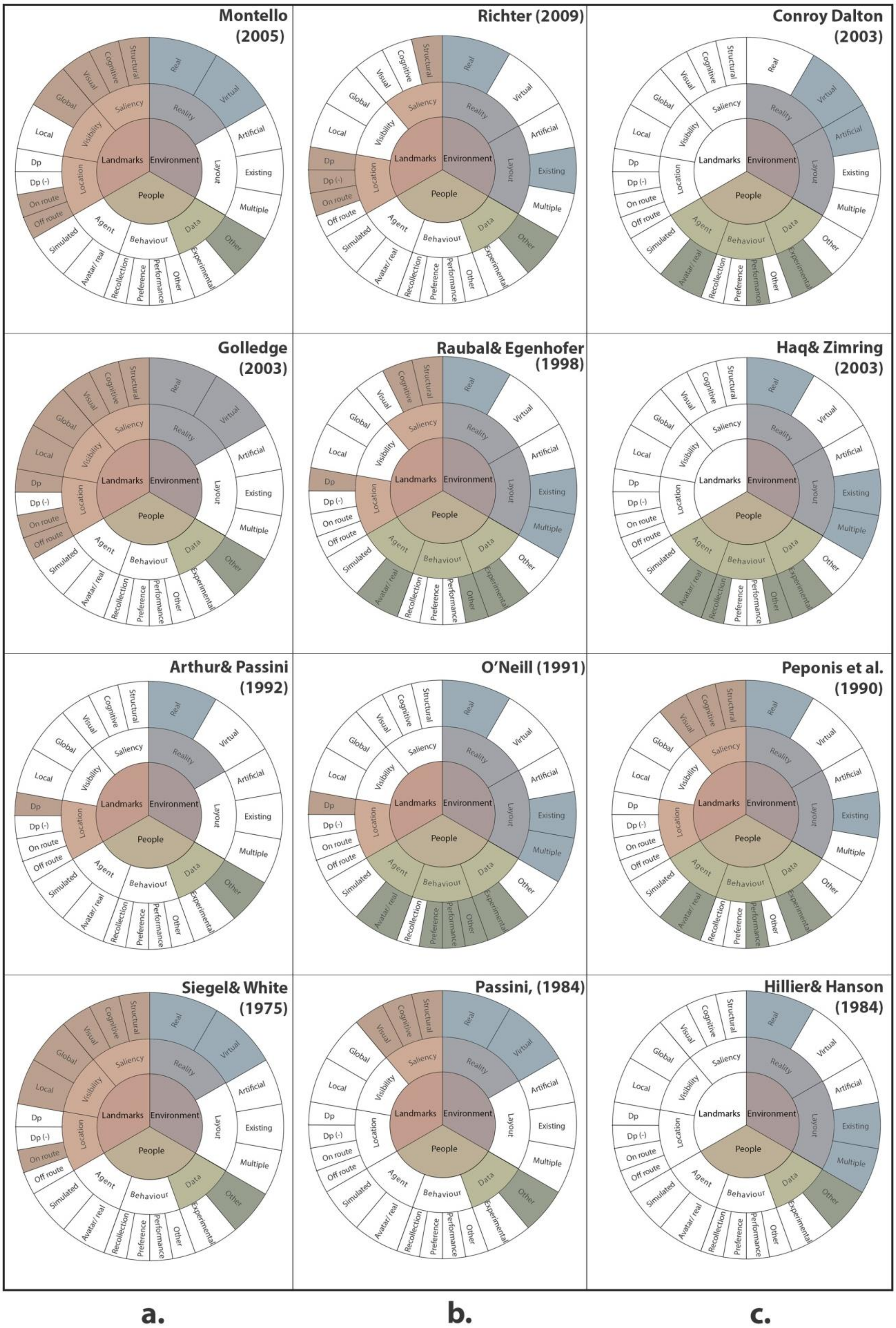


Figure 5: Visual summary diagrams for the literature on wayfinding. Diagrams were prepared to review: a. behaviour and wayfinding relationship, b. complexity analyses and wayfinding relationship and c. Space syntax measures and wayfinding relationship.

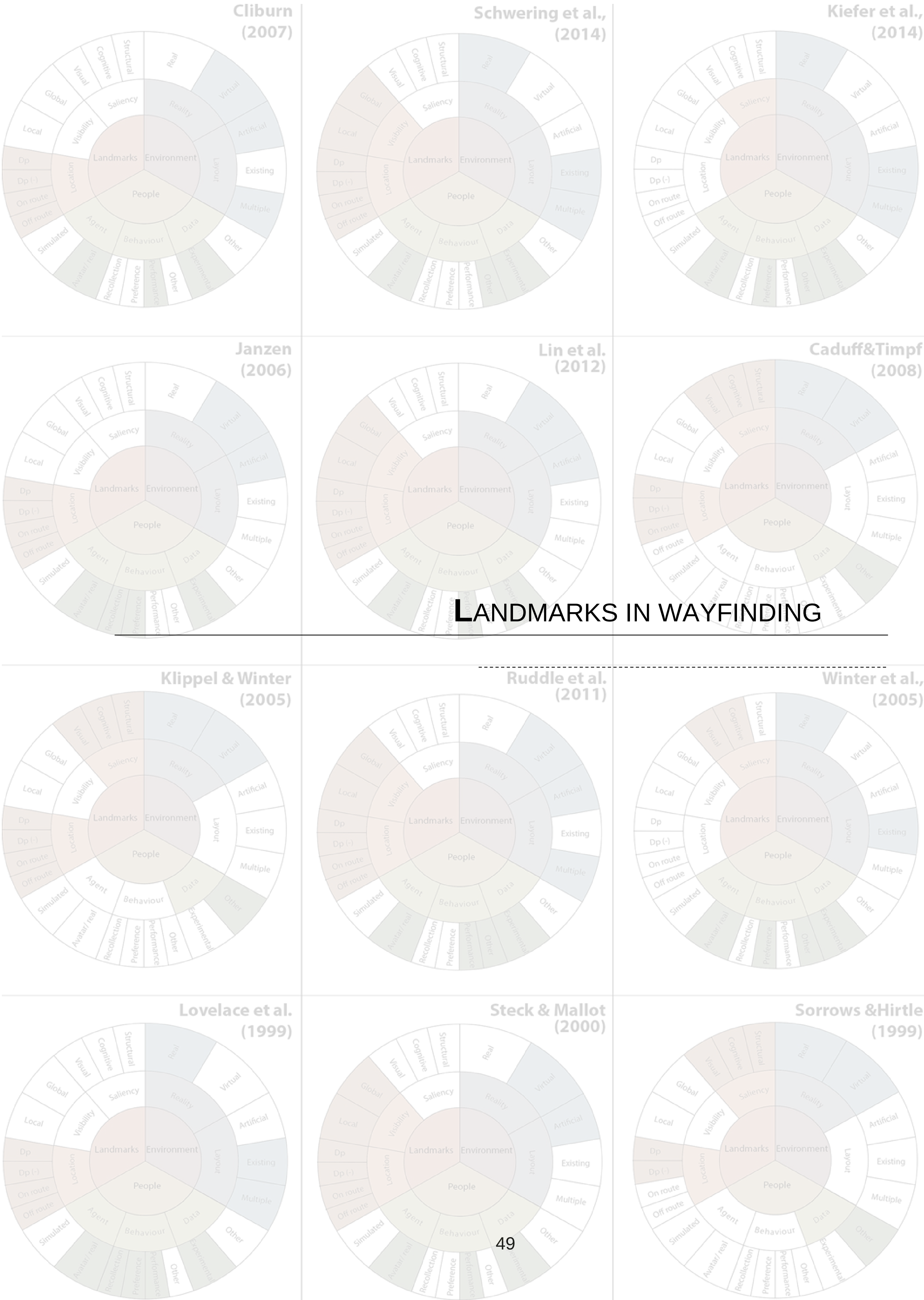
One of the most significant points that Figure 5 shows is that in studies related to Space syntax and wayfinding (column c), the use of landmarks is quite limited. As the significance of using different tools and components together was mentioned before, this can be accepted as one of the limitations in the literature. In contrast, it can be also seen from the figure that studies about behaviour focused on the impact of the landmarks and they even discussed the impact of different types of landmarks on wayfinding. Hence, it can be claimed that landmarks are important to explain people's behaviour and if the environment is analysed in order to better understand changes in behaviour, landmarks should also be considered in studies. Similarly, studies focused on the complexity analysis also mentioned landmarks; however, different types of landmarks and their impact on performance were not analysed in detail. Hence, this can also be seen as another gap in the literature.

2.4 Summary of the chapter

This chapter is essential to understand the wayfinding literature. First, the definition of wayfinding and wayfinding in different conditions are discussed (familiar or unfamiliar environments, virtual or real environments etc.). Then the environmental factors that might affect people's wayfinding performance are listed. The results of the studies show that different measures should be combined and used in wayfinding studies together to better explore the reasons underlying human wayfinding choices. Complexity and Space syntax measures are introduced here, as many studies focused on these components showing that there is a consensus in the literature about the factors that affect people's wayfinding performance. However, different measures have been shown to have different levels of significance in different studies. Hence, it is not possible to find a consensus in the literature about which components are most important. This situation suggests that more research is needed in this field. The effects of different conditions associated with both weather and maps have been observed in a limited number of studies. Hence, research can also consider these different conditions to better understand their impact and to expand the literature on these factors.

In the introduction, it was stated that the one of the questions raised in this study is: "**Which environmental factors or conditions make wayfinding easier?**". The review on wayfinding shows that wayfinding can be analysed by using complexity measures as well as Space syntax measures to understand the impact of layouts on people's performance. Moreover, different weather and map conditions can also be used to enrich the methodology and the results of the studies. Therefore, these different factors are used in this study to answer the first research question.

Environmental factors that affect wayfinding abilities of people are discussed in this section. The next chapter focuses on another key factor: landmarks.


Cliburn (2007)
Schwering et al., (2014)
Kiefer et al., (2014)
Janzen (2006)
Lin et al. (2012)
Caduff&Timpf (2008)
Klippel & Winter (2005)
Ruddle et al. (2011)
Winter et al., (2005)
Lovelace et al. (1999)
Steck & Mallot (2000)
Sorrows &Hirtle (1999)
Landmarks
Environment
People
Saliency
Visibility
Location
Reality
Layout
Agent
Behaviour
Data
Structural
Cognitive
Visual
Global
Local
Dp
Dp (-)
On route
Off route
Simulated
Avatar/ real
Recollection
Preference
Performance
Other
Experimental
Real
Virtual
Artificial
Existing
Multiple

3 LANDMARKS IN WAYFINDING

3.1 Introduction

In the previous chapter, the components of the spatial layout and other conditions are explained. In this chapter, the literature on one of the significant components of the environment, landmarks, is explored. To do this, landmarks are grouped into three categories and the methods and findings of the relevant studies are explained and compared. Visual summary diagrams are used again in order to create easily readable and comparable data and the findings of previous papers are interpreted.

According to Arthur and Passini (1992) people should be able to *remember* the objects or the key points that affect their wayfinding process. If people are able to remember the objects they see during wayfinding, then they can find their way easily and orient themselves in the environment. However, which objects do people tend to remember? It is stated that a part of our brain called the retrosplenial cortex discriminates between permanent objects and transitory ones (Bond, 2020), so that rather than remembering objects that might disappear soon, like rainbows or vehicles, we tend to remember fixed objects, such as buildings and trees. This idea gives us insights, but still it is not clear how we select objects in an environment where we are surrounded by fixed objects. Based on the literature, it can be claimed that four characteristics of objects can be remembered:

1. Form: do they have a particular shape, size or another distinctive physical characteristic?
2. Visibility and accessibility: can we move around them, or can we see them clearly?
3. Use: what function do they have? Is the function also distinctive?
4. Symbolic importance: do they have a cultural or historical meaning for citizens?

These criteria point to an important component of cities, namely landmarks. Landmarks are one of the five elements of the built environment as identified by Lynch (1960). They are easily *identifiable*, and more likely to be selected as a significant *point of reference*. Lynch did not discuss only the objects themselves, but also their relationship to their surroundings. Hence, according to the author, landmarks should have a *contrast with their background* or have a clear shape or another specific characteristic that makes them *prominent*. Moreover, he proposed the idea that an object can be recalled as a landmark by itself and as a part of a group. Hence, for example, a group of trees or high-rise buildings in an environment can be used as a reference point by people. On the other hand, the environment may change over time, and this may affect the selection of landmarks. Richter and Winter (2014), for instance, indicated that the first skyscraper in Chicago was a landmark; however, many other skyscrapers were built over time, changing what people refer to as a landmark. This is a critical point for landmarks: a unique group of objects can be used as a landmark; however, if these objects are distributed throughout an environment, they can no longer be used as landmarks, since they are no longer unique. This is why the unique or prominent characteristic of a landmark is important.

The early definition given by Lynch (1960) is still one of the most significant definitions in the literature as it provides guidance about the characteristics of landmarks. Additional characteristics have also been discussed in the literature. Richter and Winter (2014) argued that landmarks serve as anchor points and points of reference. The significance of the location of landmarks (Lovelace et al., 1999; Siegel & White, 1975; Sorrows & Hirtle, 1999), their visual characteristics (Raubal & Winter, 2002; Golledge, 1999; Couclelis et al., 1987) and their relationships with their environments as prominent objects (Caduff & Timpf, 2008), were discussed previously. It was also stated that the cultural, political or social impact of landmarks on people might make them more *noticeable* (Caduff & Timpf, 2008; Couclelis et al., 1987; Sorrows & Hirtle, 1999). Coucleis et al. (1987), for example, identified landmarks as having *distinctive* or *outstanding* features or being objects with *symbolic meanings*. Thus, these characteristics help landmarks be noticed and remembered (Presson & Montello, 1988; Sadalla & Magel, 1980). Although the phrase "landmarks which have contrast with their background" was used as one of the key terms in the literature, one group of researchers could not find any evidence for this assumption in a study organised in a virtual environment laboratory (Röser et al., 2011). Actually, this study found a low contrast situation to result in better wayfinding performance. However, many other studies agreed that landmarks should contrast with their background to become noticeable. The brevity of a landmark description (the number of words used) has also been discussed (Burnett et al., 2001). It was argued that a good landmark does not require a long explanation; instead, it should be as concise as possible (Nuhn & Timpf, 2018). For instance, rather than saying "turn right after the stone building with a wooden door and high windows", one could say "turn right after the church". This would be a shorter definition consisting of a specific function so that it would be easier to remember. The definition of landmarks usually points to the interaction between people and spaces, as landmarks are chosen as a result of this interaction. Another example for this relationship can be seen in Richter and Winter's definition where the authors defined landmarks as "geographic objects that structure human mental representations of space” (2007 Page 205). In this definition, it is stated that a space can be represented by an object in people’s mind. When we think about Paris, for instance, we may initially think of the Eiffel Tower. This landmark becomes one of the most significant representations of the city because of its unique height and shape. Hence the environment also has an effect on people’s landmark selection. These researchers concluded their work by indicating that landmarks are also related to people’s experiences. People’s interests, backgrounds and thoughts have an effect on their landmark selection. Therefore, landmarks are not independent from the environment or people.

This part of the literature review discusses the second research question: “**How do we select landmarks in unfamiliar environments?**” It was claimed previously that any item can act as a “landmark” (Ishikawa & Nakamura, 2012; Quesnot & Roche, 2015a). In this case, how can we know what makes a landmark preferable during a wayfinding study? Is it due to the previously mentioned characteristics (e.g. the uniqueness, prominence of landmarks, etc.) and if so, can we measure this? The characteristics of landmarks that make them more significant than others in different environments are examined here. The objectives of this chapter are to understand the methodology and main findings of the literature on wayfinding and landmarks (Arthur & Passini, 1992), and to identify the consensuses and the gaps in the literature.

3.2 Landmarks as route aids

Landmarks can be used for different purposes including finding one’s way to a certain location (Klippel & Winter, 2005), orienting oneself in order to understand whether the selected path is correct (Michon & Denis, 2001; Philbeck & O’Leary, 2005), or identifying specific locations (Downs & Stea, 2011). Therefore, they help people organise their spatial knowledge and locate themselves with respect to a specific destination (Couclelis et al., 1987). Most commonly, landmarks provide information for people to better understand when they should change their orientation along a route (Michon & Denis, 2001). Hence, they affect decision making (Golledge, 1999) and route learning (Tlauka & Wilson, 1994; Waller & Lippa, 2007). Thus, they can be used for various purposes at different stages of wayfinding. The literature on the effect of landmarks on wayfinding can be divided into three elements: the effect of the location of landmarks, the effect of the visibility of landmarks, and the effect of the saliency of landmarks. Actually, the location of landmarks can be thought of as part of its saliency as it is related to the structural characteristics of landmarks. The visibility of landmarks is also closely related to the saliency of landmarks. However, since these characteristics are mentioned separately in various studies, they are also discussed separately here. Nevertheless, the reader can also follow the relationship between these concepts. Based on the categories and the brief definitions already provided, the landmark definition of this thesis is: "*any salient object that is personal, communicable and visible either from a distance or close up in an environment such that it can be used in the wayfinding process for various navigational tasks (e.g. route definition, orientation etc.).*"

In the next sections, papers on the location, visibility and saliency of landmarks are discussed. The purposes, methodologies – selection of environments, selection of participants and landmarks – and results of the papers are examined. Similar to the previous chapter, articles used in this chapter were collected from Google Scholar using the search term "landmark". The majority of the search was conducted between February 2019 and September 2019. The review includes any possible step during wayfinding, such as route description, orientation or actual wayfinding. It mostly focuses on studies in large-scale urban environments and outdoors rather than indoor navigation or rural environments. Studies comparing different features of landmarks as well as studies on route knowledge are the main focus of this review. In addition, visual cues are investigated here rather than olfactory or acoustic cues. On the other hand, papers on specific topics (e.g., diseases, animal related research, research on specific age groups, people in different mood), studies only on autonomously navigating robot systems and self-movement cues are excluded in this review.

3.3 Effect of location of landmarks

The location of landmarks may be the only area on which there is a consensus. Chan et al. (2012) focused on the function of landmarks to understand how they help people in the wayfinding process. They presented a four-part taxonomy: beacons, orientation cues, associative cues and reference frames. Accordingly, the beacon landmark type includes single objects that point to the exact location of a goal location; orientation cues are visual cues that provide a heading direction; associative cues are single objects that give relevant information; and reference frames provide a framework for spatial encoding. By using the location of a landmark, one can understand several aspects of a wayfinding task. Moreover, if the cues are effective (e.g. if they can be easily seen, etc.), then it is hypothesised that it would be easier to complete the task.

A number of studies have emphasised that landmarks located at decision points are better remembered (Aginsky et al., 1997; Janzen, 2006) and more effective in wayfinding tasks (Lynch, 1960). Janzen (2006) organised three experiments using recognition tasks in a VE with landmarks located at decision points and non-decision points. Results indicated that objects at decision points were recognised more quickly. Miller and Carlson (2011) also devised two experiments in which 96 subjects learned a route through a virtual museum. They discovered that objects at decision points both with a turn and without a turn were recognised. It is also stated that the main role of landmarks at decision points is to confirm one's orientation or heading (Schwering et al., 2013), so that it can be understood if a change in trajectory is needed to find the goal (Michon & Denis, 2001). This shows the significance of landmarks at decision points.

Not only landmarks at decision points but also on-route landmarks have been discussed in different studies. Klippel and Winter (2005) created a taxonomy of landmarks based on several criteria. Accordingly, landmarks can be located at some distance from the route or somewhere along the route. If they are along the route, they can be located between decision points or at decision points. They also gave two options for landmarks at decision points: either with a direction change or with no direction change. Moreover, for landmarks at decision points with direction changes, they identified three different categories: landmarks passed before reorientation, landmarks passed after reorientation (landmarks that can be observed immediately after a turn) and landmarks not passed (reorientation without passing the landmark). The different locations of objects were then used for calculating an overall value for landmarks. Landmarks on routes and at decision points got higher scores. Lovelace et al. (1999) used landmarks according to whether they were at decision points as well as other criteria. They aimed to explore the effect of different locations on people's wayfinding performance in familiar and unfamiliar environments. They used four landmark categories: choice point landmarks (landmarks on the route and at a turn), potential choice point landmarks (landmarks on the route, but not at a turn), on-route landmarks (landmarks on the route but not at a decision point), and off-route landmarks in a campus area. People were asked to give route directions, retrace their route and remember whether or not they had seen a particular scene, which they were shown after the event, while travelling. Researchers discovered that landmarks on the route but not specifically at decision points were used for familiar and unfamiliar route descriptions. In addition, they observed that choice point landmarks were used effectively in unfamiliar route descriptions. The result on the effect of landmarks on route learning is in agreement with the findings of the previous research (Tlauka & Wilson, 1994). These studies indicated that landmarks are effective not only at decision points but also along routes.

In addition to the studies about landmarks at decision points and landmarks on routes, various studies have explored dynamically placed landmarks to better understand effective landmark placement. Darken and Sibert (1993) aimed to investigate the design principles for navigational aids. They described "breadcrumbs" (or the Hansel and Gretel Scenario), which is a manual landmarking technique where subjects mark their position with an object. They stated that landmarks can either be dropped at regular intervals along a straight line between two positions to mark places, or they can be dropped to be used as directional indicators. Researchers also discussed that if dynamically placed landmarks are also directional, they would make it easier to way-find. Cliburn et al. (2007) analysed four conditions in VEs: no landmarks; with statically placed landmarks, in which objects were located at intersections; landmarks dynamically placed at the subject's discretion and that disappear from one trial to another; and landmarks dynamically placed and that remained from trial to trial. They asked people to navigate in an environment multiple times. Researchers introduced two hypotheses: (1) dynamically placed landmarks can be effective for first-time searchers, and (2) dynamically placed landmarks, which remain between visits, can also be beneficial. They discovered that subjects travelled further during their first trial under all conditions; thus, they could not support their first hypothesis. However, they observed that dynamically placed landmarks that remain between trials could have an effect on wayfinding. Participants travelled longer distances when there were no landmarks compared to the other three conditions. Hence, all three conditions with landmarks helped people to complete the task in a shorter time compared to the no landmark condition. It was also observed that different strategies were used to drop the landmarks. Similarly, Von Stülpnagel et al. (2014) were interested in the impacts of navigator-driven and individual landmark-placement on spatial learning. They created three different conditions: no landmarks; individual landmarks, in which up to four objects were placed; and preplaced landmarks, in which four landmarks were placed so that at least one of them would be visible from any point. Researchers developed three VEs with simple geometric shapes and asked the participants to explore the environments and then draw a sketch map. As a second study, participants were asked to explore a virtual model of the Tate Gallery (London) and to find three locations. This time, researchers used non-directional and directional landmarks. They analysed both the mean time taken and mean distance travelled to complete wayfinding tasks and they observed that participants tended to place landmarks at the most central and visible locations. On the other hand, they could not find any impact of individual landmark placement on wayfinding performance. Hence, the impact of dynamically placed landmarks can still be debated. However, it can be concluded that the visibility of objects is the most important factor for dynamically placed landmarks.

3.4 Effect of the visibility of landmarks

Landmarks can be divided into two categories, global and local landmarks, depending on their visibility during the wayfinding process. Distant objects such as towers that can be observed from a great number of vantage points are accepted as global landmarks

(Steck & Mallot, 2000). Lynch (1960) described global landmarks as elements seen from many angles and distances. In contrast, local landmarks are only visible from close up (Steck & Mallot, 2000), from a limited area or from certain approach directions (Lynch, 1960). Local landmarks can be trees, or signs (Lynch, 1960) and they might be more personal (Dalton & Bafna, 2003). A vast number of studies used these definitions for global and local landmarks. Castelli et al. also made a similar definition: "global landmarks, *being potentially visible from any point within the navigational environment* and so from a great distance, become absolute points of reference, favouring orientation strategies in survey terms" (2008, Page 1648). A similar definition was also made by Lin et al. (2012). At this point, a question arises: is it necessary for a landmark to be *visible from any point* in an environment? Is it not possible for a landmark to be visible from many locations in an environment but not from all and yet still help people to have global orientation? From another perspective, if we try to apply this "visible from any point" idea to cities in which we live, how many global landmarks can we define (i.e. those that are visible from everywhere)? If we accept that global landmarks are objects that are visible from multiple points in an environment, then another question arises: how can we actually identify a threshold between a global and a local landmark? When does a landmark stop being local and become a global one? Therefore, a clear definition of global landmarks and a threshold for distinguishing global landmarks from local ones are needed, especially for large-scale environments with many visual cues.

On the other hand, an interesting approach was defined by Bhatia et al. (2013). The researchers used 3D isovists to define landmark visibility by analysing two well-known architectural designs. In this study, 3D isovists were compared to differentiate monotonous regions from more visually distinct ones. This was an important attempt at showing that the isovist view can be used to explain the effectiveness of landmarks. By using 3D isovists, landmark visibility on a route can be explored, in a similar way to the approach used in the current study, and the differences in landmark visibility can show the differences in their effectiveness on wayfinding. The authors used the term "structurally more salient landmarks", which can help us to define global or local landmarks, since the visibility also refers to the visibility of landmarks during a wayfinding task, which can provide location information to people. Hence, by defining structural saliency, the visibility of landmarks, more specifically global and local landmarks and the distinction between them, can also be analysed.

3.4.1 ***Findings of studies on the visibility of landmarks***

Although there is a considerable body of research about the visibility of landmarks, their results vary. Numerous studies have claimed that the role of local landmarks on wayfinding is more important. Ruddle et al. (2011) hypothesised that adding both types of landmarks to an environment would reduce the number of navigational errors. They designed four virtual marketplaces in a grid layout and asked people to navigate under four different conditions: no landmarks, only local landmarks, only global landmarks, and both local and global landmarks. All landmarks consisted of pictures and the positions of landmarks were automatically generated by a computer program. Researchers observed that local landmarks did reduce participants' errors; however, global landmarks did not influence the overall number of errors. Moreover, local and global landmarks interfered with each other and participants who were provided with both kinds of landmarks made more errors. In the second study within the same publication, the performance of those who walked through the VE and those who travelled by physically turning but moving forward with a joystick was compared. It was discovered that participants who physically walked in the VE made fewer errors.

In another study, Evans et al. (1984), focused on the effect of stress, landmarks and path configuration on environmental cognition. They used the terms "internal" and "external" landmarks and created four different environmental conditions: internal landmarks on non-grid pattern, external landmarks on non-grid pattern, no landmarks on a grid pattern, and no landmarks on non-grid pattern. In their experiments, a realistic model of a fictitious urban area was designed and the viewpoint of a moving automobile passenger was simulated. After watching the video of the simulation, all participants were asked to look at photos of the environment and indicate their degree of confidence in recognising each image. The images included the different landmark conditions. Internal landmarks were placed within the context of the setting while external landmarks were placed not in the immediate field of vision but in the distant line of sight. Consequently, researchers discovered no significant differences between the two landmark conditions; however, they observed a trend for internal landmarks to be more helpful in recognition than external ones. Researchers also highlighted that landmarks improved route learning more in the presence of a non-grid layout, suggesting that more research needed to be conducted in a variety of different layouts.

Meilinger et al. (2015), aiming to explain the interaction between proprioceptive and global cues, also compared two different levels of global landmark information: global landmarks providing heading-only information, and those providing both heading and distance information. They designed a virtual labyrinth layout and 33 participants were randomly assigned to one of three conditions: self-movement cues; self-movement and orientation cues; and self-movement, orientation and distance cues. Results showed that global landmarks did not have any dramatic impact on orientation. Researchers concluded that further research can be carried out with a higher number of participants.

They also highlighted that different results might be observed in a linear environment as the participants may profit from global landmarks. Moreover, Meilinger et al. (2014) aimed to explain how the locations within different spaces are represented in memory through global reference frames, multiple local reference frames and orientation-free representations. They conducted two experiments in which participants were asked to walk through an immersive VE, a labyrinth, and point to seven learned targets. As seen in previous research, this study showed that participants relied on local reference frames rather than global reference frames. Other studies conducted in VEs also found no advantages of using global landmarks (Credé et al., 2019).

In another experiment, participants navigated four VEs with different landmark conditions: only global landmarks, only local landmarks, global and local landmarks, and no landmarks (Gardony et al., 2011). The local landmarks were four different items – a rock, bush, wagon and haystack – whereas the global landmarks were four distant multi-storey buildings. Forty-eight undergraduate students were asked to find invisible target points as quickly as possible. The results of this study also showed that local cues were perceived to be key information when the environment included both global and local landmarks. It may still be important to understand the reasons why people make more errors in wayfinding tasks when they are provided with both types of landmarks, since this result was unexpected. These studies also demonstrated the effect of different layouts: it was argued that landmarks can be more effective when the environment is linear and when the layout does not have a grid format.

Another group of researchers has suggested that global landmarks are more effective during wayfinding tasks. Li et al. (2016) suggested that the existence of global landmarks might help people orient themselves between locations. They conducted three experiments. In the first experiment, four two-storey virtual buildings with the same layout complexity were used. Researchers defined two types of global landmarks: an indoor global landmark, a statue in an atrium, which was visible from multiple locations; and an outdoor global landmark, a church, visible from the building's windows. Sixteen university students participated and completed various tasks: "wayfinding" (finding a target point using the shortest route); "pointing" (turning to face a target point); and "drilling" (on arrival, stating which object/room was directly above/below them). The findings showed that increasing visual access to indoor and outdoor global landmarks significantly promoted users' cognitive map development. In another study, Li et al. (2014) presented a mobile map on a mobile device's display that visualised distant landmarks at the edge of the mobile screen to support spatial orientation. They selected 13 landmarks in Münster, Germany, to represent in the mobile device and two versions of the maps (with and without distant landmarks) were used. Researchers surveyed residents on landmark-usage and the most frequently mentioned local and global landmarks were detected. Twenty-four students who were unfamiliar with the study area were recruited for the study. They visited various locations and used mobile devices to help their spatial orientation. They were asked to estimate their direction and distance from the start point three times during the experiment. After completing the task, they were asked to perform a landmark recall task. This research showed positive impacts of global landmarks on people's orientation. Lin et al. (2012) assessed gender differences in wayfinding in virtual environments. Local landmarks were visible from only one side of the walls of a grid maze; for example, a fish, banana or bird. Global landmarks were defined as objects that could be seen from everywhere inside the maze; for example, a tower, lighthouse or windmill. After completing the learning period, participants were asked to find a specific target picture. Once they found the picture, they were asked to find another target picture. Researchers discovered that participants travelled longer distances in the local landmark condition compared to the global landmark condition. Hence, this study is also essential as it emphasises the importance of global landmarks within virtual environments. This sub-set of landmark research is important for explaining the significance of global landmarks in wayfinding tasks.

Research has also emphasised the significance of familiarity with the environment. Lynch (1960) argued that people use local landmarks to find their way if they are familiar with an environment. In his study in a real environment, Lynch observed that participants who are unfamiliar with the environment tend to use global landmarks. Other research has also supported Lynch's findings. Kelsey (2009) aimed to define global and local landmarks in a study in which she noted that there is no consensus on the definition and categorisation of landmarks. Therefore, she defined global and local landmarks based on their size and visibility, and she tested landmarks in three experiments in VEs organised using a rectangular grid layout. In the first experiment, Kelsey focused on the impact of landmark type, whether global or local, independent of their location; in the second experiment she focused on the location of landmarks, whether internal or peripheral; and in the third experiment, she focused on the combined effect of these two factors. Similar to Lynch's argument, the findings of this study also suggested that global landmarks were more effective in unfamiliar environments and when familiarity increased, local landmarks started improving the wayfinding performance. These studies highlighted the significance of the familiarity with the environment since people recall global landmarks more when they are unfamiliar with the environment.

Finally, the last group of studies focused on the idea that both global and local landmarks affect wayfinding performance. Steck and Mallot (2000) defined global landmarks as compasses and hypothesised that people might use different strategies; they might rely only on local landmarks or on global landmarks, or they might use different landmarks at different locations, or they might use both kinds of landmarks in combination. After creating a VE consisting of a regular hexagonal grid of streets, researchers defined intersections using global (e.g. television tower) and local landmarks (e.g. a phone box). Thirty-two participants, most of whom were students, participated in the experiment. Participants completed a wayfinding task after two training phases. Their movement decisions were recorded and it was observed that some participants used only local landmarks for their decisions while others relied only on global landmarks. Furthermore, some participants used local landmarks at one position and global landmarks at another. As a result of these experiments, researchers asked another question: “How do participants select a landmark for a specific decision?” Researchers discovered that at locations where participants preferred local landmarks, landmarks had different functions or visual characteristics. In addition, it was discovered that global landmarks were less visible at these points as they were occluded by trees. Hence, they argued that to understand the selection process of landmarks, not only a visibility classification but additional information (saliency) should be analysed. Moreover, Schwering et al. (2013) attempted to determine the types of information that support orientation during wayfinding. They first asked university students to draw sketch maps for first-time visitors from one direction while another group was asked to draw sketch maps from the opposite direction. Then both groups were asked to provide verbal instructions for the routes they drew. Researchers discovered that in both tasks, participants provided both global and local information to help with orientation. In addition, researchers also noted that sketch maps indicate global orientation more while verbal instructions convey local orientation.

In another study, Schwering et al. (2017) explored the use of global and local landmarks in wayfinding instructions with a larger dataset. For this purpose, they chose routes starting outside a city centre (a city centre was a global landmark according to their definition), crossing it and ending up outside it; or starting from outside, and ending inside a city centre; or passing by several cities with city centres. Twenty-one participants were recruited in Germany and they were asked to describe a familiar area with both sketch maps and verbal instructions. All participants experienced the three routes and there were at least two global landmarks on each route. Results of the study showed that local landmarks were the most commonly mentioned spatial feature in both route descriptions and sketch maps. However, all participants included global landmarks in their descriptions as well. They ended the study by saying that both global and local landmarks along the route were used for orientation. Similarly, Schwering et al. (2014) aimed to explore the use of landmarks in verbal descriptions for routes at different scales and using different transportation modes. The researchers described three routes with different scales: the first route was the shortest, at 1.2 kilometres; the second route covered the city and was approximately 5 kilometres; and the last route was at an environmental scale, at approximately 18 kilometres. All participants were given a laptop and asked to write route instructions for someone unfamiliar with the environment. While analysing the global and local landmarks, researchers focused on landmarks at potential or actual decision points or landmarks along the route to be local landmarks. They considered point-based landmarks (e.g. buildings) and regional landmarks (e.g. city centres) to be global landmarks. It was found that both local and global landmarks were used at all scales. The findings of this study suggest that global landmarks are used in wayfinding and spatial orientation in large-scale environments whereas local landmarks are mostly used in route descriptions. They concluded the study by clarifying that they only used the route descriptions task and further research could be conducted by including additional tasks and comparing the results. Finally, they suggested that using landmarks, not only at decision points but also along routes, can make route orientation more effective.

Another study, which aimed to determine the hierarchy of landmarks, used both global and local landmarks (Anacta et al., 2014). Global landmarks were categorised as point or regional features. Point-like landmarks referred to buildings, whereas regional landmarks referred to landmarks with an areal extent, such as mountains. Local landmarks were categorised as landmarks along a route and landmarks at decision points with a turn. Seventeen participants were asked to provide wayfinding instructions for someone unfamiliar with the city through verbal descriptions and a sketch map. The result of this study also showed that participants used both global and local landmarks for route descriptions. Finally, in another study aiming to clarify the effect of different verbal instructions, Li et al. (2014) concluded that wayfinding and spatial orientation can be achieved by using both global and local landmarks. They conducted the research in Germany with 11 participants and used verbal instructions consisting of landmarks at decision points, on-route landmarks and distant landmarks. Participants were instructed by machine-generated, skeletal or orientation-based instructions, and they were asked to draw sketch maps and estimate directions and distances at various locations. Researchers discovered that machine-generated instructions were less effective for acquiring spatial knowledge. They also argued that the efficiency of a wayfinding task can be increased by including both types of landmarks. All these studies demonstrated that both global and local landmarks can help people during a wayfinding task; however, a higher number of studies agreed on the impact of local landmarks, while the impact of global landmarks is still debatable. Moreover, these studies showed that the type of landmark more frequently used depends on the task being performed.

3.5 Effect of saliency of landmarks

Another important issue discussed by researchers is the saliency of landmarks. Caduff and Timpf (2008) defined the concept of saliency as being the property of distinctness or prominence of an object compared to its surroundings. They argued that a landmark must be perceptually salient and contrasting with its surroundings. Hamburger and Röser (2014) stated that landmark salience refers to those properties of an object that make it stand out from its surroundings. Götze and Boye (2016) also argued that people choose salient landmarks since they are easily recognisable and memorable.

One of the key contributions to landmark saliency research was made by Sorrows and Hirtle (1999). They defined three different landmark types in both real and virtual spaces: visual, cognitive and structural. According their definitions, a visual landmark is an object that is physically prominent due to its colour or size, for example; a cognitive – or semantic (Klippel & Winter, 2005) – landmark is an object with meaning, such as one with historical or cultural associations, or one that is well known; while the significance of a structural landmark is related to the importance of the object's location. Visual landmarks contrast with their surroundings and become memorable. A differently coloured building, or a taller building may be *visually salient.* Cognitive landmarks, on the other hand, might be culturally or historically important and as such they have significance. Cognitive landmarks can be more personal, and people may miss them if they are not familiar with the environment. Finally, structural landmarks are typically in prominent locations in an environment and thus are accessible (Sorrows & Hirtle, 1999). They can be objects in highly frequented locations, or even at intersections that are known, and possibly named, by people. This three-tiered definition of saliency is essential as it covers different aspects of saliency. However, it also poses a challenge: how can we measure landmark salience using these criteria? As the cognitive aspect is defined as the cultural or historical effect of an object, how can we measure it? As Richter and Winter (2014) stated, the experiences of people can vary in different spaces or at different times. A place that lacks any structural or visual significance can have meaning for an individual with memories of this place. Thus, familiarity is a key factor for cognitive saliency. In addition, it is also important to understand how visual, structural and cognitive saliency can be measured and compared for different landmarks.

The definition of saliency has been further refined. Burnett (1998), in his study on car navigation, aimed to identify the salient characteristics of landmarks. He proposed three factors of landmarks that can be significant for the wayfinding process: visibility, which is the ability to see a landmark; uniqueness, which refers to the likelihood of a landmark being mistaken for another object; and location, which is whether the position of a landmark allows identification. The permanence of a landmark is considered a prerequisite factor. Visibility and location relate to Sorrows and Hirtle's "visual saliency" and "structural saliency", respectively. A key study by Caduff and Timpf (2008) claimed that both Burnett's (1998) and Sorrows and Hirtle's (1999) studies failed to characterise landmarks quantitatively or to provide methods for assessing landmark salience. They introduced three terms of landmark saliency: perceptual, cognitive and contextual. In line with Sorrows and Hirtle's (1999) definition, they identified physical characteristics of objects for describing perceptual salience. However, they extended the definition by describing three categories of perceptual salience: object-based (size, shape and object orientation); location-based (colour, intensity, texture orientation); and scene-context (topology and metric refinements). In addition to these definitions, observers' knowledge and experiences are considered to be factors that affect salience. Researchers defined two components for cognitive salience: the degree of recognition, which indicates how identifiable objects are; and idiosyncratic relevance, which is the personal importance of objects for observers. For the final component, contextual saliency, two types of context were mentioned: task-based context, which includes the types of task; and modality-based context, which includes the mode of transport or the number of resources.

Recently, Von Stülpnagel and Frankenstein (2015) examined how landmarks' configurational salience impacts people's perception compared to their visual salience. In their study, the participants experienced three conditions: sketch, map and free conditions. The first and second group of participants explored a virtual environment and they were asked to produce sketch maps from their memories after exploring the environment with and without a map. The third group was asked to produce a map while they were exploring the environment. The environment contained both global landmarks – large geographic features, such as buildings – and local landmarks, such as cars. The configurational salience was measured using visibility graph analysis (VGA). Landmark size (the number of cells it occupied), integration (average visual distance to all cells) and isovist size (number of cells from which a landmark was fully or partially visible) were calculated to measure a landmark's configurational salience. Visual salience was rated by five raters using a 5-point Likert scale. Results of this study pointed to multiple issues. First, it was discovered that the best predictor of a global landmark was its size, whereas the best predictor of a local landmark it was its visual salience plus isovist size. Second, researchers could not observe any specific influence of integration. Finally, they observed that people tend to choose landmarks based not only on their visual characteristics but also on their configurational properties. Thus, in addition to other components of salience, configurational characteristics of landmarks are also fundamental in identifying landmark salience. This definition was another important contribution to the saliency literature, as it explored saliency of landmarks by using specific VGA. However, this definition can be related to structural landmarks, as it is dependent on the location of landmarks. This study is significant as it shows alternative ways of measuring salience, such as using VGA.

3.5.1 ***Automatic selection of salient features***

Many models were later developed to automatically identify visual, structural or cognitive (semantic) landmarks. Klippel and Winter (2005) referred to Sorrows and Hirtle's (1999) definitions of visual, cognitive and structural landmarks, and argued that there was a gap as structural landmarks were not defined objectively. The researchers argued that structural properties of landmarks should be countable and constant. Therefore, they approached structural salience of landmarks by considering the position of landmarks along a route (e.g. on-route/off-route landmarks, at decision points or not at decision points) and developed a taxonomy of structural landmarks. The researchers also suggested combining visual (s_v), structural (s_s) and cognitive (s_c) saliency to a weighted average of joint salience (s_o) by using this formula:

$$s_o = w_v s_v + w_c s_c + w_s s_s \text{ with } w_v + w_c + w_s = 1$$

Equation 7: Overall saliency score formula

Saliences are determined by comparing saliency properties of landmarks with the properties of objects in their neighbourhood.

Claramunt and Winter (2007) also focused on the structural salience of objects and they used Lynch's (1960) definition of the components of legible cities (see Section 2.3.2 to read about legibility) to explain structural saliency. They defined four components: nodes, paths, barriers and districts. Nodes are counted using the number of connected places, and paths are analysed according to the links between places. Thus, if places (or nodes) are directly linked to each other by one segment, they are considered to be related. Places that have more links are considered to be more salient. Barriers, on the other hand, describe spaces that are resistant to being crossed, and their connection with streets is another measure. Finally, districts are accepted as either a single graph or clusters of nodes. Since the study makes a connection with the components of settlements (Lynch, 1960), and presents a detailed explanation of how to measure structural salience, it can also be considered an important study. Raubal and Winter (2002) proposed that "semantic" salience could refer to cognitive characteristics of landmarks, arguing that landmark saliency consists of the historical characteristics of landmarks and explicit markings such as street signs. These researchers focused on visual, semantic and structural characteristics of landmarks. To analyse visual characteristics they used façade area (width x height of buildings), colour (the RGB colour chart - indicating how much of each of the red, green, and blue is included- was used to see if the colour is different from its surroundings), shape (proportion of the height of a building to its width), and visibility (two-dimensional area of the space covered by the visibility cone of the front side of a landmark). For semantic salience, the cultural importance of objects was determined as either “true” or “false” using a database of the city of Vienna, Austria. If an object was in this database, they reported it as “true”. Explicit markings, on the other hand, were defined as signs on buildings. Hence, for instance, if a building had a sign indicating its function, then it was expected that this information would be mentioned in a route description. Therefore, the presence of explicit markings was also coded as “true” or “false”. As in previous research, nodes and boundaries were used to describe structural salience. Hence, all characteristics discussed by Sorrows and Hirtle (1999) were identified with measurable properties in this study. This was an important contribution to the literature. Moreover, the concept of “visibility”, which is also significant for saliency of landmarks, was included in this research. The researchers argued that if an object is more visible than any other object around it, it may be selected by more people during wayfinding.

Nothegger et al. (2004), who measured saliency by observing the visual and semantic characteristics of objects, extended Raubal and Winter’s (2002) work by proposing that in order to define visual saliency, orthoimages (aerial photograph or satellite imagery geometrically corrected) could be used to calculate the area of differently shaped structures. The façades of buildings were examined to identify their shapes and similarly shaped (rectangular) façades were considered insignificant. If there was a façade with a different shape, then the shape deviation was calculated from the orthoimages. To analyse the colour, the outlines of façades were traced manually and the median of the intensity values of the RGB colour channels was used. To measure visibility, a line-of-sight algorithm was applied to the points close to the corners. The authors claimed that it was more challenging to measure semantic salience than visual and structural salience. They stated that if the building was designed by a famous architect, it may only be remembered by other architects, or if a building has historical importance it may not be evident from its external appearance. Thus, they suggested that objects that are explicitly marked and/or have text on them can be defined as attractive in a semantic sense. They first analysed objects to see whether they had any interesting characteristics, such as a historical façade, or if they were culturally notable and could be highlighted in a travel guide. Then they checked the function of the objects (more specifically, buildings) via the Yellow Pages to measure their identifiability. In the end, an overall saliency score was calculated. The researchers compared those scores with the results of tests with human subjects. They organised a web-based questionnaire, showed panoramic images to 40 people and asked them to rate the most prominent façade. The results of the study showed a significant relationship between the saliency model and participants' answers. With these two studies, the authors suggested objective ways to measure saliency. They suggested that it would be useful to apply these measures to larger datasets to identify the performance and the cost, which are also important issues to explore further.

Winter et al. (2008) presented another model to build hierarchies of landmarks from saliency. They started with an assumption that any location in an environment can be described with reference to landmarks; so, any point in a Euclidean map is in at least one landmark's reference region. Therefore, the researchers claimed that environments can be defined either by hierarchical partitions of space, after which the most salient landmarks can be identified; or salient landmarks can be found first and then the partitions can be searched for. In this research, the authors first defined the salient landmarks. They analysed Hanover, Germany, by focusing on junctions and using the buildings around the junctions to identify salient landmarks. Once the salient landmarks were clarified, they were considered as voronoi seeds and voronoi maps were created using the seeds. Hence, each voronoi region was described by a salient landmark that could help people to find their way or generate route descriptions. This model was important as it made clear connections with the environment by representing different urban spaces with specific landmarks. If a whole settlement can be defined with salient landmarks, this will allow people to find their way more easily and not get lost. Moreover, it can help environments to be more attractive (landmarks with different shapes, colour, etc., may attract more attention). However, rather than focusing only on buildings and their saliency scores, different landmarks could be compared and more salient ones could be used.

There is a plethora of research on the automatic selection of landmarks (Elias, 2003; Elias & Brenner, 2005; Peters et al., 2010; Lazem & Sheta, 2005; Wither et al., 2013; Tezuka & Tanaka, 2005; Richter, 2007). Elias (2003), for example, focused on building databases, and categorised buildings based on their attributes (land use, size, height, number of immediate neighbours, orientation with the road, distance from road). She used two algorithms to capture salience and stated that the results were promising as it was possible to identify salient objects. In another study, Elias and Brenner (2005) first identified landmarks by using the building information of the digital cadastral map of

Germany. Using this information, they created a table with the geometric information and semantics of the data. Similar to previous research (Elias, 2003), they focused on specific attributes such as building area, building use and orientation to street. They narrowed their selection by considering the visibility (the visibility of landmarks at decision points as well as the visibility of landmarks while approaching decision points) and the positions of landmarks relative to the route. They could define a landmark at each decision point. However, because the algorithm detected only one landmark at each decision point, the detection of other potential landmarks was not possible, which can be considered as a limitation of this study. In addition, the authors claimed that they computed visibility for a single view; however, for a wayfinding task it is crucial to understand the environment from many angles and different points. Therefore, rather than a specific point, the visibility of landmarks should be calculated along the entire route to obtain accurate results. These two studies conducted by Elias and others (Elias, 2003; Elias & Brenner, 2005) were important in relation to the automatic selection of landmarks, and the database they used might be reproduced more easily than previous auto-selection alternatives. However, it should be noted that in these latter alternatives, there were limitations with both the landmarks, as only buildings were considered, and the saliency criteria used, which were only semantic and visual.

Lazem and Sheta (2005) identified landmarks, using buildings, and created an attribute table including building colour, height and width, building order in the street (for structural saliency) and building activity (for semantic saliency). Researchers simulated three virtual cities with grid layouts, and the number of urban blocks varied in each city. Moreover, they distributed different types of landmarks realistically by using a Geographic Information System (GIS) dataset belonging to Egyptian cities. They observed that the highest scoring landmarks were institutions, governmental buildings, and other buildings with specific functions. Hence, they claimed that this selection method was effective at detecting landmarks. This study was important as it aimed to analyse all components of saliency and to adapt the results to other simulated cities. However, structural and semantic saliency were analysed using limited measures, which can be considered a limitation of this work.

Duckham et al. (2010) approached saliency of landmarks in a different manner; rather than using an actual landmark, they focused on a group of landmarks and developed a weighting system based on landmark categories (e.g. parks, hotels, etc.) and measured the visual, structural and semantic characteristics of these categories. For visual saliency, they used size, proximity to road, prominence and differentiation from surroundings (during both daytime and night-time). For structural saliency, spatial extent and permanence were analysed. Semantic saliency was measured using ubiquity and participants' familiarity with the environment as well as the length of descriptions. A scoring system was developed, and each category was ranked by a group of experts. This approach was then adapted for different routes in Melbourne, Australia. They concluded that landmark selection was both route and direction dependent. As it would be easier to produce a dataset from categories, rather than individual landmarks, this alternative methodology can be useful. However, the results would not be as specific as individual landmark research, which might be a limitation of this type of study.

Another study, which focused on a more user-related approach, was conducted by Götze and Boye (2016). They used a methodology that automatically derived salience using route instructions. They asked 10 subjects to walk a specific route and describe it. People's verbal descriptions were recorded and transcribed, and each segment was annotated with the landmarks that participants referred to. Then people's personal salience model was derived using an algorithm that determined the most appropriate landmarks to refer to. This approach is quite unique and significant as it produces personal results; however, as the model is user-related, it is necessary to include the results of a large number of participants to obtain accurate results.

On the other hand, Nuhn and Timpf (2017) proposed a multidimensional model for the selection of personalised landmarks. They extended existing approaches by using the personal dimensions of landmarks (Nuhn & Timpf, 2018). The underlying idea was that landmark selection could vary for individuals; hence, in the former study, they aimed to understand the factors that might affect people's landmark selections, focusing on people's personal interests and backgrounds. They suggested that personal interests could be closely related to different functions (e.g. art, gastronomy) and could be obtained using sensors in smartphones. Personal goals were categorised under three headings: known goals (reaching a known, particular location), new goals (reaching a different, new location – probably with the help of a wayfinding aid) or exploratory goals (travelling without having a specific goal location) (Golledge, 1999; Wiener et al., 2009). The researchers suggested that personal background could be analysed by checking demographic characteristics, such as gender, age and country of residence. This study provided a detailed explanation of how cognitive saliency can be measured. Even though these definitions are important for the selection of different landmarks or different routes, it is not clear how to adapt these classifications, quickly and efficiently, to a wayfinding task.

In the latter study (Nuhn & Timpf, 2018), authors extended the earlier research of Raubal and Winter (2002) and, in addition to visual, structural and semantic landmarks, they defined descriptive and environmental landmarks. Accordingly, attributes of descriptive landmarks were defined as explicit markings, such as signs that can be used in wayfinding tasks, and the number of words on those signs, as long descriptions can cause confusion so objects requiring a longer explanation can be excluded from a task. Environmental landmark attributes were defined through their orientation, distance, visibility and uniqueness. The authors considered travellers' interests, education, country of residence and background. This study was another important attempt in identifying landmark saliency as it extended the existing literature by using semantic and environmental attributes. These two papers were essential as they provided personalised categories to better understand semantic landmarks. However, the implementation of these measures to actual environments is still a challenge.

Models were also developed using different technologies. For instance, a mobile application was developed by Wolfensberger and Richter (2015). The researchers aimed to provide a tool for the manual selection of landmarks in which people took pictures of objects while their position was detected via GPS. Using the GPS data, the visible area was scanned for possible landmarks. Researchers focused on objects that were closer to the participants and, once the candidate landmarks were selected, their visual and semantic characteristics were quantified. Visibility (distance and azimuth deviation from the user) and size (area) of landmarks were used as visual characteristics; landmark type (tags that describe the function, such as shop, leisure) and historical or cultural significance (the number of tags and background information either from the object's web page or from Wikipedia) were used for semantic characteristics. The application was then tested in both an urban and a rural area, as well as by a naïve user. The results showed that widespread use of the application was possible. This research is promising in many aspects: both visual and semantic characteristics were used; people were asked to actively participate in the study (they took pictures and defined landmarks); the application was tested in both urban and rural areas, as well as by a naïve user. In another study, Quesnot and Roche (2015a) focused on semantic salience and hypothesised that Social Location Sharing datasets could serve as reliable sources for measuring semantic salience. The researchers argued that user-generated place databases provided information on users' interests as well as the different uses of places (during the daytime or at night-time), while providing information about not only buildings but also other objects, such as parks or mountains. They claimed that the information could be collected from social media services (e.g. Facebook, Swarm, etc.) and adapted to the automatic landmark detection systems using the geosocial activity of venues. Showing examples from Vienna and Paris, researchers observed that historically or culturally significant places did not necessarily generate the highest activity on social media. This was an important finding since it shows that semantic salience could be better understood by checking the Social Location Sharing database.

All of the studies discussed in this subsection show that automatic selection is another important area. While creating a landmark detection system, it is important to consider: (1) the reproducibility of models – whether the steps are easy to follow and the measures clearly explained; (2) the reproducibility of models at different scales; (3) whether or not the models work in practice – if the automatic selection tools identify the landmarks, and how well the results compare with people's choices (Richter, 2013, 2017). It was also established that landmark detection can differ based on the length of time taken to travel or complete the wayfinding task (Sadeghian & Kantardzic, 2008). It is important for future research to focus on all aspects of salience – visual, structural and semantic (cognitive) – through the measures described in this subsection. Even though visual and structural salience is covered by many measures, most of the existing studies failed to measure semantic salience. As well as the function of buildings, additional components, such as people's backgrounds, that might affect semantic saliency scores should be considered in future studies. Furthermore, in addition to buildings, all types of candidate landmarks, such as fountains (e.g. Piazza Navona in Rome), statues (e.g. the Statue of Liberty in New York), or stairs (e.g. the Spanish Steps in Rome) should be adapted to these algorithms, since they could have high saliency scores and hence could be used during wayfinding.

3.5.2 ***Findings of different studies on saliency of landmarks***

In addition to providing various definitions of salience, some studies have aimed to explain the most effective saliency criteria for wayfinding. However, their findings vary. Peters et al. (2010) aimed to use an automatic landmark selection tool to identify landmarks and to compare the results with people's landmark choices. They used a VE with box-like buildings and two alternative routes. Twenty-four students participated in the experiment and actively navigated through the VE using a joystick. When they completed the navigation exercise, they wrote route descriptions. Structural, semantic, visual (based on colour) saliency and visibility scores of landmarks were computed. Researchers discovered that the highest correlations between people's choices and saliency scores were observed for visibility and structural salience. Therefore, they claimed that structural salience and advance visibility have higher impacts on people's choices.

Winter et al. (2005) theorised that landmarks are more personal rather than being universally agreed features. They focused on people's landmark selections during the daytime and night-time. After being asked for demographic information and about their familiarity with the area, participants were shown four panoramic images of Vienna.

Half of the participants were shown daytime images while the other half saw night-time images. Then they were asked to select a prominent façade. In the second part of the study, the same participants were asked to rank characteristics of landmarks so that the researchers could understand which characteristics made them more noticeable. Researchers discovered that some of the landmarks were ranked significantly differently depending on whether the images were from daytime or night-time. More importantly, it was observed that the visibility and colour criteria were more significant for an object to become a salient one, compared to the area, shape or marked information.

Stankiewicz and Kalia (2007) conducted three experiments to investigate the effects of structural landmarks and object landmarks (statues) in VEs. In three experiments participants were asked to navigate in the environment and answer landmark queries. The results showed that humans tend to remember structural landmarks more than object landmarks. Moreover, even if the information content of object landmarks was greater than that of structural landmark, the two types of landmarks were still recalled equally.

In their study, Miller and Carlson (2011) also intended to determine the factors that make landmarks salient. They used Caduff and Timpf's (2008) definition and focused on contextual and perceptual characteristics of landmarks in a virtual museum. For perceptual characteristics, they focused on size and colour, while for contextual characteristics they analysed objects at decision points with a turn and without a turn, and at non-decision points. Participants were asked to learn a route and memorise the objects. Then they were asked to give route directions, draw a map with instructions and answer whether an object was in the museum or not. The findings suggested that both perceptual and contextual salience are important characteristics of objects that are deemed salient.

Von Stülpnagel and Frankenstein (2015) aimed to examine the effect of configurational salience of global and local landmarks compared with visual salience. A VE was created for this study and people were asked to explore the environment under different conditions: sketch without a map after exploring the environment, sketch with a map, or free (the third group explored the environment without additional aids). They discovered that people not only rely on visually salient objects, but they also use configurationally (or structurally) salient landmarks for orientation. Moreover, it was observed that participants who were asked to produce sketch maps added more landmarks compared to those under the map and free conditions. The differences in the task, therefore, affected people's observations in this study. This is similar to the findings of studies on the visibility of landmarks.

Röser et al. (2012) also indicated the impact of structural salience. They conducted a study in a virtual, grid environment (Squareland) and asked participants, who were mostly university students, to learn a route from a starting point to a goal location. Then participants were asked where a landmark should be located (allocentric view). In a second experiment, they used the egocentric perspective and 12 landmarks were located in the environment. Participants were asked to memorise a route and point out the location of landmarks. The findings of this study also supported those of Klippel and Winter (2005). The results of these studies mainly highlight the impact of the visual and structural characteristics of landmarks during wayfinding. The same VE, Squareland, was used in another study (Hamburger & Röser, 2014). The researchers aimed to understand the impact of famous landmarks and to determine the changes in wayfinding performance with visual, verbal and acoustic cues. In the first experiment, 25 university students were randomly assigned to one of the three conditions. In the recognition task, they indicated whether they saw a word (of an animal) or saw an image or heard animal sounds. They were re-shown the environment and were asked which way to move at each intersection. The researchers discovered that verbal and sound instructions were better remembered. In the wayfinding task, however, they did not find any significant differences in results. In the second experiment, 20 students were asked to view visually salient but unfamiliar buildings as well as visually salient and familiar buildings. The results indicated that famous buildings were better recognised by people. This study showed that both visual and cognitive characteristics of landmarks affected people's preferences.

Another study was conducted to understand the significance of semantic landmarks in unfamiliar and familiar environments (Quesnot & Roche, 2015b). Individuals familiar and unfamiliar with Quebec City, Canada, participated in an online study. After answering questions about their demographic information and familiarity with the environment, the participants were shown different parts of the city. They were asked to choose two landmarks from a set of four potential landmarks, and visual, structural and semantic saliency scores for landmarks were computed. The study showed that visual salience was closely related to people's choices. Moreover, the results of this study showed that people who were familiar with the environment focused on semantic landmarks regardless of low visual salience. On the other hand, people who were unfamiliar with the environment relied on the visual cues more. This study, therefore, is an important example of how familiarity affects people's landmark choices.

Another group of researchers focused on the combined effect of characteristics of landmarks. Albrecht and Von Stülpnagel (2018) stated that, even though visual and structural landmarks supported wayfinding, the interaction between the forms of salience have received little attention. Therefore, they aimed to explore the combined effect of visual and structural salience on wayfinding. They located visually salient objects at structurally salient and less salient locations. They used a VE where the intersections were symmetrical and consisted of four buildings. Thirty-four students participated in this study and they were first asked to study pictures of the intersections with a given turning direction. Then they were presented with one intersection and were asked to make decisions. Findings showed that people tended to remember a turn correctly if a visually salient landmark was located in the turning direction. A similar study was undertaken by Michon and Denis (2001), who asked 20 participants to learn two routes in Paris by navigation and to generate route directions. Researchers observed that visual landmarks are better remembered when they are located at decision points. Hence, a landmark can be visually salient, but if it is located in a structurally less salient position, then it might be used by less people in wayfinding tasks, as expected. This body of literature is also important for interpreting the combined effects of landmarks, rather than focusing on one or two characteristics separately. Therefore, it can be argued that all the different characteristics of landmarks influence their saliency.

Duckham et al. (2010), Götze and Boye (2016) and Elias (2003) mentioned verbal descriptions in relation to understanding cognitive saliency specifically. Research aimed to explore descriptions to better understand cognitive/semantic saliency. Duckham et al. (2010), for instance, stated that short and familiar descriptions (using a specific function, such as the name of a bank or a coffee chain) are suitable for making a route description simple and easy. Similarly, Elias (2003) mentioned that “real” landmarks are identified by the shortest description. Hence, in route descriptions, we tend to use shorter descriptions to be clearer. Krukar (2015), on the other hand, stated that the deeper people process, or fixate on, an object, the better they remember it. In relation to that, other research has also discovered that people fixate on a salient object more (Itti, 2005; Zetzsche et al., 1998). Hence, if we change the task from route description to landmark definition, we can expect people to provide more detailed descriptions for the objects they remember well, since they would fixate on them more. In fact, this shows how descriptions change depending on the task one undertakes. If someone is asked to experience a route and explain it to someone else, they would make it short and simple, as mentioned in the former papers. However, if the task is slightly altered such that someone is asked to experience the environment and explain what they see “in detail”, then they would talk more about the salient landmarks using many descriptive words, as the latter research suggested. Research has argued that hesitation can also be measured by analysing the descriptions. Hence, if specific words are used in landmark descriptions (such as “maybe”, “seems”, “I am not sure, but”, etc.), they show that people are uncertain about what they saw, so the saliency of a landmark can still be challenged (Tenbrink et al., 2019; Tenbrink, 2015). Moreover, research on cognitive salience in navigation tasks has reported the impact of landmarks in route descriptions by focusing on the location of landmarks (Denis, 1997; Daniel & Denis, 2004; Denis et al., 1999). They stated that landmarks at nodes (decision points) are mentioned by people more often. Hence, it is also expected that the location information of landmarks is seen in descriptions. Therefore, these approaches can also be used to better understand cognitively salient landmarks.

Some studies have also aimed to understand whether the saliency evaluation differs between experts and non-experts. An interesting study was performed by Cheng (2009) to analyse landmarks using the perceptions of experts and non-experts. Two groups were used for this study: the expert group was defined to include landscape architects who had lived and worked in the study area for over ten years, and the non-expert group was defined to include local residents who had also lived in the study area for more than ten years. Both groups answered questions about landmarks, and the results of the study showed that singularity (sharp visual contrast with the background) and spatial prominence (location of landmark – visibility from many points) affected the participants' ability to identify landmarks. In addition, results of the study showed similarities and differences between two groups. All these above-mentioned studies highlight that landmarks can be analysed considering their visual, structural and cognitive characteristics. In addition, there are different methods to measure these characteristics. More importantly, current research shows that there is no consensus in the literature on the types of landmarks that are preferred by people.

3.5.3 *Other methods to measure salient landmarks*

Research has discovered that people tend to look at salient objects more (Itti, 2005; Zetzsche et al., 1998) since these objects draw attention (Land & Tatler, 2009). Zetzsche et al. (1998), for instance, found that the eyes fixated on regions with multiple superimposed locations, such as corner points. In addition, as discussed in the previous section, Krukar (2015) stated that the deeper people process, or fixate on, an object, the better they remember it. Hence, many studies have aimed to find a relationship between eye fixation and saliency.

Researchers have discussed gaze behaviour and tried to explain how the wayfinding process is affected by what people look at, or the relationship between eye tracking data and landmark selection. An important study was conducted by Viaene et al. (2014), who aimed to detect indoor landmarks using eye tracking data. Twelve participants' eye tracking data was recorded and participants were asked to verbalise everything related to a navigational task. The fixated objects and the mentioned objects were then compared. Researchers discovered that eye tracking could provide qualitative data to identify landmarks. Wiener et al. (2012) aimed to explore the relationship between spatial decision making and gaze behaviour. They asked participants to search for an object in a VE. Participants were asked to choose left or right at each decision point, and their eye movements were recorded during the experiment. The results showed that people have a tendency to choose paths containing longer lines of sight. This finding again shows the effect of visibility on people's behaviour.

In another study, researchers were interested in associating the positions of decision-related information with the placement of the actual choices (Wiener et al., 2011). In the training phase, 17 participants were passively transported along a route in a VE, which consisted of 18 decision points. Both unique and non-unique landmarks occurred at each intersection. In the test phase, participants were asked to select the direction using static images. Unique landmarks in this study were images that were present only once, and non-unique landmarks were always the same image. Researchers discovered an increase in reaction times when unique landmarks were not in the required movement direction, which suggests the impact of structural salience on decision making, which could be detected by eye fixations. Wenczel et al. (2017) aimed to understand the extent to which the selection of landmarks could be established from eye tracking. Twenty-three participants took part in the study. They were asked to explore two routes and then provide route descriptions and walk both routes from memory. They were also asked to mention the landmarks on their route. Researchers estimated visual saliency by using the eye tracking data. The results were rated by two people on a 5-point scale from visually non-salient to visually very salient. Structural saliency was analysed based on landmarks being on routes, at potential choice points and at choice points. The results showed that participants mostly focused on the corners in the turning direction and gaze patterns were affected by direct line of sight. It was also highlighted that route learning is associated with structurally salient landmarks. In this example, the approach of using eye tracking data to understand salient landmarks by was introduced, and this was employed to measure visual landmarks. In a review by Kiefer et al. (2017), several advantages of using visual attention systems were listed that included the theory that wayfinding aids rely on visual information. Hence, fixations can provide information on people's wayfinding choices and landmark selections.

The relationship between eye tracking data and saliency is explored above. Research has aimed to estimate where people look in order to define salient objects automatically (Kümmerer et al., 2016; Judd et al., 2009; Itti et al., 1998; Harel et al., 2007; Kümmerer et al., 2017). One of the earliest computational models was developed by Itti, et al. (1998). These researchers developed a visual attention system based on the intensity, colour and orientation of images. Since then, many approaches have been developed (Borji & Itti, 2013). Among them, Graph-Based Visual Saliency (Gbvs) (Harel et al., 2007), which is a standardised version of the Itti et al. (1998) model, was shown to be more predictive than the Itti et al. model in explaining human fixations. Recently, saliency models based on deep learning have been shown to significantly outperform most previous shallow models. One of the most accurate models is DeepGaze II, which is based on a popular object recognition network (Kümmerer et al., 2016). Visual Geometry Group (VGG)[11] deep neural network features (VGG-19) were used to train the model to predict saliency (Simonyan & Zisserman, 2014) and the model was pretrained with SALICON dataset[12] (Jiang et al., 2015). The great advantage of deep saliency models is that they not only model low-level visual features such as orientation, contrast or luminosity, but also take into account higher level features such as whole objects, or even faces, which are known to strongly attract attention.

Many of the models discussed above have been designed to predict where people look by considering some visual characteristics of the scenes. Thus, the models are essential for studies about spatial knowledge and route learning (Grzeschik et al., 2019). Earlier studies focused on estimating the contribution of saliency to eye movements by using dynamic scenes, and found no significant relationships between model-predicted saliency and duration of fixation (Itti, 2005). However, the number of studies on the effect of salient objects on navigation is still limited. To the best of the author's knowledge, there is only one other study that has aimed to compare navigational behaviour with different saliency models (Psarras et al., 2019) in addition to the previously cited study (Grzeschik et al., 2019). Grzeschik et al. (2019) designed a VE and placed landmarks at intersections. At each intersection there was a unique landmark (one that appeared once along a route) and a non-unique landmark (one that appears at two of the intersections along a route). The saliency of landmarks also varied. Participants' eye movements were captured and saliency was assessed using an online survey as well as saliency algorithms. Researchers discovered that the results of the survey and algorithms pointed to salient landmarks. Psarras et al. (2019), in contrast, followed a different approach and recorded pedestrians' routes in a real

[11] VGG is a deep convolutional network for object recognition.

[12] SALICON dataset is a dataset that offers a large set of saliency annotations on an image database (see http://salicon.net/).

environment. The paths people used were then converted to 3D models and virtual cameras were used to capture people's field of view. Saliency algorithms were implemented to pedestrians' fields of view. Researchers stated that visual saliency was correlated with observed navigational behaviour. However, this area can be still investigated.

3.6 Visual summary diagrams for landmarks

In this chapter, the characteristics of landmarks used in wayfinding tasks have been explored. There is consensus in the literature on different aspects of landmarks: it was observed that some terms relating to characteristics of landmarks, such as *outstanding*, *distinctive*, *identifiable* or *prominent*, were repeated by authors. Landmarks were identified as communicable (so that they can be described easily), salient objects in an environment that helped people to find their way or describe a route. Past studies clarified that landmarks' specific characteristics let them be selected by more people and because of these characteristics they became distinctive, unique or identifiable. These characteristics were investigated under three headings: the *location, visibility* and *saliency* of landmarks. For the *location of landmarks*, it was seen that landmarks on routes and landmarks at decision points could be remembered more easily compared to off-route landmarks. More specifically, research stated that decision points, where people's direction is changed, can be the optimal locations for landmarks. For the *saliency of landmarks*, various papers focused on the visual, structural and cognitive (semantic) characteristics. The first consensus in saliency papers is on these three categories. Accordingly, objects should be visually (their size, shape, colour or visibility), cognitively (their historical or cultural meaning), or structurally (their location at accessible points) distinctive so that they can draw attention and be used during wayfinding tasks. Visual and structural characteristics were analysed by various researchers, who concluded that both characteristics had an impact on people's wayfinding performance. In relation to visual characteristics, colour and visibility were mentioned in different studies.

However, it is possible to claim that there are numerous gaps in the literature. The first one concerns the *saliency of landmarks*. Various studies have investigated saliency and proposed various measures such as visibility, colour, height or shape for visual saliency; the use of social media, or people's demographic data for semantic salience; or the number of nodes or barriers for structural salience. These measures are useful to understand how people select landmarks in different real and virtual environments. Research needs to focus on the defined measures and include as many of them as possible to derive more accurate results. Moreover, the literature has already underlined the impact of visual and structural landmarks in navigation-related experiments. Even though different measures were developed to explain cognitive saliency, the number of studies that have conducted experiments using these measures is still limited. Hence, new tools can be useful in comparing these three components more effectively, and in improving the understanding of the impacts of cognitive salience on wayfinding behaviour. The combined impact of different saliency measures was also studied by researchers; however, more research still needs be conducted to better understand the relationship between different landmark characteristics.

Another gap persists in the definition of the *visibility of landmarks*. Research suggests that landmarks can be seen either from everywhere (Lin et al., 2012; Castelli et al., 2008) or from many points in an environment (Lynch, 1960). Here, it is asserted that global landmarks are objects that can be seen from many points and angles, but not necessarily from everywhere, as Lynch (1960) also discussed. However, at this point another question is raised: if a global landmark is seen from many points in an environment, then how can local and global landmarks be differentiated? Many existing studies used obvious objects, such as towers or mountains, to refer to as global landmarks. But when exactly does a local landmark stop being "local" and become a "global" landmark? Can a threshold for this transition (which suggests more of a continuum of landmarks than previous research may suggest) be defined? This is a question raised in this chapter. In addition, research on global and local landmarks provided different results: a group of researchers claimed that global landmarks can be more effective, while others claimed either local landmarks, or both global and local landmarks can be more effective on wayfinding tasks. Hence, it might also be useful to explore the impact of different landmark types on wayfinding tasks.

Finally, eye fixation and its relationship with landmark selection were also discussed in this chapter. Eye tracking is another important way of explaining visually salient landmarks. Many tools have been developed to explore salient objects in images as mentioned in Section 3.5; however, there is limited literature on landmark saliency and objective saliency models. Many studies focused on salient parts of images, but they did not compare the results with people's saliency evaluations. Therefore, this can be determined as another gap in the landmark literature.

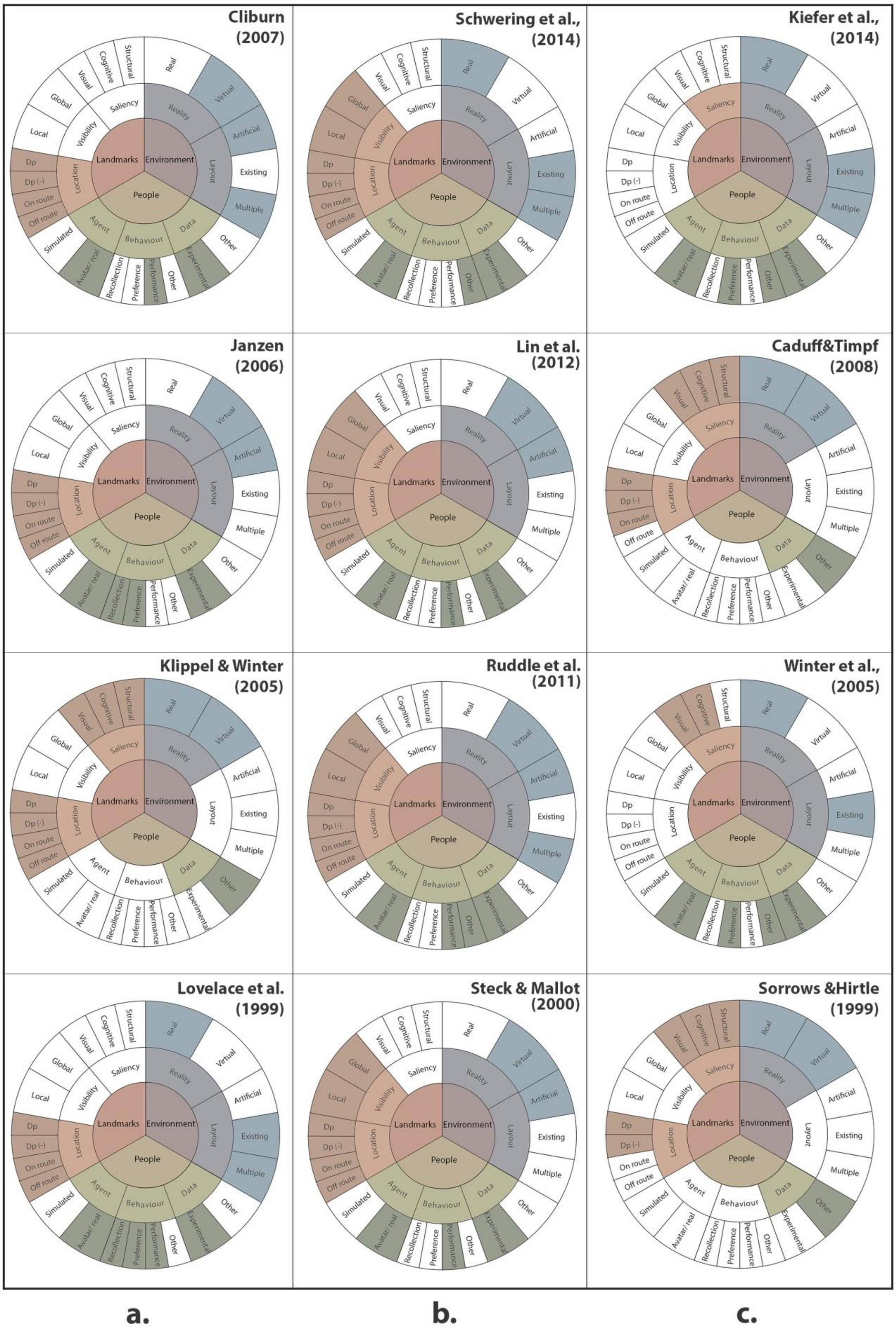


Figure 6: Visual summary diagrams for the literature on landmarks and wayfinding. Diagrams were prepared to review: a. location of landmarks, b. visibility of landmarks, and c. saliency of landmarks.

To summarise the above-mentioned studies visually, papers in the literature are chosen based on their relevance to this study as well as the originality of the findings, and compared in a similar way to those in the previous chapter about wayfinding. Again, visual summary diagrams are used, as shown in Figure 6. The same three main headings – people, environment and landmarks – and the same sub-categories are used, so that the reader is able to compare the two literature review chapters. Again, the reader can easily see that the literature on the location of landmarks focused on landmarks on or off routes, or at decision points. All main headings discussed are shown in the images.

3.7 Summary of the chapter

A number of papers stated that landmarks are one of the three knowledge types that create spatial knowledge (Siegel & White, 1975). Thus, in addition to designing relatively simple layouts (Gärling, Böök, et al., 1986; Arthur & Passini, 1992; Passini, 1984b), where people do not feel confused, it is also important to have:

- Global and local landmarks that are distributed within an environment (although not necessarily distributed evenly, as one might expect to see more landmarks in centres),
- Landmarks on routes and at more specifically at decision points (if possible),
- Landmarks that are also visually, cognitively or structurally salient. This would reduce the number of wayfinding errors that people make. Moreover, it is also possible to create more attractive routes with the aid of landmarks, such as aesthetically appealing landmarks like statues, buildings, etc.

Environment and people are also used as headings in the visual summary diagrams in order to identify the criteria that make a landmark salient. The review of relevant papers indicates that both of these factors have an effect on landmark salience. Therefore, it can be claimed that landmark selection is shaped by a multitude of factors, all of which should be taken into consideration to better understand the underlying reasons of the landmark selection process.

The aim of this chapter was to review the existing literature on landmarks in wayfinding studies, and to clarify the gaps. In order to do this, chapter was divided into three parts (excluding visual summary diagrams) in which location, visibility and saliency of landmarks were discussed. In the introduction, these questions were raised: "**Which environmental factors or conditions make wayfinding easier?**" and "**How do we select landmarks in unfamiliar environments?**" It can be claimed that landmarks are one of the components of the environment that affect the wayfinding process. In addition, it is clear that to explore landmarks, it is important to analyse their location, visibility and saliency, and work on the gaps in the literature.

More importantly, in this chapter, as in the previous chapter, gaps in the literature and different methods were discussed. The consensus on the location of landmarks is highlighted in this chapter. There were two main gaps about the visibility of landmarks: definition of the visibility of landmarks, referring to the definition of global and local landmarks, and the type of landmark that has a greater effect on wayfinding. It is also stated that the visibility can be analysed using visibility of landmarks (in other words, the visual catchment areas of landmarks). In relation to the saliency of landmarks, three headings are highlighted, visual, structural and cognitive landmarks, and various measures are discussed to examine these terms. Hence, it can be briefly stated that:

1. To understand the selection of landmarks, location, visibility and saliency of landmarks should be analysed,
2. As mentioned in the introduction, a clear definition and distinction is needed for global and local landmarks, as well as the impact of global landmarks on the wayfinding process. To clarify global and local landmarks, the visibility of landmarks can be used as suggested in the literature,
3. Visual, structural and cognitive salience can be analysed using various measures to see which characteristics make landmarks preferred by more people. In addition, computational models and experts' and non-experts' evaluations can be used for this investigation.

These two literature review chapters are important in understanding the current literature on wayfinding and landmarks. Depending on the gaps and methods mentioned in these two chapters, a series of experiments is conducted in the following chapters. The next chapter describes the methodology of the experiments and the case study used in this research.

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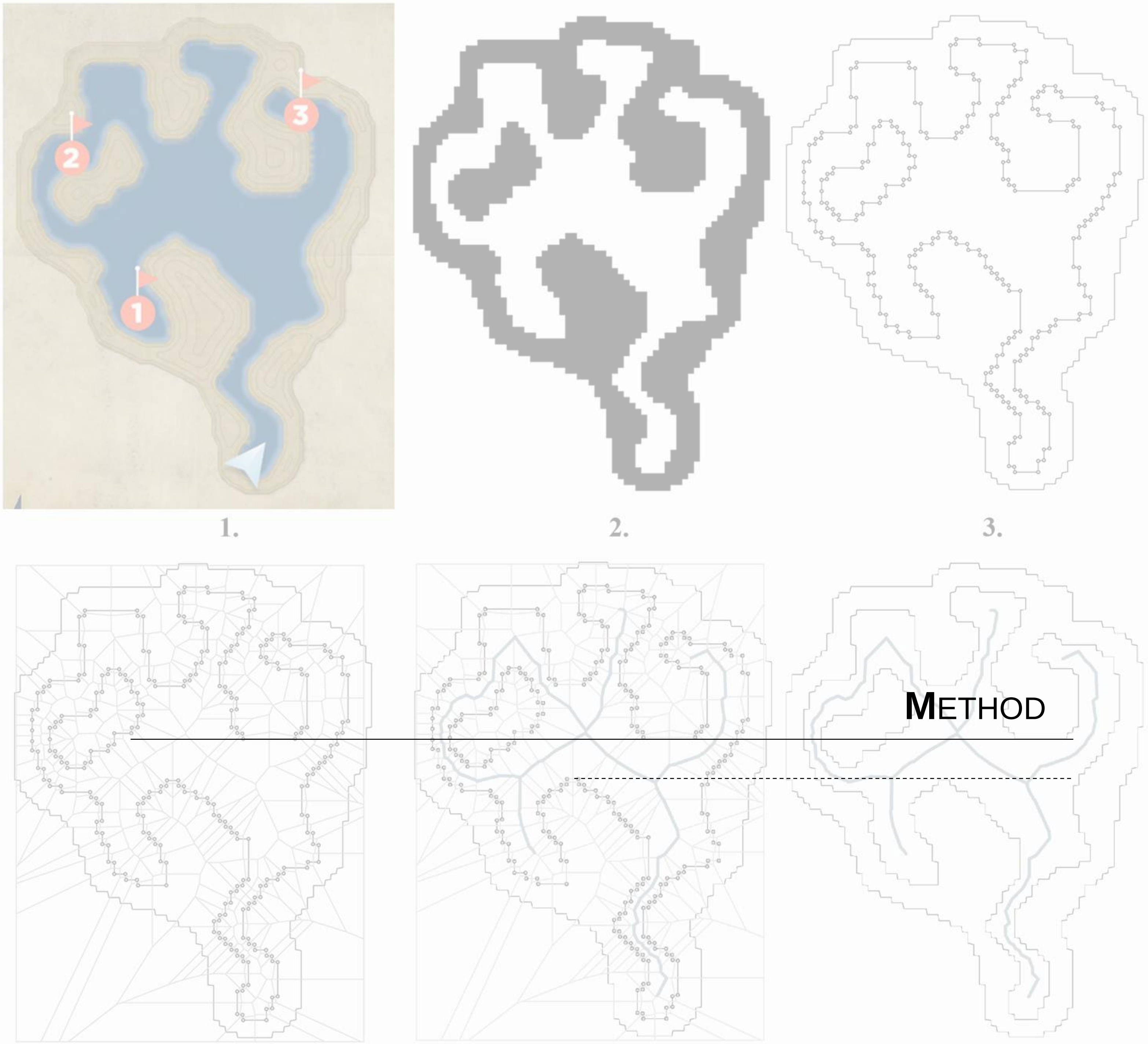

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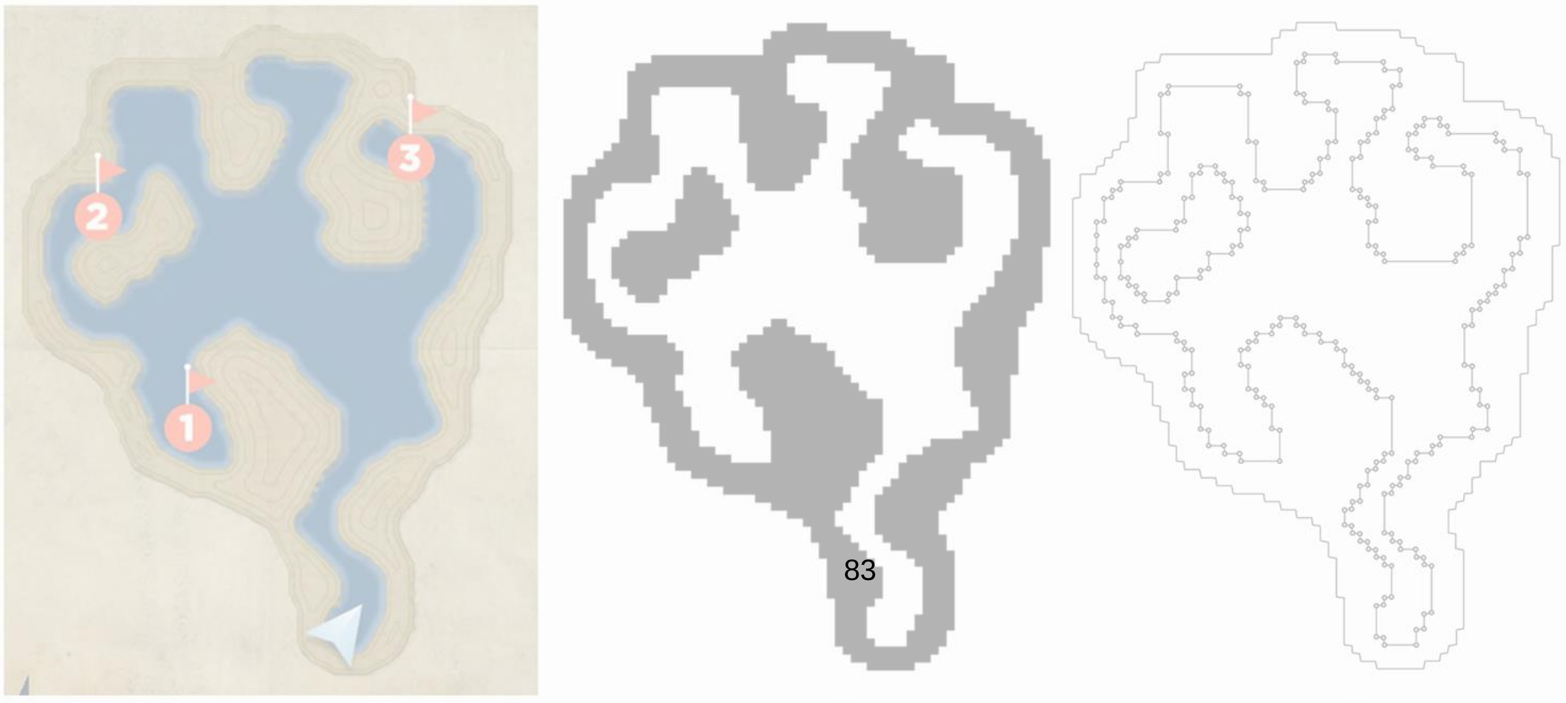

4 METHODS

4.1 Introduction

This chapter explains the methods used in the thesis. Experiments conducted for this research took place in the same virtual, game environment, Sea Hero Quest (SHQ), which is described here. The processes of how SHQ was designed, and how the data were collected from participants and distributed to researchers are explained in this chapter. The questions posed to participants and the tasks that they were asked to complete are described. Participants' results (both time and trajectories) used in this study are defined. In addition, spatial analyses are explained and coded conditions, analysed complexity and Space syntax measures are clarified. Methods to analyse landmarks are also defined. Cluster analysis, conducted to determine the levels with similar layouts, is also introduced, since these levels are used in the following chapters. The methods used to investigate visual, structural and cognitive saliency are also explained in this chapter.

In the following chapters (Chapters 5 to 7), the analyses conducted for the thesis are explained. In this chapter, the main justification for the methods is given, and then the method of each study is explained in more detail under the relevant heading.

Three components were mentioned in the literature review for successful wayfinding: *people* – as their behaviour can affect wayfinding; *environment* – as the complexity of layouts, connectivity or other factors can have effects; and *landmarks* – as these components are specifically mentioned in wayfinding research (Figure 7). Accordingly, the main methods used in this study consist of these three components, or the interaction between three components. Hence, it is expected to explore the spatial layout of an environment by using different measures and characteristics of landmarks, and see their impact on people's wayfinding performance.

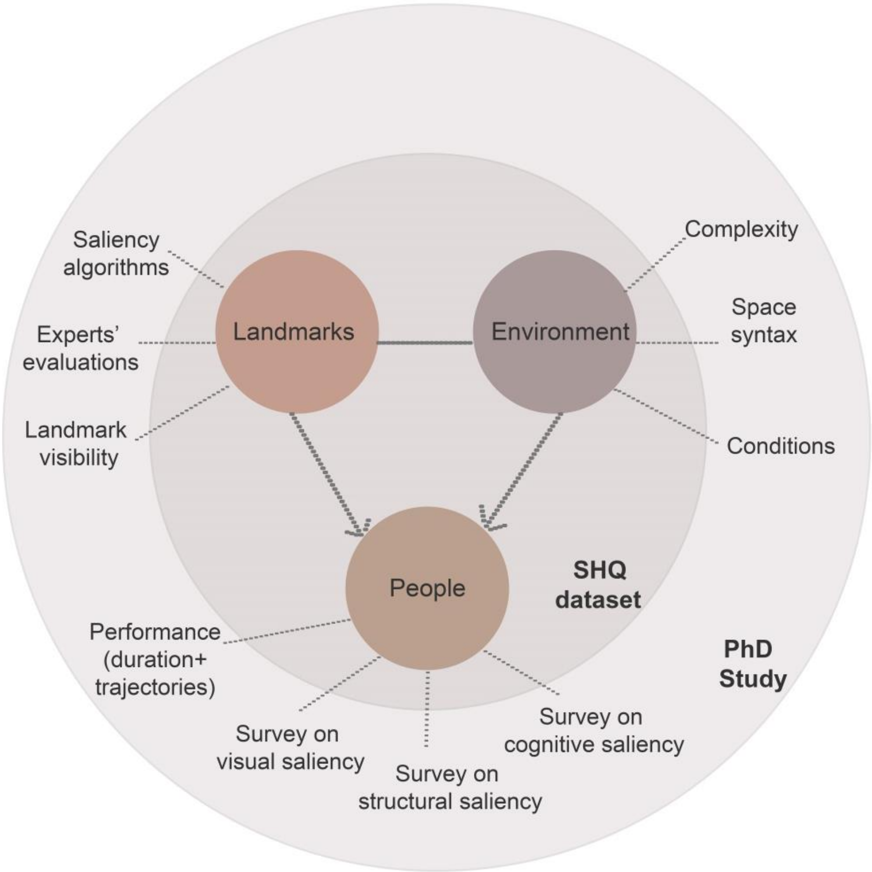

Figure 7: The main components that shaped the method

4.1.1 ***Games as a research tool***

Virtual environments are practical for analysing spatial layouts rapidly and accurately. As mentioned in the literature review, research has stated that results of virtual environments are correlated with those of real environments; hence, virtual environments can be used to test real environments or real environmental projects. Games and game environments are a way of producing virtual environments and testing them.

Video games have been said to be the fastest growing form of entertainment in the world (Adachi & Willoughby, 2013). Even though some negative effects of video game playing, such as addiction and aggression, was discussed in early research (Anderson et al., 2010), researchers have also discovered some benefits of game playing, including but not limited to, effects on motivation, emotions and social interaction (Granic et al., 2014). Moreover, some studies have also shown that video games can develop skills in some areas, such as language, basic maths and reading, as well as social skills in various ways (Griffiths, 2002), including bringing families together (Mitchell, 1985; Gentile et al., 2009).

Playing video games requires memory, coordination and fast reactions (Goldstein et al., 1997). Hence, playing games has a positive effect on cognitive skills (Zelinski & Reyes, 2009; Granic et al., 2014; Adachi & Willoughby, 2013) as they can be used to develop problem solving and spatial skills in a short period of time. Therefore, it is possible to state that, in addition to some negative effects, games also have some positive effects on people. This is the reason why they have recently been playing an important role in research.

4.2 Selection of the case subject: why Sea Hero Quest?

Sea Hero Quest (SHQ) is an online game that has been available through the app store for phones and tablets since 2016 to 2019. A virtual reality (VR) version is still available – for more information visit http://www.seaheroquest.com/site/en. The game was designed by researchers in different universities and was produced by a game company, Glitchers Ltd (Hyde et al., 2016). To the best of author's knowledge, SHQ is the first attempt in the gaming industry to develop a game to be used directly in scientific research.

Since the game was released in 2016, it has been played by more than 4.3 million people. Therefore, it has provided the largest dataset in wayfinding and landmark studies up to the time of writing, which makes the game an important source of data.

The game includes different spatial layouts, as well as different conditions relating to landmarks, weather and map features. In some levels the weather is kept clear and in others, it is foggy or the water is wavy. Therefore, the visibility within these environments is low because of the fog or waves, and landmarks and other cues are not always clear under these conditions. In addition, in some levels, participants see a clear map showing their locations, the layout and the goal locations, while in some levels they see an obscured map that does not allow participants to see the spatial layout of levels and they can only see the order of the goal locations. Landmark conditions also vary in relation to "global landmark" conditions and "saliency" conditions. Accordingly, in some levels there are only local landmarks, whereas in others there are both local and global landmarks. The saliency condition varies as "none", "easy" and "hard" landmark conditions depending on the visual and structural characteristics of landmarks. Hence the game provides an opportunity to analyse the effect of different conditions in addition to the impact of different layouts.

A previous article on SHQ by Coutrot, Silva, et al. (2018) discovered an important finding: the overall performance of people decreased gradually with age up to the age of 70. However, after this age, researchers discovered an increase in performance again, which was unexpected. Hence, this study will use the results from participants aged below 71 to be consistent with the literature. In addition, recent work of Coutrot, Schmidt, et al. (2018) compared people's wayfinding performance in real and virtual environments. Researchers used specific levels of SHQ for the virtual task and Covent Garden, London, for the real-world task. Participants' performance in real and virtual environments was compared and the results showed that the VE navigation task was significantly correlated with the real-world task. This result is significant for the current study as it demonstrates that SHQ can be used to better understand real-world environments and the results of the current study can be considered applicable to real environments.

4.2.1 ***Why SHQ in wayfinding & landmark research?***

SHQ consists of 75 levels with different spatial layouts. Researchers from University College London (UCL), University of East Anglia, McGill University, Northumbria University, ETH Zurich, University of Cambridge and Bournemouth University gathered and worked on the different phases of the design process with Glitchers Ltd. The structures of environments, as well as different conditions related to weather, maps, etc., were designed by researchers. While designing the levels, researchers began with simple environments, which became more complex and maze-like. Thus, it would be easy for participants to way-find in the beginning and as they become familiar with the commands and the game, it would become more challenging. This was important for researchers to understand the impact of layouts on wayfinding: using various measures, the environments could be analysed and the most significant factors could be detected.

Different layouts were designed by the researchers. While designing them, researchers aimed to increase the complexity gradually from very simple through to extremely challenging, based on their previous findings (Carlson et al., 2010; Hölscher & Dalton, 2008). In SHQ, researchers used "reverse-engineering intelligibility", since the approach is the opposite of established methods. Architects design intelligible, user-friendly spaces, while the opposite is generally not requested. During the design phase of the game, it was hypothesised that landmarks may play a role in navigational performance. Subsequent work by the authors provide evidence this (Emo et al., 2012; Grzeschik et al., 2019). The original game was designed based on a rigorous framework of controlled landmark conditions in order to further explore the role of landmarks in navigation. Hence, not only the spatial layouts of levels, but also landmarks were designed to help people find their way. The landmarks were defined and created previously by the game company Glitchers Ltd. with the help of academic researchers. Researchers defined both global and local landmarks, as well as salient and less salient landmarks. Therefore, the game is not only valid because of above-mentioned health-related reasons, but it is also essential as it can be used to analyse the effect of different landmark conditions.

4.3 Collection of the data

As mentioned previously, the game consists of 75 levels. These are large-scale VEs in which participants cannot see the destination from the start point, except in the first level. All levels have different spatial layouts, except for five levels where the same layout is repeated and conditions are changed. Participants are asked to complete three different tasks (see Figure 8). At the beginning of the *wayfinding levels*, players first see a map that includes their specific locations and the goal locations that they should reach. The map then disappears, and players need to navigate a boat in the VE while they look for a sequence of destinations. In the *path integration* levels, participants are asked to find a flare and shoot it back toward the starting point as the purpose of the second task is to determine how well players can work out the direction they have travelled. Finally, as a third task, players chase a sea creature and take a picture of it in the *chase levels.* This task was intended to gauge people's familiarity with game playing (Coutrot, Silva, et al., 2018). In this thesis, wayfinding levels were considered, since the aim of this study is to explore the impact of different conditions on people's wayfinding performance. In the wayfinding levels, people saw a map first (that is, the allocentric view), then closed it, navigated the boat in different virtual environments and looked for the goal locations (using the egocentric view).

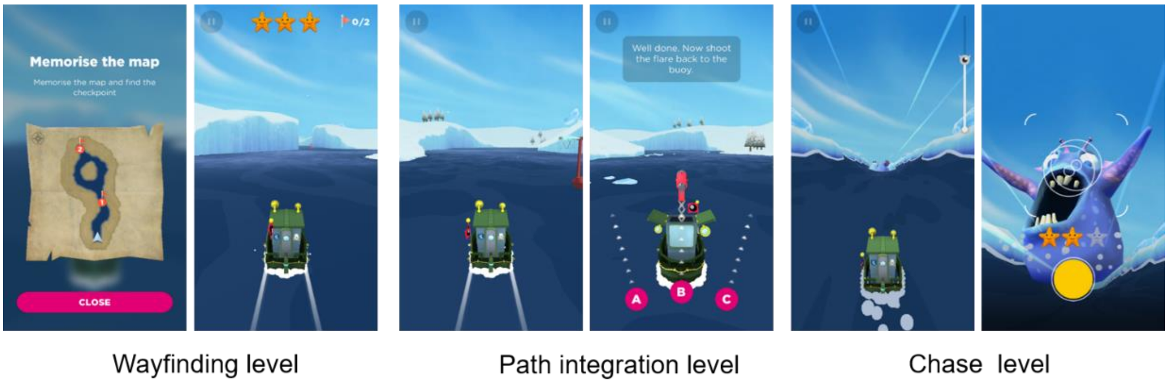

Figure 8: Sea Hero Quest (SHQ): the three tasks participants are asked to complete (Image source: Glitchers Ltd.)

Five different environments were designed: arctic rivers, golden shores, mystic marshes, kano reef and high rollers (Figure 9). In these different environments, different environmental components (e.g. landmarks) were used.

People used three commands to move the boat: tap right to go to right, tap left to turn left and swipe up to speed up. Between levels, participants were asked to answer questions as follows:

- What gender are you (male / female / other)?
- How old are you (open ended question)?
- Which country do you live in (selection from a list)?
- Which hand do you write with? (left/right)
- What's your education level? (no formal education / high school / college / university)
- What's your daily travel time (less than 30 minutes / 30 minutes – 1 hour / 1 hour or more)
- How good are you at navigating? (very good / good / bad / very bad)
- How much sleep do you get on average each night? (1–16 hours)
- What environment did you grow up in? (city / suburbs / rural / mix)

The questions were all optional and people could proceed to the next levels without answering them.

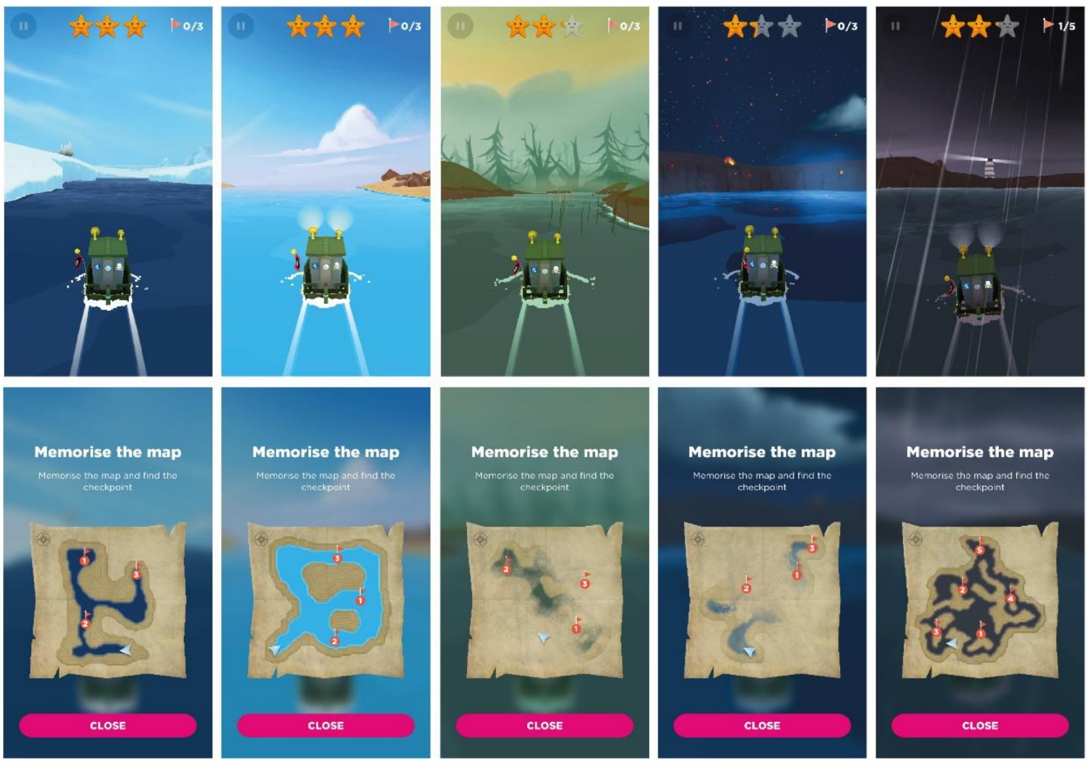

Figure 9: Five themes designed for SHQ: above, the environments people see while playing the game and below, the maps – clear or obscured – they view before starting the game

The results were collected by the game company as soon as people completed a level. If people were offline, then the data was stored on their device and sent when they were online again.

4.4 Data sharing

Participants' results were collected by the game company and the first results from 2.5 million people were shared with UCL, and these were then shared with other schools working on SHQ. The dataset was stored within the UCL firewall on a Structured Query Language (SQL) server and it was accessed via a web portal with a secure log in. Dr Nick Dalton and Sam Noble (both from the Computer and Information Sciences (CIS) department, Northumbria University) accessed the server and converted the data from Java Script Object Notation (JSON) to '.csv' files, which are not publicly available yet. This data included the participants' trajectories and duration (the time taken to complete each level). Survey results were also collected using the same approach.

The layout of the levels, on the other hand, was obtained from one of the researchers of the game (Professor Ruth Conroy Dalton). This data was in .png format and the navigable spaces were shown in white whereas the land was shown in black. Similarly, the conditions of the levels were also received from the researchers as an excel file (Appendix Table A 1).

4.5 Analysing the data

As previously mentioned, this study explores the existing layout and existing landmark definitions to see how well they explain people's wayfinding performance. Figure 10 outlines the overall method followed in this thesis. In consideration of the discussions in the literature review, landmarks are analysed based on their location, visibility and saliency. To be consistent with the literature about visibility of landmarks, in the game levels, global landmarks were defined as objects that could be seen from a great number of vantage points while local landmarks were defined as landmarks that could be seen from nearby.

For landmark saliency, one of the fundamental definitions in the literature, Sorrows and Hirtle's (1999) three-tiered definition (mentioned in Section 3.5) is used. Hence, structural, visual and cognitive characteristics of landmarks are explored. The researchers of SHQ evaluated landmark saliency based on the visual characteristics of objects, independent of the context. Hence, first, the saliency description that was used in SHQ is considered and the sufficiency of this description is explored. As a further step, all characteristics of landmarks are measured, and the visibility and saliency of landmarks are analysed. The location of landmarks, on the other hand, is analysed based on their relationship with participants. Hence the intention is to focus on landmarks that are close to the observer, and landmarks that are further away from the viewer during the game. Visibility and location of landmark (structural characteristics) are analysed as a part of saliency in this study, since they can be considered to be a part of saliency.

Environment-related data is analysed under three headings: spatial comparison (Space syntax analysis), complexity of layouts and level comparison. Finally, participants' performance is compared based on the time they took to complete wayfinding tasks as well as the length of path they followed.

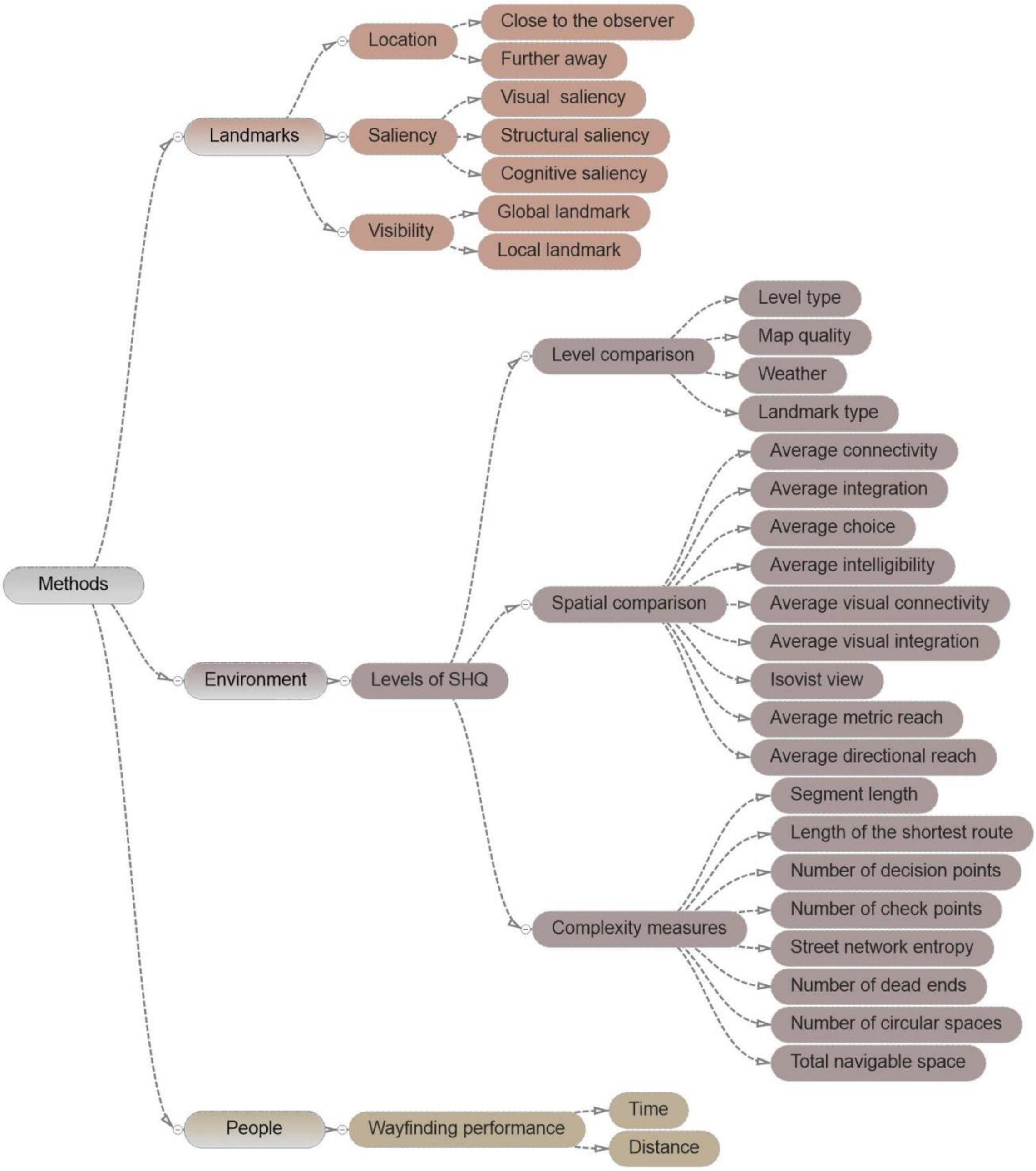

Figure 10: Overall method of the thesis

4.6 Trajectories and duration

In addition to the duration to complete a wayfinding task, the trajectories are also measured to see the distance that participants covered in each level. Data about the players' trajectories are collected on a grid every 0.5 seconds by the game company (sampling rate: Fs = 2 Hz.). The origin of the coordinate system is at the bottom left of a grid, and x increases with movement to the right and y increases vertically. Furthermore, the orientation of participants is also recorded in 16 discrete steps for every 22.5° (so for example north was coded as 0°, east was coded as 90°, south was coded as 180°, etc.). This data is also a part of the coordinate system, and was defined as r (so trajectory data included x, y and r data).

The coordinate information is also recorded in an SQL database and the information is converted to a .csv file. The trajectory lengths are calculated based on the coordinate information of participants (Coutrot, Schmidt, et al., 2018; Coutrot, Silva, et al., 2018).

The trajectories are then used to determine a difficulty score for each level using the following equation:

$$\text{Difficulty Score} = \frac{\text{median(trajectory length)} - \text{min(trajectory length)}}{\text{min(trajectory length)}}$$

Equation 8. Difficulty score calculation by using trajectories

Accordingly, the difficulty score is determined by subtracting the minimum trajectory length from the median trajectory length, and then normalising that value with the minimum trajectory length. The underlying reason here is to normalise the difficulty score by the size of each level, in order to avoid having big difficulty scores just because of the relatively larger size of the level. Min(trajectory length) represents the length of the 'optimal' trajectory (the trajectory people would follow if they do not get lost). Hence, "median(trajectory length) – min(trajectory length)" shows how far the median performance is from being optimal. By using this formula, a score is calculated for each level. Hence, a higher difficulty score means that the level was more challenging for people and the difference between the maximum and the minimum trajectory length was greater. In contrast, a lower value shows that the difference between the lengths of trajectories was not high and the level was not too hard to complete. Difficulty score was used as one of the dependent variables in the statistical models.

Similarly, the time taken by participants to complete levels was also obtained. In order to correct the results with people's gaming abilities, the time taken by participants to complete levels was divided by the time taken by participants to complete the first two levels, which were the training levels. Duration was included as another dependent variable in the statistical analysis.

4.7 Spatial analysis of levels

In order to understand the factors that affect people's wayfinding performance, the spatial layouts of levels were analysed. As mentioned previously, the layouts were collected from one of the designers of SHQ as .png files (please see the second image of Figure 11 for an example). This data was used to analyse the environments. Accordingly, Space syntax measures were used in addition to complexity measures in order to analyse the environments objectively and to be able to compare results between levels. To perform Space syntax analysis, Depthmap X 0.50 software was used and axial maps were automatically created with the software through the use of fewest-line maps. Similarly, VGA was automatically calculated in the same software.

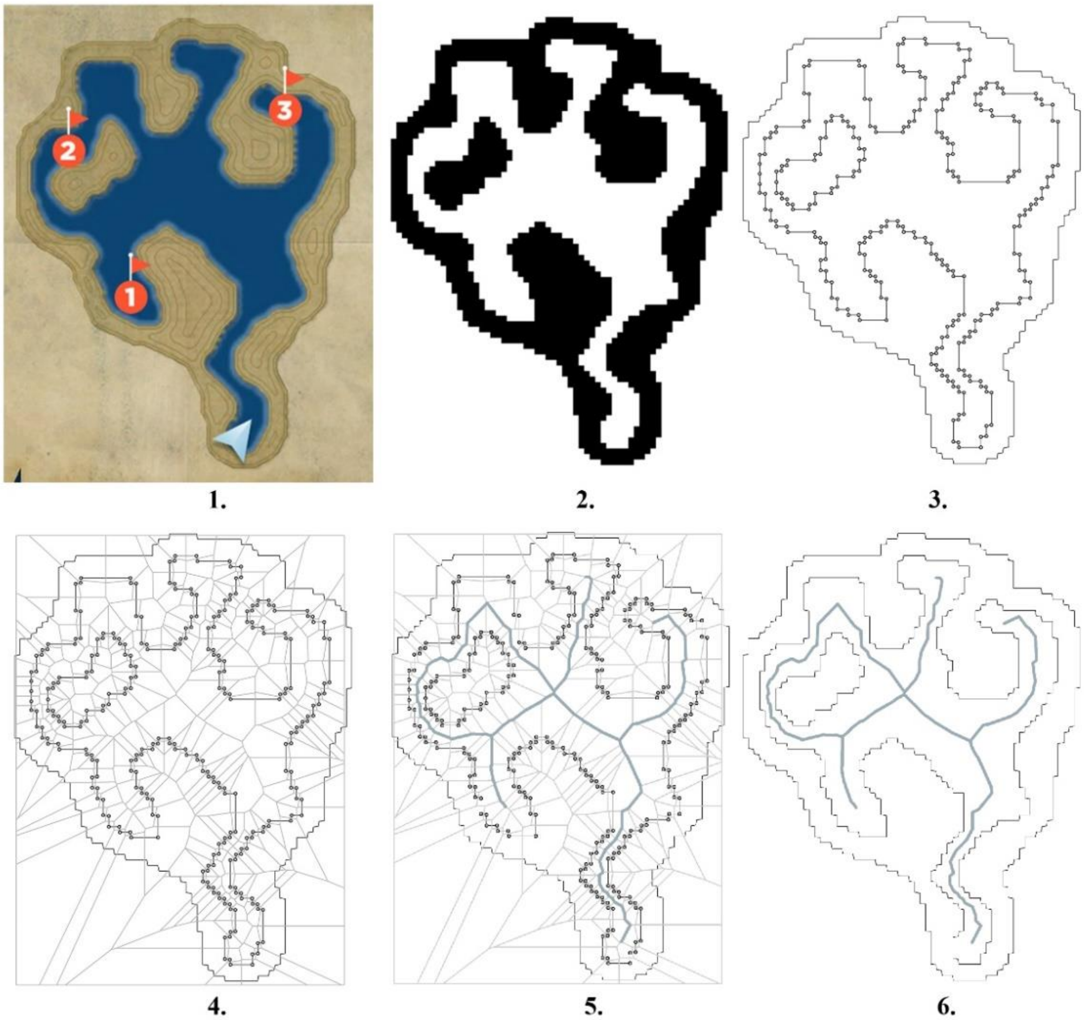

Figure 11: Process of creating segment maps (level 46 is used as an example): 1. the maps presented to participants in which the arrow shows the start point and the numbers represent goal locations, 2. the .png version of the layout obtained from the game's designers, 3. edges of the environment defined by points, 4. voronoi polygons were created, 5. segment lines were defined using voronoi regions 6. the layout and the segment map.

As there were no road-centre lines in the game environments, an unusual method was used to create segment maps in the canal-like environments. As a first step, the edges of navigable spaces were defined with points in ArcMap and then voronoi polygons were created using the points. In voronoi polygons, each location within a polygon was closer to this point in this polygon rather than any other point. Hence, these polygons were used to define segment maps and the edges of voronoi polygons shaped segment lines (Figure 11).

Some principles were followed to create segment maps:

- Try to define the layout clearly,
- Do not define the edges of environments if voronoi lines are shorter than 10 metres,
- Add additional points randomly if no edges are defined within the navigable spaces (this happened only when there were long straight patterns).

Once the segment maps were created, analyses were computed for both axial and segment maps including:

- Connectivity,
- Number of lines (for axial maps),
- Global (radius- r:n) and local (r:2,3,5,7) integration,
- Global (r:n) and local (r:2,3,5,7) choice and normalised choice,
- All lines integration and choice (r:n, 2, 3, 5, 7 for axial maps),
- Intelligibility (for axial maps),
- Metric reach (10, 25, 50, 75 and 100 metres[13]),
- Directional reach (10°, 0 and 2 direction changes and 20°, 0 and 2 direction changes[14]).

Visibility graph analyses (visual integration and visual connectivity) were also computed in Depthmap X (Varoudis, 2014; Turner & Friedrich, 2011), and visual intelligibility and isovist analysis were performed. To perform isovist analysis, a 90° isovist view was used (as the camera in the game used a similar angle – 80°) and the visible area from the start point was measured. The ratio between the visible area from the start point and the whole navigable space was calculated and added as another measure.

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[13] Measures that are used for metric reach depend on the purpose of the study. It can be 400, 800 or 1600 metres for walkability studies, for instance, as the values represent 5, 10 or 20 minutes of walking distance respectively (Institute of Highways & Transportation, 2000). In this study, the values were selected based on the scale of the environments.

[14] As mentioned previously, direction changes influence spatial cognition as they are an aspect of configurational complexity, and direction changes are related to pedestrian movement (Peponis et al., 2008). Hence, as mentioned by Turner (2000), it gets harder to find locations when the angular separation is higher. In this study, directional reach was computed for 0 and 2 direction changes subject to 10° and 20°, as the threshold was low enough to analyse the street sinuosity sensitively. Having 0 direction change was useful to see the effect of linearity, and having 2 direction changes was selected based on the findings of an earlier study, which mentioned that integration computed for 2 direction changes can be a better predictor of movement than integration computed for more direction changes (Hillier, 1996b).

Using segment maps, complexity was also analysed with numerous measures. Average segment length, minimum segment length and total segment length were measured and added to the data table. The shortest realistic route (the metric shortest route with respect to the order of checkpoints), number of dead ends and the SNE, calculated using Shannon's entropy description, were also measured for each level. In addition, the number of decision points (intersections) and number of checkpoints, which varied between one and five, participants should find for each level, number of circular spaces and the area of the total navigable space were calculated.

To calculate SNE, segment lines were used and the Douglas-Peucker algorithm (1973) was used to simplify the line made of the connected segments. For all game levels, maximum offset tolerance was used between the original and the simplified line of three pixels. The entropy of the orientation distribution of the game levels' segments were then computed with Shannon's entropy formula. The space was divided in 36 bins (1 bin is 10° wide), and each bin was a "subset" in the formula. Hence, if there was an equal probability for each bin to contain a segment, the entropy was very high (hard to predict in which bin the segments were). If all the segments were in the same bin (i.e. have the same orientation), the entropy was very low.

4.7.1 *Conditions of levels*

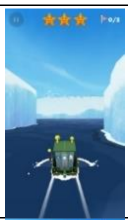
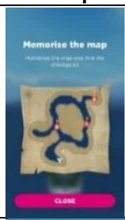
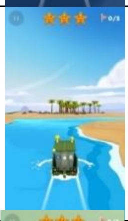
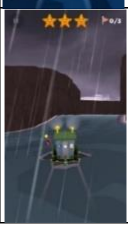
In order to use the conditions as measures in statistical analysis, all conditions were coded as follows:

- Weather condition: if the environment was foggy or the water had waves, it is coded as "0" and if the weather was clear and the water flat, it is coded as "1".
- Map condition: if the map was obscured, it is coded as "0" and if the map was clear, it is coded as "1".
- Global landmark condition: if the environment included no global landmarks, it is coded as "0" and if it included global landmarks, it is coded as "1" (all environments included local landmarks except for the environments with "no landmarks" condition).
- Landmark condition (saliency): if there were no landmarks in the environment it is coded as "0", if there were hard (less salient) landmarks only it is coded as "1" and if there were easy (salient) landmarks, it is coded as "2".

4.7.2 *Levels with the same layout*

Another aim of this research is to investigate the impact of different weather, map and landmark conditions. SHQ is a good case study to make this comparison, since there are five levels with the same spatial structure. Levels 13, 22, 36, 51 and 66 of the game, in which the layout and checkpoints are exactly the same, were used to analyse the impact of conditions. Table 1 displays the conditions within the five levels and the image of the map on the row for level 13 shows the layout of these levels. As mentioned before, all these different conditions were defined by the researchers of the game, specifically by Professors Ruth Dalton, Christoph Hölscher, Jan Wiener and Hugo Spiers. In the five levels that are used in this study, there are no global landmarks that can be seen from many angles and points, and the environments include only local landmarks that can be seen from close up. Weather conditions vary between clear, in which visibility is high, and foggy, in which it is harder to see environmental clues and destinations as the visibility is low. In addition, the map condition varies from normal, in which the map is easily read, and obscured, in which the layout cannot be seen clearly, although the goal locations can still be seen.

Table 1: The five levels where the same spatial structure was used and conditions of levels were changed

Level	Theme	Image of the theme	Difficulty	Landmark	Global	Weather	Map	Image of the map
13	Arctic Rivers		Easy	Easy	No	Clear	Normal	
22	Golden Shores		Easy	Easy	No	Clear	Obscured	
36	Mystic Marshes		Easy	Easy	No	Fog	Obscured	
51	Kano Reef		Easy	Hard	No	Clear	Obscured	
66	High Rollers		Easy	None	No	Waves	Obscured	

As shown in the table, level 13 has the easy landmark condition, clear weather and a normal map. Level 22 has the same landmark and weather conditions; however, the map of this level is obscured. Level 36 also has obscured map and easy landmark conditions, but this level has foggy weather. Level 51 has similar conditions to level 22 as it also has clear weather and an obscured map; however, landmarks of this level are less salient and less accessible, so it has the hard landmark condition. Finally, level 66 includes an obscured map just like levels 22, 36 and 51. Moreover, two conditions vary in this level; landmarks and weather. There are no landmarks, and the canal is wavy so that the visibility changes constantly. Hence, the effects of these different conditions as well as the combined impact of conditions can be analysed through the use of these five levels.

4.7.3 *Cluster analysis*

In order to better understand the impact of different landmark conditions, levels with similar layout properties are analysed. For this purpose, a cluster analysis is conducted. Both the Space syntax tool (Hillier & Hanson, 1984) and complexity measures are used. Levels that have similar values were gathered and a more comparable system was created through the use of clusters (see Figure 12; also see Appendix Figure A 3 to see two-dimensional scaling).

Results of the cluster analysis were checked for both global landmark and salient landmark conditions. The levels with same map and weather conditions and that differ only in the global landmark condition or saliency condition, were selected to make a fair comparison for landmark investigation in the following chapters (see Table 2). Based on the factors described, levels 3 and 13 were selected to see the impact of global landmarks, whereas levels 31 and 32 were selected to see the impact of the saliency of landmarks. Levels 46 and 56 were also in the same clusters and they had same conditions, except the global landmark condition. However, in level 56, participants experienced “obstacles” for the first time, which could cause a dramatic change in performance. Hence, these two levels (levels 46 and 56) are not included in the study and the former levels, 3 and 13, are used. Levels 61 and 62 also had the same conditions, except the salient landmark condition, and they were located in the same cluster; however, in these levels the wave condition was introduced to participants, for the first time in level 61. As this would also affect performance, these two levels are not considered in this study and only levels 31 and 32 are thought to be levels that can be used to explore the impact of salient landmarks.

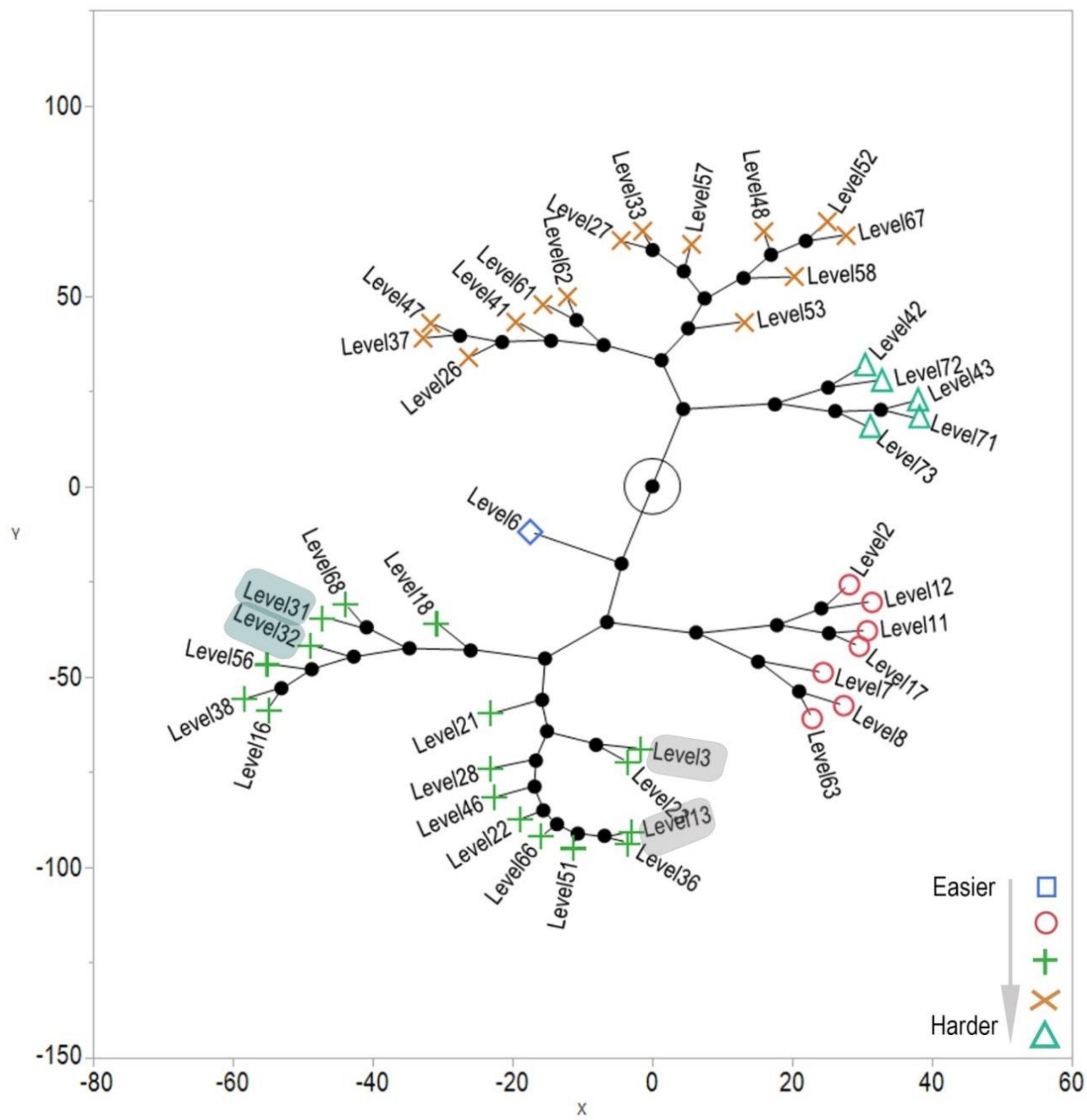


Figure 12: Constellation plot shows the result of the hierarchical clustering. Five clusters are shown with different colours and marks.

Table 2: Attribute table of levels 3 and 13 and levels 31 and 32.

Level	Theme	Landmarks	Global	Weather	Map
3	Arctic Rivers	Easy	Yes	Clear	Normal
13	Arctic Rivers	Easy	No	Clear	Normal
31	Mystic Marshes	Easy	Yes	Clear	Normal
32	Mystic Marshes	Hard	Yes	Clear	Normal

4.8 Landmark analysis

The researchers of SHQ defined salient landmarks as mentioned above. While doing this, four researchers (Professors Ruth Conroy Dalton, Christoph Hölscher, Jan Wiener, Hugo Spiers) evaluated landmarks using images where the landmarks had been cropped from their original background. They created a matrix in order to decide salient and less salient landmarks (see Table 3). Salient landmarks were defined as visually salient objects (Sorrows & Hirtle, 1999) located at accessible points, and less salient objects refer to visually salient or less salient objects located at segregated points. Global and local landmarks were also defined by the researchers and the landmarks were designed by the game company using the definitions provided by the researchers. Global landmarks were defined as objects that can be seen from many angles, whereas local landmarks were defined as objects that can be seen from a limited area.

Table 3: Saliency of landmarks by the definition of the researchers

	Large & Salient Landmark	**Small, Less Salient Landmark**
High Spatial Integration	Best	Average
Low Spatial Integration	Average	Worst

Consistent with the literature, this thesis aims to analyse landmarks based on their visual, structural and cognitive characteristics (see Figure 13). For visual saliency, saliency algorithms are used and experts' and non-experts' saliency evaluations are compared. For structural saliency, the locations of landmarks are considered as well as the visibility of landmarks, since higher visibility would mean that a landmark could help someone to find his/her position or orient himself/herself from many angles. In order to test the results of the visibility of landmarks, a survey is also conducted. Cognitive saliency, on the other hand, is explored using personal saliency evaluations via another survey.

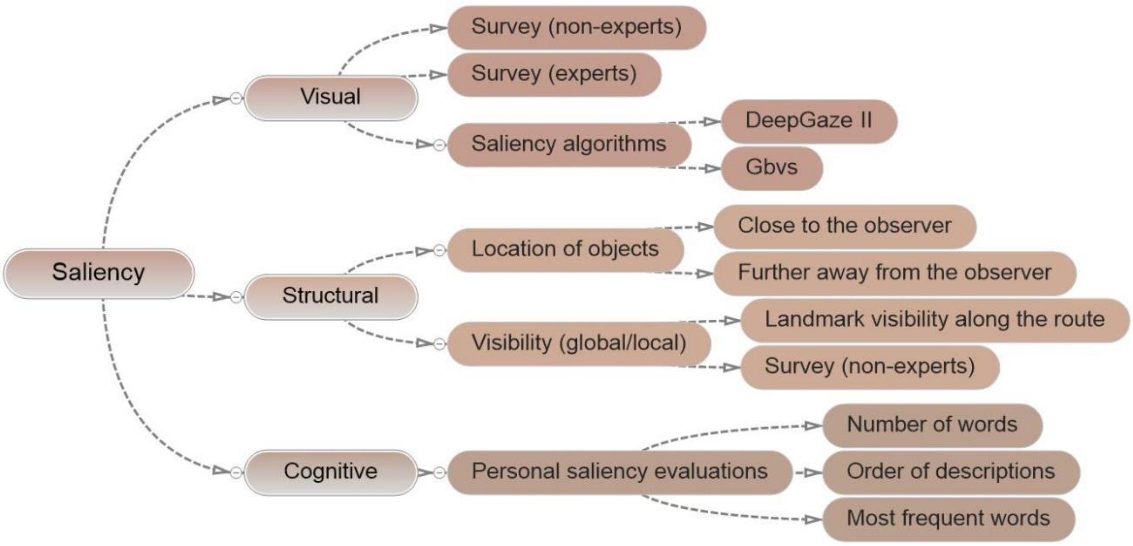


Figure 13: The criteria used to explain visual, structural and cognitive saliency in the thesis

The following subsections explain the methodology used to analyse visual, structural and cognitive saliency in detail, as well as introducing the procedures and participants.

4.8.1 ***Procedures***

For all of the mentioned characteristics of landmarks, a survey was conducted and the procedure followed for each survey was similar. To explore visual, structural and cognitive saliency, the same levels (levels 31 and 32) are used, where the spatial structures are similar, the theme and the conditions associated with global landmarks, weather and map are the same, and only the landmark saliency differs (see Figure 14). Level 31 had the easy landmark condition and level 32 had the hard landmark condition, as defined by the researchers of SHQ. Easy landmarks are visually and structurally salient landmarks. As Sorrows and Hirtle (1999) defined, they can be differentiated from their surroundings by their visual characteristics, such as colour, shape or size, and they are placed at integrated locations, for instance, at intersections. Hard landmarks are visually less salient landmarks or salient landmarks at segregated places, such as dead ends.

For the survey studies, participants were asked to focus on environments and not to consider their spatial performance. Hence, for each level one video was recorded in which a boat navigated through the environment, all goal locations were found and an optimal path taken. The length of each video was between 60 and 90 seconds, and it was at 750x1334 pixel resolution on a screen size of 5.44 inches (138.3 mm) height by 2.64 inches (67.1 mm) width. The video was converted to silent mode as the noise could distract participants.

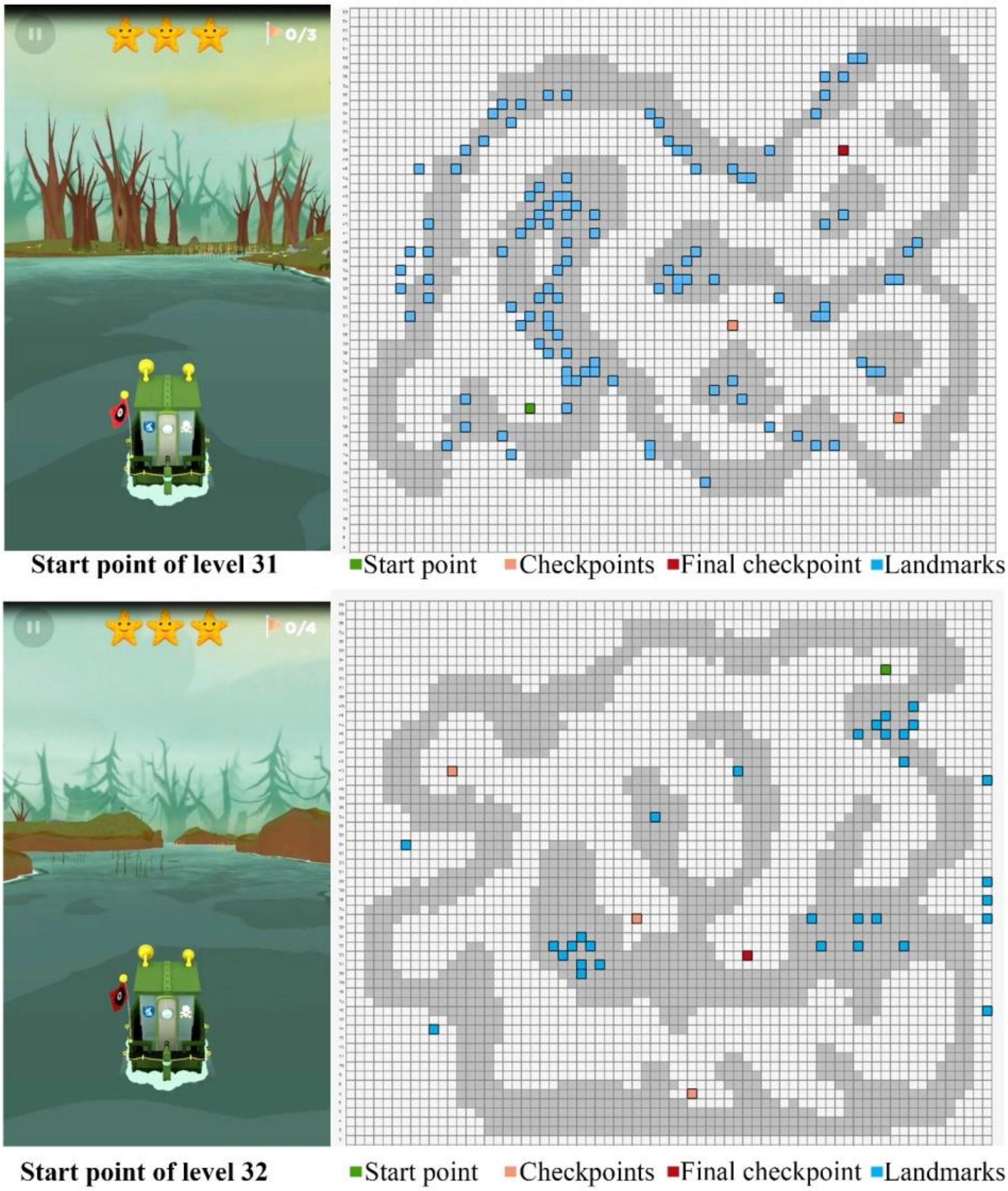


Figure 14: Layout of levels 31 and 32 and position of landmarks: screenshots were taken from the start points of level 31 (above) and 32 (below) and the start points, checkpoints, and final checkpoints are shown on the maps

All previously designated landmarks in each level were used in the saliency studies since any of these could help people navigate within the environment. Visual characteristics of landmarks include colour, size, shape and material. Structural characteristics, on the other hand, include the location or visibility of landmarks; that is, landmarks seen clearly from a shorter distance versus those that fail to be recognised clearly due to increased distance. For level 31, nine landmarks, and for level 32, seven landmarks were used. In order to create the online survey, Google Forms was chosen among other online survey pages, as it allowed us to randomise questions, and upload videos and images for free.

Before starting the survey, participants were provided with project information and an informed consent form. The consent form and the procedure were approved by Northumbria University Ethics Committee (Submission ID: 7939). Then participants were asked to answer demographic questions (age and gender). They were informed that they could leave the survey at any time and the results would be anonymous. As they answered questions and moved to the next page, they were able to start the videos using the play button. Information about the video was inserted on the top of the video, which stated that participants should view the video in order to answer the questions. They were instructed: "In this study, you will be asked to watch two videos that have been recorded in a virtual environment. In these environments, you will see a boat navigating through a canal/river. The boat will travel to a series of destinations. Please watch these videos and pay attention to the landscape through which the boat is moving." During the video, all checkpoint destinations were found in sequence and when the task was completed, the video stopped. Then participants were asked to complete the questions about the first video.

For visual and structural saliency evaluations, participants were shown images to evaluate the landmarks; however, they were not shown any images for the evaluation of cognitive saliency, as the aim of this part of the survey was to clarify which objects participants could remember better. For visual and structural saliency, once the video had stopped, participants were asked to view the images that had been taken from the video for each landmark (see Figure 15 for an example). They saw all the landmarks related to level 31. In one of the images, the transparency of the background was increased so that the landmarks could be seen clearly, and in the second image, participants viewed the image just as it was in the video. All images belonging to the same level were positioned on one page (centre-aligned) and the image size was 550x680 pixels. The order of the pictures was randomised across participants.

Figure 15: A landmark image is taken from the video of level 31. While ranking the visual and structural landmarks, participants viewed objects both with a transparent background (left) and as they were in the video (right)

Once they completed the questions for the first video (that of level 31), they followed the same procedure for the second video (level 32). The video order was not counter-balanced to match to the game experience. When participants had completed the questions for the two levels, they were presented with a page that notified them that the survey was complete, and they submitted their results by using the “submit” button. None of the questions, except the ones about their agreement on data protection and the procedure, was mandatory.

4.8.2 ***Visual saliency***

Visual saliency was first analysed using a survey similar to those used in previous research (Wenczel et al., 2017; Von Stülpnagel & Frankenstein, 2015) and participants followed the survey steps described above (see Appendix Table A 2 to see the details of the survey instructions). Survey results on visual saliency could be closely related with cognitive salience as well; however, cognitive salience was beyond the scope of this part of the study. Hence, participants were asked questions to identify visual saliency only. Previous literature argued that people’s attention level is lower when they complete a passive wayfinding task (Afrooz et al., 2018). However, other research stated that no difference was observed between active and passive navigators (Wilson et al., 1997). Based on the findings of the latter research, people were asked to explore the environment without completing any navigation task. Moreover, they were also directed to pay attention to the environment.

When participants (non-experts) viewed the images, they were asked to rank the landmarks (Appendix Figure A 4) on a 5-point Likert scale, from highly noticeable to unnoticeable.[15].

Before the online survey was released, a laboratory survey was held with 25 architecture students at Northumbria University. The purpose of the laboratory study was to control the online survey and to better understand whether or not participants were distracted during the online survey. The sample size was limited to 25 students, which represents 10% of the total number of participants. Participants were invited to the laboratory one by one and were asked to connect via their email addresses, through which they started the survey. After completing the laboratory survey, the online survey was released and participants were recruited online via a range of social media channels. The procedures and format of the online survey and laboratory survey were the same.

Four experts evaluated landmarks during the design process of the game as well. Experts in navigation studies, who had worked in wayfinding or navigation fields for over ten years, were selected from different disciplines (architecture, psychology, cognitive science) and different universities. As mentioned before, while evaluating the landmarks, experts viewed them on a white background and evaluated them out of context, rather than viewing them in their final game-environment context.

4.8.2.1 Objective saliency measurement

To explore visual saliency objectively, on the other hand, both Harel et al.'s (2007) method and DeepGaze II (Kümmerer et al., 2016) were used. Having run the analysis and examined the results of Gbvs and DeepGaze II, both sets of results seemed to intuitively capture some aspects of what makes a landmark salient. To be able to compare the saliency of objects, regions of interest (ROIs)[16] were used. In this study, boundaries of landmarks were used to define the regions (with rectangles). However, as the size of objects varied, the size of the ROIs also varied. Hence, the mean values inside the regions were calculated to be able to compare the saliency values.

[15] Rather than using the term "saliency", the term "noticeability" is preferred to make it easier for participants to understand and answer the questions.

[16] Region of interest means a selected area within a dataset that is identified for a purpose. So different rectangular areas were defined for each landmark, which is why the average values were calculated for each ROI. Where the ROI included a large amount of background image, multiple contiguous ROIs were used and the values produced were averaged. In most cases, the area included hardly any background information.

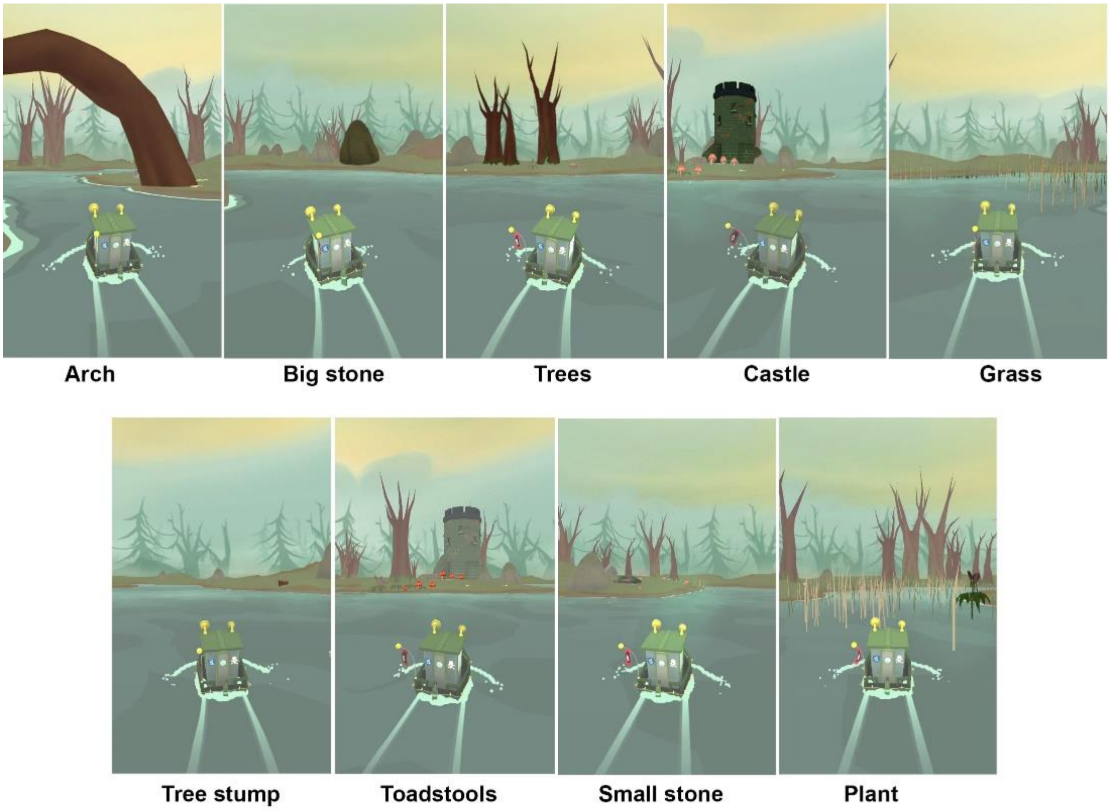


Figure 16: Screenshots from level 31, which consist of all landmarks that were used for the survey. Only images with transparent backgrounds are shown here rather than two images for each landmark.

In order to test whether there is a correlation between survey analysis and objective saliency measures, the same images used in the survey study were used in models (Figure 16). The objects were kept at the same distance for the screenshots and all objects were included in each level, as they were in the survey. The top part of the images, where the results of participants' performance could be seen, was cropped, as was the boat, so that they did not have any impact on saliency scores (Figure 17). In addition, in DeepGaze II, images were rotated by 90° to become a landscape image as the DeepGaze II algorithm is trained with landscape images. However, in the Gbvs, the analysis was unaffected by orientational effects. As DeepGaze II was trained with images of size 1024x786 pixels (Kümmerer et al., 2016), images in this study were resized to have the same ratio.

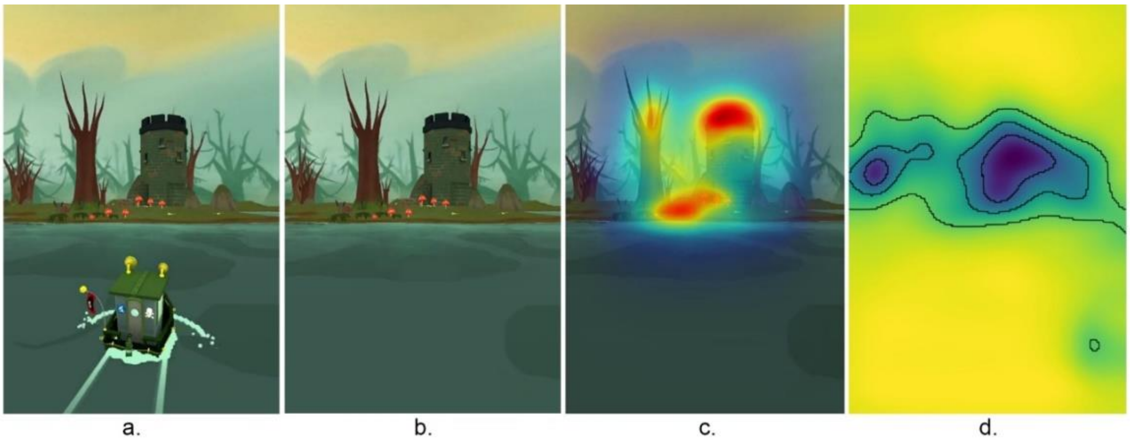


Figure 17: Objective measurement of saliency for level 31. Images from left to right: a. a screenshot from the game with the boat; b. an image with the boat excluded; c. Gbvs analysis; and d. DeepGaze II analysis. Both objective analyses were run in landscape orientation and only shown in portrait orientation to show the relationships. In image c., warm colours around the castle and toadstools indicate areas of high saliency and in image d., dark blue around the castle and trees indicates areas of high saliency.

The saliency map of the image of each landmark was computed with the two saliency models. To see the saliency maps, please see Appendix Figure A 5, Figure A 6, Figure A 7 and Figure A 8. Maps for DeepGaze II were prepared using a webpage (https://deepgaze.bethgelab.org/) and the Gbvs model was computed in Matlab (Mathworks, Natick, USA).

4.8.3 ***Structural saliency***

As the descriptions of global and local landmarks are about the visibility of landmarks (Castelli et al., 2008; Lynch, 1960), and as the previous research used a similar approach (Bhatia et al., 2013), in this study, landmark visibility is used to define global and local landmarks.

When people completed playing a level of the game, their result was sent to the game company automatically and all results were collected this way. During the data collection, players' paths were collected on a grid twice every second (so every 0.5 seconds) this way. The percentage of the journey time when the landmarks were visible was recorded for each landmark and for each participant, which made SHQ a great case study for investigating landmark visibility. Hence, it was possible to see the periods when the landmarks were visible for each participant. The data was stored as SQL data, and a program was developed in Java by Sam Noble from Northumbria University, CIS department, to convert the SQL data to .csv files, based on different queries (Figure 18). Rather than using all performance data, the first 10,000 results were imported using the program to make the download process faster. A hundred results were selected randomly for each level from this dataset.

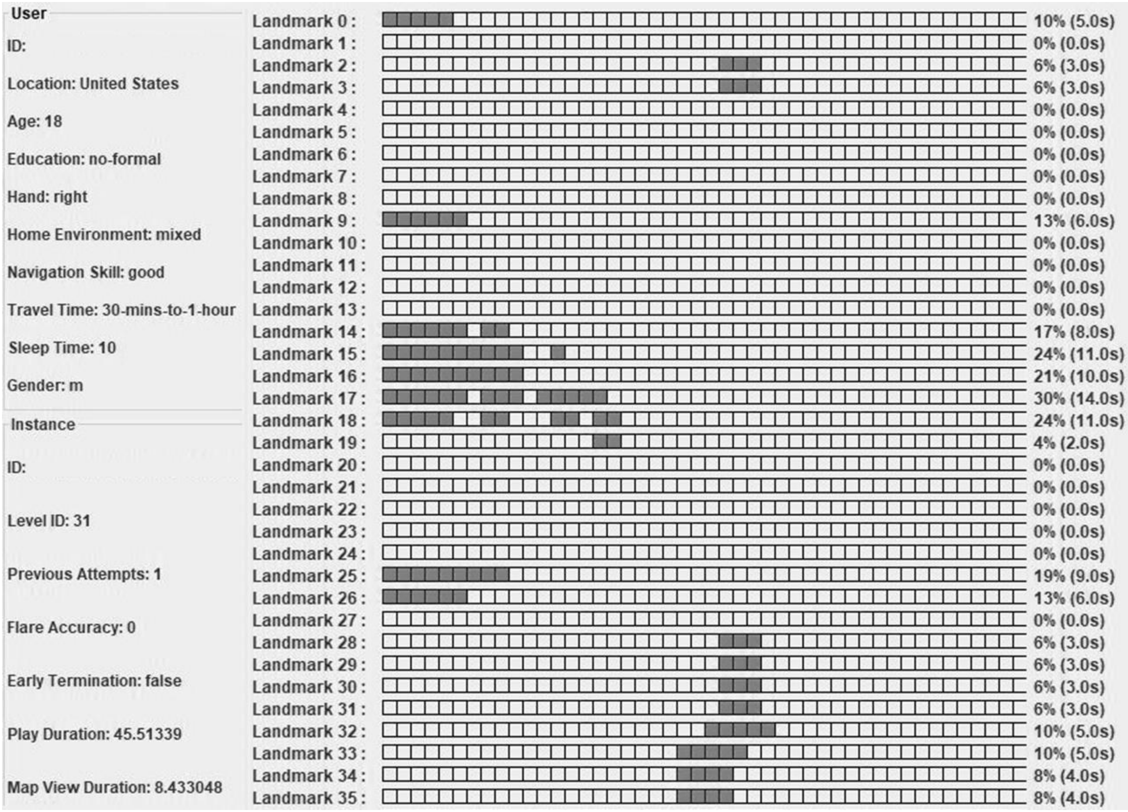


Figure 18: Output of Java program showing the landmark visibility for each participant. On the right, the dark grey squares, each representing 2% of journey time, show when the landmark is visible. On the left, the demographic and performance information of the participant can be seen.

In order to control the results of the visibility study, an online survey was also conducted (Appendix Table A 3). The details of the procedure of the survey study is explained above in the procedures section. In addition to this procedure, participants were introduced to global and local landmark definitions before they started watching the videos. When they watched the videos, they were shown screenshots of each landmark taken from the video (the same images used in visual saliency study). Finally, they were asked to define each landmark as either a "global" or a "local" one.

4.8.4 *Cognitive saliency*

For cognitive saliency, an online survey was completed again (for the survey instructions, see Appendix Table A 4). In the survey, people were instructed to watch the recorded videos and then were asked: "Which objects or landmarks did you see in the video? Please name them and describe each of them in a couple of sentences (you can mention anything that comes to mind about them)." The question was deliberately open ended; therefore, participants could describe the game's objects or landmarks in the way they would like. Only native English speakers were selected for this study so that the answers would not be affected by any language issues.

Survey results were downloaded as .csv files and they were first analysed with NVivo software to calculate word frequency. This method was chosen as it gives a fast and rough idea of dominant keywords. Words that did not refer to a landmark in this context, such as boat, buoys, stars that indicated a participant's performance, were excluded. In addition, synonymous words, like hill and mound, as well as identical ones in different grammatical forms, such as tree and trees, were categorised together and then the words' frequency in the text was used to visualise words in a cloud form. Second, the comments were read and the number of descriptions and different explanations used for each object were analysed, similar to the way described in the literature. Finally, the order of mentions was analysed, as it is expected to see cognitively more salient objects to be mentioned before other objects.

4.9 Participants and dates

The number of participants attending the studies varied. For the first analysis chapter of the thesis, "Analysing the levels of SHQ", the intention was to analyse all 45 wayfinding levels of SHQ. For the first part of the first study, difficulty scores are used to understand the relationship between performance and the layouts. For the second part of this study, the first two wayfinding levels were excluded from the study as they were practice levels, and the environments were not relatively large-scale environments.[17] Next, levels with unexpected obstacles necessitating an alternative path were also excluded as they would make changes in participants' performance independent from the environment; thus levels 56, 58, 67 and 72 were excluded. The results were recorded in seconds. Any results from participants playing the same level more than once were also excluded from the study; hence, each participant's first attempt was used for each level. In addition, any results from people aged over 70 were excluded from all analyses conducted in this research.

The total number of results collected from all wayfinding levels from participants who answered demographic questions is 15,873,128. When the results of the first two levels and those with obstacles, and the results of people aged over 70 are excluded, 11,848,523 results remain. These results are from 1,242,329 participants, including 532,722 female, 709,316 male and 291 other (preferred not to say) participants aged between 18 and 70 (Table 4).

[17] In the first level, specifically, participants could see the goal location from the origin.

Table 4: Conducted studies, dates, and demographic information of participants

Chapter	Study	#of results	#of people	Female particip.	Male particip.	Other particip.	Age	Date (for survey)
Analysing the levels of SHQ	Study-I-Part-II	11,848,523	1,242,329	532,722	709,316	291	18–70	
Analysing the levels of SHQ	Study-II	98,490	19,698	9,192	10,504	2	18–70	
Analysing the levels of SHQ	Study-III	1,388,974	694,487	299,876	394,422	189	18–70	
Visual saliency	Study-I		251	165	84	2	18–70	March 22nd–April 5th 2019
Structural and Cognitive Saliency	Study -I: Java		100	51 (level 31), 38 (level 32)	49(level 31), 62 (level 32)		18–70	
Structural and Cognitive Saliency	Study -I		70	44	22	4	18–70	May 18th–May 21st 2020
Structural and Cognitive Saliency	Study -II		32	10	21	1	18–70	December 5th–-25th 2019

For the second study of the “Analysing the levels of SHQ”, the same layout was used and the impact of different conditions was explored. The total number of results collected from five levels with the same layout was 1,382,053. However, as there were players who did not play all five levels, the results of those participants were excluded from the study (n=1,277,628). The duration data from the first two wayfinding levels were also included the study to normalise the duration based on the gaming abilities of participants. The results from participants who did not answer demographic questions were also excluded (n=2,230). Finally, the results from participants aged over 70 were also excluded (n=3,705). Consequently, 98,490 results that were collected from participants for the five levels were used. The total number of participants was 19,698. They were aged between 18 and 70, and the number of male participants was 10,504, the number of female participants was 9,192 and number of participants who selected “other” was 2.

In the third and the last study of the first analysis chapter, the impacts of global landmarks are examined using similar layouts and the same conditions. The total number of results collected from levels 3 and 13 was 2,038,776. However, the results from people over 70 (n=95,927) and results of players who played only one level (n=553,875) were excluded from the analysis to make a fair comparison. The number of participants who played the two levels was 694,487. The number of female participants was 299,876 and the number of male participants was 394,422 while 189 participants selected the “other” option.

For the second analysis chapter, “Saliency of landmarks: visual saliency”, the number of participants who took part in the survey was 254, including 25 people who attended the laboratory survey. The results of two participants were excluded from the study as they were over the age of 70. Additionally, one participant who answered only questions about the first level (level 31) was also excluded, so that only the results of the participants who completed questions about both levels were used (n=251). Eventually, 165 female, 84 male and 2 other (preferred not to say) participants aged between 18 and 70 took part in this study.

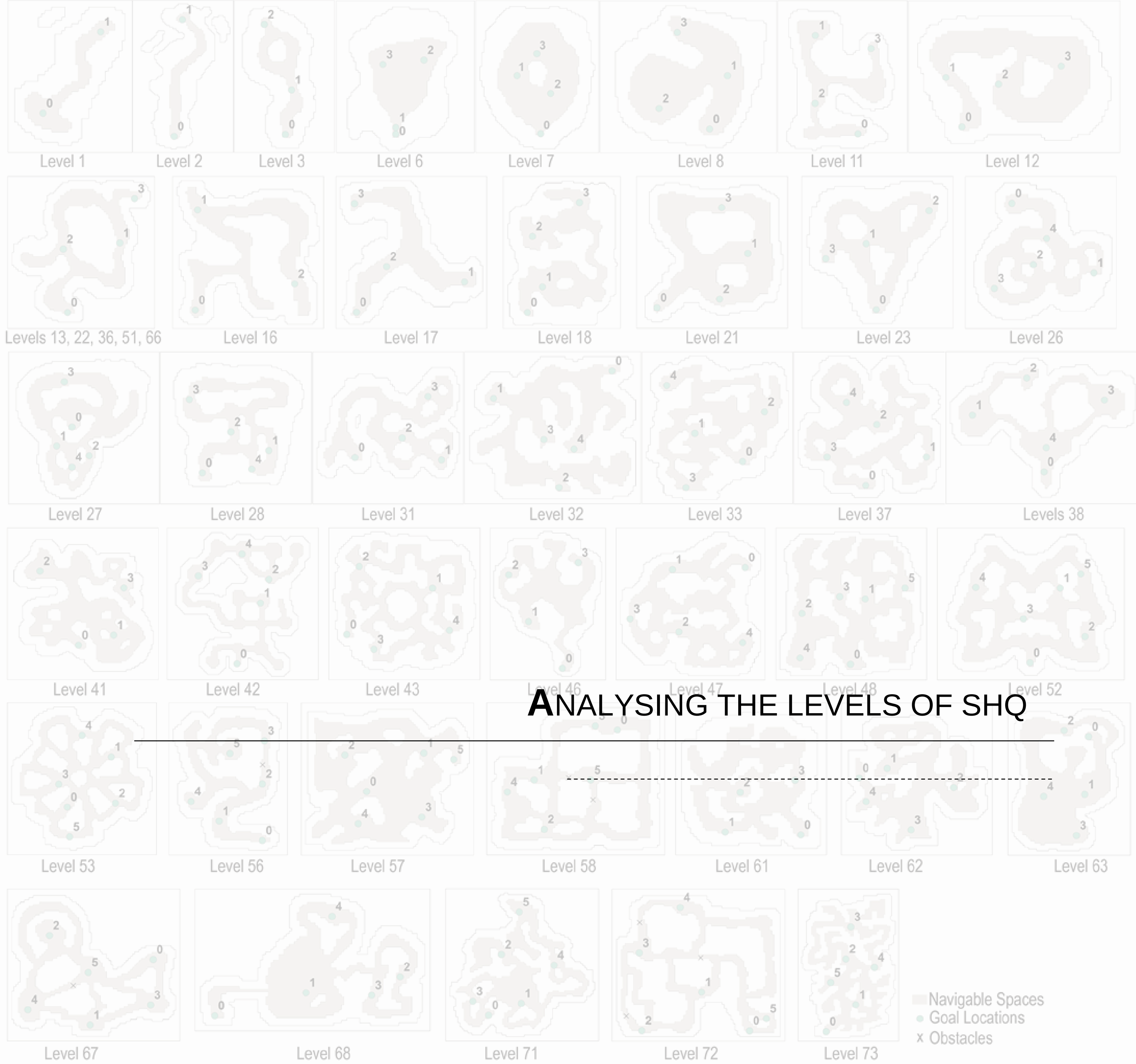
For the first study in “Structural and cognitive saliency”, which was about structural saliency, results from 100 participants between 18 and 70 were used to measure the visibility of landmarks during game playing. This number included 51 female and 49 male participants in level 31; 38 female and 62 male participants in level 32. On the other hand, 70 people participated in the survey, including 22 male and 44 female participants, while 4 participants preferred not to give gender information. All participants were aged between 18 and 70.

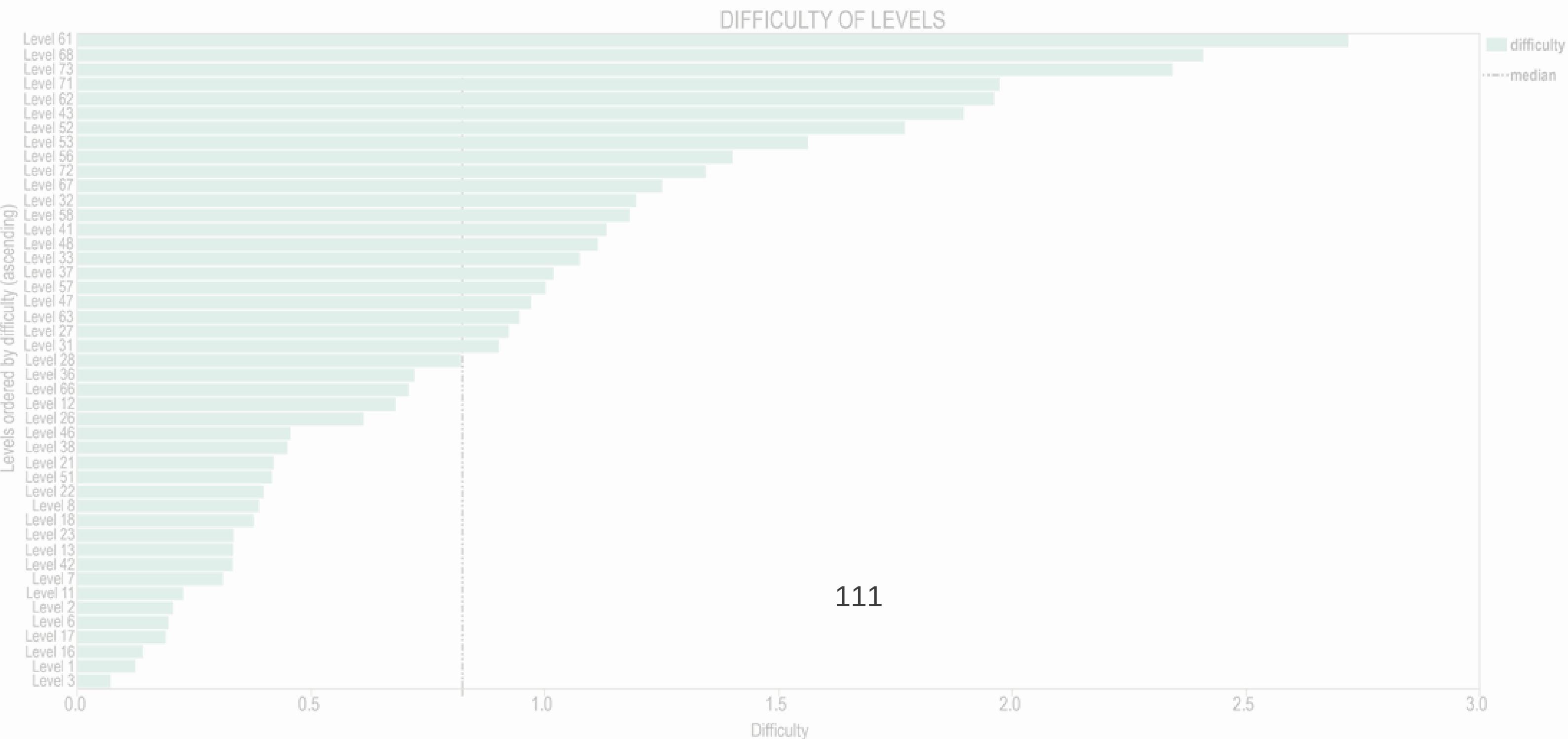
For the second study in the same chapter, the cognitive saliency study, 32 people aged between 18 and 70 completed the survey, including 21 male, 10 female and 1 other participant who preferred not to give gender information.

4.10 Summary of the chapter

This chapter describes the methodology used in this study. This is followed by the analysis chapters, where the gaps in the literature are investigated using a series of analyses. While doing this, first all of the measures that affect people’s wayfinding performance are discussed. Then, the impact of conditions is investigated in detail. As a last step, landmarks are investigated using the categories defined in the literature.

ANALYSING THE LEVELS OF SHQ





5 ANALYSING THE LEVELS OF SHQ

5.1 Introduction

Wayfinding studies aim to explore the environmental factors influencing purposeful and goal-directed movement, and to observe the influence of different elements, such as the number of decision points (Arthur & Passini, 1992; Raubal & Egenhofer, 1998), the spatial integration values of street networks (Hillier et al., 1993; Kim & Penn, 2004) or connectivity measures (Ozbil et al., 2016, 2015). There are numerous studies on wayfinding and associated environmental factors, and this subject is of great interest to urban planners and designers. In this chapter of the thesis, the effects of various spatial factors on the wayfinding performance of participants are analysed. In the first study, wayfinding levels of SHQ are introduced to the reader. All wayfinding levels are described and considered alongside participants' results. Moreover, correlation analysis is used to show the relationship between the variables. Statistical analysis is used to explain how people's wayfinding performance relates to complexity and Space syntax measures. In the second part of the study, the impact of different conditions, including salient landmarks, is analysed. In the third study, the effects of global landmarks are analysed.

In the first part of this chapter, wayfinding levels of SHQ are introduced and the layouts are analysed in detail. The differences between levels are visualised using the complexity and Space syntax measures introduced in the previous chapter. Here, a general picture is drawn for the reader; hence, all the measures discussed in the methodology section as well as the conditions associated with weather, maps and landmarks are used in this chapter. In the first part of the study, environmental measures were compared with the difficulty scores. In the second part of the first study, the time taken by participants to complete levels was used to explore the relationship in detail. In the second study, different weather, map and landmark conditions are analysed. And in the last part of the study, the global landmark condition was examined using two levels of the game.

5.2 Study-I

5.2.1 *Part-I – Analysis*

As mentioned previously, in this first part of the study, SHQ levels are introduced to the reader. Although SHQ has 75 levels, only the 45 wayfinding levels are used in this study. Figure 19 shows the wayfinding layouts of SHQ, including their checkpoints and any obstacles present. As the same layout was used for levels 13, 22, 36, 51 and 66, and these levels differed in their landmark, weather and map conditions, 41 layouts are displayed in the figure. In the images, “0” represents the start point and the numbers refer to the order of the checkpoints. Obstacles, represented by a cross, show where a wall suddenly appears in front of the participants while they are navigating. Therefore, at these positions people need to change their direction to reach the next checkpoint. As it can be seen from upper part of the figure, layouts were designed using different patterns (radial, organic, grid etc.) for variety. As described previously, researchers aimed to have simpler layouts in the beginning and designed them to become gradually harder to navigate. The difficulty of levels is shown in the lower part of the figure and levels are sorted based on the difficulty score (Section 4.6). Based on the game’s design process, it is expected that the last wayfinding levels are the hardest and the first are the simpler ones. Even though it cannot be claimed that there is a gradual increase in the complexity of layouts, it can be seen that highest levels of SHQ are harder for people to complete than the lowest levels. Considering path lengths, levels 61, 68, 73, 71, 62 and 43 are the hardest levels of SHQ since they have the highest trajectory length ratios, while levels 3, 1, 16, 17, 6 and 2 are the easiest. This demonstrates that researchers succeeded in designing levels with a gradual increase in complexity.

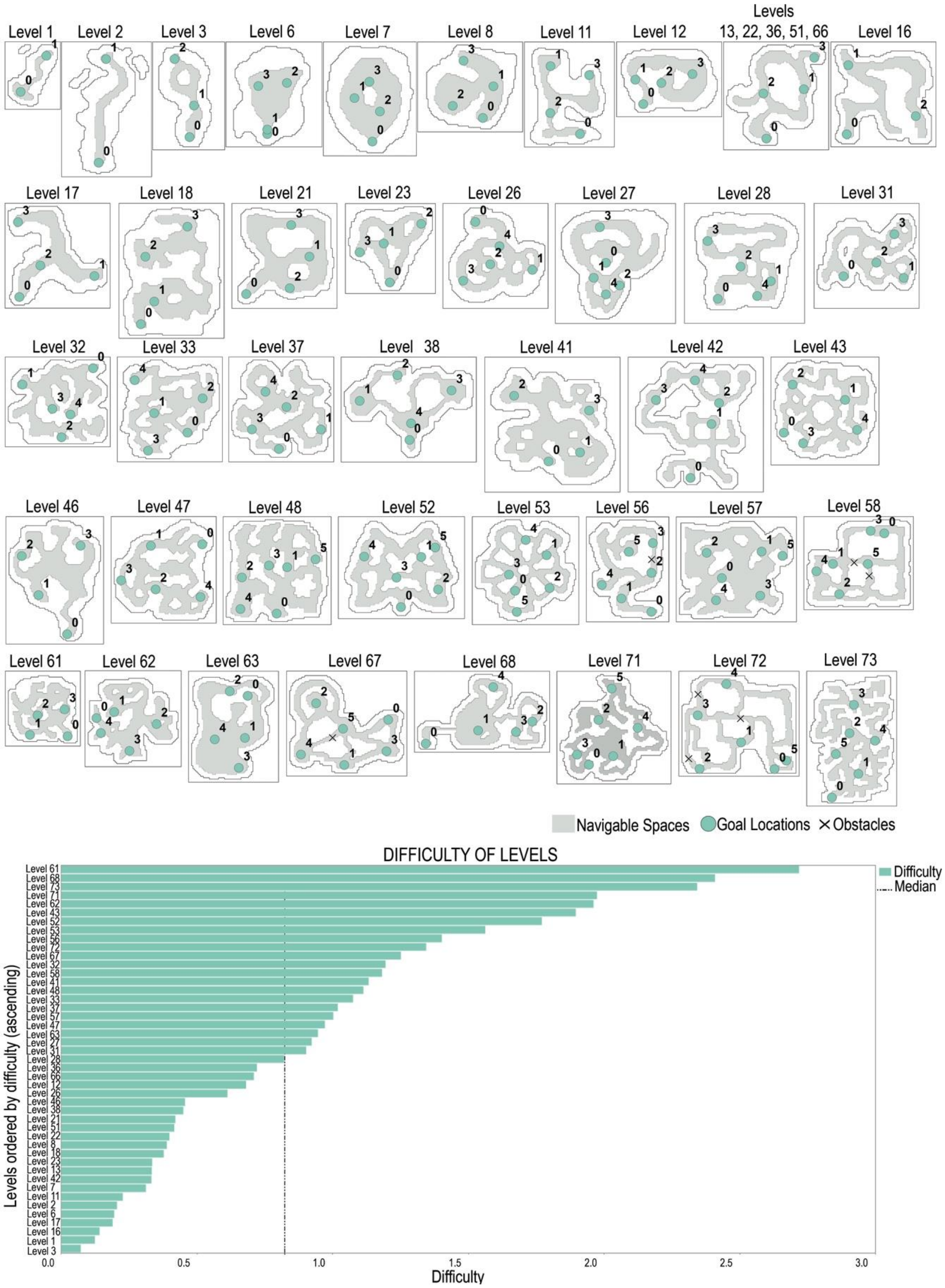


Figure 19: Layouts of all wayfinding levels (with checkpoints and obstacles) in SHQ and the difficulty of levels in ascending order

In order to clarify the analyses that are conducted in this study, different visuals are prepared. Figure 20 shows the results of the axial analysis for three different levels of the game. A gridded (level 58), an organic and more circular (level 68), and a more complex (level 73) layout were selected for this visualisation. Axial choice (r:n), and axial integration (r:n and r:3) were selected, and the same numeric range was used to compare levels easily. Warm colours represent higher values whereas cool colours represent lower values. Hence, for instance, one can see that there are a number of low-integrated lines in level 73 (dark blue lines), which suggests that the level includes more segregated lines, compared to levels 58 and 68. Similarly, results of the global axial choice indicate that level 73 has many lines with low preferability (dark blue lines – they are not likely to be selected as a shortest route).

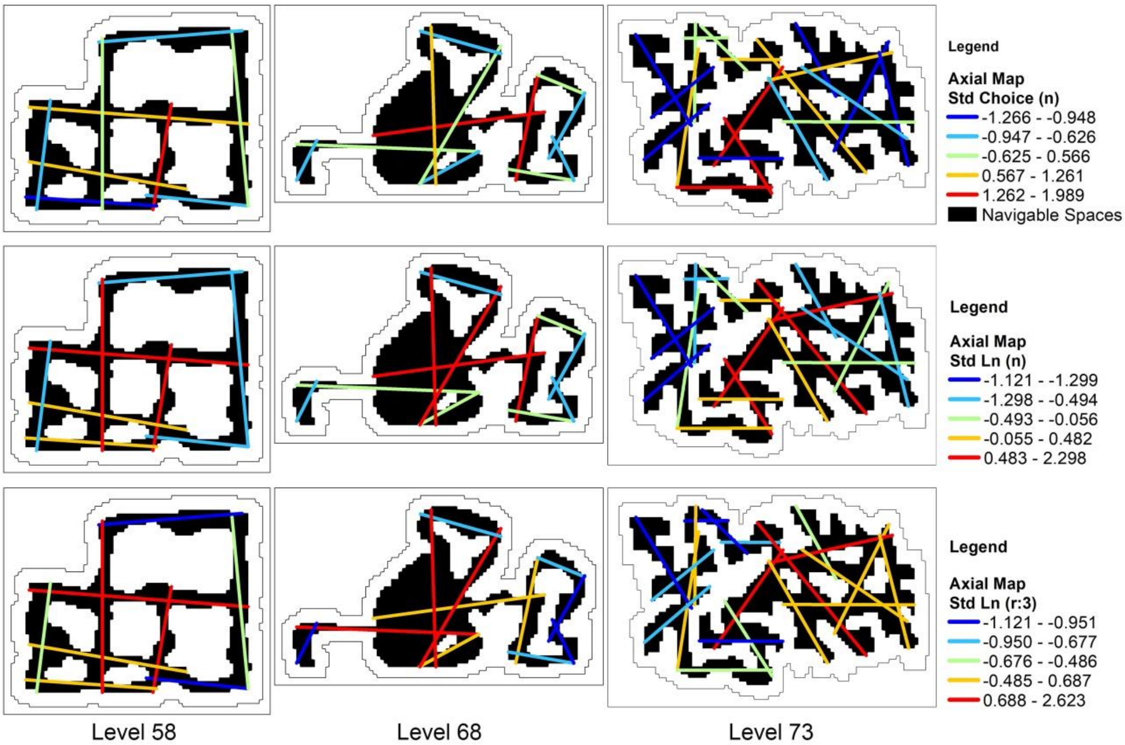


Figure 20: Results of the axial-based analysis for selected levels and measures (red lines represent the highest value and blue lines represent the lowest value). Level 73 is rotated 90° anticlockwise in the figure.

Figure 21, on the other hand, shows the results of segment analysis (to see examples of axial- and segment-based maps produced for this study please see Appendix Figure A 1 and Figure A 2). For this visualisation, the same levels (levels 58, 68 and 73) were used, and global choice and integration as well as metric reach (100 m) and directional reach (20º, 0 direction changes) were chosen. Again, choice shows the potential of a segment to be chosen as a shortest route. Therefore, warm colours have higher movement potential whereas cool ones have a lower movement potential. Integration shows the accessibility of the system and hence, red lines have higher accessibility (they can be reached more easily from the rest of the system) while blue lines have lower accessibility.

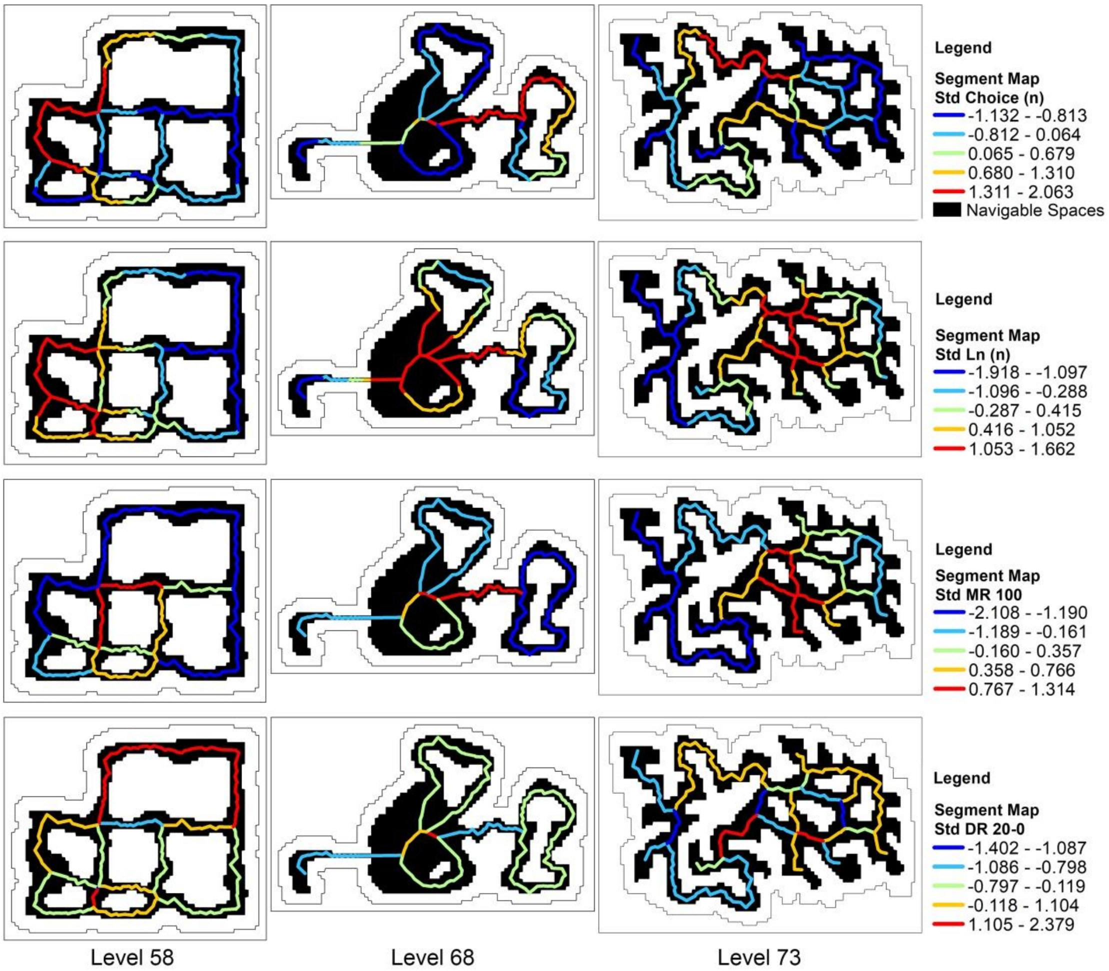


Figure 21: Results of the segment-based analysis for selected levels and measures (red lines represent the highest value and blue lines represent the lowest value). Level 73 is rotated 90° anticlockwise in the figure.

Directional reach demonstrates how far one can go by using 20º and 0 direction changes from each segment. Hence, red lines show that one can go further with this direction change (so it shows the linearity) and cool colours show that one can reach a more limited area (so it shows the sinuosity). Finally, the metric reach of 100 metres shows how far one can go from each segment by moving 100 metres. Hence, the values increase if the density of the street network increases. It can be seen that the central points have higher results, since more of the system can be covered from their centres. Since all levels here are measured in the same way, the edge effect was not considered, which is a possible problem in Space syntax analysis related to the sensitivity to boundary conditions (Penn et al., 1998).

5.2.2 ***Results***

As a next step, the correlation between variables is determined. Figure 22 demonstrates the resultant correlation matrix. Dark brown rectangles represent a high positive correlation while dark blue rectangles represent a high negative correlation.

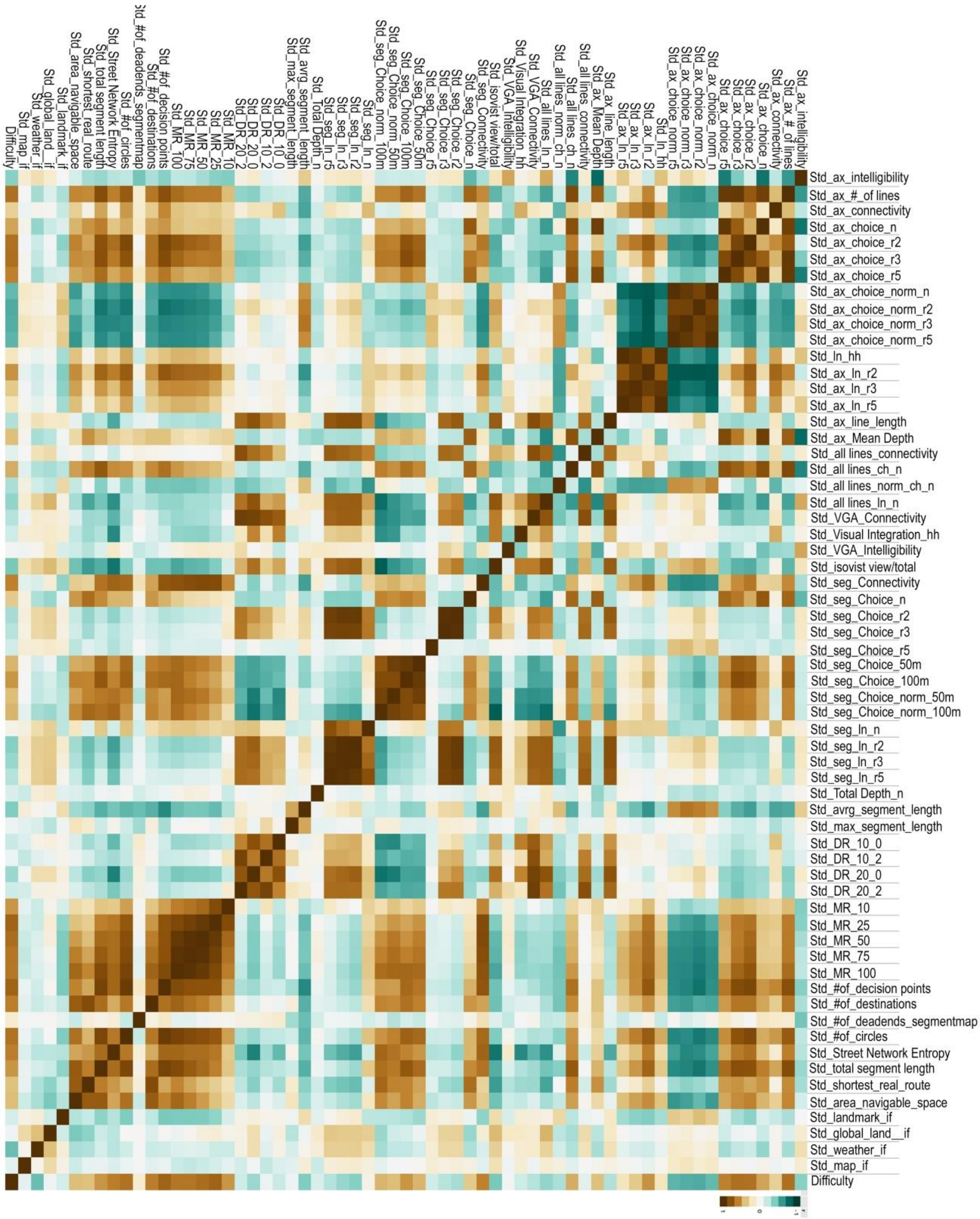


Figure 22: Correlation matrix of the measures: brown indicates a positive correlation while blue indicates a negative correlation between variables.

Difficulty is also added as another metric to the matrix so that the relationship between difficulty and all other measures can be detected. Accordingly, the following measures correlate positively with difficulty: metric reach (25 m: 0.72; 50 m: 0.68; 75 m: 0.64; 100 m: 0.64, 10 m: 0.54), number of decision points (0.72), number of axial lines (0.67), number of circles (0.66), SNE (0.61), number of destinations (0.61), segment connectivity (0.60), total segment length (0.54), area of navigable spaces (0.41) and length of the shortest route (0.40). The results suggest that an increase in metric reach (in other words, the density of the street network), the number of decision points, or the number of axial lines, for instance, might cause an increase in difficulty as determined by the length of the trajectories.

On the other hand, other variables have a negative correlation with difficulty: axial normalised local choice (r2: -0.53, r3: -0.51, r5: -0.49) and normalised global choice (-0.47), weather condition (-0.51), isovist view (area of the viewable space from the start point/all navigable area -0.42), average segment length (-0.40), segment-based local integration (r:2, -0.38) and axial intelligibility (-0.37). These results suggest that an increase in axial normalised choice, isovist view or average segment length can cause a decrease in difficulty.

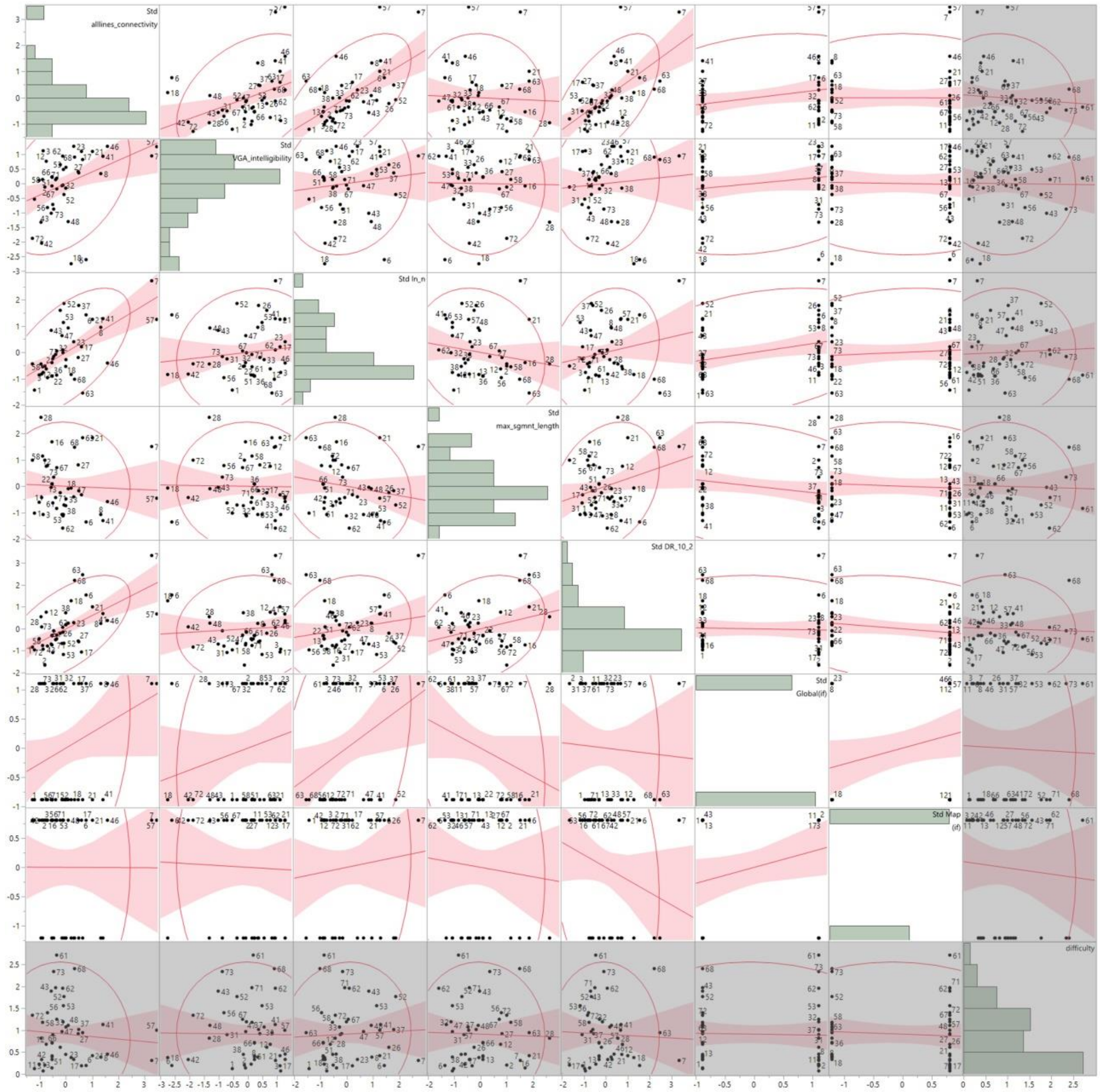


Figure 23: The scatterplot of the least correlated measures and the distribution of levels (difficulty is highlighted in grey)

The least correlated variables are also considered. Figure 23 shows the scatterplot of the measures with a weak correlation, from -0.1 to 0.1, between difficulty and variables. Density ellipses and the line of fit were also shown to highlight the relationship between the variables. The points in the scatterplot represent levels. Surprisingly, a weak correlation is observed between difficulty and segment-based integration (r:n), visual intelligibility, global landmark condition, maximum segment length, directional reach (10º, 2 direction changes), map condition and all lines connectivity. Both all lines connectivity (-0.083) and visual intelligibility (-0.014) have a negative correlation with difficulty. Segment based global integration has a positive correlation (0.050), while maximum segment length also has a negative correlation (-0.032) with the dependent variable. Last three factors; directional reach 10º, 2 direction changes (-0.042), global landmark condition (-0.030), map condition (-0.072) have negative correlation with difficulty. No significant relationships were found between the variables. Hence, even though literature pointed to a significant relationship between people's wayfinding performance and visual intelligibility, global landmark condition (Li et al., 2016; Lin et al., 2012), directional reach (Ozbil et al., 2016) or map condition (Soh & Smith-Jackson, 2004; Devlin & Bernstein, 1997; Lobben et al., 2014), for instance, this relationship could not be supported using the correlation matrix and scatterplots.

5.2.3 ***Part-II - Analysis***

In the first part of the study, all measures are used and the correlation between the variables and the difficulty are explored. The second part of the first study aims to understand the relationship between the environmental measures and wayfinding performance statistically.

The standardised environmental measures are used in this part of the study as well, since the measures are not measured at the same scale. Participants' performance in terms of duration is added to the data table. No outliers are detected since longer tails can be expected in a wayfinding study. To see the relationship between performance and the spatial layout and conditions, highly correlated variables were excluded first and principal components analysis (PCA) was conducted in JMP statistical software (SAS Institute Inc., Cary North Carolina, USA) to reduce the number of independent variables that are included in the model. The Kaiser–Meyer–Olkin (KMO) measure verified the sampling adequacy for the analysis, KMO = 0.665, which is well above the acceptable limit of 0.5 (Field, 2009). Bartlett's test of sphericity χ^2 (105) = 466.313, $p < 0.001$ (limit of acceptance < 0.50), indicated that correlations between items are sufficiently large for PCA. An initial analysis was run to obtain eigenvalues for each component in the data. Kaiser's criterion was used to specify the number of principal components (Kaiser, 1961). Five components had eigenvalues over Kaiser's criterion of 1 and in combination explained 81.4% of the variance. Factor loadings lower than 0.6 are not interpreted and Table 5 shows the formatted loadings.

Table 5: Results of the principal components analysis. Five components were defined based on their eigenvalues

Independent variables	Prin1	Prin2	Prin3	Prin4	Prin5	Components
Axial # of lines	**0.897**	0.135	0.225	0.017	-0.082	
Shortest route	**0.857**	0.147	-0.023	0.086	0.330	
MR-100	**0.848**	-0.326	0.106	0.220	0.092	
Street network ent.	**0.808**	-0.030	-0.236	0.266	0.082	
Area-navigable spaces	**0.791**	-0.203	-0.059	-0.341	-0.031	Complexity and saliency
# of circles	**0.768**	-0.441	0.192	-0.002	-0.116	
# of destinations	**0.724**	-0.099	0.276	-0.360	0.281	
Landmark saliency	**-0.617**	0.422	-0.391	-0.087	-0.135	
Ax. Choice norm. r:2	**-0.722**	0.192	0.038	-0.079	0.375	
# of dead ends	0.260	**0.841**	0.079	0.117	0.120	
Axial mean depth	0.558	**0.689**	0.092	-0.053	0.257	
Axial intelligibility	-0.464	**-0.665**	-0.151	0.219	0.251	Accessibility
Global landmark	-0.560	-0.177	**0.721**	0.181	0.075	Global landmark
Seg. Ln r:2	-0.495	-0.064	0.379	**-0.701**	0.124	Segment-integration
Map condition	-0.321	-0.204	-0.263	0.095	**0.673**	Map condition
Eigenvalues	6.96	2.35	1.5	1.2	1.01	
% of variance	43.51	14.71	9.4	7.52	6.25	

Note: Factor loadings over 0.60 appear in bold

Component 1 represents complexity and saliency, and this involves the number of axial lines, shortest (realistic) route, MR (100), SNE, area of navigable spaces, number of circles and destinations, normalised axial choice (r:2) and landmark saliency. Component 2 represents accessibility, which includes number of dead ends, axial mean depth and axial intelligibility. The third component, global landmark, relates to the existence of global landmarks. Component 4, segment integration, involves segment-based integration (r:2) and the last component, map condition involves one variable, namely map condition.

5.2.4 *Results*

The principal components were then used in a linear mixed model, which was run in Matlab due to the increased size of the data. A linear mixed model was chosen because the data included the same participants' performance data for different levels. Hence, participants were defined as a random effect in the model and principal components were identified as fixed factors to predict travel durations. Table 6 shows the effect of each component on participants' duration results.

Table 6: Results of the linear mixed models

Fixed effects coefficients (95% CIs):							
Name	**Estimate**	**SE**	**tStat**	**DF**	**pValue**	**Lower**	

							Upper
'(Intercept)'	1.440	0.001	2617.300	10606000.0	0.000	1.439	1.441
Complexity and saliency	0.254	0.000	2050.900	10606000.0	0.000	0.254	0.254
Accessibility	0.070	0.000	414.260	10606000.0	0.000	0.069	0.070
Global landmark	0.015	0.000	68.245	10606000.0	0.000	0.014	0.015
Segment-integration	-0.023	0.000	-80.030	10606000.0	0.000	-0.024	-0.022
Map condition	0.196	0.000	744.810	10606000.0	0.000	0.196	0.197

SE: Standard error, DF: Degrees of freedom, pValue: statistical significance

The results of the mixed model indicate that there is a positive relationship with components 1, 2, 3 and 5 whereas there is a negative relationship with the fourth component. For the first group, complexity and saliency, the result suggests that if the number of axial lines, the shortest (realistic) route, metric reach (100 m), SNE, the number of circles (circular roads) and/or the number of destinations increase, the time taken by participants to complete a level also increases. Moreover, the results also suggest that if axial-based local choice (r:2) decreases or if the environment does not include salient landmarks, then the duration increases. The result of the second component, accessibility, indicates that as the number of dead ends or axial mean depth increases, or axial intelligibility decreases, people's wayfinding performance gets worse and it takes more time to complete levels. The result of the third component, global landmarks, suggests that the time taken by participants to complete levels increases if an environment includes global landmarks. The same kind of relationship was found for the condition associated with the readability of the map. Finally, results for the fourth group, segment integration, indicate that duration decreases if the segment-based integration (r:2) decreases. This part of the study, once again showed the significance of "complexity" in explaining people's wayfinding performance.

It is important to note that the results were unexpected for landmark conditions. For the first part of the study, no significant correlation was observed for global landmark or salient landmark conditions and the second part of the study suggested no significant impact of global landmarks on the wayfinding process. Previous research has varied on this topic as some studies suggested that global landmarks help people to find their way more easily (Li et al., 2016; Lin et al., 2012) and others found no impact of global landmarks (Gardony et al., 2011; Ruddle et al., 2011). The unexpected results in this study show that a better understanding of the impact of different conditions, more specifically different landmark conditions, on wayfinding performance is required.

5.3 Study-II

The first study attempted to explore all factors that may affect people's wayfinding performance. The second study explores how different conditions affect people's wayfinding performance. More specifically, it considers the impact of different conditions associated with landmarks as well as the weather and maps. To do this, two extra studies were conducted. In this study (Study-II), five levels with the same layout (mentioned in Section 4.7.2) were used and the impact of conditions related to salient landmarks, weather and maps were compared.

As discussed in the literature review chapter (see Section 2.3.2.1 and Chapter 3), conditions relating to landmarks, weather and maps have also been evaluated by researchers and it was stated that all these conditions can affect people's performance. Results of the previous analysis showed that salient landmarks or a change in the weather conditions could improve performance. This study is designed to explore the degree to which different conditions, including landmark conditions, affect wayfinding performance, as well as to understand which conditions are more influential than others.

5.3.1 *Analysis and results*

For the analysis, results of participants were first normalised through the use of practice levels, levels 1 and 2. To do this, the sum of the duration to complete the two levels was calculated and the time taken by people to complete the levels was divided by this value. No outliers were detected or excluded from the study. A t-test was conducted in JMP software to see the relationship between variables as pairs (Table 7). First of all, when the mean values of levels are compared, the mean duration to complete level 36 is the highest for these levels (M=2.003). As level 36 only differs from level 22 in that the weather is foggy rather than clear (see Section 4.7.2 Table 1), this shows that the weather condition affects people's performance more than conditions related to landmarks and maps in the same spatial structure. The next longest duration was that for level 66 (M=1.750), where there are no landmarks and the water is wavy (so the visibility changes in this level as well). However, even though two important conditions change in this level, participants' performance is still better than in level 36. The duration to complete level 66 was followed by that to complete level 13 (M=1.739), where the weather is clear, map is normal and landmark condition is easy. This is surprising since all conditions are good; however, the fact that this was the first time participants experienced this layout may explain why it may be challenging for them to complete the level. The next longest duration was for level 22 (M=1.638), where the map is obscured for the first time. Finally, level 51, where the landmark condition was hard, was completed by the participants in the shortest time.

Table 7: Paired t-tests of levels

Statistics	Level 22 and 36	Level 51 and 66	Level 13 and 22	Level 22 and 51

Mean value of the first variable	1.638	1.627	1.739	1.638
Mean value of the second variable	2.003	1.750	1.638	1.627
Mean Difference	-0.365	-0.123	0.101	0.012
Std Error	0.006	0.006	0.006	0.006
Std Dev.	0.855	0.822	0.851	0.809
Upper 95%	-0.353	-0.112	0.112	0.023
Lower 95%	-0.377	-0.135	0.089	0.000
N	19698	19698	19698	19698
Correlation	0.419	0.432	0.417	0.395
t-Ratio	-59.836	-21.055	16.598	1.999
DF	19697	19697	19697	19697
Prob > |t|	<.0001*	<.0001*	<.0001*	0.0456*
Prob > t	1	1	<.0001*	0.0228*
Prob < t	<.0001*	<.0001*	1	0.9772

*Paired levels: "first variable" refers to the first level mentioned in each column and "second variable" refers to the second level mentioned. * p < 0.05.*

The mean values of performance between levels were compared to understand the impact of different conditions and their significance on navigation. The significant difference (p<.0001) between levels 22 and 36 shows that the weather condition has a significantly negative impact on wayfinding. In addition, the comparison between levels 51 and 66 also suggests that conditions of waves and no landmarks strongly and negatively influence performance. These two results suggest that the visibility within environments significantly affects people's wayfinding performance. The way of relationship in the table, however, changes in levels 13 and 22, and levels 22 and 51. This result suggests that neither the obscured map or the hard landmark condition has a significant or negative effect on wayfinding performance.

5.4 Study-III

In Study-II, levels with same spatial layouts were used and the effect of different conditions was compared, including the salience of landmarks. No significant effect of the salience of landmarks was observed. Previous research conducted to explore the impact of global and local landmarks has stated that global landmarks improve people's wayfinding performance (Steck & Mallot, 2000; Li, Fuest, et al., 2014; Lin et al., 2012; Schwering et al., 2013). In the five levels used in the second study the global landmark condition is the same, so it is not possible to observe its impact on wayfinding. Hence, in this third study, the impact of global landmarks is investigated.

5.4.1 *Analysis*

Levels 3 and 13 were used in this study, since these were the levels where the spatial structure was as similar as possible, and conditions were same except the existence of global landmarks (please see Section 4.7.3 and Table 2). The time taken by participants to complete levels 3 and 13 was used for this study. The results, again, were normalised based on the gaming abilities of participants by considering their performance in first two levels. The mean duration shows that it took more time for participants to complete level 13, where there were no global landmarks, (average duration M=1.6197), compared to level 3, where there were global landmarks (average duration M=0.5119). Paired t-test analysis was used as the same participants' results were compared for two conditions. Results of the t-test analysis showed that there is a significant change in duration between levels 3 and 13 (mean difference=1.1078, p<.0001).

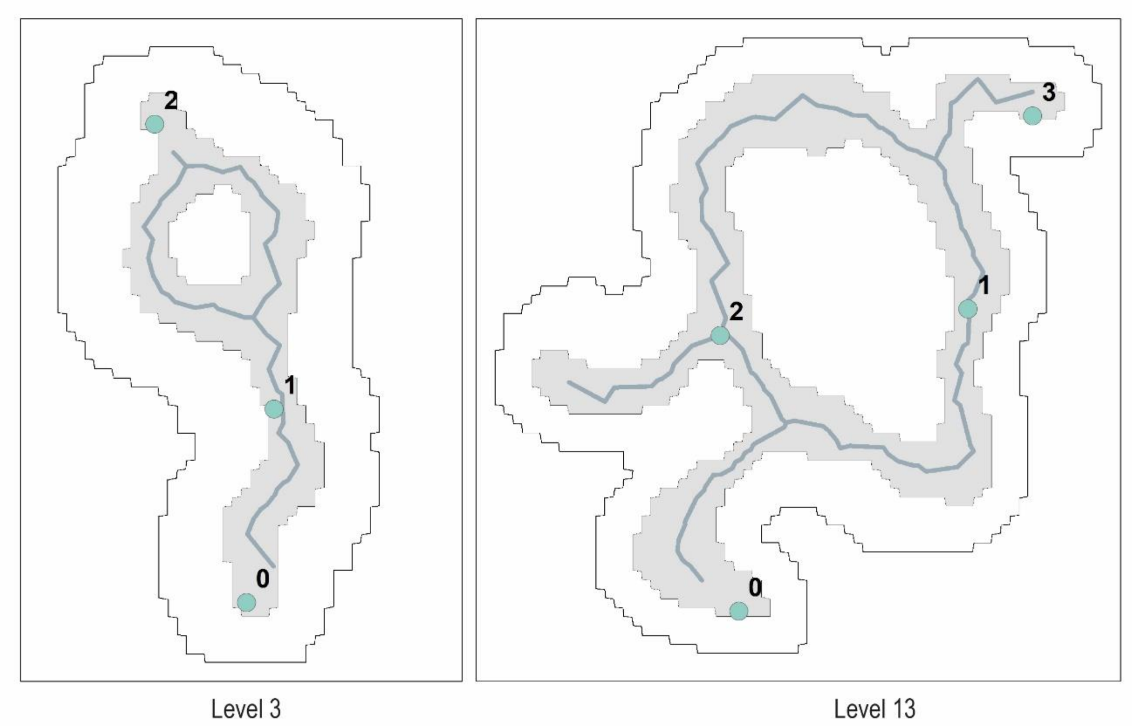


Figure 24: Layout of levels 3 and 13, segment maps (shown with grey), segment lines (shown with light blue) and checkpoints shown with green circles)

Results were then analysed in more detail. To do this, estimates of the time to complete levels were found; hence, it would be possible to compare these results with the actual durations. To calculate the estimated time, the shortest realistic routes were first defined. Segment maps of levels 3 and 13 were used to measure the shortest realistic routes and all goal locations were tracked (Figure 24).

5.4.2 *Results*

Once the shortest realistic routes were measured for two levels, the maximum speed (using the speed up command during the level) and minimum speed (without boost) of the boat were used to calculate the time that would be taken to complete the levels (for the expected durations, see Table 8, columns A and B). The mean duration (the average time for participants to complete the levels) is also shown in the table (column C). The ratios of real duration to expected duration at maximum speed (D), and at minimum speed (E) are also shown in the table. In both scenarios, it can be seen that it took participants more time to complete level 13. Considering the global landmark condition, it can be said that it was harder to complete level 13 because of the lack of global landmarks; hence, the duration was longer than for level 3.

Table 8: Comparison between real and expected duration

Levels	Average of normalised duration (C)	Min. time to complete levels (A)	Max. time to complete levels (B)	Ratio real duration and min time (D)	Ratio real duration and max time (E)
Level 3	0.5119	13.9687	22.5263	0.0366	0.0227
Level 13	1.6197	42.8198	69.0526	0.0378	0.0235

5.5 Summary of the results

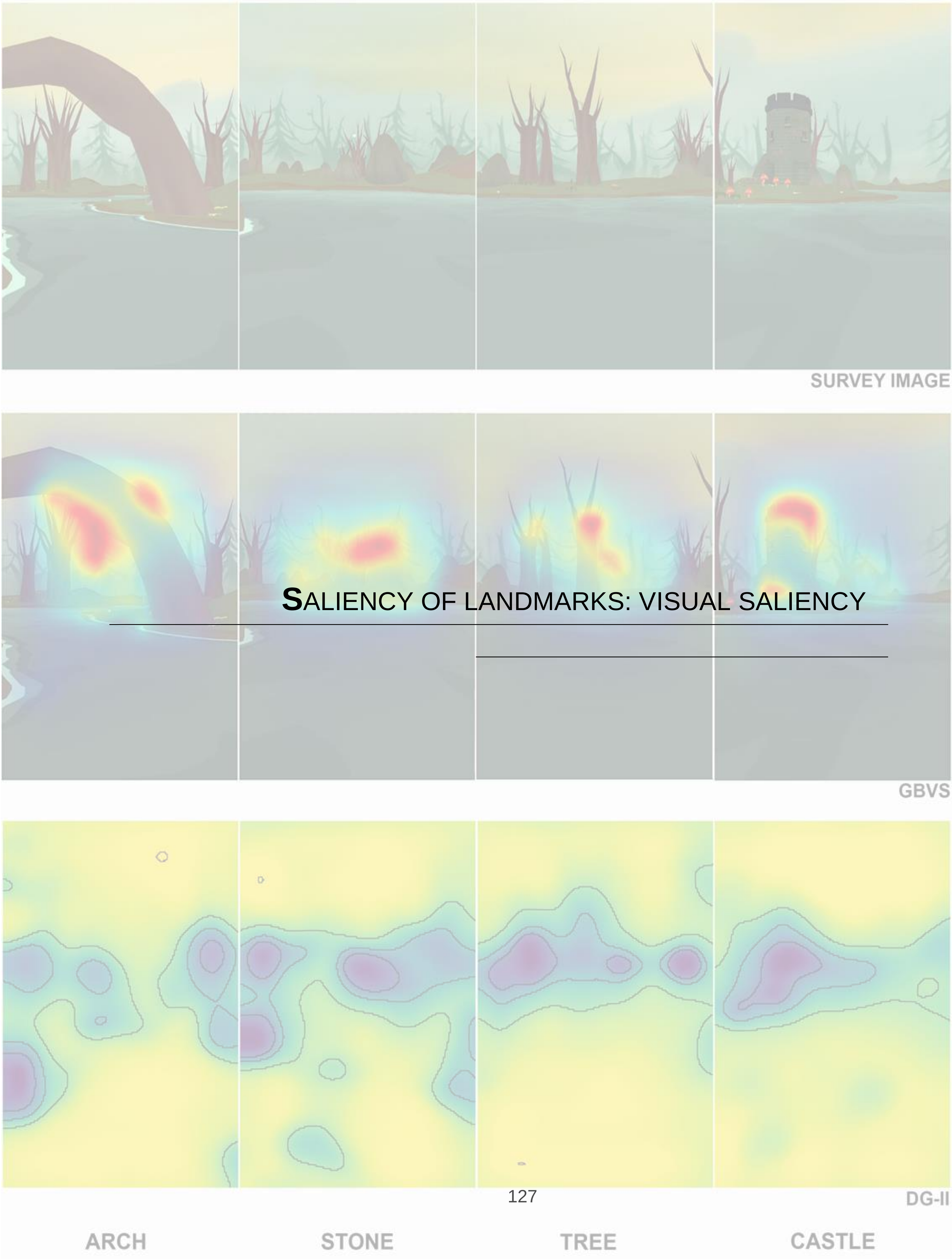
The first analysis chapter gave us insights about the factors that affect people's wayfinding performances. Accordingly, to create an easily navigable environment, it is important to have layouts that consist of fewer axial lines, destinations and dead ends. Additionally, it is also important to have a lower entropy (SNE) value and metric reach, short route length and lower area of navigable spaces. Many measures mentioned here pointed to the fact that the complexity of layouts is fundamental in wayfinding tasks. Hence, while designing an environment, it is important to consider its complexity (O'Neill, 1991a, 1991b). The first study also highlighted the impact of weather and saliency conditions on wayfinding.

The second and third studies, on the other hand, were designed to explore the impact of different conditions on wayfinding. Various conditions, particularly landmarks, were analysed. Results of the second experiment showed that the weather (specifically fog condition) affects people's wayfinding performance. This condition had the greatest effect, compared to the conditions associated with landmarks and maps. This finding is consistent with the previous research, which discussed the impact of weather conditions (Hurlebaus et al., 2008; Ruddle & Péruch, 2004; Burns, 1998) and with the first study conducted in this chapter. Hence, it is possible to claim that visibility is an important factor for people to find their way more easily. If the visibility within environments is reduced, then participants will not be able to see the alternative paths to follow or the landmarks that might help them understand where they are. Therefore, the wayfinding task will become more challenging for people. Changes in the conditions associated with maps or saliency of landmarks, however, did not cause any significant change to participants' results. This result is in contrast with the results reported in the literature, especially the those about salient landmarks (Albrecht & Von Stülpnagel, 2018; Von Stülpnagel & Frankenstein, 2015).

On the other hand, the third study showed that the existence of global landmarks improved participants' performance. This result was predicted, since other studies in the literature have argued that global landmarks help people to find their way (Steck & Mallot, 2000; Li, Fuest, et al., 2014; Lin et al., 2012; Schwering et al., 2013). Therefore, not only the layout itself but the conditions are important in explaining people's wayfinding performance. This is an important finding since it shows the significance of exploring environments in different conditions. By using all these different criteria, one can better understand reasons underlying people's performance.

This chapter points to many important findings. However, it is important to state that global and local landmarks, as well as the salient landmarks, were defined by the designers of the game, which can be considered as a limitation of the current study. In this chapter, no additional experiments were organised to analyse the details of levels and conditions, and the data collected by the game company in addition to measured environmental factors were discussed. However, as the intention is to learn more about landmarks, additional experiments are conducted. Both saliency and visibility of landmarks are investigated in this respect and, rather than using predefined landmarks, each landmark is analysed individually in the following chapters by presenting a series of additional experiments/surveys.

SALIENCY OF LANDMARKS: VISUAL SALIENCY



6 SALIENCY OF LANDMARKS: VISUAL SALIENCY

6.1 Introduction

In the previous chapter, landmarks were studied based on designers' evaluations. In the game, both landmark saliency and global/local landmarks were predefined. This part of the thesis examines whether or not these predefined saliency categories align with people's landmark selections. To do this, visual saliency is analysed first in detail and then the findings are compared with the experts' evaluations. Moreover, structural salience is also analysed via a comparative study to identify whether or not it affects people's choices.

This comparative study is performed in two parts. In the first part of the study, visual saliency is analysed through an online survey, where participants rate the saliency of landmarks within SHQ. Then the results are compared with those of two objective saliency models (Gbvs and DeepGaze II). Hence, the relationship between objective saliency measures and people's saliency evaluations -a gap in the literature- is explored. In the second part of the study, non-experts' and experts' evaluations are compared. This chapter of the thesis is crucial not only because the experts' evaluations are tested but also because visual saliency is analysed using two different criteria (survey and objective measures). In addition, not only the visual salience, but also the structural salience and their impact on people's choices during navigation are better understood through this chapter.

The factors that may affect people's wayfinding performance have been identified in the previous chapters. The environment was analysed through different measures; however, landmarks were analysed using experts' evaluations in the previous chapter. In this and the following analysis chapters, rather than using the full dataset, specific levels in SHQ were investigated, additional surveys were conducted, and observations were made to learn more about landmarks. In the following sections, the visual, structural, and cognitive characteristics of landmarks within SHQ are analysed using different methods. In this chapter, visual saliency is investigated. As discussed in the methodology chapter, only levels 31 and 32 were used in the saliency studies. Hence, studies undertaken in this and the following chapter are conducted using these two levels only.

The literature review describes the impact of visual and structural landmarks, or the combined effects of different saliency measures. However, this topic is still under debate. As described in the literature review (Section 3.5.3), eye tracking data has been used to train saliency models, but is it possible to confirm that they really correlate with what people find salient? In this chapter, it is hoped that answers will be found to this question. Saliency models and a survey are used to explore visual saliency and the association between these two approaches are investigated. Moreover, the impact of structural landmarks on people's saliency evaluations is examined.

6.2 Study-I

In the first study, an online survey and saliency algorithms are used to see whether the algorithms are sufficient to explain people's evaluations. In addition, people's saliency evaluations are interpreted.

6.2.1 *Analysis*

For the survey study, as mentioned in the method chapter (4.8.2), a laboratory survey was conducted with 25 people prior to the online survey to see whether or not people's attention is distracted during online survey. A t-test was used to investigate the significance of the differences between the results from the online survey and the laboratory survey (please see Section 4.8.2 for more details). The average rating score that each participant assigned to each landmark in the survey was calculated for each level from both laboratory and online survey results, and a t-test was implemented on the average values (Table 9). Levene's test showed a homogeneity of variance for level 31 (F=0.273, p=.602) and for level 32 it showed that homogeneity of variance cannot be assumed (F=8.156, p=.005). The p-value was >0.05 in all cases. In other words, no significant changes were present between online and the laboratory surveys for the two levels. Therefore, the results of both surveys were used in this study.

Table 9: Mean ratings and results of the independent samples t-tests for levels 31 and 32 (grey-highlighted values show the significance of the t-test based on Levene's test)

Level	Survey Mode	N	Mean	Std. Dev.	Levene's test for Equality of Variances		Variance (t-test)	95% Confidence Interval		t	Sig. (2-tailed)
					F	Sig.		Lower	Upper		
Level 31	Online	226	3.290	0.588	0.273	0.602	Equal variances assumed	-0.280	0.202	-0.320	0.749
	Lab.	25	3.329	0.507			Equal variances not assumed	-0.260	0.182	-0.360	0.721
Level 32	Online	226	3.205	0.588	8.156	0.005	Equal variances assumed	-0.243	0.227	-0.066	0.947

	Lab.	25	3.213	0.304			Equal variances not assumed	-0.153	0.137	-0.110	0.913

Cronbach's alpha was also calculated in SPSS to test the reliability coefficient for the internal consistency of the survey results. Cronbach's alpha was 0.74 when all landmarks and all participants' evaluations were used, indicating that the questionnaire has good internal consistency. Hence all results are included in the study. A reliability test was not conducted for the experts' evaluations since they agreed on the saliency of landmarks.

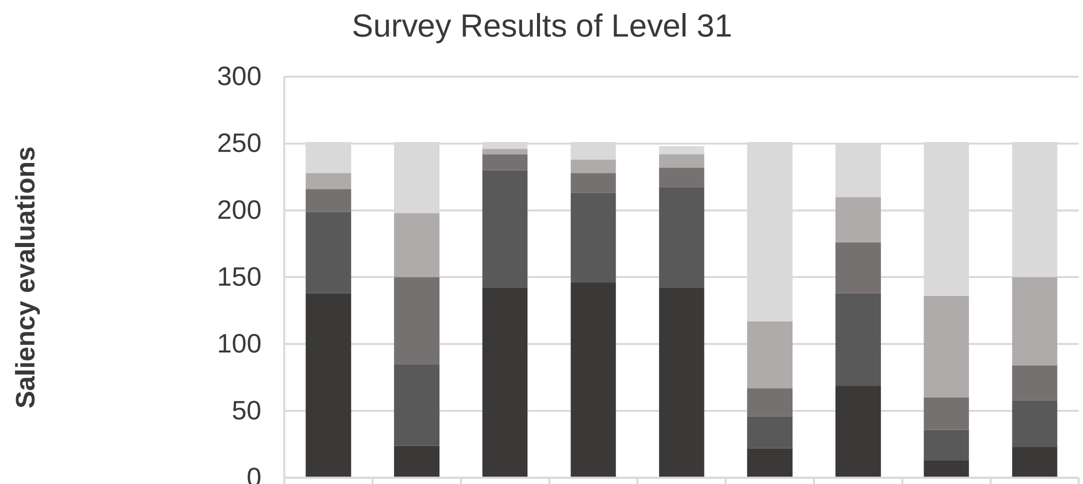
To consider the saliency algorithms, saliency maps were created using the two algorithms, DeepGaze II and Gbvs, so that the saliency scores could be computed for each object. The regions of interest were used to find an average saliency value for each landmark and each level. To normalise the results, a z-score (also called a standard score) was applied to each saliency map.

6.2.2 ***Results***

6.2.2.1 Survey results

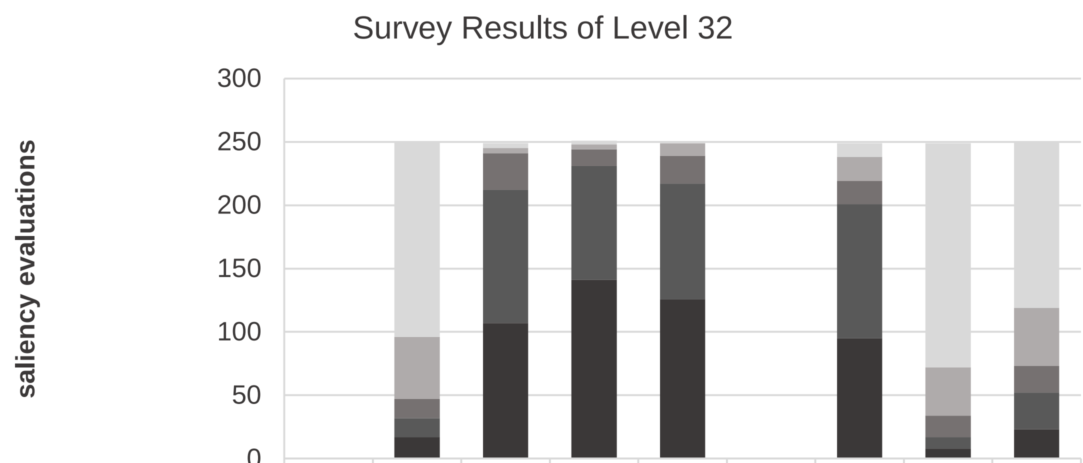
The survey results suggest a number of features regarding the saliency of the landmarks in the two levels (see Table 10 and Table 11). The first is that the castle was the most outstanding object in both levels. This could be anticipated because the castle was differentiated with respect to its size and colour. Moreover, in level 31 it was located at a decision point where the boat made a turn. This may be part of the reason that the castle was rated as the most noticeable object. It was followed by trees, grass, and the arch in level 31, whereas it was followed by grass, trees and toadstools in level 32. Again, the arch and trees were notable due to their height and colour.

Table 10: Survey results of level 31 showing the number of ratings



	Arch	Stone	Trees	Castle	Grass	T. stump	Toadstool	Stone(s)	Plant
unnoticeable	23	53	5	13	6	134	40	115	101
fairly unnoticeable	12	48	4	10	10	50	34	76	66
neither noticeable nor unnoticeable	17	65	12	15	15	21	38	24	26
noticeable	61	61	88	67	75	24	69	23	35
highly noticeable	138	24	142	146	142	22	69	13	23

Table 11: Survey results of level 32 showing the number of ratings (there was no arch or tree stump in level 32, but these columns are retained to provide a comparable image)



	Arch	Stone	Tree	Castle	Grass	T.stump	Toadstool	Stone(s)	Plant
unnoticeable		154	4	3	1		11	177	131
fairly unnoticeable		49	4	4	10		19	38	46
neither noticeable nor unnoticeable		15	29	13	22		18	17	21
noticeable		15	105	90	91		106	9	29
highly noticeable		17	107	141	126		95	8	23

Surprisingly, grass was ranked highly in both levels. This may be due to the fact that during the video the boat moved through the grass, such that it became quite close to the viewers at certain points, as can be seen in Figure 25. Thus, even though the object would not be easily noticeable in terms of the contrast with the background or shape, it was still noticed by people. The number of participants who found grass highly noticeable decreased from 142 in level 31 to 126 in level 32. This decrease can be explained by the reduction in the amount of grass in level 32.

Figure 25: Screenshots from the video of levels 31 and 32 showing how the grass is seen at different times

Toadstools were also considered notable objects by participants, despite their size and shape. This is likely to be due to their red colour, which was unique in the environment and contrasted with the background. This idea was also supported by participants in the discussions after the lab study. The number of people who found the toadstools either noticeable or highly noticeable increased from 138 in level 31 to 201 in level 32. In the videos it can be seen that the boat moved quite close to the toadstools in level 32. Hence, participants could have a chance to see this landmark closer, which can account for this change. The plant was unremarkable for participants, which was not surprising, as it did not have any strong visual characteristics. Moreover, people did not notice either types of stone, even though one type differentiated from the background due to its size.

6.2.2.2 Objective saliency measurement

The results of the algorithms are shown in Table 12. Using Gbvs analysis, the toadstool, castle and small stone (Sstone) were detected as the most salient objects in level 31, while the tree, castle and toadstool were detected as the most salient objects in level 32. The results of the DeepGaze II analysis showed that the plant, tree stump and castle were the most salient objects in level 31, while the stone, castle and toadstool were the most salient objects in level 32.

Table 12: Results of the objective saliency measures (z-scored, higher values represent higher saliency)

Landmarks_level 31	Gbvs	DG II	Landmarks_ level 32	Gbvs	DG II
Arch	0.133	0.189			

Stone	0.868	0.904	Stone	0.909	1.757
Tree	0.661	0.634	Tree	1.499	0.922
Castle	1.103	1.402	Castle	1.213	1.594
Grass	0.029	0.009	Grass	0.055	0.016
Treestump	-0.206	1.438			
Toadstool	1.366	0.956	Toadstool	1.084	1.141
Sstone	0.946	0.520	Sstone	-1.213	0.326
Plant	-0.978	1.661	Plant	1.026	-1.324

As a second step, the relationship between the survey and the models were explored in detail. The results of both the survey and the models were kept as continuous data. A regression analysis was calculated to predict the survey results based on Gbvs and DeepGaze II. No significant relationship was found between the models and the survey results ($p>.05$, $R^2=0.266$ and 0.254 for levels 31 and 32, respectively, see Table 13).

Table 13: Results of the regression analysis between model prediction and survey data

Levels	R^2	Term	Estimate	Std Error	t Ratio	Prob>|t|	Lower 95%	Upper 95%	Std Beta
31	0.266	Intercept	3.876	0.730	5.310	0.002	2.089	5.663	0.000
		Gbvs (Std)	0.259	0.501	0.520	0.624	-0.968	1.486	0.185
		DG II (Std)	-0.816	0.655	-1.250	0.259	-2.419	0.787	-0.445
32	0.254	Intercept	2.661	0.713	3.730	0.020	0.681	4.641	0.000
		Gbvs (Std)	0.623	0.636	0.980	0.383	-1.142	2.389	0.437
		DG II (Std)	0.205	0.558	0.370	0.732	-1.344	1.754	0.164

6.3 Study-II

In Study-I, people’s visual saliency evaluations were compared with objective saliency measures. The results showed that the saliency models alone failed to predict people’s landmark evaluation. However, while designing the game, the researchers also evaluated landmark salience, and this leads to another question: how exactly do experts’ saliency evaluations match with those of non-experts? This study investigates whether the visually salient landmarks vary between wayfinding experts and non-experts; an area that is quite limited in the literature.

6.3.1 ***Analysis and results***

Figure 26 shows the number of non-experts who rated objects as “highly noticeable” for levels 31 and 32. It can be seen that, with the exception of the toadstool, objects that were present in both levels were rated as highly noticeable by more people in level 31 than in level 32; this suggests the effect of structural saliency. In the videos, it can be seen that objects were further away in level 32, and there were fewer landmarks in this level. Hence, it can be said that the structural saliency evaluation of the experts was appropriate for the two levels. The videos also show that the boat moved quite close to the toadstools in level 32 (Figure 27), giving the participants a chance to see this landmark more closely, which can account for the increase in people's ratings in level 32.

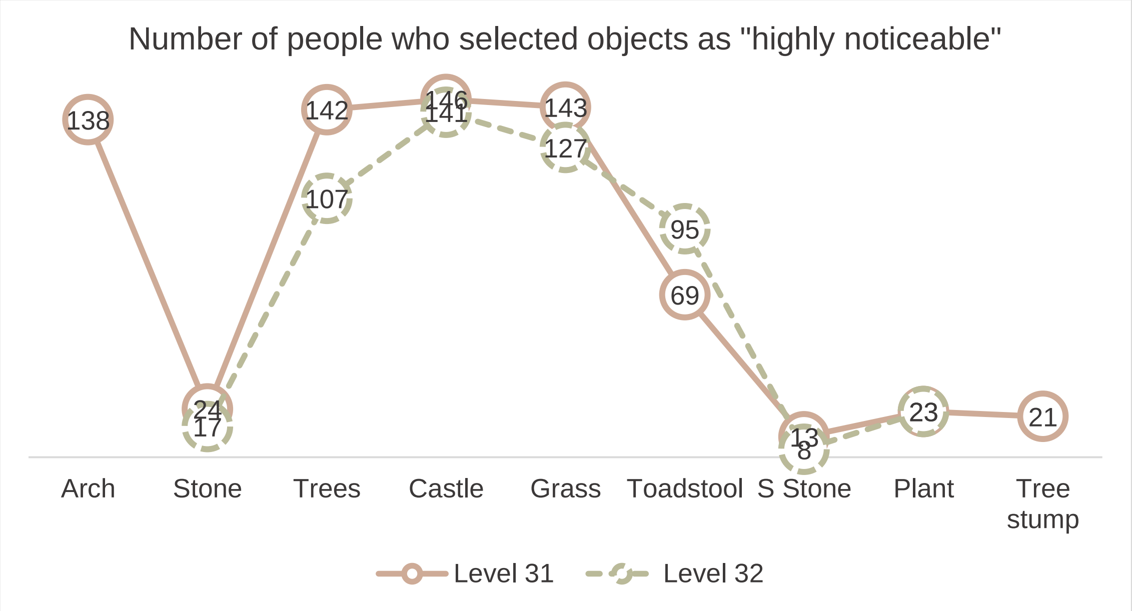


Figure 26: Number of people who selected landmarks as "highly noticeable" for each level

Figure 27: The image used in level 31 and 32 to evaluate the toadstool

When the landmarks are viewed within their context, it can be seen that highly rated objects tend to stand out from their surroundings particularly due to their size and colour, as mentioned in the first part of the study. The toadstools and trees contrast with the background, while the castle, tree and arch are differentiated from their surroundings due their size. The least rated objects, on the other hand, are smaller objects with a colour similar to that of the background. Hence, we can assume that it was harder for participants to notice these objects.

In addition, experts' results were compared with those of non-experts'. Experts' saliency evaluation included two categories: salient objects (1) and less salient objects (0). Hence, non-experts' evaluations were also categorised as salient and less salient objects. Figure 28 shows the results of the two groups together. Results suggest that the ratings are the same for all landmarks, except for stone and grass. The stone was selected as a salient object by experts and grass was selected as a salient object by non-experts, while they were selected as less salient landmarks by the other group.

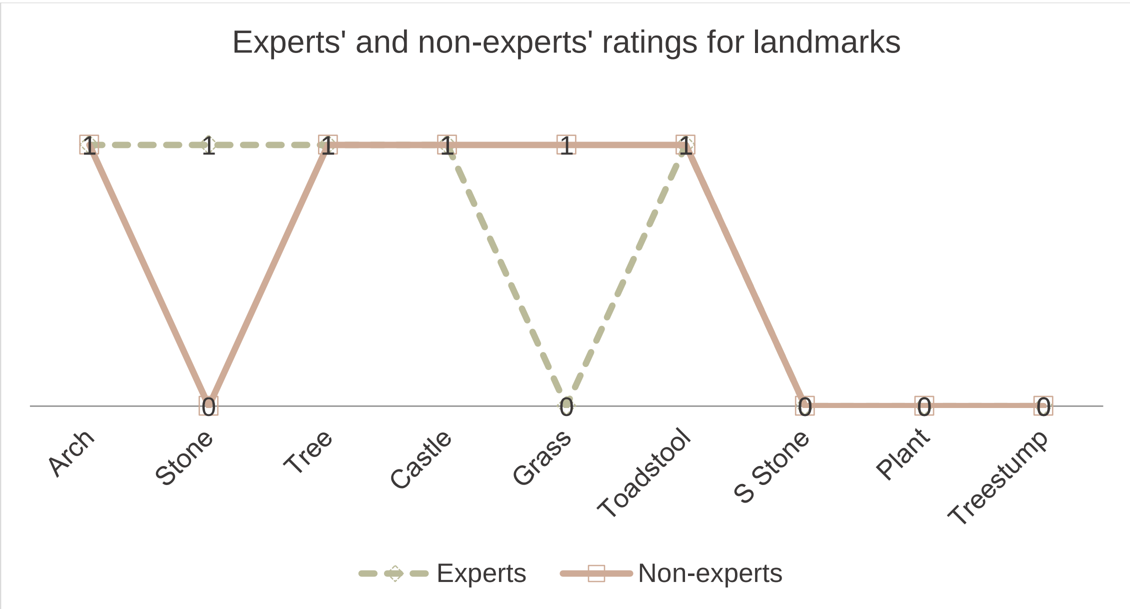


Figure 28: Results of experts' and non-experts' evaluations. The value "1" represents salient landmarks and "0" represents less salient landmarks.

6.4 Summary of the results

In this chapter of the thesis, visual saliency was analysed in detail in various ways: a survey was completed and the results were compared with objective saliency analyses and experts' evaluations. One of the goals of this chapter was to assess what features of objects make them more likely to be selected as landmarks. Analysis of the subjective ratings showed that landmark saliency is predicted by the size of the object and its visual distinctiveness, such as its colour contrast with the background (Quesnot & Roche, 2015b; Winter et al., 2005; Miller & Carlson, 2011).

In addition, the findings also highlighted the impact of the spatial position of landmarks in determining landmark salience in navigation: objects encountered in close proximity to the navigator when travelling were judged to be highly salient despite their low visual saliency. For instance, grass was visible at different points and multiple times in the environment. Even though it was not differentiated from its surroundings by its shape and colour, it was still selected as a salient object as it could easily be seen by participants from a relatively short distance.

Similarly, changing the location of toadstools in level 32 presumably had an impact on people's ratings since more people rated them as noticeable or highly noticeable when they were closer to the participants. This suggests that not only the visual characteristics of landmarks but also their structural characteristics are important for landmarks to become salient. The findings about the location of landmarks are very important because the landmarks were consistent between levels, and the location altered – visual saliency was same and structural saliency changed. This implies that changing structural saliency can affect people's perception of visual saliency.

The extent to which computational models of saliency, specifically Gbvs and DeepGaze II, would predict the subjective ratings of landmark saliency when watching the navigation of cue-rich virtual environments was also examined. It was found that there was no significant relationship between the saliency model predictions and the subjective ratings.

The second study investigated whether the evaluations made by the experts would be parallel to those of non-experts. The findings indicated that this was the case as non-experts' saliency evaluation was consistent with those of the experts' for seven landmarks out of nine. Only stone and grass were not consistent with this finding. While non-experts saw the objects within the context, experts saw the objects only with a white background without any context. This might be the reason for this discrepancy. During the videos, non-experts could see grass or stone more closely, hence the impact of location may affect their saliency evaluation. Hence, it can be stated that, even though experts' evaluations are quite similar to those of the non-experts, there are some differences.

This chapter of the thesis has contributed to knowledge in different ways. First, visual and structural characteristics of landmarks were analysed to see the characteristics that make landmarks salient. It is suggested that to make wayfinding tasks easier, visual landmarks located at accessible points, such as on routes and at decision points, can be chosen. Second, saliency models were used and the results were compared with the survey results. This type of comparison is quite limited in the literature. Experts' and non-experts' saliency evaluations were also compared in this chapter.

As mentioned before, the literature discusses three characteristics of landmarks. Here, visual saliency was explored in detail and structural saliency was also mentioned. However, all of the different characteristics of landmarks are to be considered in this thesis. Therefore, in the next chapter, structural and cognitive saliency are analysed. When all characteristics of landmarks are examined, an overall saliency score can be determined, as mentioned in the literature. Hence, one score will be given for each landmark and it will be possible to compare landmarks and define salient landmarks in the analysed levels of SHQ.

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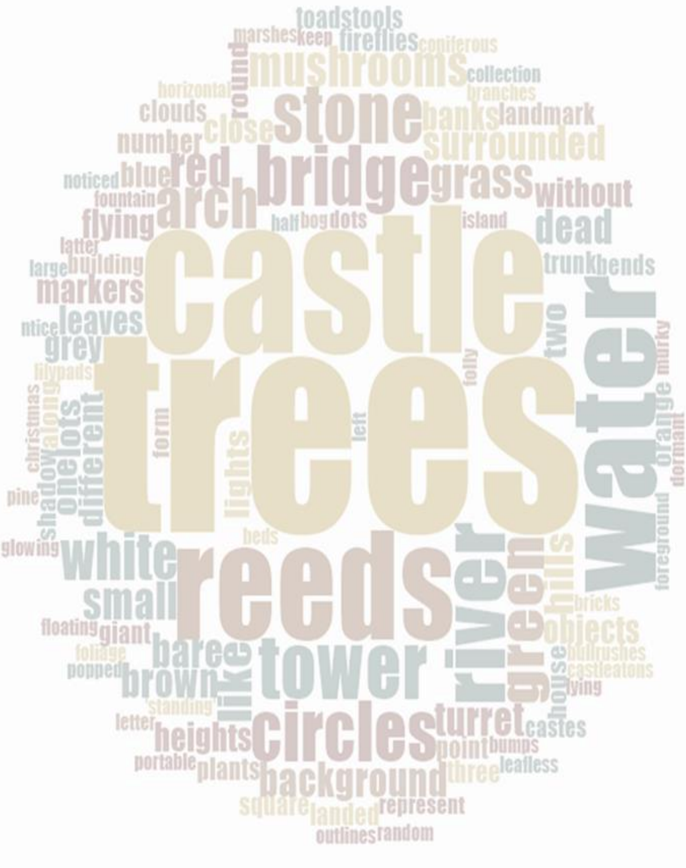
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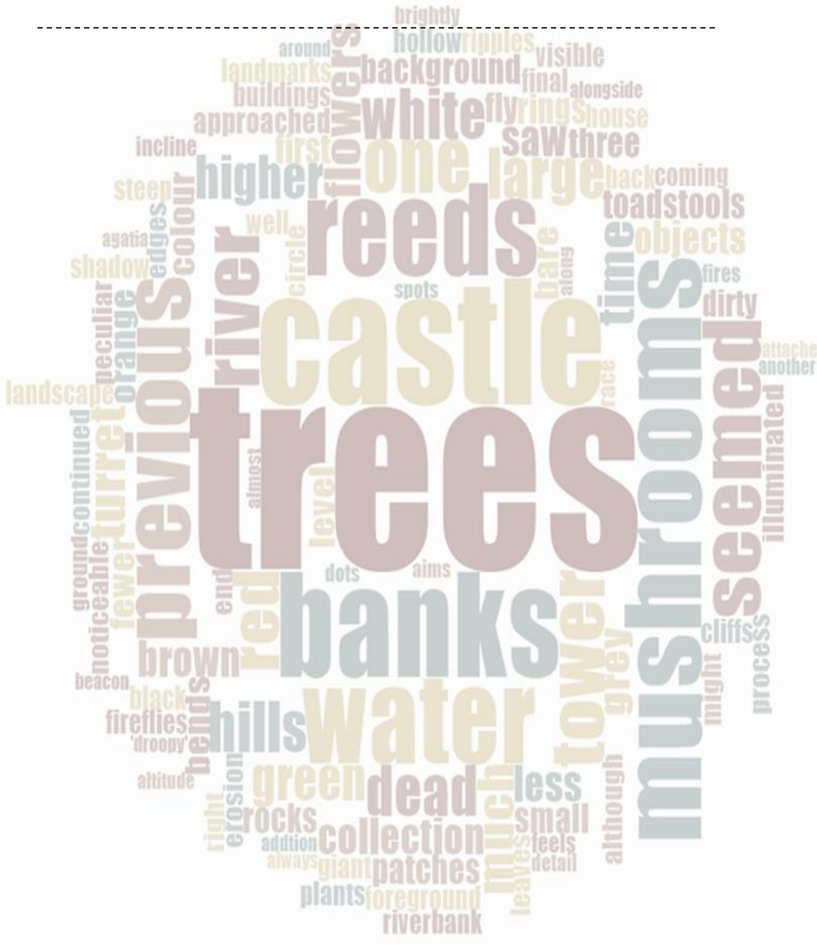
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circle
spots
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fires
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landscape
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7 STRUCTURAL AND COGNITIVE SALIENCY

7.1 Introduction

Chapter 6 focused on visually salient landmarks and the findings pointed to the significance of the colour and size of objects as well as their structural saliency. In this chapter, structurally and cognitively salient landmarks are explored in detail. The goal of this chapter is to redefine global and local landmarks, in other words, categorise structurally salient landmarks based on their visibility. While each participant explored the game environments, the visibility of landmarks from the participant's point of view was recorded and these records are used for this investigation. Participants were then asked to answer questions designed to measure both structural and cognitive saliency. The results of structural saliency suggest a threshold that can be used to distinguish global landmarks from local landmarks, or in other words, structurally salient landmarks from structurally less salient ones. The results of the cognitive saliency study show that cognitive saliency is closely related to visual and structural saliency in unfamiliar environments.

The impact of global and local landmarks in wayfinding has been explored by many researchers and different results have been discussed (Meilinger et al., 2015; Ruddle et al., 2011). In the previous chapters, the impact of global landmarks in wayfinding has also been discussed. In this chapter, global and local landmarks are explored in detail. Also, as previously mentioned, one point about the visibility of landmarks is still not clear: when can a landmark be called "global", and when can it be called "local"? Is it necessary for a global landmark to be seen from every point in a system (Castelli et al., 2008), or is it acceptable if it is seen from many angles and many points (Lynch, 1960)? The first part of the study is designed to answer these questions.

In the second part of this study, cognitive saliency is examined via a survey. By using people's saliency descriptions, the factors that shape cognitively more salient landmarks are clarified. As a final step, the three characteristics of landmarks – visual, structural and cognitive – are combined to find an overall saliency score for each object.

7.2 Study-I

While describing structural saliency, the location of landmarks is considered in various ways: whether the objects are located at decision points, on routes, or on a road with many connections, for example. Hence, any characteristics of landmarks that would help us to locate or orient ourselves in an environment could be thought of as structural characteristics of the objects. Therefore, in this section, the location information about landmarks is examined to better understand its influence on the salience of landmarks.

As has been done in previous research, the visibility of landmarks is used here to explain their structural salience (Bhatia et al., 2013). While comparing visual saliency within two levels of SHQ in the previous chapter, structural characteristics of landmarks were also discussed. It was mentioned that if the visibility of landmarks increases, then they become more noticeable and so more salient. Therefore, the approach used here of considering the visibility of landmarks along a route is also consistent with the findings of the previous chapter.

7.2.1 ***Analysis***

The Java program designed for this analysis (see in Section 4.8.3) determined the visibility of each landmark along a route and calculated the percentage of the journey time for which the landmark was visible for each participant. An average value was calculated for each landmark using the results from 100 people. This then was used to compare the visibility of landmarks. Figure 29 and Figure 30 show the average values for levels 31 and 32, respectively. Accordingly, it was observed that the average landmark visibility was between 5% and 35% for all landmarks in level 31 whereas it was between 10% and 40% for all landmarks in level 32. Hence the visibility varied between ~5% and ~40%. There are many entries for landmarks shown in the charts since each landmark is categorised individually rather than grouped in the way they were in the analysis in the previous chapter. Hence, rather than explaining all IDs, the analysis focuses on the landmarks with extraordinary values.

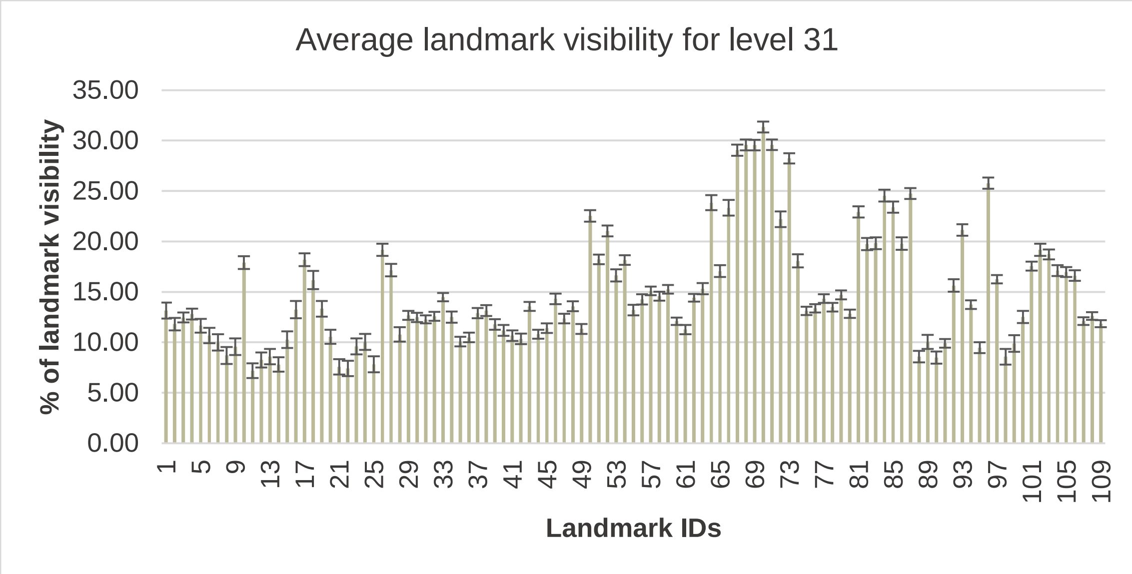


Figure 29: Average landmark visibility (%) for each landmark in level 31. Error bars express the standard error of the mean

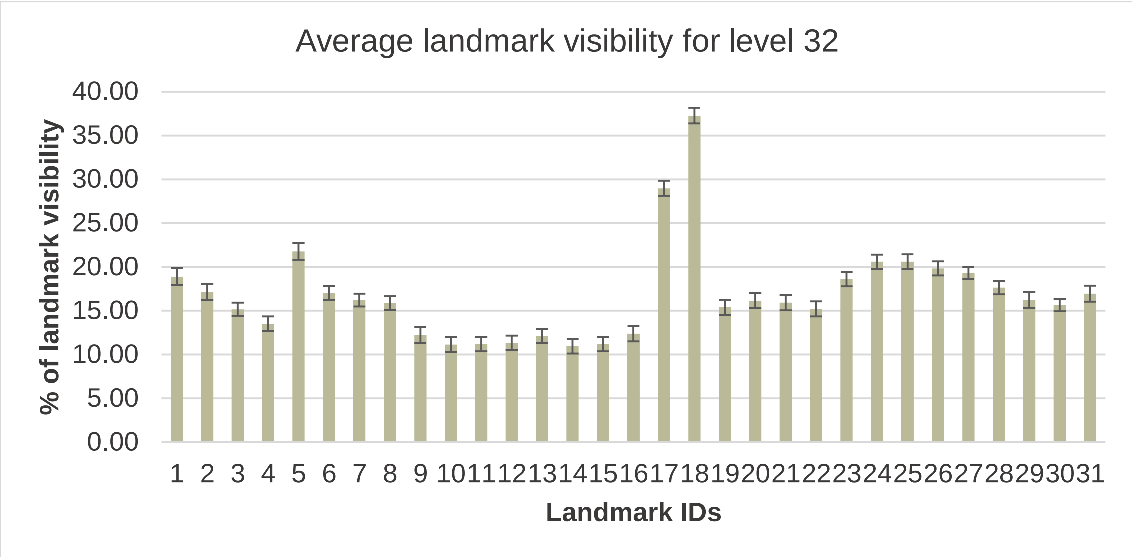


Figure 30: Average landmark visibility (%) for each landmark in level 32. Error bars express the standard error of the mean

7.2.2 ***Results***

To find a threshold for visibility, a boxplot analysis is applied to the mean values. The outliers, which could represent global, or structurally salient, landmarks, were detected using these formulas:

$$upper\ value = upper\ quartile + (1.5 * (interquartile\ range)),$$

$$lower\ value = lower\ quartile - (1.5 * (interquartile\ range)).$$

Equation 9: Outlier formulas

These formulas were set in JMP software. Figure 31 shows the boxplot analysis. According to this, five landmarks (IDs: 67, 68, 69, 70, 71) are detected as outliers for level 31 and 2 landmarks (IDs: 17, 18) are detected as outliers in level 32.

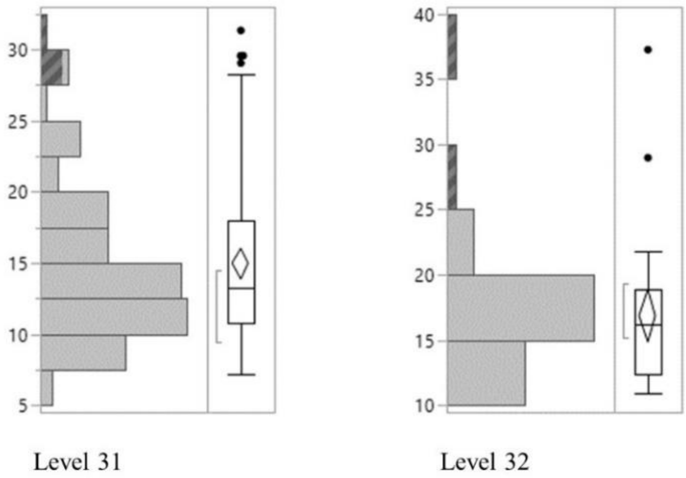


Figure 31: Boxplot of average landmark visibility (%) for levels 31 and 32. Outliers are shown with black dots

The landmark IDs of these outliers show that they were all trees. As they have a higher percentage of visibility than the other landmarks, they can be called global landmarks in the levels analysed (see Figure 32). They could indeed be observed from a great number of vantage points and many angles in these SHQ environments. Boxplots identify the objects as outliers with visibility values higher than ~25%. Therefore, it can be said that this value can be accepted as a threshold for different environments.

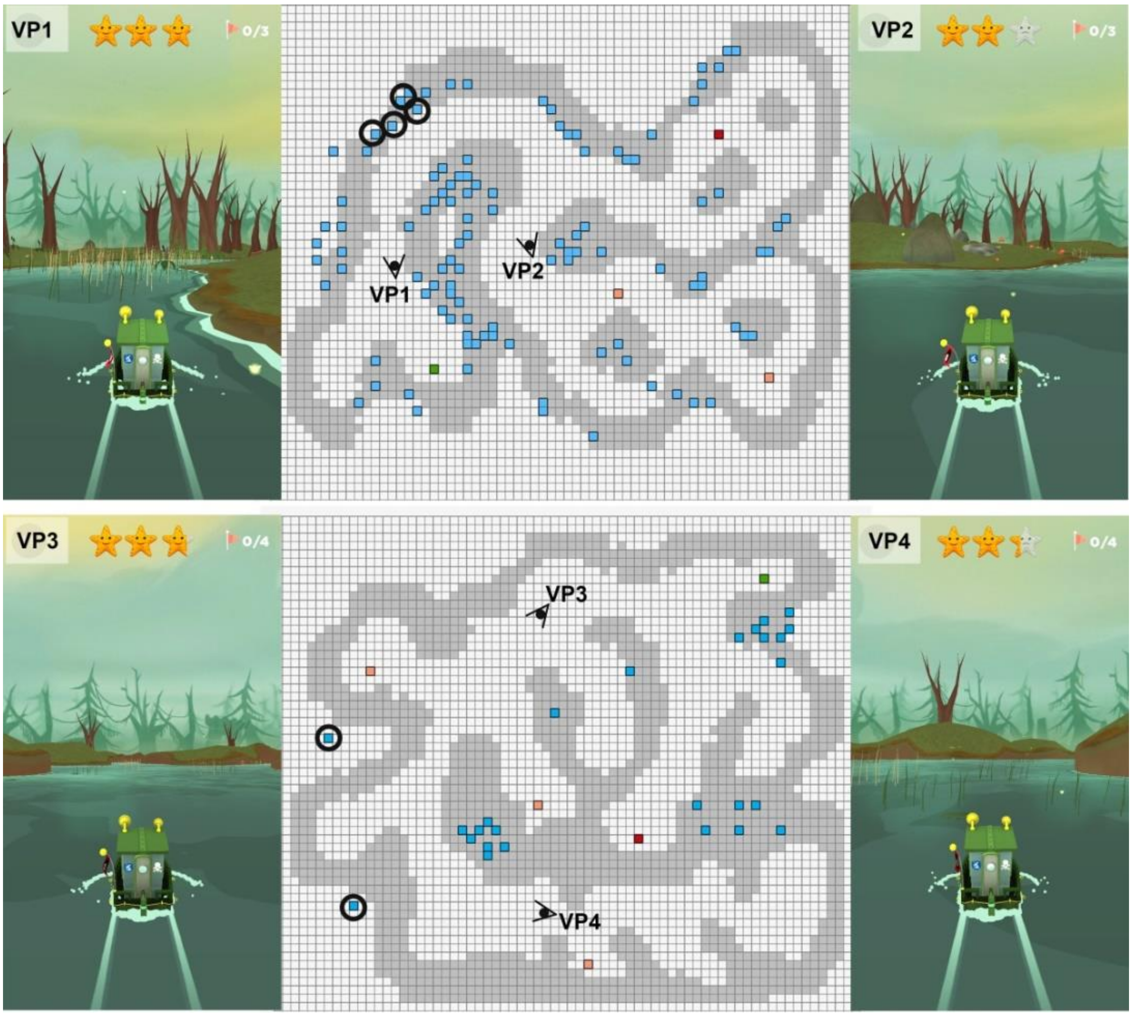


Figure 32: Global landmarks and their visibility from different viewpoints along the shortest possible route (level 31 is shown above and level 32 is shown below; landmarks are shown in blue)

Finally, Figure 33 and Figure 34 show the results of the survey (N=70 and the landmarks in the survey were in the 9 and 7 as described in Chapter 6). Accordingly, three objects were selected by people as “global” landmarks, namely the castle, arch and tree. In level 31, 54 people defined the castle as a global landmark. This was followed by the arch (45 ratings) and trees (38 ratings). All other landmarks were defined as local in this level. For level 32, the castle and trees were defined as global landmarks with 58 and 47 ratings respectively. The other five landmarks were defined as local landmarks. Two landmarks mentioned in level 31 did not exist in level 32 (the arch and tree stump), but have been included as columns in Figure 32 for ease of visual comparison with Figure 31.

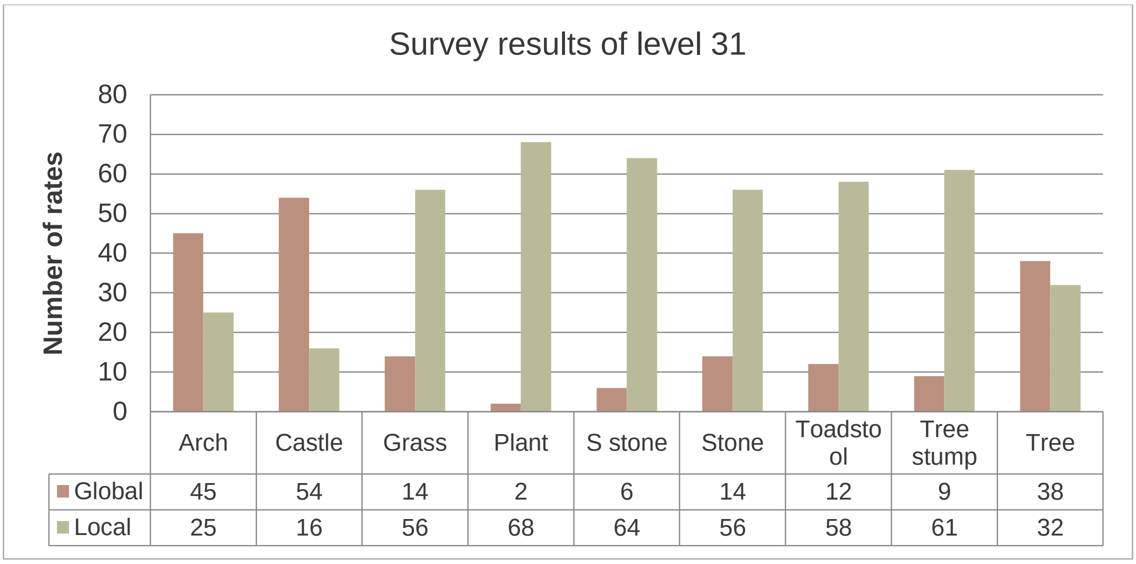


Figure 33: Survey results for the visibility of landmarks in level 31

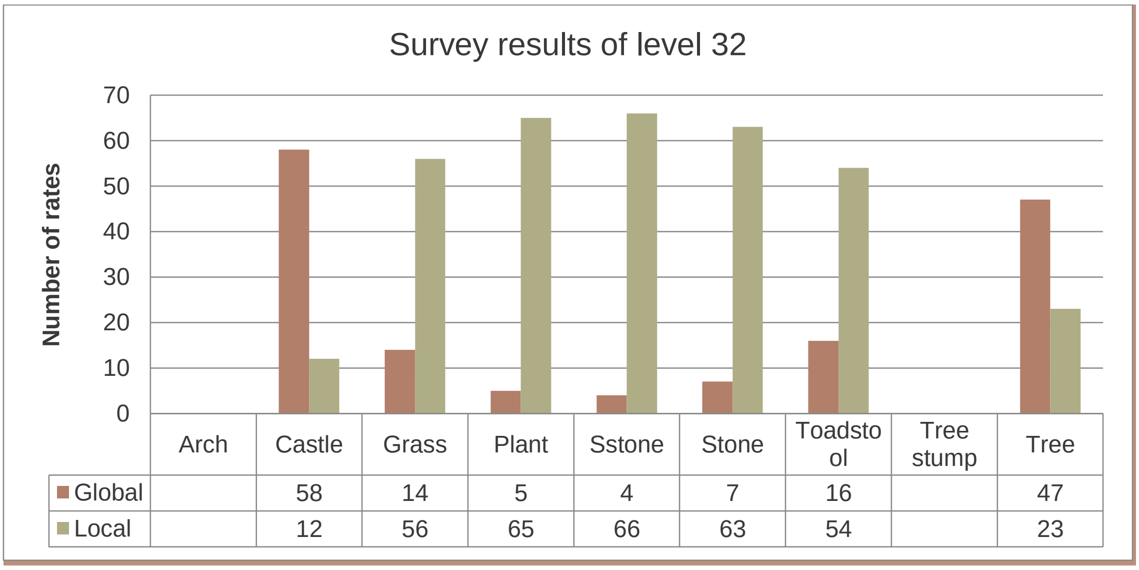


Figure 34: Survey results for the visibility of landmarks in level 32

7.3 Study-II

As stated in the previous chapter, one of the best-known definitions of saliency states that there are three categories of landmark saliency, these being visual, structural and cognitive (Sorrows & Hirtle, 1999). In this part of the study, cognitively salient objects are examined, as the number of studies about cognitive saliency is limited. Previous research has mentioned that cognitive salience is closely related to visual salience in unfamiliar environments (Quesnot & Roche, 2015b). Therefore, it is expected that cognitive salience will be associated with visual salience in this study as well.

7.3.1 *Analysis and results*

Word frequency analysis is conducted using the results of the survey study. The results of the word frequency analysis (Section 4.8.4) are shown in Figure 35. Various words were used to describe the same objects; for instance, the castle was also referred to as a turret or tower. Therefore, in order to clarify the number of mentions of each object, a detailed classification was needed. The results of the analysis showed that trees and the castle were mentioned most frequently in both levels 31 and 32. This was followed by reeds (grass) and bridge (arch) in level 31, and by reeds and mushrooms (toadstools) in level 32. Some descriptive words related to visual or structural characteristics, such as colour, shape and size, could also be seen in the results.

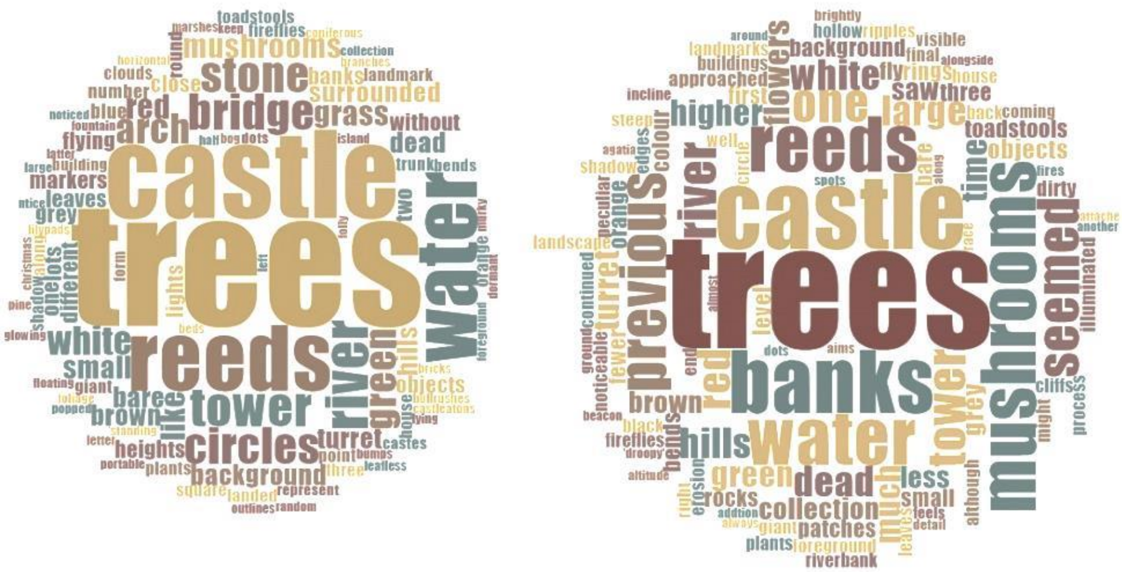


Figure 35: Most frequent words in the survey study (results of level 31 on left and level 32 on right)

To clarify the synonymous words used, landmarks were categorised based on the names they were introduced by and the descriptions people used (Figure 36). The landmarks were categorised by their colour, size, shape, material, number and location, based on the results received. Any other results were analysed separately. As expected, the castle, trees and toadstools were mentioned using many different words and multiple descriptive characteristics. However, smaller objects, such as stones or plants, were mentioned less. It was also expected that participants would focus on landmarks at decision points; however, this effect was limited. Only one participant reported that he saw toadstools “after a turn”. Participants mentioned that they saw trees “along the river” and banks “throughout the river”. They also reported when they saw an object more than once, or when they got closer or further away from objects (please see Appendix Figure A 9, Figure A 10, Figure A 11 and Figure A 12 to view the descriptions for all landmarks).

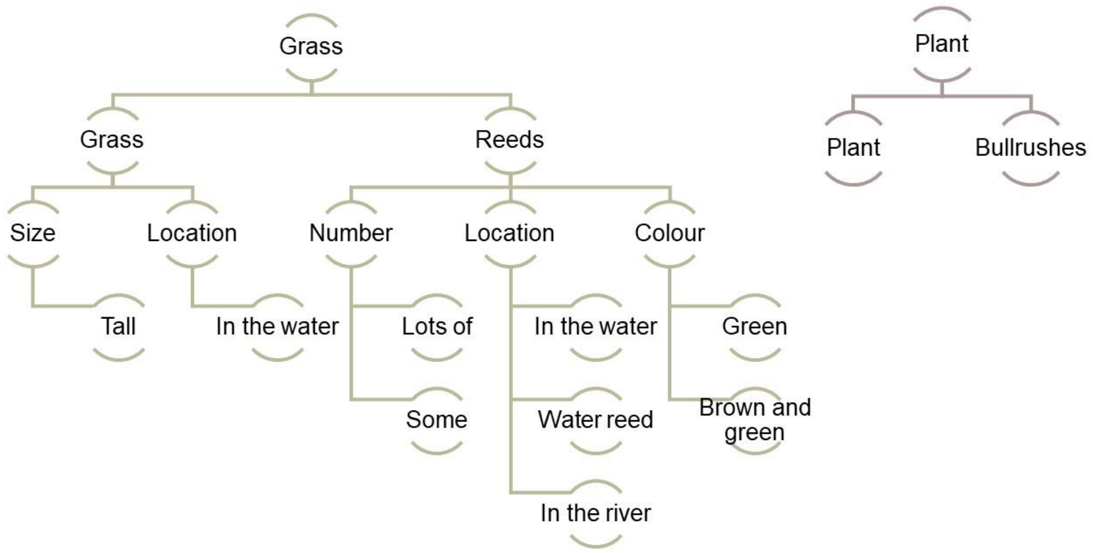


Figure 36: The descriptions are visualised for two landmarks in level 31: the grass was described using various words (on left); whereas the plant was described with a limited number of words

As a third step, the sum of mentions of the categorised landmarks was compared. Figure 37 shows the frequencies of the use of the words referring to landmarks. Here, both types of stones were categorised together since no participants mentioned them separately. The results of this analysis confirmed that the trees and castle were mentioned most frequently in both levels, indicating that they were cognitively more salient in this context. This was followed by the grass (17%), arch (14%) and toadstools (9%) in level 31, and by toadstools (24%) and grass (14%) in level 32 respectively. Not surprisingly, tree stump and stones were identified as the least salient landmarks.

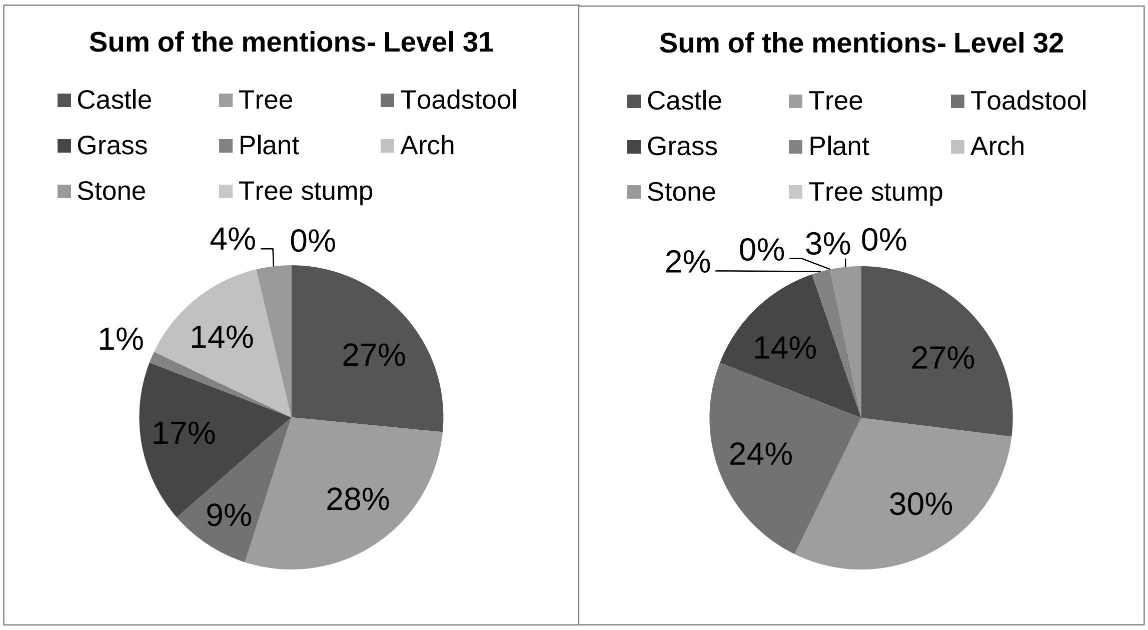


Figure 37: The percentage of the number of words that are used to define each object in levels 31 and 32 (the legend – read left to right, then top to bottom – was ordered clockwise from the 12 o'clock position)

The order of mentions was also analysed, since it is expected that more salient landmarks would be mentioned earlier. Figure 38 shows the results of this analysis. Here, the earlier mentioned landmarks scored higher values, while landmarks that are mentioned later scored lower values; the value of 0 was assigned to the landmark mentioned last, and increasing values were assigned to objects mentioned progressively earlier. Accordingly, it can be seen that the trees and castle were mentioned by people earlier than other objects during the survey. These were followed by grass, toadstool and arch in level 31; and by toadstool and grass in level 32. This result is consistent with the earlier findings.

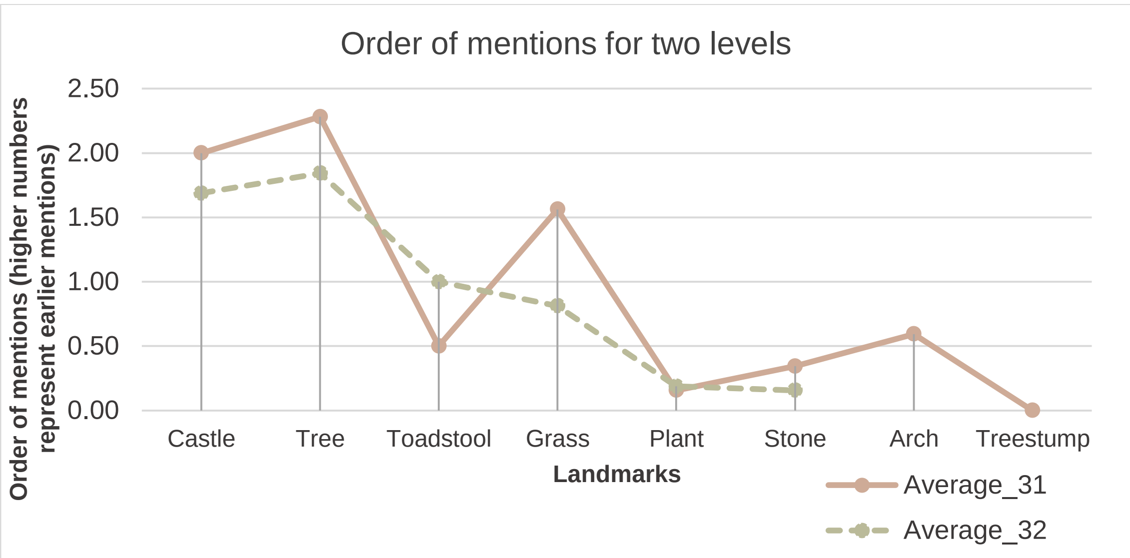


Figure 38: Order of mentions of landmarks in levels 31 and 32

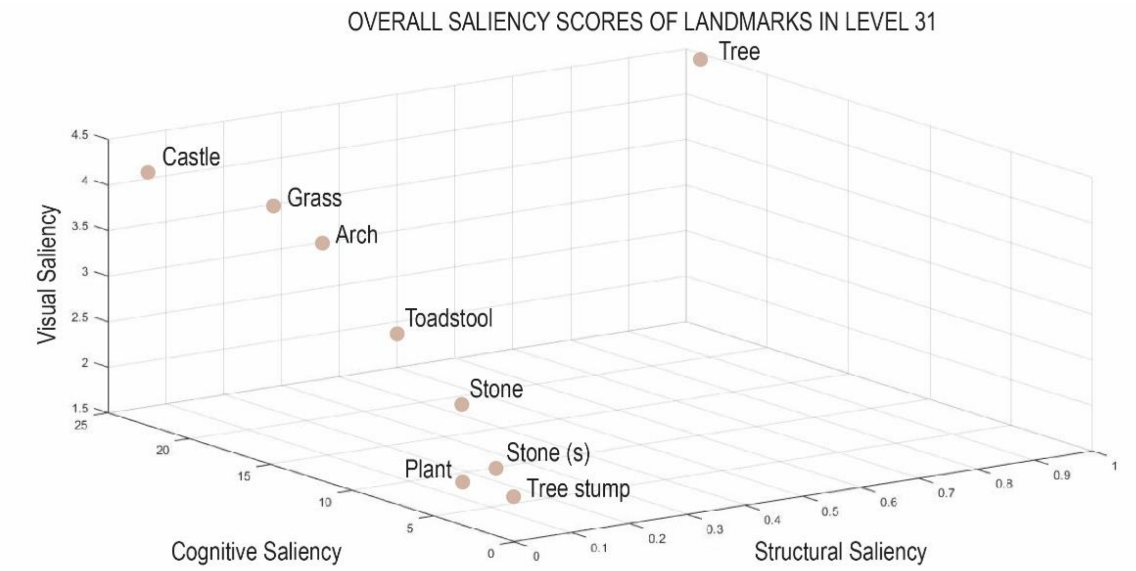
Finally, the degree of uncertainty was analysed. Hence, answers that included any expression of uncertainty, such as “maybe”, “seems like”, were checked (Tenbrink et al., 2019). Only four hesitation expressions were found in the two levels. For the first level, two people could not recall two objects or some of the details well: “*If I remember correctly,* there were also trees” and “an arched bridge, *possibly stone*”. For level 32, again two comments included hesitation: “There are, *it seems*, less large boulders on the river bank” and “Mushrooms on a hillside, *seemed to be red*”. However, in the first of these comments, “*it seems*” was used to explain an interpretation, rather than meaning confusion. In the latter comment, the hesitation was about the colour of landmarks. However, in this example, the hesitations can be related to the perspective of the camera, rather than the attention or memory. Hence, no significant impact of hesitation can be alleged.

Participants also focused on the changes in the number of the objects between two levels: “Single trees, apparently dead or dormant, were on the banks although *fewer than previously*”, “*there were fewer trees* in the foreground”, and they also focused on the similarities “*same tower as before*”. Hence, changes in the number and similarities between the levels were also observed by the participants.

7.4 Overall saliency evaluation

As all three characteristics of landmarks have been explored in this study, the next step is to visualise an overall saliency score of landmarks in a manner similar to that used in other studies on landmarks (Klippel & Winter, 2005; Nothegger et al., 2004). Since three characteristics of landmarks have been identified (visual, structural and cognitive) 3D plots are used to explore overall saliency scores. For visual saliency, people’s saliency evaluations (between 1 and 5) are used and an average value is calculated for each landmark. Since automatic saliency algorithms (objective measures) failed to explain people’s evaluations, they are not taken into consideration while measuring overall saliency. For structural saliency, the global and local landmark distinction is used; local landmarks are coded as “0” and global landmarks are coded as “1”. Only objects that are defined as global by both the survey and the boxplot analysis are defined as structurally more salient. Finally, for cognitive saliency, both the order of mentions and number of descriptions people used are considered, and an average value is calculated. As people’s evaluations differed between the levels, it was seen that changes in the context caused changes in saliency, therefore, overall saliency scores are also calculated for each level individually.

Figure 39 shows the results of the overall saliency scores, visualised in Matlab 19 (MathWorks, Inc., Natick, Massachusetts) for the two levels. To the best of author's knowledge, this is the first time that a systematic attempt has been made to categorise landmarks using all three saliency types brought together and visualised in this way. In the graphs, the *x*-axis represents structural saliency, the *y*-axis represents cognitive saliency and the *z*-axis represents visual saliency. Thus, the figures suggest that the tree has the highest saliency score in both levels of SHQ. Hence, the most salient, noticeable object is the tree compared to all other landmarks. It is followed by the castle, grass and arch in level 31; and by the castle, toadstool and grass in level 32. The stone, plant and tree stump are detected as the least salient objects overall.



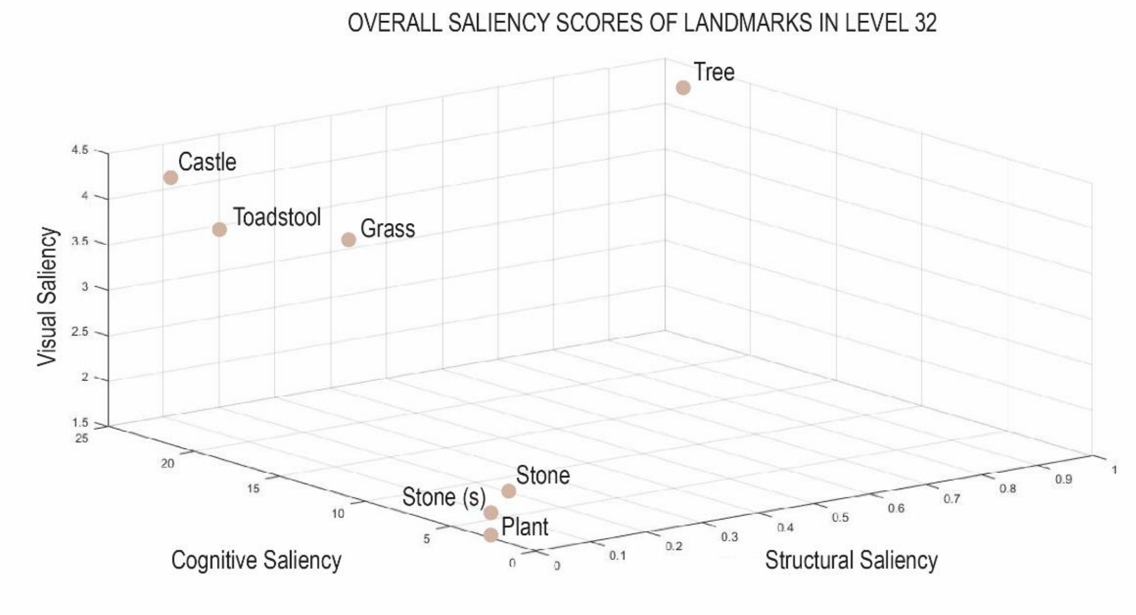


Figure 39: Overall saliency scores of landmarks in levels 31 and 32

7.5 Summary of the results

In this chapter, two components of salient landmarks, structural and cognitive saliency, were analysed. First, structurally salient landmarks were explored using the visibility of landmarks, which was also used to define a threshold to identify global and local landmarks. As in previous studies, for example, Lynch (1960), in this study, *global landmarks were considered as objects that can be seen from a great number of vantage points in an environment, but not necessarily from everywhere. Local landmarks were considered as objects that can only be seen from nearby.* By considering this idea, the visibility of landmarks was analysed for two levels of SHQ and the percentage of the journey time during which the landmarks were visible was calculated for each participant and for each landmark. A boxplot analysis was then conducted to find a threshold and it was discovered that objects with visibility scores higher than 25% can be thought of as global landmarks, as they are differentiated from the other landmarks. Or to put it heuristically, if a landmark is visible either continuously or intermittently for more than 25% of our journey, it can be considered as a global landmark. Another gap in the literature is, therefore, explained and a threshold is suggested for use in the future studies in this chapter. This is important to understand the visibility of landmarks and explore the objects around us as global and local ones. Hence, we can easily determine which landmarks are local and which are global in a 3D version of an environment by using this threshold, and wayfinding experiments can be organised using this information.

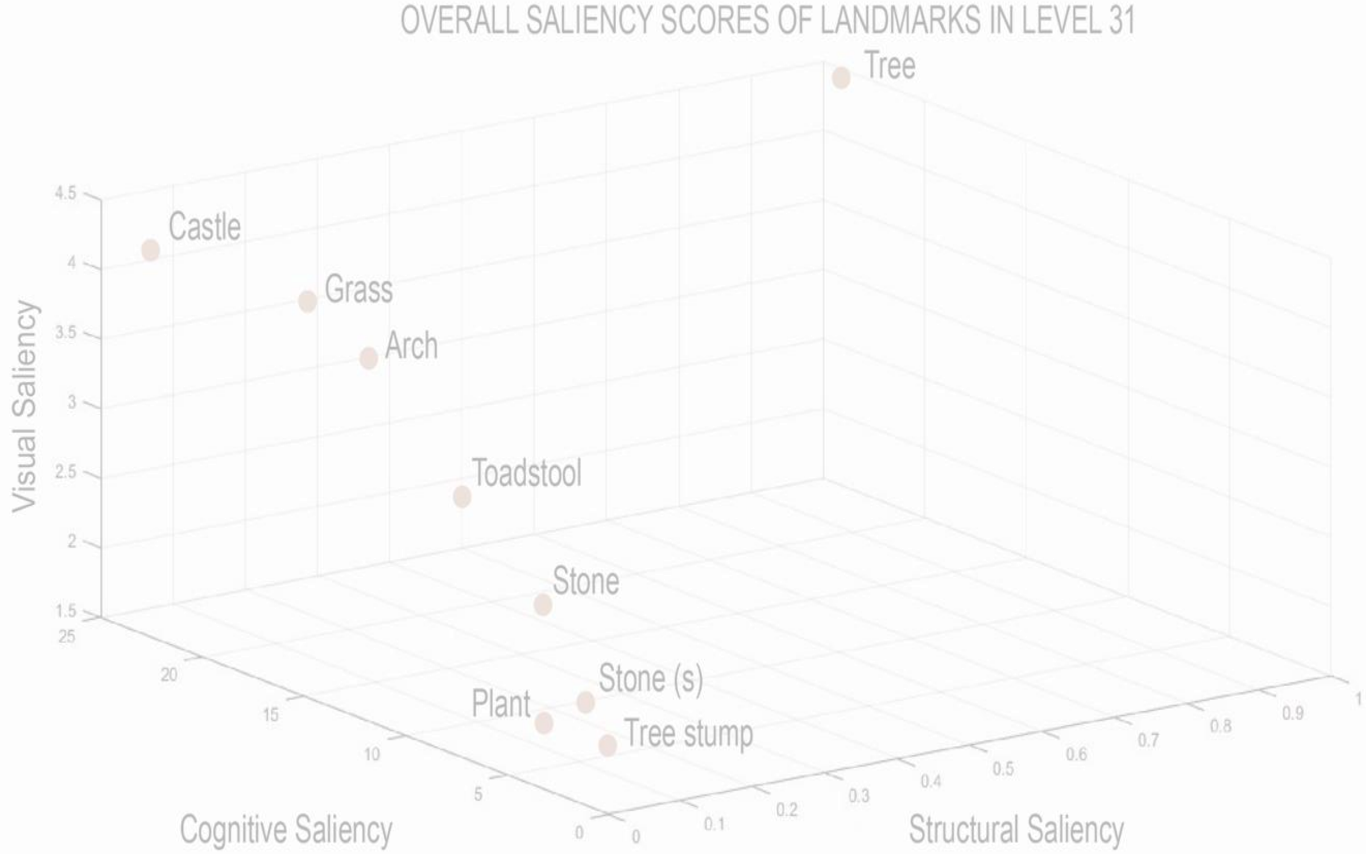
On the other hand, 70 people were also asked to define landmarks as either global or local for the same game levels using an online survey. Results of the survey showed that three landmarks were detected as global landmarks: the castle, arch and tree. Actually, castle was rated by more participants as a global landmark than trees. Hence, even though the survey results were similar to the results that identified the threshold, two more landmarks were identified by participants as global landmarks.

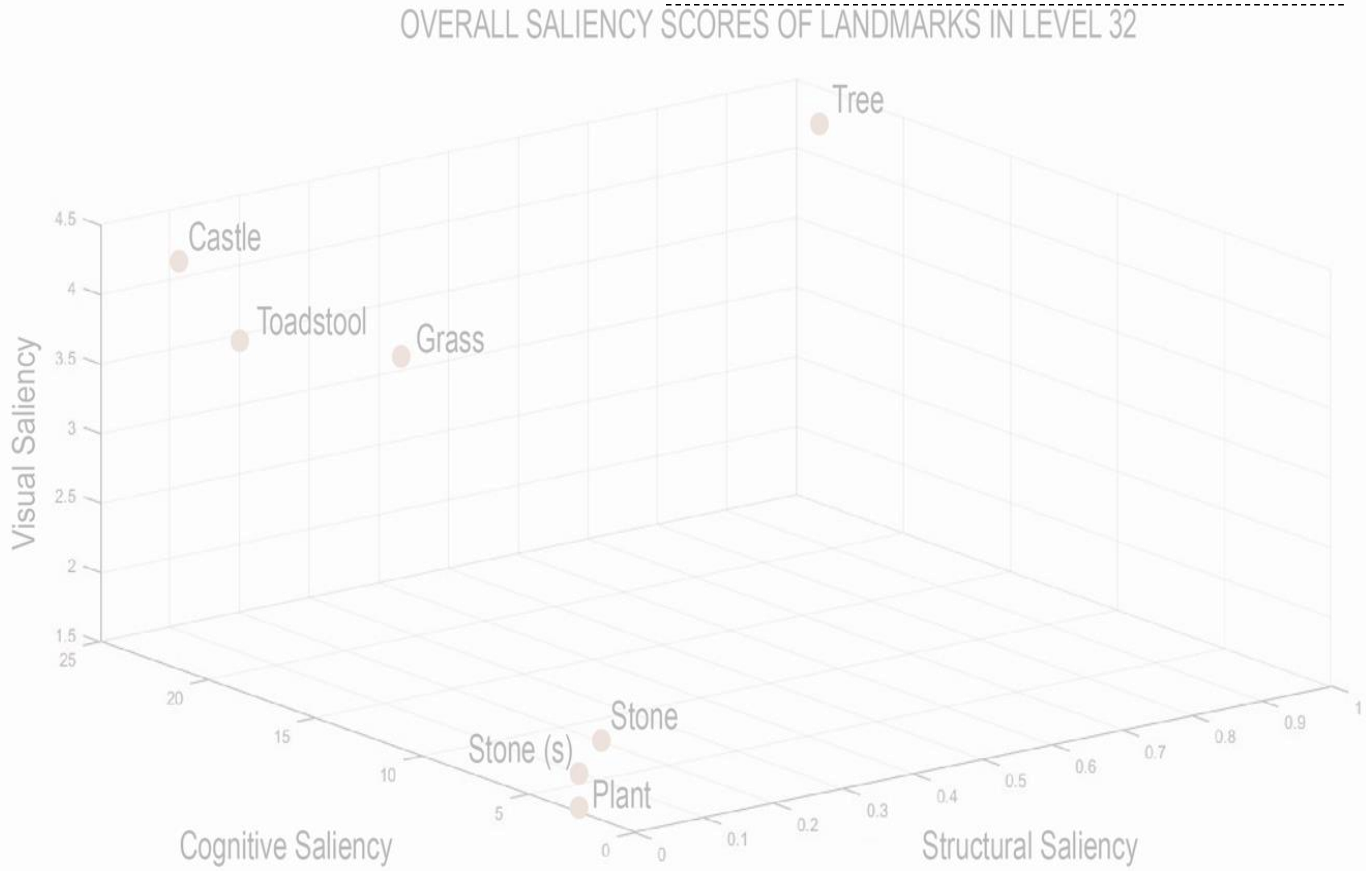
For the second study, cognitive saliency was investigated using a survey. The results showed that some of the objects that differ from their surroundings in their size, colour and visibility (so with their visual characteristics), were mentioned by more people or with more descriptive words. In addition, limited location information was also provided by people in this study. This suggests that cognitive saliency is closely related to visual saliency in an unfamiliar environment, and structural saliency also plays a role in cognitive saliency, since people could recognise changes in the location of landmarks.

This chapter contributes to knowledge in five ways:

- Global and local landmark definitions are discussed and a threshold is suggested to clarify the distinction.
- Landmark visibility during a journey is calculated via a Java program; hence, the visibility of landmarks could be seen for each participant at different times.
- Structurally salient landmarks are explained using an innovative approach (decision points or landmarks on routes are not used and landmark visibility is analysed instead).
- Cognitively salient landmarks are discussed using people's descriptions.
- An overall saliency score is defined using visual, structural and cognitive characteristics of landmarks.

All the main criteria used in the literature to define saliency (Sorrows & Hirtle, 1999), therefore, were used in this thesis. As a further step, the overall saliency was analysed by visualising all three characteristics of landmarks. The most salient and the least salient landmarks in the SHQ levels were detected via this approach. Many saliency studies have also analysed the three components mentioned here; however, people's saliency evaluations and descriptions were used effectively in this study to explain visual, structural and cognitive saliency, which makes this study significant. In the following chapters, the consensuses with the literature and the unique findings of the thesis are identified. Limitations of the study as well as future research directions are also listed.


OVERALL SALIENCY SCORES OF LANDMARKS IN LEVEL 31
Tree
Castle
Grass
Arch
Toadstool
Stone
Stone (s)
Plant
Tree stump
Visual Saliency
Cognitive Saliency
Structural Saliency


OVERALL SALIENCY SCORES OF LANDMARKS IN LEVEL 32
Tree
Castle
Toadstool
Grass
Stone
Stone (s)
Plant
Visual Saliency
Cognitive Saliency
Structural Saliency

8 DISCUSSION & CONCLUSION

8.1 Introduction

This chapter revisits the original motivating factors of the research as well as the research questions. The findings of the analysis chapters are summarised and interpreted in this chapter. The contributions to knowledge are listed. The theoretical and practical implications of these findings are discussed. In the final section, limitations of the study and possible future research directions are also discussed.

With this thesis, the impact of environmental factors, in particular landmarks, on people's wayfinding performance is explained, and the criteria that make a landmark preferable are listed. Various complexity and Space syntax measures are used and the environments analysed accordingly. It was discovered that the complexity of layouts was a significant component that affected the difficulty of wayfinding tasks. This finding demonstrated the success of the SHQ researchers, since they had designed simple layouts that became progressively more complex to make the wayfinding task harder. The impact of the weather condition, in other words, visibility, is also highlighted, since the time taken by participants to complete the wayfinding tasks was longer when the weather was foggy. The impact of the existence of global landmarks in an environment was also highlighted in this research; however, no impact of the saliency of landmarks was established. This is also a reason why the saliency of landmarks was investigated in detail. To analyse the saliency of landmarks, the visual, structural and cognitive characteristics of landmarks were analysed and it was discovered that visual and structural characteristics of landmarks were important to identify their saliency in unfamiliar environments. More specifically, it was observed that the colour and size of landmarks were significant characteristics of visually salient landmarks and the visibility of landmarks was significant for them to be structurally more salient.

The hypotheses listed in the introduction were:

1. People's wayfinding performance is affected by the spatial layout and different conditions, in particular landmarks.
2. Landmarks play an important role in wayfinding, and salient landmarks that have a unique colour, size, spatial location and that can be seen from many angles are expected to be preferred by a higher number of people as salient landmarks.

3. The complexity of layouts is key in wayfinding and the factors that reduce the availability of information about the environment (weather conditions, map readability) also can make wayfinding more challenging.

Therefore, it can be stated that the first and third hypotheses have been confirmed in this study. The impact of the layout, weather condition and existence of global landmarks were observed in the experiments. Complexity was analysed via a range of measures, such as the number of checkpoints, decision points, and the length of the shortest route, and the impacts of these factors were highlighted. No significant impact of saliency of landmarks could be observed during wayfinding. At this point, it was argued that the experts' saliency evaluations could be tested against non-experts' evaluations and that saliency could be explored using various measures.

The second hypothesis was also confirmed in this study. During visual saliency analysis, it was discovered that people tend to choose objects that have a unique colour or size as salient landmarks. From the example of grass as a landmark, it is also concluded that the location and visibility of a landmark is also important for that landmark to be selected by higher number of people. In the next section, findings of this thesis are explained in detail.

8.2 Summary of the findings and interpretations

At the end of the introduction chapter (Chapter 1), two research questions were raised:

- Which environmental factors or conditions make wayfinding easier?
- How do we select landmarks in unfamiliar environments?

The findings associated with these questions are discussed under two headings.

8.2.1 *Environmental factors and conditions*

For this study, Sea Hero Quest, an online game was used and various methods and different analyses were conducted. The first research question was "**Which environmental factors or conditions make wayfinding easier?**" To answer this question, all wayfinding levels of SHQ were used and the first analysis chapter, Chapter 5, presented the analysis of the environment using various measures and under different conditions. It was discovered that the complexity of layouts is key in wayfinding performance. This finding was consistent with previous research (Slone et al., 2015; O'Neill, 1991a, 1991b). Different measures were used to understand the complexity of the environments, such as the shortest route or the number of checkpoints. These results can be interpreted separately as well. For instance, as the shortest possible route required to complete a wayfinding task increases, it takes longer for people to complete the task. Hence, the positive relationship between these variables is not surprising. Similarly, the number of axial lines increases when the system gets bigger in scale or when it is harder to see navigable spaces from different points within an environment, as more lines are then needed to define the navigable areas. Hence, an increase in the number of axial lines causes an increase in path length. If there is only one checkpoint rather than a number of checkpoints, we can also expect this task to be completed quickly, and more checkpoints make the task harder, as each checkpoint must be found sequentially. This represents both a memory and a spatial planning challenge – the player has to remember the order in which to visit the targets and this task becomes harder as the number of targets increases. In addition, a higher number of checkpoints may cause an increase in the length of the shortest possible path, although this is not necessarily the case in all levels. Hence, the positive relationship between the difficulty and the number of checkpoints is also expected.

The results of the first analysis chapter also suggested that metric reach, number of decision points and dead ends, SNE, number of circles in circular environments, and area of navigable space have positive relationships with difficulty. Metric reach is about the density of the street network: if one can reach more alternative routes by moving a specific distance, then the system has higher metric reach values. This, therefore, can be thought of as another measure of complexity. Although studies stated that higher street density is likely to encourage increased pedestrian movement (Ozbil et al., 2016; Kubat et al., 2013), the findings of this study contradicted this idea. Yet, it could be argued that as the density of streets increases, the number of decision points, where people need to decide whether or not to make a turn, is likely to increase, leading to a more complex layout. Therefore, this finding actually supported the idea that complexity of layouts is significant in wayfinding. Another explanation could be related to familiarity with the environment. In the reviewed studies, authors worked with participants familiar with the environment. Hence, people may choose shortcuts and other alternative routes in familiar environments, while first time explorers may prefer simpler layouts with longer segments and fewer decision points. This suggests that as the number of decision points increases, the likelihood of making a wrong turn also increases, and this in turn lengthens the path to the destination. Therefore, the findings replicate previous findings, which reported the significance of the number of decision points in wayfinding (Raubal & Egenhofer, 1998; Arthur & Passini, 1992; O'Neill, 1991b). The number of circles also has a positive relationship with difficulty, although a negative relationship was expected, since people could recover their mistakes more easily in circular layouts. However, in this case, layouts with circles made it more challenging for people to way-find. As mentioned before, lower SNE indicates predictable systems whereas higher SNE indicates unpredictable systems. Hence, the difficulty of levels tends to increase as the SNE increases, as expected. The area of navigable space also had a positive relationship with the duration. This result also suggests that as the environment gets larger, it is likely that it will become more challenging for people to complete a wayfinding task. The number of dead ends has a positive relationship with the duration, as seen in the existing literature (Hölscher et al., 2006, 2012). This result is not surprising since dead ends make it harder to explore an area and develop a cognitive map.

Various measures, on the other hand, have negative relationships with difficulty. An increase in axial normalised choice, for instance, caused a decrease in difficulty. Findings related to axial choice suggest that people find it easier to navigate within environments consisting of segments that can be used as a shortest route, which have higher potential for frequent use. These findings conform with the findings of earlier research about choice (Ozbil et al., 2015; Emo et al., 2012). Higher integration is a predictor of higher movement potential. Thus, as integration increases, one can expect to see a decrease in difficulty, since the layout becomes more accessible. The results on integration are also consistent with the literature (Hillier, Burdett, et al., 1987; Peponis et al., 1990; Emo et al., 2012). Furthermore, axial intelligibility also has a negative correlation with difficulty. These findings imply that in an environment that can be assessed from any point within itself, and so is intelligible, it would be less challenging for people to complete a wayfinding task. Previous research also suggested that intelligibility is significant in explaining movement (Haq & Zimring, 2003; Kim, 1999; Conroy, 2001).

Findings of the research also suggest that not only the layout but also visibility affects people's results. It was discovered that weather conditions affected people's wayfinding abilities and it became more challenging for them to find their way as visibility decreased. This is also consistent with the existing literature (Hurlebaus et al., 2008; Ruddle & Péruch, 2004). Thus, no matter how careful someone is, if the environment is complex and the visibility is low, wayfinding can become a challenge. In addition, a negative relationship between the duration and landmark saliency was observed, which suggests that salient landmarks help people to complete a wayfinding task faster. The first analysis chapter of the thesis, therefore, explained the relationship between the layout and people's wayfinding performance. It also showed the significant impact of weather and salient landmark conditions on wayfinding. This gives insights to future comparative studies. If researchers aim to compare people's wayfinding performance in unfamiliar environments, the control of these conditions is key; otherwise, the results would also depend on any changes in these factors.

Since no impact of global landmarks could be seen in the first study, and the impact of salient landmarks was observed in correlation analysis in Section 5.2.3, another study was conducted, where different conditions, more specifically, landmarks, were analysed. At first (see Section 5.3), the environment was kept as similar as possible so that the changes in results could be seen by focusing only on the conditions. In order to better understand the impact of different conditions, five levels with same layout were analysed where the weather, maps and saliency of landmarks varied. All conditions used in this section were predefined by the researchers of the game. Some of the findings were consistent with the previous study. Again, the weather condition had a more significant impact than the other conditions. No impact of landmark saliency was observed and this finding contradicted the findings of the previous research, which suggested that salient landmarks affect wayfinding (for example, Albrecht & Von Stuelpnagel, 2018; Hamburger & Röser, 2014).

The five levels compared in this study had same global landmark conditions; therefore, they could not be used for the global landmark study. The global landmark condition was analysed using the layouts of levels 3 and 13, which had with similar syntactic values (see Section 5.4). It was discovered that global landmarks also affected people's performance. This result suggested that when the environment consists of objects that help us to globally orient ourselves, then we can complete a wayfinding task more easily. Similar findings were also presented by other researchers (for example, Li et al., 2016; Li, Korda, et al., 2014; Lin et al., 2012).

8.2.2 ***Landmarks in unfamiliar environments***

The analysis described in Chapter 5 was conducted using the complete dataset received from the game company. The results confirmed the findings in the literature in general, with the exception of the results about salient landmarks. To test these findings, different questions were asked: would those predefined saliency and visibility (global/local landmarks) categories match with people's thoughts? If we ask non-experts to evaluate landmarks, would the results support researchers' (experts') evaluation?

Before answering those questions, definitions were proposed for landmarks for the thesis, as well as for global and local landmarks. This was another purpose of the thesis. A landmark is defined as *any salient object that is personal, communicable and visible either from a distance or nearby in an environment such that it can be used in the wayfinding process for various tasks (e.g. route definition, orientation etc.).* Parallel to the previous research (Lynch, 1960), in this thesis, global landmarks are defined as *objects that can be seen from many points in an environment, but not necessarily from everywhere.* Local landmarks are defined as *objects that are seen from nearby* (visible only from a limited area and only from certain directions).

To perform more detailed analysis on landmarks, two levels of the game, levels 31 and 32, were selected and used for the saliency study. Once landmarks, including global and local landmarks, had been identified, the saliency of the landmarks was analysed in detail according to the categories in the literature: visual, structural and cognitive landmarks. This also would be important in understanding the second research question asked: "**How do we select landmarks in unfamiliar environments?**" In this context, first the visual characteristics of landmarks were analysed using a survey and by measuring objective saliency scores (Gbvs and DeepGaze II algorithms). The results of these two approaches were compared and no significant relationship could be found. The survey results showed that people choose objects that are differentiated from their surroundings by their size and colour. Similar visual characteristics had also been stated in previous studies (Michon & Denis, 2001; Winter et al., 2005). Therefore, landmarks can be considered to be more salient if they have a unique colour or size, or both. Moreover, as two levels were used in this study, it was possible to compare the evaluations for the two levels. In level 31, which had an easy landmark condition according to the experts, participants of the survey evaluated a higher number of landmarks as noticeable, compared to level 32, which was assessed as having a hard landmark condition. When the videos shown to the participants were watched carefully, it could be observed that landmarks were indeed located at more segregated points in the environment (in level 32), with the exception of the toadstools. This finding is critical because the landmarks were consistent between levels, as of the nine landmarks in level 31 only two were not in level 32, and the location altered – that is, the visual saliency was same and the structural saliency changed. This implies that changing structural saliency can affect people's perception of visual saliency. This finding replicated the findings of the previous research (Albrecht & Von Stülpnagel, 2018). As mentioned, only toadstools were rated differently and the number of people who found toadstools more noticeable in level 32 was higher. In this level, participants were able to see the toadstools at closer range, which may affect their saliency evaluation and cause an increase in the number of ratings. In addition, in level 31, the toadstools were seen with many other objects, while in level 32 they were seen alone. This can support the findings of previous studies (Raubal & Winter, 2002; Sadeghian & Kantardzic, 2008) which stated that the existence of salient landmarks can make other landmarks less salient.

The results of the survey were compared with experts' saliency evaluations. The results showed that these two evaluations were consistent for many landmarks. The impact of context was highlighted for the landmarks where the evaluation varied; two out of nine evaluations were different. The experts evaluated landmarks without seeing the objects in their context while the non-experts saw the objects against the background used in the game. Hence, this was considered to be a reason for this difference. This finding might suggest that in order to measure the saliency of landmarks, we should always consider their context in order to make a more effective distinction, as stated by Caduff and Timpf (2008). It is found that what makes a landmark salient is not only its visual characteristics, but also how we perceive it. If we were to move within an environment and observe landmarks from a short distance, or from specific locations, then we may recollect them more easily. Hence, it can be said that both visual and structural characteristics of landmarks are significant.

The last analysis chapter of the thesis included both structural and cognitive saliency analyses. For structural saliency, the visibility of landmarks was investigated and an average visibility was calculated for each landmark. The visibility of landmarks is important since it helps people to understand where they are and to complete a wayfinding task. If a landmark is local, then it helps people to find their way in a limited area; if it is global, it helps people to orient themselves in a larger area. Hence, this differentiation can also be considered as a way to evaluate structurally salient landmarks. Here, global landmarks are thought of as structurally more salient landmarks. A threshold was identified to distinguish local landmarks from global ones. The findings suggested that l*andmarks that are visible from 25% or more of the environment are considered to be global landmarks whereas the others are considered to be local landmarks*. Of all the landmarks in these levels, only trees were identified as global or structurally more salient landmarks. These findings were then tested using a survey in which people were asked to evaluate landmarks as either global or local. The results of the survey also showed that trees were evaluated as salient landmarks, in addition to two other landmarks, namely the castle and arch. Even though the results did not completely match between these two observations, the threshold defined here was useful to distinguish landmarks based on their visibility. Hence, this threshold can be applied to different environments and the landmarks can be distinguished, as global or local, based on their visibility.

In order to identify cognitive saliency, another survey asked people to define the objects they saw in videos. The results of the analysis showed that in an unfamiliar environment, people tend to focus on visually salient objects. In addition, it was observed that structural salience affected the results in unfamiliar environments, which was rarely mentioned in the literature. Therefore, in this study we observed the impact of visual and structural saliency in virtual, unfamiliar environments and no direct impact of cognitive salience could be seen. Other studies also discussed that cognitive salience can be closely related to visual salience in unfamiliar environments (Quesnot & Roche, 2015b). In addition, the findings also provide support for the importance of spatial positioning of landmarks in determining landmark salience in navigation (Michon & Denis, 2001): objects encountered in close proximity to the navigator when travelling were judged highly salient despite their low visual saliency. Hence, the results were similar to the findings of the existing literature. All these findings are combined as a final step and an overall saliency score was found for each landmark examined in this thesis. Hence, all points mentioned in the landmark literature were considered in this thesis and they were analysed using various measures.

8.3 Contributions of the thesis

This thesis contributes to the existing wayfinding literature in various dimensions. First of all, in the first analysis chapter of the thesis the largest dataset ever used in this type of research was deployed to examine the factors that might affect people's wayfinding performance. This dataset contained results from approximately 1.5 million people who contributed to the study by playing SHQ. Moreover, 45 levels of the game were used and compared. The dataset introduced here and the results were significant in themselves, since the existing literature focused on a limited dataset. By using this dataset, accurate results about the factors that shape people's wayfinding behaviour were defined, and that was another contribution of the current research. Hence, the findings of this study supported the findings of the previous research and highlighted the significance of complexity measures in unfamiliar environments. Not only the layout but also different conditions associated with the weather, map and landmarks were investigated. The studies on the impact of weather and the readability of the map were also limited in the literature. Therefore, it was also important to touch upon these factors. Moreover, previous studies on the impact of visibility of landmarks on wayfinding concluded different results. In this study, by comparing two similar layouts of SHQ, the impact of global landmarks was investigated. It was discovered that the existence of global landmarks improved people's wayfinding performance. Hence, it can be claimed that not only local landmarks but also global landmarks are significant in wayfinding. This was another contribution of this research.

In the following analysis chapters, different characteristics of landmarks were evaluated and three landmark salience criteria were used: visual, structural and cognitive. All characteristics were evaluated in this study using a multitude of objective measures, which is rare in the existing literature. First, visual saliency was evaluated through the use of objective saliency measures and a survey. There are few studies that have combined automatic saliency detection tools and wayfinding behaviour (Psarras et al., 2019; Grzeschik et al., 2019). In the current study, two automatic saliency detection tools were tested to see whether or not they corresponded with people's evaluations. In addition, experts' saliency evaluations were compared with those of non-experts. This was also quite limited in the literature. To the best of author's knowledge, there were two other studies where experts' saliency evaluations were compared with those of non-experts (Hölscher & Dalton, 2008; Cheng, 2009). These three perspectives – using a survey, using automatic tools and comparing survey results with experts' results – therefore, can be seen as significant in explaining visual saliency.

Another gap in the literature was also examined in this study. It was stated that the distinction between global and local landmarks was unclear. By using two levels of SHQ and by calculating an average visibility value for each landmark, a threshold was determined. Landmarks that are visible for more than 25% of travel time are defined as global landmarks and the rest of the landmarks are thought of as local landmarks. This clarification would allow future studies to distinguish global landmarks from local ones more easily. A different technique (a Java program showing the landmark visibility for each participant-see section 4.8.3) was also used here to visualise landmark saliency and saliency was evaluated for each participant during a wayfinding task, which can be claimed as another contribution of the current study. Since structural saliency related to the location of landmarks, and how much they help people to orient themselves in an environment, global landmarks were considered as structurally salient landmarks in this study.

Furthermore, cognitive saliency was also addressed in this study and, rather than focusing on objects with explicit markings (Nothegger et al., 2004; Raubal & Winter, 2002) or by considering their functions (Lazem & Sheta, 2005), people's personal saliency evaluations were investigated in a manner similar to that used in a previous study (Götze & Boye, 2016). Here a survey was created and people were asked about the landmarks they remembered. Linguistic analyses were used to investigate this question, which is also unusual in landmark saliency literature. The analyses were completed using an overall saliency graph. All three characteristics discussed throughout the thesis were combined and the most salient and the least salient landmarks were listed. Hence, all main topics discussed in the landmark literature were touched upon. The thesis contributed to the wayfinding literature by using a number of measures, including complexity measures as well as Space syntax, in addition to analysing landmarks.

Finally, the overall saliency score was described using a 3D scatterplot. An overall saliency score was described as described in the review in Chapter 3. The method followed here was unusual since this is the first study to show the overall saliency using a 3D scatterplot, to the best of author's knowledge. This, therefore, can be considered as another contribution.

8.4 Implications of the findings

As well as contributing to the theory, this thesis also has valid practical implications. Findings here suggest that people get lost more easily when an environment is "complex". Therefore, it is important for architects at the building scale, and urban planners and designers at the urban scale to control the layouts they design by using complexity measures. When we plan a park or an entertainment centre, for instance, we might consider having complex systems inside those areas. In this case we can increase the number of intersections, have shorter segments, and provide many alternative and similar paths to follow, which would make the environment one in which it is hard to way-find. These areas can be attractive for people who like to test their abilities to find their way or who basically want to get lost. If, however, we design a building or an urban area, then we may prefer to make it simple and easy to navigate. In this case, it is important to consider the measures mentioned in this thesis and analyse the developed areas accordingly.

As it is stated here, increased visibility is another important factor in environments for people to find their way more easily and quickly. Therefore, if we were to plan a building, it would be important to place significant functions that will be used by many people at highly visible points. Similarly, if the whole building, or environment, is highly visible, then it would also be easier for people to circulate within these systems. These implementations would make wayfinding easier for people who are unfamiliar with these systems. However, it is also important to consider walkability. Previous research discussed that it is important to have shorter urban blocks, which can be achieved by increasing the number of decision points and decreasing the segment length, to have more walkable spaces (Jacobs, 1961) or to prevent the feeling of discomfort (Salingaros & Pagliardini, 2016). In this context, research on walkability also focused on the capacity of urban systems to permit movement of people and stated that it is important to have shorter segments to have more movement (Ujang et al., 2012). These components are significantly important for local people who are familiar with an environment. Thus, at the urban scale, it is important to have a balance between simple layouts and the ease of walking. While one group, visitors, would like to have simpler layouts to explore, another group, the locals, would be keen to have "easy solutions" (e.g. short cuts). It would be beneficial for architects and planners to have harmony in a planned environment where these two groups would easily navigate themselves.

Research has already shown the impact of landmarks on finding a location (Klippel & Winter, 2005) or on orientation (Michon & Denis, 2001). In this research, the impact of global landmarks on people's wayfinding performance was also highlighted. The most effective characteristics of landmarks, those which make them salient, were also discussed. Therefore, it can be stated that to make wayfinding tasks easier, it is important to use landmarks. Here, the approach of a previous study can be used to explain how to adapt landmarks to the buildings or cities of today (Winter et al., 2008). Winter et al. defined landmarks and used voronoi regions to define the catchment areas of landmarks. If we can do the same and define regions with highly salient landmarks, especially those which are visually and structurally salient, then it might be easier for people to find their way and orient themselves in any part of an environment. By using different characteristics of landmarks, such as colour or size, it is also possible to create more attractive environments. Moreover, landmark-based mobile applications can also be developed to detect salient landmarks, in which the measures introduced here can be used. It was mentioned in the literature review (Section 3.5.1) that different mobile applications were created (see, for example, Wolfensberger & Richter, 2015). To make the detection tools more efficient, it is important to focus on personal saliency scores, as was done in this study, and integrate people's evaluations into the process as much as possible.

8.5 Limitations

8.5.1 ***Limitations related to the case study***

This study also has limitations that should be acknowledged. The benefits of using SHQ as a case study were mentioned in the thesis. However, there are also limitations related to the game. First, during the data collection, people were not tested in a laboratory environment and their results were collected online. Hence, their attention level could not be controlled while playing the game. Even though the game environments were tested and compared with real environments (Coutrot, Schmidt, et al., 2018) and a significant relationship was found, this could be the first limitation of the current study.

The second limitation of this research was related to the game's design process. Since the researchers had a limited time, overall saliency scores were defined for landmarks and, rather than considering each level individually, researchers determined landmark salience from the visual characteristics of landmarks, as they saw landmarks independent from their context, against a white background. Due to this process, their saliency evaluation did not completely match with non-experts' salience evaluations in this study. The results may have been different if experts could see the landmarks in context.

Another limitation of the study is that the saliency of landmarks was analysed using two levels of the game. Nine landmarks were analysed in level 31 and seven landmarks were analysed in level 32. Even though the landmarks varied in visual characteristics (colour, shape, size etc.), the number of landmarks was still limited to conduct statistical analysis. Moreover, in the saliency analyses, participants watched videos instead of actively navigating themselves in the environments. This was deliberately done to ensure that people focused fully on landmarks. However, as the content of the task can affect visual attention, the results of the survey could be different in a study where people actively navigated themselves rather than passively watching the pre-recorded videos.

In addition, structural saliency has most commonly been analysed by considering objects at decision points or on routes. In this study, because of the simple nature of the layouts of the first levels, there was no opportunity to make this kind of categorisation of landmarks. This was another limitation of this study, which necessitated the use of the alternative method of using the visibility of landmarks to determine their catchment areas, as described in Chapter 7.

8.5.2 *Limitations of the method*

There are also limitations related to the approach followed in this study. First, while one object type, tree, was defined as a structurally salient landmark according to the defined threshold, the results of the survey identified two extra objects as global landmarks. This could imply that either the way the threshold is defined should be reconsidered, or factors other than visibility that might affect people's ratings should be considered. For the former idea, the distribution of the calculated percentage of the journey for which the objects are visible was checked and a threshold was defined using a standard formula. Another method of defining the threshold could be tested to identify how the survey results compared with the new threshold. For the latter idea, consideration should be given to how people's landmark visibility rating may have been affected by other characteristics of landmarks, which could cause different results. For instance, it can easily be stated that the time period during which participants saw the arch while watching the video was limited; however, people still evaluated it as a global landmark. If a global landmark is defined as an object that can be seen from a great number of vantage points, the arch should also have been visible from a great number of points during a defined route. Is it possible that people are affected by other aspects of landmarks, such as their visual characteristics? Even though the global landmark definition was developed before the commencement of the survey and briefly repeated immediately before people's evaluation, visual characteristics of landmarks (e.g. landmark size) can be assumed to shape people's evaluation and affect the results. This can be thought of as another limitation of the current study.

Furthermore, while analysing the landmarks, all predefined landmarks were used. However, Study-II of Chapter 7 pointed to additional potential landmarks. For instance, the background trees and topography were also mentioned by the participants, but these were not defined as landmarks by the experts. Answers were also received that focused on the changes in the environment: "*Ground level was higher* than in the previous video", "*Much higher banks,* as the previous landscape had shallower incline", "The river banks *were much higher and steeper*". Either the topography or the background were considered as landmarks in this study. However, future research can also consider these factors and analyse them as landmarks to evaluate how salient they are. Also, it would be more meaningful for future studies to ask people for their landmark descriptions first and define landmarks accordingly. Then the visual and structural characteristics of landmarks could also be analysed using all the landmarks mentioned by people.

Additionally, several limitations were also defined for the algorithms used to define visual saliency, which are mentioned in the following subsection.

8.5.3 ***Model-based limitations***

As mentioned earlier, objective saliency models alone were not sufficient to understand the results of the survey of visual saliency. This can be explained through model-based limitations. One of the model-based limitations is due to the relative position of individual objects. For instance, if an object is close to a salient one, this could affect the saliency scores of the object and make it a salient landmark as well. However, in contrast, previous studies have argued that the existence of a salient landmark may make another one less salient, as it decreases the probability of the other object being selected as a point of reference (Raubal & Winter, 2002; Sadeghian & Kantardzic, 2008)). Therefore, the saliency regions (as in DeepGaze II model) that are described through the use of models can become misleading, especially when the objects are quite close to each other or when one of them is in front of another, as shown in Figure 40c–d. Similarly, the backgrounds of the objects also affected our analysis, as they affected the saliency of objects. For example, the trees located further away than the plant whose saliency was being considered had a colour that blended in with the background. The trees were detected as salient objects in some of the images and they had an impact on the results of the plant (please see Figure 40a–b). Hence, models could be more sensitive in relation to overlapping objects or they could consider the locational relationships.

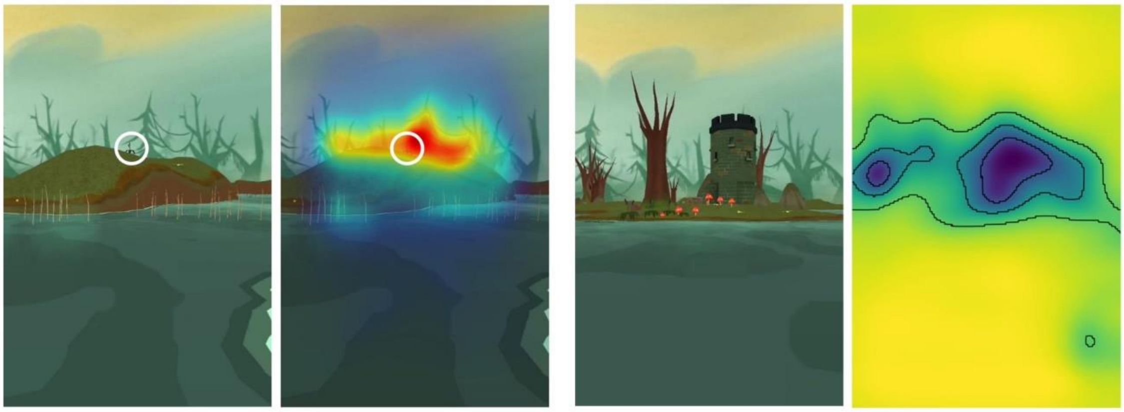


Figure 40: An example of the anomalous results from the saliency software: a. shows the image used to measure the saliency of the plant that is shown within a white circle, and b. shows the impact of the background on the Gbvs model. Because of the trees in the background, the plant is also detected as a salient object. c. shows the image used to measure the saliency of toadstools, and d. shows the impact of the castle on the DeepGaze II model. Objects around the castle, the toadstools and stones, are also detected as salient.

A second limitation is that saliency models were tested with only images rather than dynamic scenes due to the nature of the algorithms. Even though they were sufficient to explain an image and the saliency of objects in that image, they were unable to explain people's choices in dynamic scenes. Hence, new models could be developed that could analyse videos rather than static images to better understand and measure the saliency of objects. Recently, video saliency detection has attracted the attention of researchers, since image-based detection depends on the calculation of low-level features, which change dramatically in video scenes, and as videos need more attention to extract saliency information between consecutive frames (Bi et al., 2019). Hence, video saliency detection (Bi et al., 2019; Li et al., 2019; Leifman et al., 2017) as well as saliency in virtual reality (Sitzmann et al., 2018) has been studied by different researchers. More research is needed to detect salient objects and, as a next step, one of the video-based saliency detection models can be used to see if it is sufficient to explain people's choices.

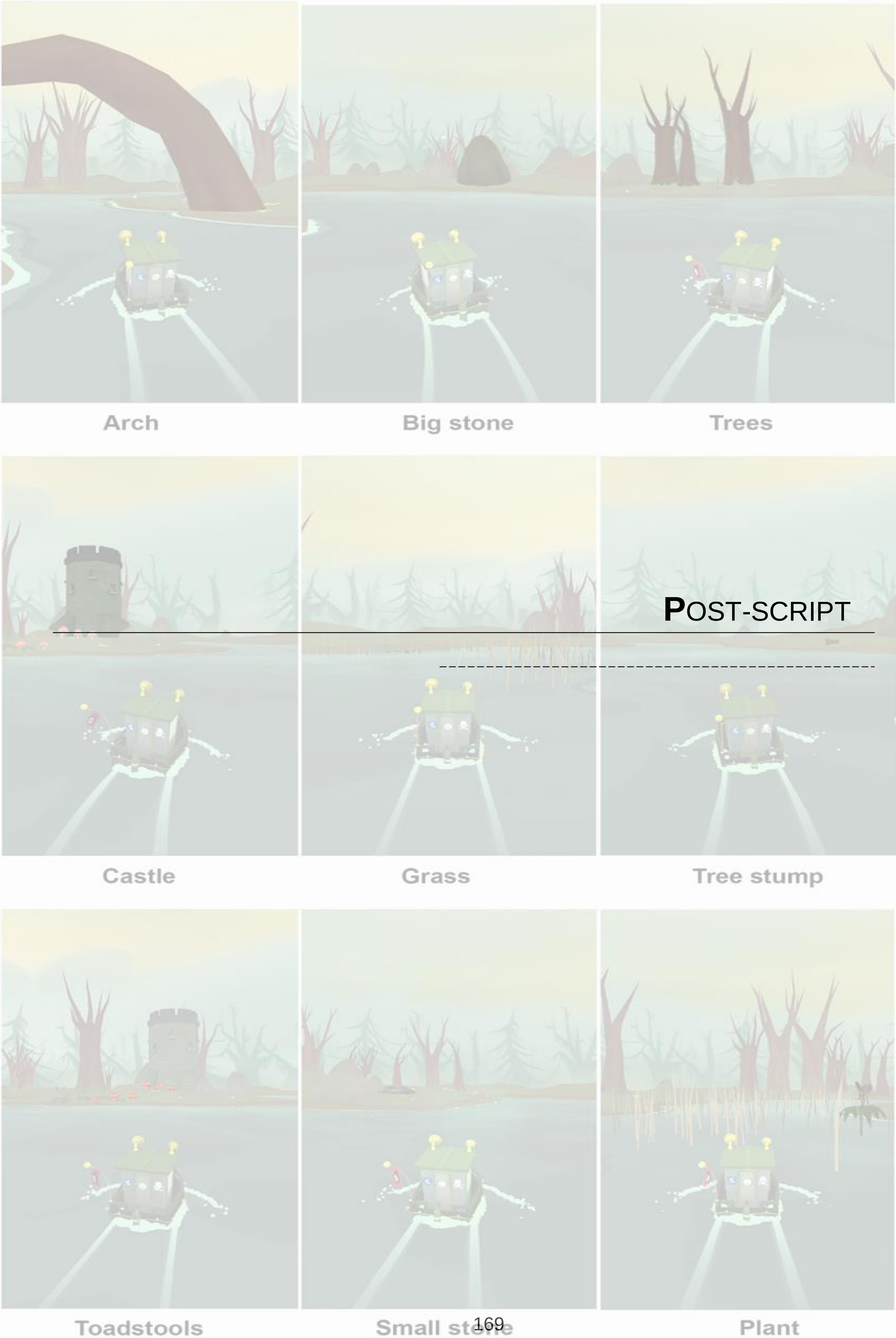
8.6 Future research directions and applications

Further work can be conducted to better study landmarks. First, a limited number of studies have explored the relationship between automatic saliency detection tools and wayfinding. In this study, two popular image-based detection tools were used. Future studies can use video-based saliency detection tools (Bi et al., 2019; Li et al., 2019; Leifman et al., 2017) or saliency tools that use virtual reality (Sitzmann et al., 2018), and compare these results with people's saliency evaluations. The relationship between people's saliency evaluations and the algorithms may be significant using different tools. Or, if the image-based algorithms are improved considering the suggestions here, they could also be tested.

In addition, mobile-based saliency systems are another important topic that can be elaborated on further. Previous studies have stated various challenges to the effective use of landmarks by navigation services (Richter, 2013). This research discussed how salient landmarks can be identified and which measures can be used. Future research on mobile-based systems, therefore, can use the criteria mentioned here and adapt them to an application. It would be interesting to see whether or not their findings support the results of this research. In addition, it was observed that the location of landmarks and the context are also important in saliency evaluation. Future studies can be conducted using different environments and structurally salient and less salient landmarks. In this respect, the orientation of landmarks along a route might be another key issue that can be explored. If a landmark has different façades from different perspectives, then people's evaluations would also be affected. Hence, future studies can focus on the impact of landmark orientation on saliency, in addition to the other components. It was also stated that eye tracking can be used in wayfinding studies and to detect landmarks. Hence, more studies can be performed and eye tracking data can be used to explore visual saliency.

In this study, a threshold was also defined to detect global landmarks. This threshold can be used in future studies in both real and virtual environments, and global and local landmarks can be defined accordingly. Then, it would be possible to examine the impact of both types of landmarks on wayfinding.

Finally, in the reviews (Chapter 3), it was observed that people's landmark selection is related to their familiarity with the environment and is affected by the given task and the layout of the environment, such as grid or organic format. Hence, further research can be conducted with people who are familiar and unfamiliar with an environment, or using different tasks (e.g. wayfinding, route description) and environments. This would help researchers to examine the impact of these different factors in detail.


Arch
Big stone
Trees
Castle
Grass
Tree stump
Toadstools
Small stone
Plant

POST-SCRIPT

This thesis contributes to the wayfinding and landmark literature and practice in various ways, as explained in the previous chapters. In a broader sense, the impacts of dementia were discussed in the Preface, indicating that it is even more crucial to create environments where everybody can find their way easily, including people with dementia. This research, hopefully, will not only give insights to studies about architecture and the built environment, but it will also contribute to research related to dementia. Here, an overall picture has been drawn of how people find their way in environments and what makes it harder and easier to way-find. Different environments can be created using the metrics here, and they can be tested by analysing the performance of healthy people and people with dementia, for instance. Alternatively, by using clusters of levels, as suggested in this study, different levels of SHQ with different complexity can be selected and used in dementia-related studies. There are several alternative ways to adapt this study to dementia-related research. It is hoped that these will be investigated by the researchers and a connection will be made, and that, by doing this, dementia will also be better understood. Furthermore, it is hoped that environments will be created in the future where both healthy people and people with diseases that cause confusion in orientation and make it harder to way-find, can find their way more easily.

REFERENCES

Adachi, P.J.C. & Willoughby, T. (2013) More than just fun and games: the longitudinal relationships between strategic video games, self-reported problem solving skills, and academic grades. *Journal of Youth and Adolescence*. 42 (7), 1041–1052.

Afrooz, A., White, D. & Parolin, B. (2018) Effects of active and passive exploration of the built environment on memory during wayfinding. *Applied Geography*. 10168–74.

Aginsky, V., Harris, C., Rensink, R. & Beusmans, J. (1997) Two strategies for learning a route in a driving simulator. *Journal of Environmental Psychology*. 17 (4), 317–331.

Al-Sayed, K., Turner, A., Hillier, B., Iida, S. & Penn, A. (2014) *Space syntax methodology*. 4th Editio. London: Bartlett School of Architecture, UCL.

Albrecht, R. & Von Stülpnagel, R. (2018) 'Memory for Salient Landmarks: Empirical Findings and a Cognitive Model', in Sarah Creem-Regehr, Johannes Schöning, & Alexander Klippel (eds.) *Spatial Cognition XI*. [Online]. 2018 Cham: Springer International Publishing. pp. 311–325.

Allen, G.L. (1999) 'Spatial abilities, cognitive maps, and wayfinding', in Reginald G. Golledge (ed.) *Wayfinding behavior: cognitive mapping and other spatial processes*. [Online]. The Johns Hopkins University Press. pp. 46–80.

Anacta, V.J., Schwering, A. & Li, R. (2014) Determining hierarchy of landmarks in spatial descriptions. *Eighth International Conference on Geographic Information Science*.

Anderson, C.A., Shibuya, A., Ihori, N., Swing, E.L., Bushman, B.J., Sakamoto, A., Rothstein, H.R. & Saleem, M. (2010) Violent video game effects on aggression, empathy, and prosocial behavior in Eastern and Western countries: A meta-analytic review. *Psychological Bulletin*. 136 (2), 151–173.

Appleyard, D. (1970) Styles and methods of structuring a city. *Environment and Behavior*. 2100–117.

Arthur, P. & Passini, R. (1992) *Wayfinding : people, signs, and architecture*. McGraw-Hill Book Company.

Asami, Y., Kubat, A.S., Kitagawa, K. & Lida, S. (2003) 'Introducing the third dimension on Space Syntax: Application on the historical Istanbul', in *4th International Space Syntax Symposium*. [Online]. 2003 London: . p.

Batty, M. (2005) *Cities and complexity: Understanding cities with cellular automata, agent-based models, and fractals*. Cambridge, MA: The MIT Press.

Batty, M. (2001) Exploring isovist fields: Space and shape in architectural and urban morphology. *Environment and Planning B: Planning and Design*. 28 (1), 123–150.

Batty, M., Morphet, R., Masucci, P. & Stanilov, K. (2014) Entropy, complexity, and spatial information. *Journal of Geographical Systems*. 16 (4), 363–385.

Benedikt, M.L. (1979) To take hold of space: isovists and isovist fields. *Environment and Planning B: Planning and Design*. 6 (1), 47–65.

Bhatia, S., Chalup, S.K. & Ostwald, M.J. (2013) Wayfinding: a method for the empirical evaluation of structural saliency using 3D isovists. *Architectural Science Review*. 56 (3), 220–231.

Bi, H., Lu, D., Li, N., Yang, L. & Guan, H. (2019) 'Multi-Level Model for Video Saliency Detection', in *2019 IEEE International Conference on Image Processing (ICIP)*. [Online]. 2019 pp. 4654–4658.

Boeing, G. (2018) Measuring the complexity of urban form and design. *Urban Design International*. 23 (4), 281–292.

Bond, M. (2020) *Wayfinding: the art and science of how we find and lose our way*. London, United Kingdom: Picador.

Borji, A. & Itti, L. (2013) State-of-the-Art in Visual Attention Modeling. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 35 (1), 185–207.

Borst, H.C., de Vries, S.I., Graham, J.M.A., van Dongen, J.E.F., Bakker, I. & Miedema, H.M.E. (2009) Influence of environmental street characteristics on walking route choice of elderly people. *Journal of Environmental Psychology*. 29 (4), 477–484.

Bovy, P.H.L. & Stern, E. (1990) 'Elements of route choice behavior', in *Route Choice: Wayfinding in Transport Networks*. [Online]. Dordrecht: Springer Netherlands. pp. 35–122.

Bryden, K.J., Charlton, J.L., Oxley, J.A. & Lowndes, G.J. (2013) Self-reported wayfinding ability of older drivers. *Accident Analysis & Prevention*. 59277–282.

Burnett, G., Smith, D. & May, A. (2001) Supporting the navigation task: characteristics of ‘good’ landmarks. *Contemporary ergonomics*. 1441–446.

Burnett, G.E. (1998) *‘Turn right at the King’s Head’ Drivers’ requirements for route guidance information*. [Online]. Loughborough University, UK.

Burns, P.C. (1998) Wayfinding errors while driving. *Journal of Environmental Psychology*. 18 (2), 209–217.

Caduff, D. & Timpf, S. (2008) On the assessment of landmark salience for human navigation. *Cognitive Processing*. 9 (4), 249–267.

Cambridge Dictionary Online (2020) *Cambridge Dictionary Online*. [Online] [online]. Available from: https://dictionary.cambridge.org/tr/sözlük/ingilizce/dead-end (Accessed 2 March 2020).

Carlson, L.A., Hölscher, C., Shipley, T.F. & Conroy Dalton, R. (2010) Getting lost in buildings. *Current Directions in Psychological Science*. 19 (5), 284–289.

Casakin, H., Barkowsky, T., Klippel, A. & Freksa, C. (2007) 'Schematic maps as wayfinding aids', in *Spatial Cognition II*. [Online]. Springer Berlin Heidelberg. pp. 54–71.

Castelli, L., Latini Corazzini, L. & Geminiani, G.C. (2008) Spatial navigation in large-scale virtual environments: gender differences in survey tasks. *Computers in Human Behavior*. 24 (4), 1643–1667.

Chan, E., Baumann, O., Bellgrove, M. & Mattingley, J. (2012) From objects to landmarks: the function of visual location information in spatial navigation. *Frontiers in Psychology*. 3304.

Cheng, S.-Y. (2009) *Suburban landmarks in north arlington: perceptions of experts and non-experts*. [Online]. The University of Texas at Arlington.

Chrastil, E.R. & Warren, W.H. (2012) Active and passive contributions to spatial learning. *Psychonomic Bulletin {&} Review*. 19 (1), 1–23.

Chrastil, E.R. & Warren, W.H. (2013) Active and passive spatial learning in human navigation: Acquisition of survey knowledge. *Journal of experimental psychology: learning, memory, and cognition*. 39 (5), 1520–1537.

Claessen, M.H.G., Visser-Meily, J.M.A., De Rooij, N.K., Postma, A. & Van Der Ham, I.J.M. (2016) A direct comparison of real-world and virtual navigation performance in chronic stroke patients. *Journal of the International Neuropsychological Society*. 22 (4), 467–477.

Claramunt, C. & Winter, S. (2007) Structural salience of elements of the city. *Environment and Planning B: Planning and Design*. 34 (6), 1030–1050.

Cliburn, D., Winlock, T., Rilea, S. & Van Donsel, M. (2007) 'Dynamic landmark placement as a navigation aid in virtual worlds', in ACM (ed.) *Proceedings of the 2007 ACM symposium on Virtual reality software and technology - VRST '07*.

[Online]. 2007 pp. 211–214.

Conroy Dalton, R. (2003) The secret is to follow your nose: route path selection and angularity. *Environment and Behavior*. 35 (1), 107–131.

Conroy, R. (2001) *Spatial navigation in immersive virtual environments*. [Online]. University College London.

Couclelis, H., Golledge, R.G., Gale, N. & Tobler, W. (1987) Exploring the anchor-point hypothesis of spatial cognition. *Journal of Environmental Psychology*. 7 (2), 99–122.

Coutrot, A., Manley, E., Yesiltepe, D., Dalton, R.C., Wiener, J.M., Hölscher, C., Hornberger, M. & Spiers, H.J. (2020) Cities have a negative impact on navigation ability: evidence from 38 countries. *bioRxiv*.

Coutrot, A., Schmidt, S., Coutrot, L., Pittman, J., Hong, L., Wiener, J.M., Holscher, C., Dalton, R.C., Hornberger, M. & Spiers, H.J. (2018) Virtual navigation tested on a mobile app is predictive of real-world navigation performance. *bioRXiv*. 1–10.

Coutrot, A., Silva, R., Manley, E., de Cothi, W., Sami, S., Bohbot, V.D., Wiener, J.M., Hölscher, C., Dalton, R.C., Hornberger, M. & Spiers, H.J. (2018) Global determinants of navigation ability. *Current Biology*. 28 (17), 2861-2866.e4.

Credé, S., Thrash, T., Hölscher, C. & Fabrikant, S.I. (2019) The acquisition of survey knowledge for local and global landmark configurations under time pressure. *Spatial Cognition & Computation*. 19 (3), 190–219.

Cushman, L.A., Stein, K., Duffy, C.J., Dickson, D.W., Parisi, J.E., Crook, R., Caselli, R.J., Knopman, D.S. & Petersen, R.C. (2008) Detecting navigational deficits in cognitive aging and alzheimer disease using virtual reality. *Neurology*. 71 (12), 888–95.

Dalton, R.C. & Bafna, S. (2003) 'The syntactical image of the city: A reciprocal definition of spatial elements and spatial syntaxes', in *4th international space syntax symposium*. [Online]. 2003 p.

Daniel, M.-P. & Denis, M. (2004) The production of route directions: investigating conditions that favour conciseness in spatial discourse. *Applied Cognitive Psychology*. 18 (1), 57–75.

Darken, R.P. & Peterson, B. (2001) *Spatial orientation, wayfinding, and representation*. Stanney, K. Handbook of Virtual Environment Technology.

Darken, R.P. & Sibert, J.L. (1993) 'A toolset for navigation in virtual environments', in *Proceedings of the 6th annual ACM symposium on User interface software and* *technology - UIST '93*. [Online]. 1993 pp. 157–165.

Darken, R.P. & Sibert, J.L. (1996) 'Wayfinding strategies and behaviors in large virtual worlds', in *ACM CHI 96*. [Online]. 1996 pp. 142–149.

Davis, R., Ohman, J.M. & Weisbeck, C. (2017) Salient Cues and Wayfinding in Alzheimer's Disease Within a Virtual Senior Residence. *Environment and Behavior*. 49 (9), 1038–1065.

Denis, M. (1997) The description of routes : A cognitive approach to the production of spatial discourse. *Cahiers de psychologie cognitive*. 16 (4), 409–458.

Denis, M., Pazzaglia, F., Cornoldi, C. & Bertolo, L. (1999) Spatial discourse and navigation: an analysis of route directions in the city of Venice. *Applied Cognitive Psychology*. 13 (2), 145–174.

Devlin, A.S. & Bernstein, J. (1997) Interactive way-finding: Map style and effectiveness. *Journal of Environmental Psychology*. 17 (2), 99–110.

Dogu, U. & Erkip, F. (2000) Spatial factors affecting wayfinding and orientation: A case study in a shopping mall. *Environment and Behavior*. 32 (6), 731–755.

Douglas, D.H. & Peucker, T.K. (1973) Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. *Cartographica: The International Journal for Geographic Information and Geovisualization*. 10 (2), 112–122.

Downs, R. & Stea, D. (1973) 'Cognitive maps and spatial behavior: process and products', in Roger M Downs & David Stea (eds.) *Image and environment*. [Online]. Edward Arnold Ltd. pp. 8–26.

Downs, R.M. & Stea, D. (2011) 'Cognitive maps and spatial behavior: process and products', in *The Map Reader: Theories of Mapping Practice and Cartographic Representation*. [Online]. John Wiley & Sons. pp. 8–26.

Downs, R.M. & Stea, D. (1973) *Image and environment: Cognitive mapping and spatial behavior*. Piscataway, NJ, USA: Transaction Publishers.

Duckham, M., Winter, S. & Robinson, M. (2010) Including landmarks in routing instructions. *Journal of Location Based Services*. 4 (1), 28–52.

Ekstrom, A.D., Spiers, H.J., Bohbot, V.D. & Rosenbaum, R.S. (2018) *Human Spatial Navigation*. Princeton, New Jersey: Princeton University Press.

Elias, B. (2003) 'Extracting landmarks with data mining methods', in *International Conference on Spatial Information Theory*. [Online]. 2003 Springer Berlin Heidelberg. pp. 375–389.

Elias, B. & Brenner, C. (2005) Automatic generation and application of landmarks in navigation data sets. *Developments in Spatial Data Handling*. 469–480.

Emo, B., Hölscher, C., Wiener, J.M. & Conroy Dalton, R. (2012) 'Wayfinding and spatial configuration: evidence from street corners', in *Eighth International Space Syntax Symposium*. [Online]. 2012 Santiago de Chile: . pp. 8098:1–8089:16.

Evans, G.W., Skorpanich, M.A., Bryant, K.J. & Bresolin, B. (1984) The effects of pathway configuration, landmarks and stress on environmental cognition. *Journal of Environmental Psychology*. 4 (4), 323–335.

Farrell, M.J., Arnold, P., Pettifer, S., Adams, J., Graham, T. & MacManamon, M. (2003) Transfer of Route Learning From Virtual to Real Environments. Journal of Experimental Psychology: Applied 9 (4) p.219–227.

Field, A.P. (2009) *Discovering statistics using SPSS (and sex and drugs and rock' n' roll)*. 3rd Ediito. London: SAGE Publications.

Gardony, A., Brunyé, T.T., Mahoney, C.R. & Taylor, H.A. (2011) Affective states influence spatial cue utilization during navigation. *Presence: Teleoperators and Virtual Environments*. 20 (3), 223–240.

Gärling, T., Böök, A. & Lindberg, E. (1986) Spatial orientation and wayfinding in the designed environment: A conceptual analysis and some suggestions for postoccupancy evaluation. *Journal of Architectural and Planning Research*. 3 (1), 55–64.

Gärling, T., Lindberg, E., Carreiras, M. & Böök, A. (1986) Reference systems in cognitive maps. *Journal of Environmental Psychology*. 6 (1), 1–18.

Gaunet, F., Vidal, M., Kemeny, A. & Berthoz, A. (2001) Active, passive and snapshot exploration in a virtual environment: influence on scene memory, reorientation and path memory. *Cognitive Brain Research*. 11 (3), 409–420.

Gentile, D.A., Anderson, C.A., Yukawa, S., Ihori, N., Saleem, M., Ming, L.K., Shibuya, A., Liau, A.K., Khoo, A., Bushman, B.J., Rowell Huesmann, L. & Sakamoto, A. (2009) The effects of prosocial video games on prosocial behaviors: international evidence from correlational, longitudinal, and experimental studies. *Personality and Social Psychology Bulletin*. 35 (6), 752–763.

Gershenson, C. & Fernández, N. (2012) Complexity and information: Measuring emergence, self-organization, and homeostasis at multiple scales. *Complexity*. 18 (2), 29–44.

Goldstein, J.H., Cajko, L., Oosterbroek, M., Michielsen, M., Van Houten, O. & Salverda, F. (1997) Video games and the elderly. *Social Behavior and Personality: An* *international journal*. 25 (4), 345–352.

Golledge, R. (1999) 'Human wayfinding and cognitive maps', in *Wayfinding behavior: cognitive mapping and other spatial processes*. [Online]. Baltimore: The Johns Hopkins University Press. pp. 5–45.

Golledge, R.G. (2003) 'Human wayfinding and cognitive maps', in Marcy Rockman & James Steele (eds.) *The Colonization of Unfamiliar Landscapes*. [Online]. Routledge. pp. 25–43.

Golledge, R.G. (1992) Place recognition and wayfinding: Making sense of space. *Geoforum*. 23 (2), 199–214.

Golledge, R.G., Jacobson, R.D., Kitchin, R. & Blades, M. (2000) Cognitive maps, spatial abilities, and human wayfinding. *Geographical review of Japan, Series B*. 73 (2), 93–104.

Götze, J. & Boye, J. (2016) Learning landmark salience models from users' route instructions. *Journal of Location Based Services*. 10 (1), 47–63.

Granic, I., Lobel, A. & Engels, R.C.M.E. (2014) The benefits of playing video games. *American Psychologist*. 69 (1), 66–78.

Griffiths, M. (2002) The educational benefits of videogames. *Education and Health*. 20 (3), 47–51.

Grzeschik, R., Conroy Dalton, R., Innes, A., Shanker, S. & Wiener, J.M. (2019) The contribution of visual attention and declining verbal memory abilities to age-related route learning deficits. *Cognition*. 18750–61.

Gudmundsson, A. & Mohajeri, N. (2013) Entropy and order in urban street networks. *Scientific Reports*. 3 (1), 3324.

Hamburger, K. & Röser, F. (2014) The role of landmark modality and familiarity in human wayfinding. *Swiss Journal of Psychology*. 73 (4), 205–213.

Han, C., Jun, S. & Junling, L. (2008) Modelling and simulation wayfinding in unfamiliar campus environment. *Proceedings - 4th International Conference on Natural Computation, ICNC 2008*. 648–53.

Haq, S. & Girotto, S. (2003) 'Ability and intelligibility: Wayfinding and environmental cognition in the designed', in *4th International Space Syntax Symposium*. [Online]. 2003 London, United Kingdom: . pp. 68.1-68.20.

Haq, S., Hill, G. & Pramanik, A. (2005) 'Comparison of configurational, wayfinding and cognitive correlates in real and virtual settings', in *Proceedings of the 5th International Space Syntax Symposium*. [Online]. 2005 pp. 387–405.

Haq, S. & Zimring, C. (2003) Just down the road a piece: The development of topological knowledge of building layouts. *Environment and Behavior*. 35 (1), 132–160.

Harel, J., Koch, C. & Perona, P. (2007) 'Graph-based visual saliency', in *Advances in neural information processing systems*. [Online]. 2007 pp. 545–552.

Harnis, M., Brown, P.A. & Johnson, K.L. (2014) Cognitive technologies for wayfinding. *Assistive Technologies for Cognition*. 146–159.

Harris, M.A. & Wolbers, T. (2014) How age-related strategy switching deficits affect wayfinding in complex environments. *Neurobiology of Aging*. 35 (5), 1095–1102.

Head, D. & Isom, M. (2010) Age effects on wayfinding and route learning skills. *Behavioural Brain Research*. 209 (1), 49–58.

Hillier, B. (1996a) Cities as movement economies. *Urban Design International*. 1 (1), 41–60.

Hillier, B. (1996b) *Space is the machine: a configurational theory of architecture*. Space Syntax (ed.). London, United Kingdom: Cambridge University Press.

Hillier, B., Burdett, R., Peponis, J. & Penn, A. (1987) Creating life: or, does architecture determine anything? *Architecture et Comportement / Architecture and Behaviour*. 3 (3), 233–250.

Hillier, B. & Hanson, J. (1984) *The social logic of space*. Cambridge University Press.

Hillier, B., Hanson, J. & Peponis, J. (1987) Syntactic Analysis of Settlements.pdf. Arch. & Comport. 3 p.217–231.

Hillier, B. & Iida, S. (2005) 'Network and Psychological Effects in Urban Movement', in Anthony G Cohn & David M Mark (eds.) *Spatial Information Theory*. [Online]. 2005 Berlin, Heidelberg: Springer Berlin Heidelberg. pp. 475–490.

Hillier, B., Penn, A., Hanson, J., Grajewski, T. & Xu, J. (1993) Natural movement: or, configuration and attraction in urban pedestrian movement. *Environment and Planning B: Planning and Design*. 20 (1), 29–66.

Hillier, B. & Stonor, T. (2010) *Space Syntax-Strategic Urban Design*.

Hillier, B. & Tzortzi, K. (2006) 'Space syntax: the language of museum space', in Sharon Macdonald (ed.) *A companion to museum studies*. [Online]. Malden, MA: Blackwell. pp. 282–301.

Hölscher, C., Brösamle, M. & Vrachliotis, G. (2012) Challenges in multilevel wayfinding: A case study with the space syntax technique. *Environment and Planning B: Planning and Design*. 39 (1), 63–82.

Hölscher, C. & Dalton, R.C. (2008) 'Comprehension of layout complexity: Effects of architectural expertise and mode of presentation', in John S Gero & Ashok K Goel (eds.) *Design Computing and Cognition'08*. [Online]. 2008 Dordrecht: Springer Netherlands. pp. 159–178.

Hölscher, C., Meilinger, T., Vrachliotis, G., Brösamle, M. & Knauff, M. (2006) Up the down staircase: Wayfinding strategies in multi-level buildings. *Journal of Environmental Psychology*. 26 (4), 284–299.

Hunt, E. & Waller, D. (1999) *Orientation and wayfinding: a review*.

Hurlebaus, R., Basten, K., Mallot, H.A. & Wiener, J.M. (2008) 'Route learning strategies in a virtual cluttered environment', in *Spatial Cognition VI. Learning, Reasoning, and Talking about Space*. [Online]. 2008 Berlin, Heidelberg: Springer. pp. 104–120.

Hyde, M., Scott-Slade, M., Scott-Slade, H., Hornberger, M., Spiers, H., Dalton, R., Hoelscher, C., Wiener, J. & Bohbot, V. (2016) *Sea Hero Quest: the World's first mobile game where anyone can help scientists fight dementia*.

Institute of Highways & Transportation (2000) *Guidelines for providing for journeys on foot*.

Ishikawa, T. & Montello, D.R. (2006) Spatial knowledge acquisition from direct experience in the environment: Individual differences in the development of metric knowledge and the integration of separately learned places. *Cognitive Psychology*. 52 (2), 93–129.

Ishikawa, T. & Nakamura, U. (2012) Landmark selection in the environment: relationships with object characteristics and sense of direction. *Spatial Cognition & Computation*. 12 (1), 1–22.

Itti, L. (2005) Quantifying the contribution of low-level saliency to human eye movements in dynamic scenes. *Visual Cognition*. 12 (6), 1093–1123.

Itti, L., Koch, C. & Niebur, E. (1998) A model of saliency-based visual attention for rapid scene analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence*. 20 (11), 1254–1259.

Jacobs, J. (1961) NULL. *The death and life of great American cities*. New York: .

Jansen-Osmann, P. & Fuchs, P. (2006) Wayfinding behavior and spatial knowledge of adults and children in a virtual environment: The role of landmarks. *Experimental Psychology*. 53 (3), 171–181.

Jansen-Osmann, P. & Wiedenbauer, G. (2004) The representation of landmarks and routes in children and adults: A study in a virtual environment. *Journal of Environmental Psychology*. 24 (3), 347–357.

Janzen, G. (2006) Memory for object location and route direction in virtual large-scale space. *Quarterly Journal of Experimental Psychology*. 59 (3), 493–508.

Jiang, B. & Claramunt, C. (2002) Integration of Space syntax into GIS: New perspectives for urban morphology. *Transactions in GIS*. 6 (3), 295–309.

Jiang, M., Huang, S., Duan, J. & Zhao, Q. (2015) 'SALICON: Saliency in Context', in *The IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*. [Online]. 2015 pp. 1072–1080.

Judd, T., Ehinger, K., Durand, F. & Torralba, A. (2009) 'Learning to predict where humans look', in *2009 IEEE 12th International Conference on Computer Vision*. [Online]. 2009 pp. 2106–2113.

Kaiser, H.F. (1961) A note on Guttman’s lower bound for the number of common factors. *Multivariate Behavioral Research*. 1249–276.

Kaplan, S. (1976) 'Adaptation, structure and knowledge.', in Gary T. Moore & Reginald G. Golledge (eds.) *Environmental knowing: Theories, research and methods*. [Online]. Stroudsburg, Penn: Downden, Hutchinson and Ross. pp. 32–45.

Kelsey, S.R. (2009) *The" what" and" where" of Landmarks: Impact on Way-finding and Spatial Knowledge*. [Online]. Carleton University.

Kiefer, P., Giannopoulos, I., Raubal, M. & Duchowski, A. (2017) Eye tracking for spatial research: Cognition, computation, challenges. *Spatial Cognition & Computation*. 17 (1–2), 1–19.

Kim, Y.O. (1999) *Spatial configuration, spatial cognition and spatial behaviour: the role of architectural intelligibility in shaping spatial experience*. [Online]. University College London.

Kim, Y.O. (2001) 'The role of spatial configuration in spatial cognition', in *3rd International Space Syntax Symposium*. [Online]. 2001 p.

Kim, Y.O. & Penn, A. (2004) Linking the spatial syntax of cognitive maps to the spatial syntax of the environment. *Environment and Behavior*. 36 (4), 483–504.

Kitchin, R.M. (1994) Cognitive maps: What are they and why study them? *Journal of Environmental Psychology*. 14 (1), 1–19.

Klippel, A. & Winter, S. (2005) 'Structural salience of landmarks for route directions', in *International Conference, COSIT*. [Online]. 2005 pp. 347–362.

Kort, Y.A.W. de, IJsselsteijn, W.A., Kooijman, J. & Schuurmans, Y. (2003) Virtual laboratories: comparability of real and virtual environments for environmental psychology. *Presence: Teleoperators and Virtual Environments*. 12 (4), 360–373.

Krukar, J. (2015) *The influence of an art gallery's spatial layout on human attention to and memory of art exhibits*. [Online]. University of Northumbria at Newcastle.

Kubat, A.S., Ozbil, A., Ozer, O. & Ekinoglu, H. (2012) 'The effect of built space on wayfinding in urban environments : a study of the historical peninsula in Istanbul', in *Eighth International Space Syntax Symposium*. [Online]. 2012 pp. 1–20.

Kubat, A.S., Ozer, O. & Ozbil, A. (2013) 'Defining a strategical framework for urban pedestrianization projects: assessment of walkability in 3 urban squares in Istanbul', in *Proceedings of the Ninth International Space Syntax Symposium*. [Online]. 2013 Seoul, Korea: . p.

Kuipers, B. (1982) The 'Map in the Head' Metaphor. *Environment and Behavior*. 14 (2), 202–220.

Kümmerer, M., Wallis, T.S.A. & Bethge, M. (2016) DeepGaze II: Reading fixations from deep features trained on object recognition. *arXiv preprint*. 1–16.

Kümmerer, M., Wallis, T.S.A., Gatys, L.A. & Bethge, M. (2017) 'Understanding low- and high-level contributions to fixation prediction', in *The IEEE International Conference on Computer Vision (ICCV)*. [Online]. 2017 pp. 4789–4798.

Land, M. & Tatler, B. (2009) *Looking and acting: Vision and eye movements in natural behaviour*. Oxford: Oxford University Press.

Law, S., Chiaradia, A. & Schwander, C. (2012) 'Towards a multi-modal space syntax analysis. A case study of the London street and underground network', in *8th International Space Syntax Symposium*. [Online]. 2012 Chile: . pp. 8021-1-8021–20.

Lazem, S.Y. & Sheta, W.M. (2005) 'Automatic landmark identification in large virtual environment: A spatial data mining approach', in *Proceedings of the International Conference on Information Visualisation*. [Online]. 2005 IEEE. pp. 752–757.

Leifman, G., Rudoy, D., Swedish, T., Bayro-Corrochano, E. & Raskar, R. (2017) 'Learning Gaze Transitions from Depth to Improve Video Saliency Estimation', in *2017 IEEE International Conference on Computer Vision (ICCV)*. [Online]. 2017 pp. 1707–1716.

Leiser, D. & Zilbershatz, A. (1989) The traveller: A computational model of spatial network learning. *Environment and Behavior*. 21 (4), 435–463.

Li, H., Chen, G., Li, G. & Yu, Y. (2019) Motion Guided Attention for Video Salient

Object Detection. *arXiv*. arXiv:1909.07061.

Li, H., Corey, R.R., Giudice, U. & Giudice, N.A. (2016) 'Assessment of visualization interfaces for assisting the development of multi-level cognitive maps', in Dylan D Schmorrow & Cali M Fidopiastis (eds.) *Proceedings, part II, of the 10th international conference on foundations of augmented cognition: Neuroergonomics and operational neuroscience*. [Online]. Cham: Springer International Publishing. pp. 308–321.

Li, R., Fuest, S. & Schwering, A. (2014) 'The effects of different verbal route instructions on spatial orientation', in *The 17th AGILE Conference on Geographic Information Science*. [Online]. 2014 p.

Li, R. & Klippel, A. (2010) 'Using space syntax to understand knowledge acquisition and wayfinding in indoor environments', in *9th IEEE International Conference on Cognitive Informatics (ICCI'10)*. [Online]. 2010 pp. 302–307.

Li, R. & Klippel, A. (2012) Wayfinding in libraries: can problems be predicted? *Journal of Map & Geography Libraries*. 8 (1), 21–38.

Li, R., Korda, A., Radtke, M. & Schwering, A. (2014) Visualising distant off-screen landmarks on mobile devices to support spatial orientation. *Journal of Location Based Services*. 8 (3), 166–178.

Lin, C.-T., Huang, T.-Y., Lin, W.-J., Chang, S.-Y., Lin, Y.-H., Ko, L.-W., Hung, D.L. & Chang, E.C. (2012) Gender differences in wayfinding in virtual environments with global or local landmarks. *Journal of Environmental Psychology*. 32 (2), 89–96.

Lloyd, S. (2001) Measures of complexity: A nonexhaustive list. *Control Systems Magazine, IEEE*. 21 (4), 7–8.

Lobben, A., Lawrence, M. & Pickett, R. (2014) The Map Effect. *Annals of the Association of American Geographers*. 104 (1), 96–113.

Long, Y., Baran, P.K. & Moore, R. (2007) 'The role of Space Syntax in spatial cognition', in *6th International Space Syntax Symposium*. [Online]. 2007 Istanbul: . p.

Lovelace, K.L., Hegarty, M. & Montello, D.R. (1999) Elements of good route directions in familiar and unfamiliar environments. *Spatial information theory. Cognitive and computational foundations of geographic information science*. 166165–82.

Lynch, K. (1981). *[A theory of] Good city form*. Cambridge: MIT Press.

Lynch, K. (1960) *The image of the city*. MIT Press.

MacEachren, A.M. (1992) Application of environmental learning theory to spatial knowledge acquisition from maps. *Annals of the Association of American Geographers*. 82 (2), 245–274.

Mandler, J.M. (1998) 'Representation.', in John Wiley & Sons Inc. (ed.) *Handbook of child psychology: Vol. 2. Cognition, perception, and language*. [Online]. Hoboken, New Jersey: . pp. 255–308.

Marín-Morales, J., Higuera-Trujillo, J.L., De-Juan-Ripoll, C., Llinares, C., Guixeres, J., Iñarra, S. & Alcañiz, M. (2019) Navigation comparison between a real and a virtual museum: time-dependent differences using a head mounted display. *Interacting with Computers*.

Marquardt, G. (2011) Wayfinding for People with Dementia: A Review of the Role of Architectural Design. *HERD: Health Environments Research & Design Journal*. 4 (2), 75–90.

Marquardt, G. & Schmieg, P. (2009) Dementia-Friendly Architecture: Environments That Facilitate Wayfinding in Nursing Homes. *American Journal of Alzheimer's Disease & Other Dementias®*. 24 (4), 333–340.

Marshall, S. (2004) *Urban pattern specification*.

Matthews, J.W. & Turnbull, G.K. (2007) Neighborhood Street Layout and Property Value: The Interaction of Accessibility and Land Use Mix. *The Journal of Real Estate Finance and Economics*. 35 (2), 111–141.

Mazuryk, T. & Gervautz, M. (1999) *Virtual reality - history, applications, technology and future*.

Meilinger, T., Riecke, B.E. & Bülthoff, H.H. (2014) Local and global reference frames for environmental spaces. *Quarterly Journal of Experimental Psychology*. 67 (3), 542–569.

Meilinger, T., Schulte-Pelkum, J., Frankenstein, J., Berger, D. & Bülthoff, H.H. (2015) 'Global landmarks do not necessarily improve spatial performance in addition to bodily self-movement cues when learning a large-scale virtual environment', in M Imura, P Figueroa, & B Mohler (eds.) *International Conference on Artificial Reality and Telexistence Eurographics Symposium on Virtual Environments*. [Online]. 2015 p.

Michon, P.-E. & Denis, M. (2001) 'When and why are visual landmarks used in giving directions?', in Daniel R Montello (ed.) *Spatial Information Theory*. [Online]. 2001 Berlin, Heidelberg: Springer Berlin Heidelberg. pp. 292–305.

Miller, J. & Carlson, L. (2011) Selecting landmarks in novel environments. *Psychonomic Bulletin and Review*. 18 (1), 184–191.

Mitchell, E. (1985) The dynamics of family interaction around home video games. *Marriage & Family Review*. 8 (1–2), 121–135.

Monacelli, A.M., Cushman, L.A., Kavcic, V. & Duffy, C.J. (2003) Spatial disorientation in Alzheimer’s disease. *Neurology*. 61 (11), 1491–1497.

Montello, D., Waller, D., Hegarty, M. & Richardson, A. (2004) Spatial memory of real environments, virtual environments, and maps. *Human spatial memory: Remembering where*. 251–285.

Montello, D.R. (1998) 'A new framework for understanding thr acquisition of spatial knowledge in large-scale environments', in M. J. Egenhofer & R. G. Golledge (ed.) *Spatial and Temporal Reasoning in Geographic Information Systems*. [Online]. New York: Oxford University Press. pp. 143–154.

Montello, D.R. (2005) 'Navigation', in *The Cambridge Handbook of visuospatial thinking*. [Online]. New York: Cambridge University Press. pp. 257–294.

Montello, D.R. (1993) 'Scale and multiple psychologies of space', in Andrew U Frank & Irene Campari (eds.) *Spatial Information Theory A Theoretical Basis for GIS*. [Online]. 1993 Berlin: Springer Berlin Heidelberg. pp. 312–321.

Montello, D.R. (2001) Spatial cognition. International Encyclopedia of the Social and Behavioral Sciences p.14771–14775.

Montello, D.R. (2007) 'The contribution of space syntax to a comprehensive theory of environmental psychology.', in *6th International Space Syntax Symposium*. [Online]. 2007 Istanbul: . p.

Montello, D.R. & Sas, C. (2006) Human factors of wayfinding in navigation. International encyclopedia of ergonomics and human factors p.2003–2008.

Münzer, S. & Stahl, C. (2007) 'Providing individual route instructions for indoor wayfinding in complex, multi-level buildings', in *GI-Days 2007 Young Researchers Forum*. [Online]. 2007 pp. 241–246.

Nothegger, C., Winter, S. & Raubal, M. (2004) Selection of salient features for route directions. *Spatial Cognition and Computation*. 4 (2), 113–136.

Nuhn, E. & Timpf, S. (2018) 'An overall framework for personalised landmark selection', in Peter Kiefer, Haosheng Huang, Nico Van de Weghe, & Martin Raubal (eds.) *LBS 2018: 14th International Conference on Location Based Services*. [Online]. 2018 Cham: Springer International Publishing. pp. 231–253.

Nuhn, E. & Timpf, S. (2017) 'Personal dimensions of landmarks', in Arnold Bregt, Tapani Sarjakoski, Ron van Lammeren, & Frans Rip (eds.) *The Annual*

International Conference on Geographic Information Science. [Online]. 2017 Cham: Springer International Publishing. pp. 129–143.

O'Neill, M.J. (1991a) Effects of signage and floor plan configuration on wayfinding accuracy. *Environment and Behavior*. 23 (5), 553–574.

O'Neill, M.J. (1991b) Evaluation of a conceptual model of architectural legibility. *Environment and Behavior*. 23 (3), 259–284.

O'Sullivan, D. & Turner, A. (2001) Visibility graphs and landscape visibility analysis. *International Journal of Geographical Information Science*. 15 (3), 221–237.

Ozbil, A., Argin, G. & Yesiltepe, D. (2016) Pedestrian route choice by elementary school students: the role of street network configuration and pedestrian quality attributes in walking to school. *International Journal of Design Creativity and Innovation*. 4 (2), 67–84.

Ozbil, A., Yesiltepe, D. & Argin, G. (2015) Modeling walkability: the effects of street design, street-network configuration and land-use on pedestrian movement. *A| Z ITU Journal of the Faculty of Architecture*. 12 (3), 189–207.

Pagkalinawan, H. (2019) 'Measuring the Street Layout Orientation Entropy of Cities in the Philippines', in *Abstracts of the ICA*. [Online]. July 2019 p. 285.

Passini, R. (1984a) Spatial representations, a wayfinding perspective. *Journal of Environmental Psychology*. 4 (2), 153–164.

Passini, R. (1984b) *Wayfinding in architecture*. P. Richard & AICP Dober (eds.). New York: Van Nostrand Reinhold Company Inc.

Passini, R., Rainville, C., Marchand, N. & Joanette, Y. (1998) Wayfinding and dementia: Some research findings and a new look at design. *Journal of Architectural and Planning Research*. 15 (2), 133–151.

Passini, R., Rainville, C., Marchand, N. & Joanette, Y. (1995) Wayfinding in dementia of the Alzheimer type: Planning abilities. *Journal of Clinical and Experimental Neuropsychology*. 17 (6), 820–832.

Penn, A., Hillier, B., Banister, D. & Xu, J. (1998) Configurational modelling of urban movement networks. *Environment and Planning B: Planning and Design*. 25 (1), 59–84.

Peponis, J., Allen, D., French, S. & Scoppa, MartinBrown, J. (2007) 'Street connectivity and urban density: spatial measures and their correlation', in *Proceedings of the 6th International Space Syntax Symposium*. [Online]. 2007 İstanbul: . p.

Peponis, J., Bafna, S. & Zhang, Z. (2008) The connectivity of streets: reach and directional distance. *Environment and Planning B: Planning and Design*. 35 (5), 881–901.

Peponis, J., Wineman, J., Rashid, M., Bafna, S. & Kim, S.H. (1998) Describing plan configuration according to the covisibility of surfaces. *Environment and Planning B: Planning and Design*. 25 (5), 693–708.

Peponis, J., Zimring, C. & Choi, Y.K. (1990) Finding the building in wayfinding. *Environment and Behavior*. 22 (5), 555–590.

Peruch, P., Vercher, J.-L. & Gauthier, G.M. (1995) Acquisition of Spatial Knowledge Through Visual Exploration of Simulated Environments. *Ecological Psychology*. 7 (1), 1–20.

Peters, D., Wu, Y. & Winter, S. (2010) 'Testing landmark identification theories in virtual environments', in Christoph Hölscher, Thomas F Shipley, Marta Olivetti Belardinelli, John A Bateman, & Nora S Newcombe (eds.) *Spatial Cognition VII*. [Online]. 2010 Berlin, Heidelberg: Springer Berlin Heidelberg. pp. 54–69.

Philbeck, J.W. & O'Leary, S. (2005) Remembered landmarks enhance the precision of path integration. *Psicologica*. 26 (1), 7–24.

Porter, B. (2016) *Sea Hero – Gaming and citizen science to fight dementia*. [Online] [online]. Available from: https://www.blakeporterneuro.com/sea-hero-gaming-and-citizen-science-to-fight-dementia/ (Accessed 25 September 2019).

Presson, C.C. & Montello, D.R. (1988) Points of reference in spatial cognition stalking the elusive landmark. British Journal of Developmental Psychology 6 (4) p.378–381.

Psarras, S., Fatah, A., Zarkali, A. & Hanna, S. (2019) 'Visual saliency in navigation: modelling navigational behaviour using saliency and depth analysis', in *Proceedings of 12th International Space Syntax Symposium*. [Online]. 2019 Beijing: . p.

Quesnot, T. & Roche, S. (2015a) Measure of Landmark Semantic Salience through Geosocial Data Streams. *ISPRS International Journal of Geo-Information*. 4 (1), 1–31.

Quesnot, T. & Roche, S. (2015b) 'Quantifying the significance of semantic landmarks in familiar and unfamiliar environments', in Sara Irina Fabrikant, Martin Raubal, Michela Bertolotto, Clare Davies, Scott Freundschuh, & Scott Bell (eds.) *Spatial Information Theory*. [Online]. 2015 Cham: Springer International Publishing. pp. 468–489.

Ratti, C. (2004) Space Syntax: Some Inconsistencies. *Environment and Planning B:*

Planning and Design. 31 (4), 487–499.

Raubal, M. (2008) 'Wayfinding: affordances and agent simulation', in *Encyclopedia of GIS*. [Online]. Boston, MA: Springer US. pp. 1243–1246.

Raubal, M. & Egenhofer, M.J. (1998) Comparing the complexity of wayfinding tasks in built environments. *Environment and Planning B: Planning and Design*. 25 (6), 895–913.

Raubal, M. & Winter, S. (2002) 'Enriching wayfinding instructions with local landmarks', in *International Conference on Geographic Information Science*. [Online]. 2002 Springer Berlin Heidelberg. pp. 243–259.

Richardson, A.E., Montello, D.R. & Hegarty, M. (1999) Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory & Cognition*. 27 (4), 741–750.

Richter, K.-F. (2007) 'A uniform handling of different landmark types in route directions', in Stephan Winter, Matt Duckham, Lars Kulik, & Ben Kuipers (eds.) *Proceedings of the 8th international conference on spatial information theory*. [Online]. 2007 Berlin, Heidelberg: Springer Berlin Heidelberg. pp. 373–389.

Richter, K.-F. (2009) 'Adaptable path planning in regionalized environments', in Kathleen Stewart Hornsby, Christophe Claramunt, Michel Denis, & Gérard Ligozat (eds.) *Spatial Information Theory*. [Online]. 2009 Berlin, Heidelberg: Springer Berlin Heidelberg. pp. 453–470.

Richter, K.-F. (2017) Identifying landmark candidates beyond toy examples. *KI - Künstliche Intelligenz*. 31 (2), 135–139.

Richter, K.-F. (2013) 'Prospects and challenges of landmarks in navigation services', in Martin Raubal, David M Mark, & Andrew U Frank (eds.) *Cognitive and Linguistic Aspects of Geographic Space: New Perspectives on Geographic Information Research*. [Online]. Berlin, Heidelberg: Springer Berlin Heidelberg. pp. 83–97.

Richter, K.-F. & Winter, S. (2014) *Landmarks: GIScience for intelligent services*. Cham: Springer International Publishing.

Röser, F., Hamburger, K. & Knauff, M. (2011) The Giessen virtual environment laboratory: Human wayfinding and landmark salience. *Cognitive Processing*. 12 (2), 209–214.

Röser, F., Hamburger, K., Krumnack, A. & Knauff, M. (2012) The structural salience of landmarks: Results from an on-line study and a virtual environment experiment. *Journal of Spatial Science*. 57 (1), 37–50.

Ruddle, R. a., Payne, S.J. & Jones, D.M. (1997) Navigating buildings in '"desk-top"' virtual environments: Experimental investigations using extended navigational experience. *Journal of Experimental Psychology: Applied*. 3 (2), 143–159.

Ruddle, R.A., Payne, S.J. & Jones, D.M. (1999) The effects of maps on navigation and search strategies in very-large-scale virtual environments. *Journal of Experimental Psychology Applied*. 5 (1), 54–75.

Ruddle, R.A. & Péruch, P. (2004) Effects of proprioceptive feedback and environmental characteristics on spatial learning in virtual environments. *International Journal of Human-Computer Studies*. 60 (3), 299–326.

Ruddle, R.A., Volkova, E., Mohler, B. & Bülthoff, H.H. (2011) The effect of landmark and body-based sensory information on route knowledge. *Memory & Cognition*. 39 (4), 686–699.

Sadalla, E. & Magel, S. (1980) The perception of traversed distance. *Environment and Behavior*. 12 (1), 65–79.

Sadeghian, P. & Kantardzic, M. (2008) The new generation of automatic landmark detection systems: challenges and guidelines. *Spatial Cognition & Computation*. 8 (3), 252–287.

Salingaros, N.A. & Pagliardini, P. (2016) 'Geometry and life of urban space', in *Back to the Sense of the City: International Monograph Book*. [Online]. Barcelona: Centre de Política de Sòl i Valoracions. pp. 13–32.

Schwering, A., Krukar, J., Li, R., Anacta, V.J. & Fuest, S. (2017) Wayfinding through orientation. *Spatial Cognition & Computation*. 17 (4), 273–303.

Schwering, A., Li, R. & Anacta, V.J.A. (2013) 'Orientation information in different forms of route instructions', in *Short Paper Proceedings of the 16th AGILE Conference on Geographic Information Science, Leuven, Belgium*. [Online]. 2013 Leuven, Belgium: . p.

Schwering, A., Li, R. & Anacta, V.J.A. (2014) 'The use of local and global landmarks across scales and modes of transportation in verbal route instructions', in *Poster session presented at the 2014 Spatial Cognition Conference*. [Online]. 2014 Bremen: . p.

Shannon, C.E. (1948) A mathematical theory of communication. *Bell System Technical Journal*. 27 (3), 379–423.

Shatu, F., Yigitcanlar, T. & Bunker, J. (2019) Shortest path distance vs. least directional change: Empirical testing of space syntax and geographic theories concerning pedestrian route choice behaviour. *Journal of Transport Geography*. 7437–52.

Sholl, M.J. (1996) 'From visual information to cognitive maps', in Juval Portugali (ed.) *The Construction of Cognitive Maps*. [Online]. Dordrecht: Springer Netherlands. pp. 157–186.

Siegel, A.W. & White, S.H. (1975) The development of spatial representations of large-scale environments. *Advances in Child Development and Behavior*. 109–55.

Simonyan, K. & Zisserman, A. (2014) Very deep convolutional networks for large-scale image recognition. *ICLR 2015. ArXiv*. (1409), 1–14.

Simpson, M., Richter, K.-F., Wallgrün, J.O. & Klippel, A. (2017) Quantifying space, understanding minds: A visual summary approach. *Journal of Spatial Information Science*. 14 (14), 95–136.

Sitzmann, V., Serrano, A., Pavel, A., Agrawala, M., Gutierrez, D., Masia, B. & Wetzstein, G. (2018) Saliency in VR: How Do People Explore Virtual Environments? *IEEE Transactions on Visualization and Computer Graphics*. 24 (4), 1633–1642.

Skorupka, A. (2009) 'Comparing human wayfinding behavior in real and virtual environment', in *Proceedings of the 7th International Space Syntax Symposium*. [Online]. 2009 Stockholm: KTH Royal Institute of Technology: . pp. 104:1-104:7.

Skorupka, A. (2008) Do you know your way? A mixed-method study on the use of virtual environments in wayfinding research Saif Haq, Christoph Hölscher, & Sue Torgrude (eds.). Movement and Orientation in Built Environments: Evaluating Design Rationale and User Cognition

Slone, E., Burles, F., Robinson, K., Levy, R.M. & Iaria, G. (2015) Floor plan connectivity influences wayfinding performance in virtual environments. *Environment and Behavior*. 47 (9), 1024–1053.

Soh, B.K. & Smith-Jackson, T.L. (2004) Influence of map design, individual differences, and environmental cues on wayfinding performance. *Spatial Cognition & Computation*. 4 (2), 137–165.

Solnit, R. (2006) *A field guide to getting lost*. Canongate Books.

Sorita, E., N'Kaoua, B., Larrue, F., Criquillon, J., Simion, A., Sauzéon, H., Joseph, P.A. & Mazaux, J.M. (2013) Do patients with traumatic brain injury learn a route in the same way in real and virtual environments? *Disability and Rehabilitation*. 35 (16), 1371–1379.

Sorrows, M.E. & Hirtle, S.C. (1999) 'The nature of landmarks for real and electronic spaces', in *International Conference on Spatial Information Theory*. [Online]. 1999 Springer Berlin Heidelberg. pp. 37–50.

Spiers, H., Manley, E., Silva, R., Dalton, R.C., Wiener, J., Hoelscher, C., Bohbot, V. & Hornberger, M. (2017) Population-level spatial navigation ability to detect and predict alzheimer's disease. *Alzheimer's & Dementia*. 13 (7, Supplement), P1404.

Stankiewicz, B.J. & Kalia, A.A. (2007) Acquistion of structural versus object landmark knowledge. *Journal of Experimental Psychology: Human Perception and Performance*. 33 (2), 378–390.

Steck, S.D. & Mallot, H.A. (2000) The role of global and local landmarks in virtual environment navigation. *Presence: Teleoperators and Virtual Environments*. 9 (1), 69–83.

Von Stülpnagel, R. & Frankenstein, J. (2015) Configurational salience of landmarks: an analysis of sketch maps using Space Syntax. *Cognitive Processing*. 16 (1), 437–441.

Von Stülpnagel, R., Kuliga, S., Büchner, S.J. & Hölscher, C. (2014) 'Supra-individual consistencies in navigator-driven landmark placement for spatial learning', in *Proceedings of the 36th Annual Conference of the Cognitive Science Society*. [Online]. 2014 pp. 1706–1711.

Taillade, M., Sauzéon, H., Dejos, M., Pala, P.A., Larrue, F., Wallet, G., Gross, C. & N'Kaoua, B. (2013) Executive and memory correlates of age-related differences in wayfinding performances using a virtual reality application. *Aging, Neuropsychology, and Cognition*. 20 (3), 298–319.

Tenbrink, T. (2015) Cognitive Discourse Analysis: accessing cognitive representations and processes through language data. *Language and Cognition*. 7 (1), 98–137.

Tenbrink, T., Dalton, R.C. & Williams, A.J. (2019) 'The language of architectural diagrams', in Sabine Timpf, Christoph Schlieder, Markus Kattenbeck, Bernd Ludwig, & Kathleen Stewart (eds.) *14th International Conference on Spatial Information Theory (COSIT 2019)*. Leibniz International Proceedings in Informatics (LIPIcs). [Online]. 2019 Dagstuhl, Germany: Schloss Dagstuhl--Leibniz-Zentrum fuer Informatik. pp. 17:1--17:14.

Tezuka, T. & Tanaka, K. (2005) 'Landmark extraction: A web mining approach', in Anthony G Cohn & David M Mark (eds.) *International Conference on Spatial Information Theory*. [Online]. 2005 Berlin, Heidelberg: Springer Berlin Heidelberg. pp. 379–396.

Thorndyke, P.W. & Hayes-Roth, B. (1982) Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology*. 14 (4), 560--589.

Tlauka, M. & Wilson, P.N. (1994) The effect of landmarks on route-learning in a computer-simulated environment. *Journal of Environmental Psychology*. 14 (4), 305–313.

Troffa, R. (2010) 'Visibility and wayfinding: a VR study on emergency strategies', in Drew Dara-Abrams, Christoph Hölscher, Ruth Conroy-Dalton, & Alasdair Turner (eds.) *Proceedings of the Workshop at Spatial Cognition 2010*. [Online]. 2010 Mt Hood, Oregon: . p.

Turner, A. (2000) *Angular analysis: A method for the quantification of space*.

Turner, A. (2007) From axial to road-centre lines: A new representation for space syntax and a new model of route choice for transport network analysis. *Environment and Planning B: Planning and Design*. 34 (3), 539–555.

Turner, A. (2009) 'The role of angularity in route choice', in Kathleen Stewart Hornsby, Christophe Claramunt, Michel Denis, & Gérard Ligozat (eds.) *Spatial Information Theory*. [Online]. 2009 Berlin, Heidelberg: Springer Berlin Heidelberg. pp. 489–504.

Turner, A., Doxa, M., O'Sullivan, D. & Penn, A. (2001) From isovists to visibility graphs: A methodology for the analysis of architectural space. *Environment and Planning B: Planning and Design*. 28 (1), 103–121.

Turner, A. & Friedrich, E. (2011) *Depthmap Software*.

Uc, E.Y., Rizzo, M., Anderson, S.W., Shi, Q. & Dawson, J.D. (2004) Driver route-following and safety errors in early Alzheimer disease. *Neurology*. 63 (5), 832–837.

Ujang, N., Salim, A. & Maulan, S. (2012) The influence of context and urban structure on the walkability of Bukit Bintang commercial district, Kuala Lumpur. *International Journal of Sustainable Tropical Design Research and Practice*. 5 (1), 15–26.

Varoudis, T. (2014) *Depthmap X (Computer Program)*.

Viaene, P., Ooms, K., Vansteenkiste, P., Lenoir, M. & De Maeyer, P. (2014) 'The use of eye tracking in search of indoor landmarks', in *2nd International Workshop on Eye Tracking for Spatial Research*. [Online]. 23 September 2014 Vienna, Austria: . pp. 52–56.

Waller, D., Hunt, E. & Knapp, D. (1998) The Transfer of Spatial Knowledge in Virtual Environment Training. *Presence: Teleoperators and Virtual Environments*. 7 (2), 129–143.

Waller, D. & Lippa, Y. (2007) Landmarks as beacons and associative cues: Their role in route learning. *Memory & Cognition*. 35 (5), 910–924.

Wallet, G., Sauzéon, H., Pala, P.A., Larrue, F., Zheng, X. & N'Kaoua, B. (2011) Virtual/real transfer of spatial knowledge: benefit from visual fidelity provided in a virtual environment and impact of active navigation. *Cyberpsychology, Behavior, and Social Networking*. 14 (7–8), 417–423.

Wang, Q., Ni, J. & Tenhunen, J. (2005) Application of a geographically-weighted regression analysis to estimate net primary production of Chinese forest ecosystems. *Global Ecology and Biogeography*. 14 (4), 379–393.

Weisman, J. (1981) Evaluating Architectural Legibility: Way-Finding in the Built Environment. *Environment and Behavior*. 13 (2), 189–204.

Wenczel, F., Hepperle, L. & Von Stülpnagel, R. (2017) Gaze behavior during incidental and intentional navigation in an outdoor environment. *Spatial Cognition & Computation*. 17 (1–2), 121–142.

Wiedenbauer, G. & Jansen-Osmann, P. (2006) Spatial knowledge of children with spina bifida in a virtual large-scale space. *Brain and Cognition*. 62 (2), 120–127.

Wiener, J., De Condappa, O. & Hölscher, C. (2011) 'Do you have to look where you go? Gaze behaviour during spatial decision making', in Laura Carlson, Christoph Hölscher, & Thomas F. Shipley (eds.) *Proceedings of the 33rd Annual Meeting of the Cognitive Science Society*. [Online]. 2011 Austin: Cognitive Science Society. p.

Wiener, J.M., Büchner, S.J. & Hölscher, C. (2009) Taxonomy of human wayfinding tasks: A knowledge-based approach. *Spatial Cognition and Computation*. 9 (2), 152–165.

Wiener, J.M., Hölscher, C., Büchner, S. & Konieczny, L. (2012) Gaze behavior during space perception and spatial decision making. *Psychological Research*. 76 (6), 713–729.

Wilson, P.N., Foreman, N., Gillett, R. & Stanton, D. (1997) Active versus passive processing of spatial information in a computer-simulated environment. *Ecological Psychology*. 9 (3), 207–222.

Winter, S., Raubal, M. & Nothegger, C. (2005) 'Focalizing measures of salience for wayfinding', in *Map-based Mobile Services: Theories, Methods and Implementations*. [Online]. Berlin, Heidelberg: Springer. pp. 125–139.

Winter, S., Tomko, M., Elias, B. & Sester, M. (2008) Landmark hierarchies in context. *Environment and Planning B: Planning and Design*. 35 (3), 381–398.

Wither, J., Au, C.E., Rischpater, R. & Grzeszczuk, R. (2013) 'Moving beyond the map: Automated landmark based pedestrian guidance using street level panoramas', in

Proceedings of the 15th International Conference on Human-Computer Interaction with Mobile Devices and Services. MobileHCI '13. [Online]. 2013 New York, NY, USA: Association for Computing Machinery. pp. 203–212.

Witmer, B.G., Bailey, J.H., Knerr, B.W. & Parsons, K.C. (1996) Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human Computer Studies*. 45 (4), 413–428.

Wolfensberger, M. & Richter, K.-F. (2015) 'A mobile application for a user-generated collection of landmarks', in Jérôme Gensel & Martin Tomko (eds.) *International Symposium on Web and Wireless Geographical Information Systems*. [Online]. 2015 Cham: Springer International Publishing. pp. 3–19.

World Health Organization (2019) *Dementia*. [Online] [online]. Available from: https://www.who.int/news-room/fact-sheets/detail/dementia (Accessed 6 August 2019).

Yang, Y. & Diez-Roux, A. V (2012) Walking distance by trip purpose and population subgroups. *American Journal of Preventive Medicine*. 43 (1), 11–19.

Zelinski, E.M. & Reyes, R. (2009) Cognitive benefits of computer games for older adults. *Gerontechnology : international journal on the fundamental aspects of technology to serve the ageing society*. 8 (4), 220–235.

Zetzsche, C., Schill, K., Deubel, H., Krieger, G., Umkehrer, E. & Beinlich, S. (1998) 'Investigation of a sensorimotor system for saccadic scene analysis: An integrated approach', in *Proceedings of the Fifth International Conference on Simulation of Adaptive Behavior on From Animals to Animats 5*. [Online]. 1998 Cambridge, MA, USA: MIT Press. pp. 120–126.

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APPENDIX

Table A 1: Conditions of all wayfinding levels

Level	Theme	Type	Difficulty	Landmarks	Global	Weather	Map
1	Arctic Rivers	Simple	Super Easy				Normal
2	Arctic Rivers	Simple	Super Easy	Easy	Yes	Clear	Normal
3	Arctic Rivers	Simple	Super Easy	Easy	Yes	Clear	Normal
6	Arctic Rivers	Checkpoint	Easy	Easy	Yes	Clear	Normal
7	Arctic Rivers	Checkpoint	Easy	Easy	Yes	Clear	Normal
8	Arctic Rivers	Checkpoint	Easy	Easy	Yes	Clear	Obscured
11	Arctic Rivers	Checkpoint	Easy	Easy	Yes	Clear	Normal
12	Arctic Rivers	Checkpoint	Easy	Easy	No	Fog	Normal
13	Arctic Rivers	Checkpoint	Easy	Easy	No	Clear	Normal
16	Golden Shores	Checkpoint	Easy	Easy	No	Clear	Normal
17	Golden Shores	Checkpoint	Easy	Hard	Yes	Clear	Normal
18	Golden Shores	Checkpoint	Easy	Easy	No	Clear	Obscured
21	Golden Shores	Checkpoint	Easy	Hard	No	Fog	Normal
22	Golden Shores	Checkpoint	Easy	Easy	No	Clear	Obscured
23	Golden Shores	Checkpoint	Medium	Hard	Yes	Clear	Obscured
26	Golden Shores	Checkpoint	Medium	None	Yes	Clear	Normal
27	Golden Shores	Checkpoint	Medium	Hard	No	Fog	Normal
28	Golden Shores	Checkpoint	Medium	None	Yes	Clear	Obscured
31	Mystic Marshes	Checkpoint	Medium	Easy	Yes	Clear	Normal
32	Mystic Marshes	Checkpoint	Medium	Hard	Yes	Clear	Normal
33	Mystic Marshes	Checkpoint	Medium	Hard	No	Fog	Obscured
36	Mystic Marshes	Checkpoint	Easy	Easy	No	Fog	Obscured
37	Mystic Marshes	Checkpoint	Medium	Hard	Yes	Clear	Obscured
38	Mystic Marshes	Checkpoint	Medium	Easy	No	Fog	Obscured
41	Mystic Marshes	Checkpoint	Easy	None	No	Clear	Obscured
42	Mystic Marshes	Checkpoint	Medium	Hard	No	Fog	Normal
43	Mystic Marshes	Checkpoint	Medium	None	No	Fog	Normal
46	Kano Reef	Checkpoint	Easy	Easy	Yes	Clear	Normal
47	Kano Reef	Checkpoint	Medium	Easy	No	Clear	Obscured
48	Kano Reef	Checkpoint	Hard	Easy	No	Clear	Normal
51	Kano Reef	Checkpoint	Easy	Hard	No	Clear	Obscured
52	Kano Reef	Checkpoint	Hard	Easy	No	Fog	Obscured
53	Kano Reef	Checkpoint	Hard	None	Yes	Clear	Normal
56	Kano Reef	Checkpoint	Hard	Easy	No	Clear	Normal
57	Kano Reef	Checkpoint	Hard	Hard	Yes	Clear	Normal
58	Kano Reef	Checkpoint	Hard	Easy	No	Clear	Obscured
61	High Rollers	Checkpoint	Easy	Easy	Yes	Waves	Normal
62	High Rollers	Checkpoint	Medium	Hard	Yes	Waves	Normal
63	High Rollers	Checkpoint	Medium	Hard	No	Waves	Obscured
66	High Rollers	Checkpoint	Easy	None	No	Waves	Obscured
67	High Rollers	Checkpoint	Hard	None	Yes	Waves	Normal
68	High Rollers	Checkpoint	Medium	Easy	No	Fog	Obscured
71	High Rollers	Checkpoint	Hard	Easy	No	Waves	Normal
72	High Rollers	Checkpoint	Hard	Easy	No	Fog	Normal
73	High Rollers	Checkpoint	Hard	Hard	Yes	Waves	Obscured

Figure A 1: An example of an axial map produced for all wayfinding levels

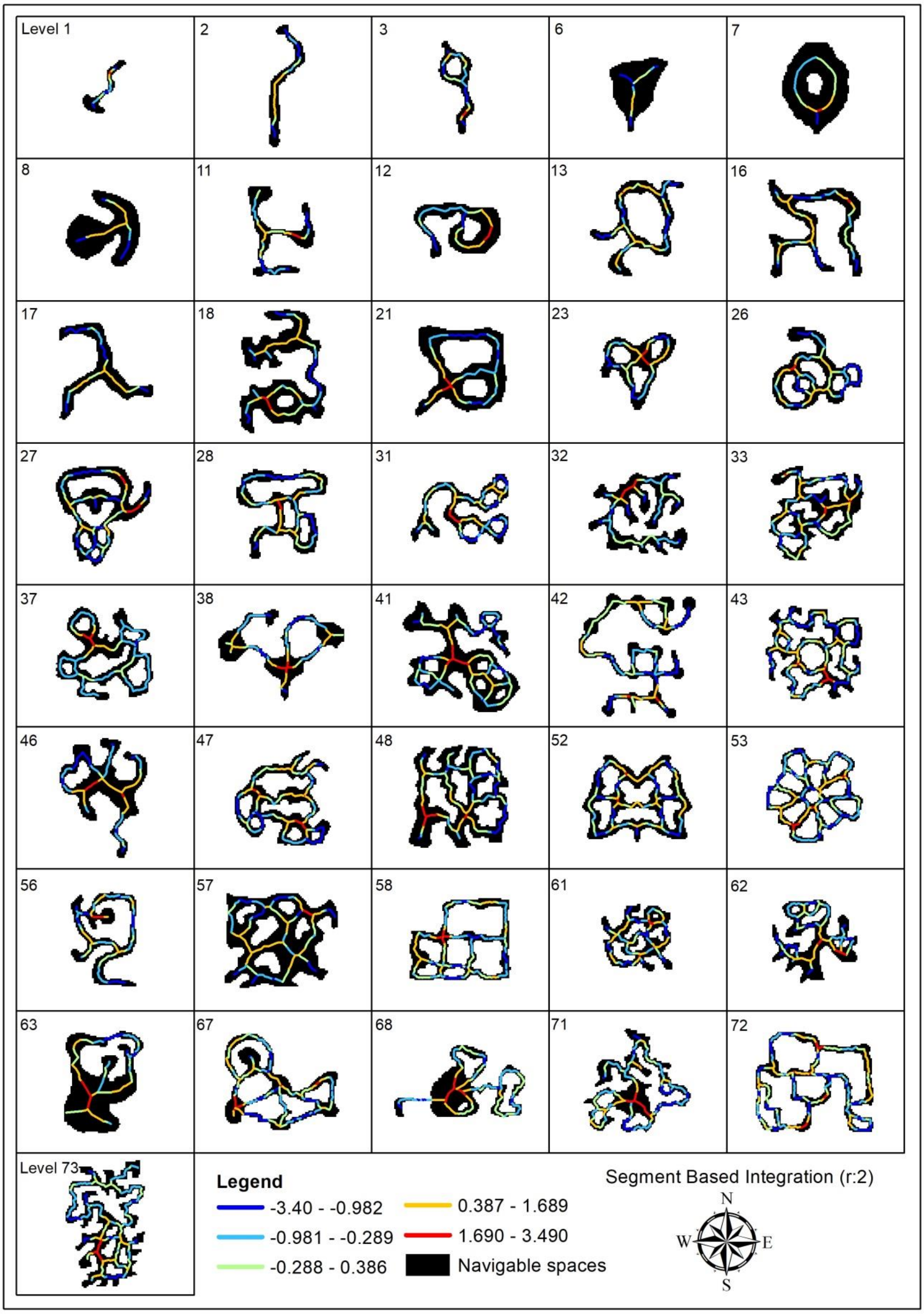


Figure A 2: An example of a segment map produced for all wayfinding levels

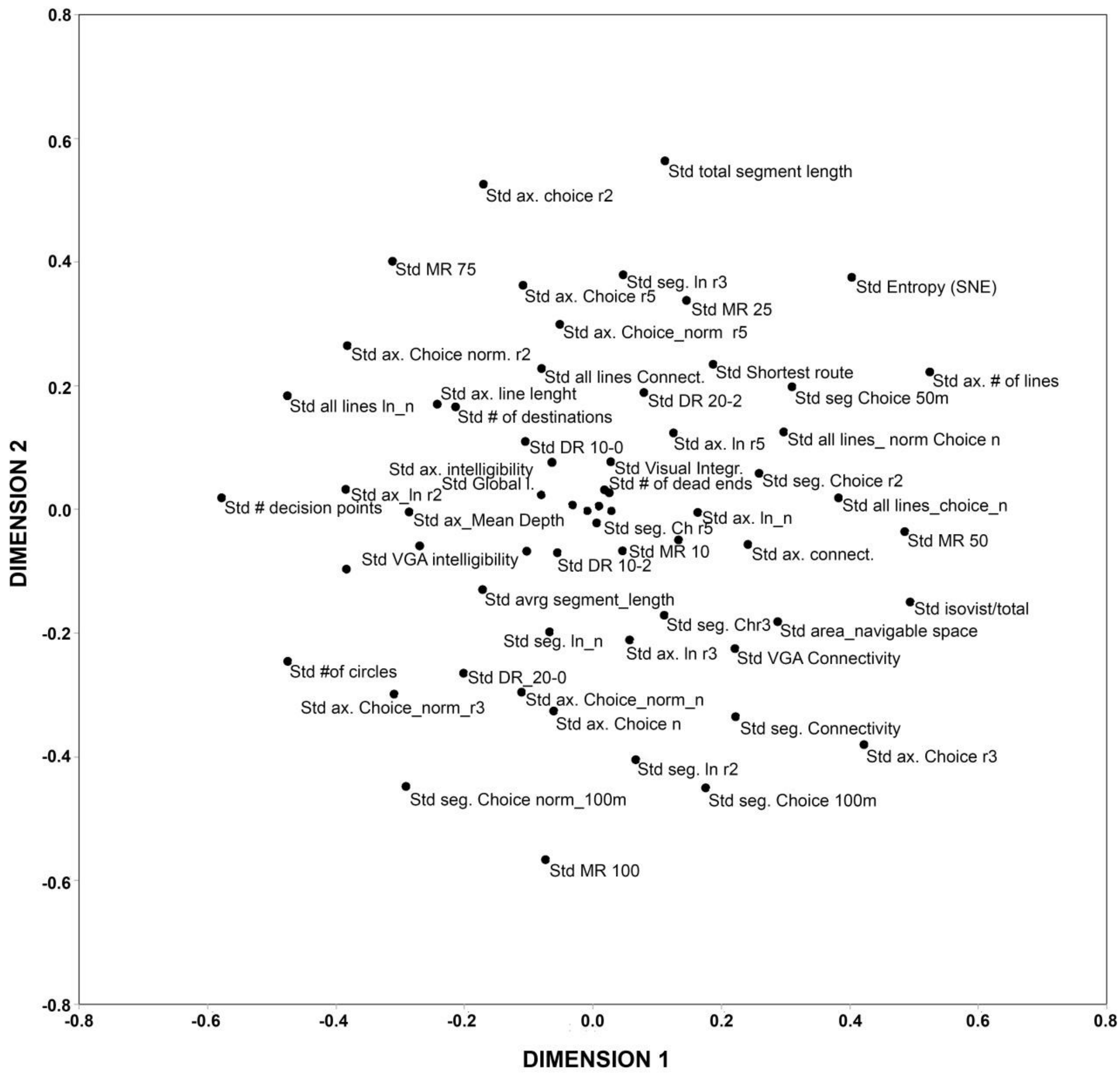


Figure A 3: Results of the two-dimensional scaling (MDS). All components in the first analysis chapter are used in this visual.

Table A 2: Instructions for the visual saliency survey study

Hi! Thank you for participating in this study. It is part of Demet Yesiltepe's PhD research at the University of Northumbria in Newcastle, UK. If you agree to take part in this study, first you will be asked some standard demographic questions. Then you will complete a questionnaire (in the next sections) in which you will be shown 2 videos and some images. You will be asked questions about the videos you are shown. The whole questionnaire should take no longer than 10 minutes.

Any responses to the questions that you give us will be held securely on password-protected computers, with data stored on a secure and encrypted server area. Anonymity will be maintained at all times.

The project has been approved by the Ethics Committee of the University of Northumbria.

If you have any questions, concerns or problems, you can contact me via email: demet.yesiltepe@northumbria.ac.uk

If you agree to participate by taking part in the study, please make sure that for the next few minutes nothing is likely to distract you from your computer.

1. I understand that my participation in this questionnaire is voluntary and that I am free to withdraw at any time without giving a reason and without detriment to myself. *
    - Yes, I understand
2. I agree to my responses being retained indefinitely for further research by the researchers related to the topic of the study. *
    - Yes, I understand
3. I understand that my data will remain confidential unless requested otherwise. *
    - Yes, I understand
4. I agree to take part in this questionnaire. *
    - Yes, I understand

*Required questions

Thank you again for participating. In this study, you will be asked to watch two videos that have been recorded in a virtual environment. In these environments, you will see a boat navigating through a canal/river. The boat will travel to a series of destinations. Please watch these videos and pay attention to the landscape through which the boat is moving.

Please follow all the steps below one by one.

Before we start, can you please answer the following questions?

5. What gender are you? (F/M/O)
6. How old are you? (Open Ended)

Experiment-I

Now you will be able to view the first video and will be asked to answer some very short questions based on this video.

Please do not move to the next page before the video ends and pay attention to the landscape through which the boat is moving.

(Video is inserted here)

Survey

In the series of questions below you will see a set of images of objects, all of which appeared somewhere in the video of the environment that you have just viewed (it does not matter if you do not recall seeing them. The video was simply to give you an idea of the environment within the objects appear). Please consider how much you think these objects might attract your attention. Choose "highly noticeable" or "noticeable" for the objects that most attract your attention "fairly unnoticeable" or "unnoticeable" for the objects that least attract your attention.

(Images are inserted here)

Experiment-II

The survey of the first video has been completed! Now, please start to view the second video and then answer the questions.

Please do not move to the next page before the video ends and pay attention to the landscape through which the boat is moving.

Please do not go back to the previous page unless you would like to change your answers for the images.

(Second video is inserted here)

Survey

In the series of questions below you will see a set of images of objects, all of which appeared somewhere in the video of the environment that you have just viewed (it does not matter if you do not recall seeing them. The video was simply to give you an idea of context). Please consider how much you think these objects might attract your attention. Choose "highly noticeable" or "noticeable" for the objects that most attract your attention "fairly unnoticeable" or "unnoticeable" for the objects that least attract your attention.

(Images are inserted here)

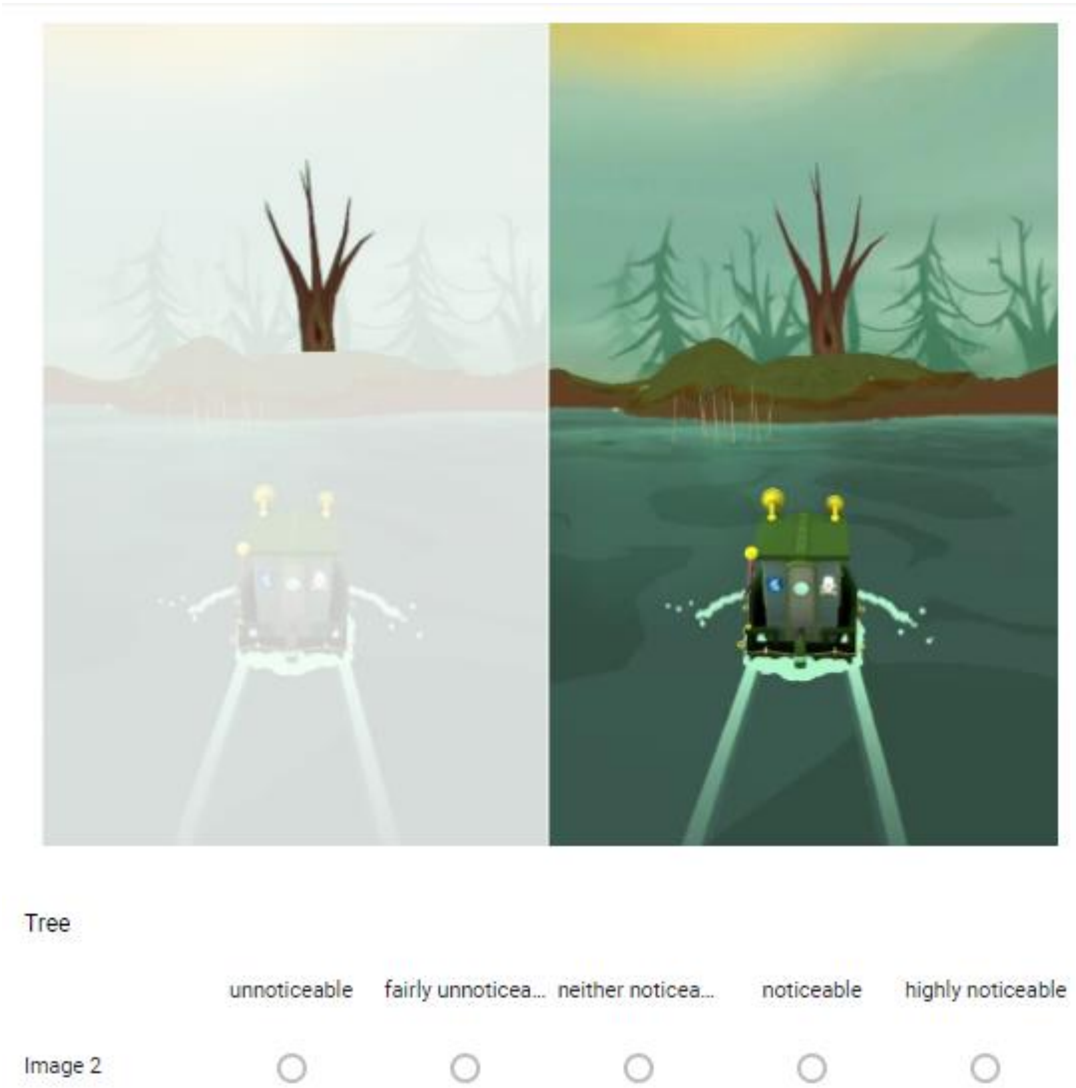


Figure A 4: A screenshot from the visual saliency survey study. On the right, participants saw the image as it was in the video, and on the left, they saw the mentioned landmark with a transparent background. Participants were then asked to choose an option that represents the landmark (5-point Likert scale).

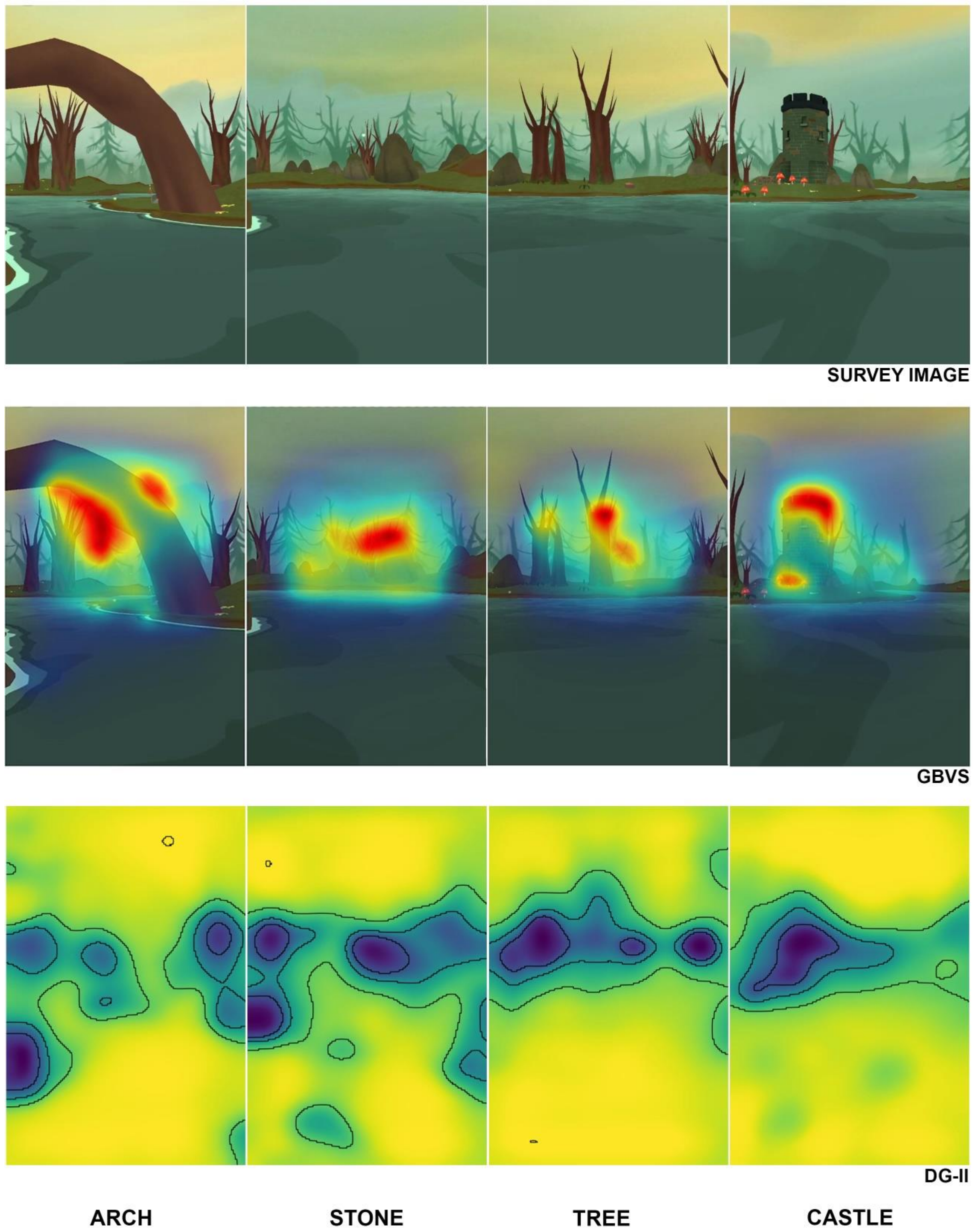


Figure A 5: Results of the Gbvs and DeepGaze II algorithms for level 31

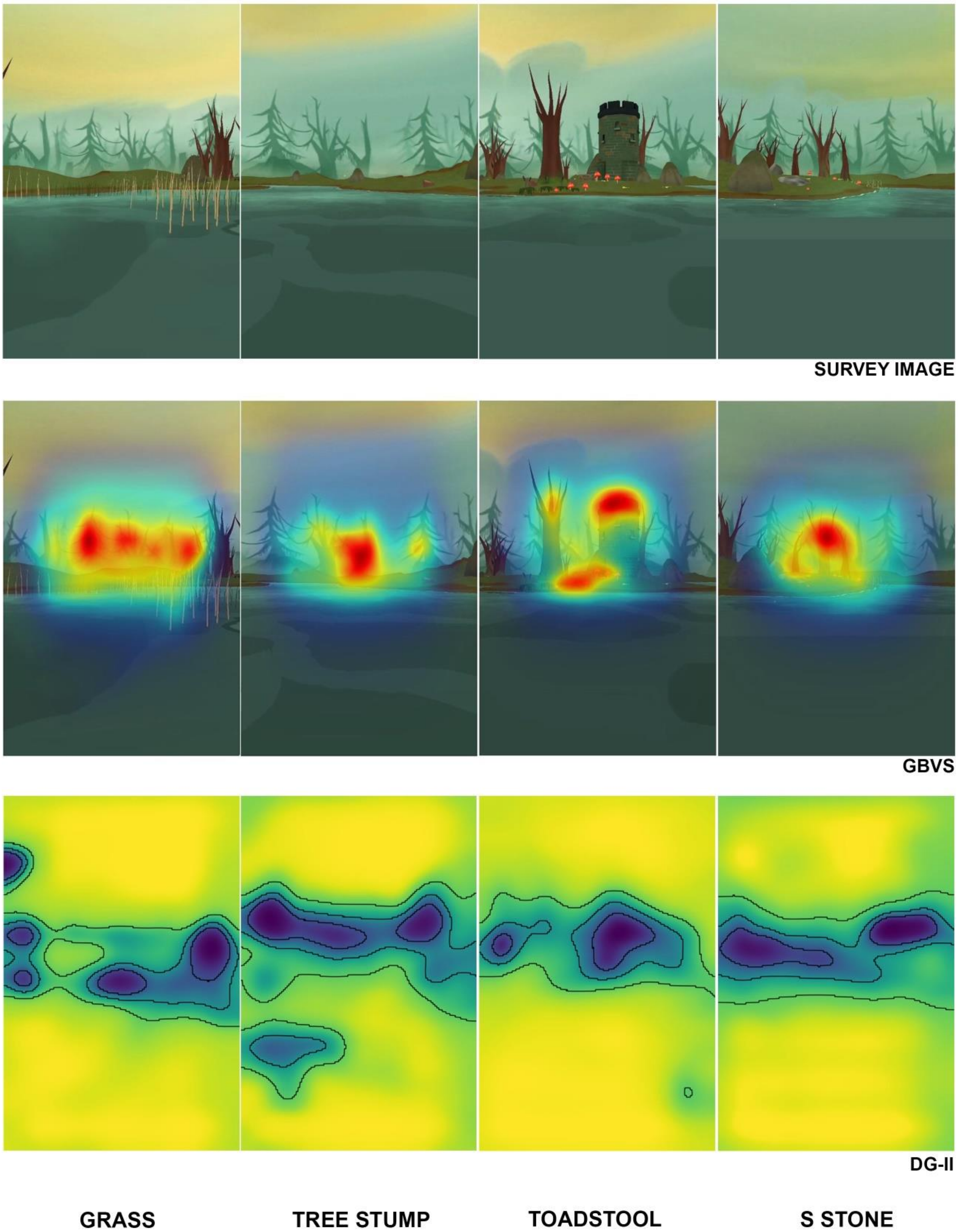


Figure A 6: Results of the Gbvs and DeepGaze II algorithms for level 31

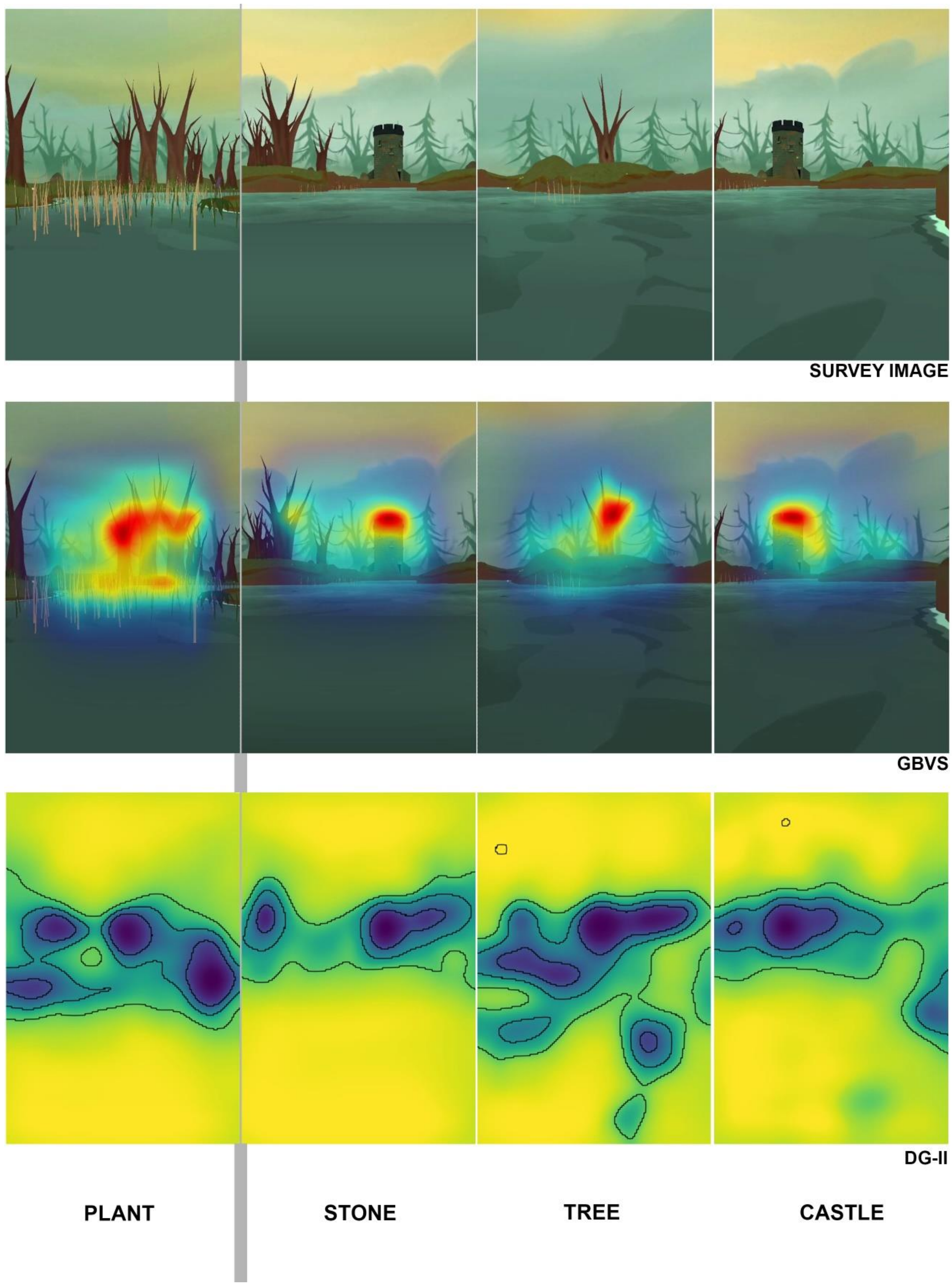


Figure A 7: Results of the Gbvs and DeepGaze II algorithms for levels 31 and 32

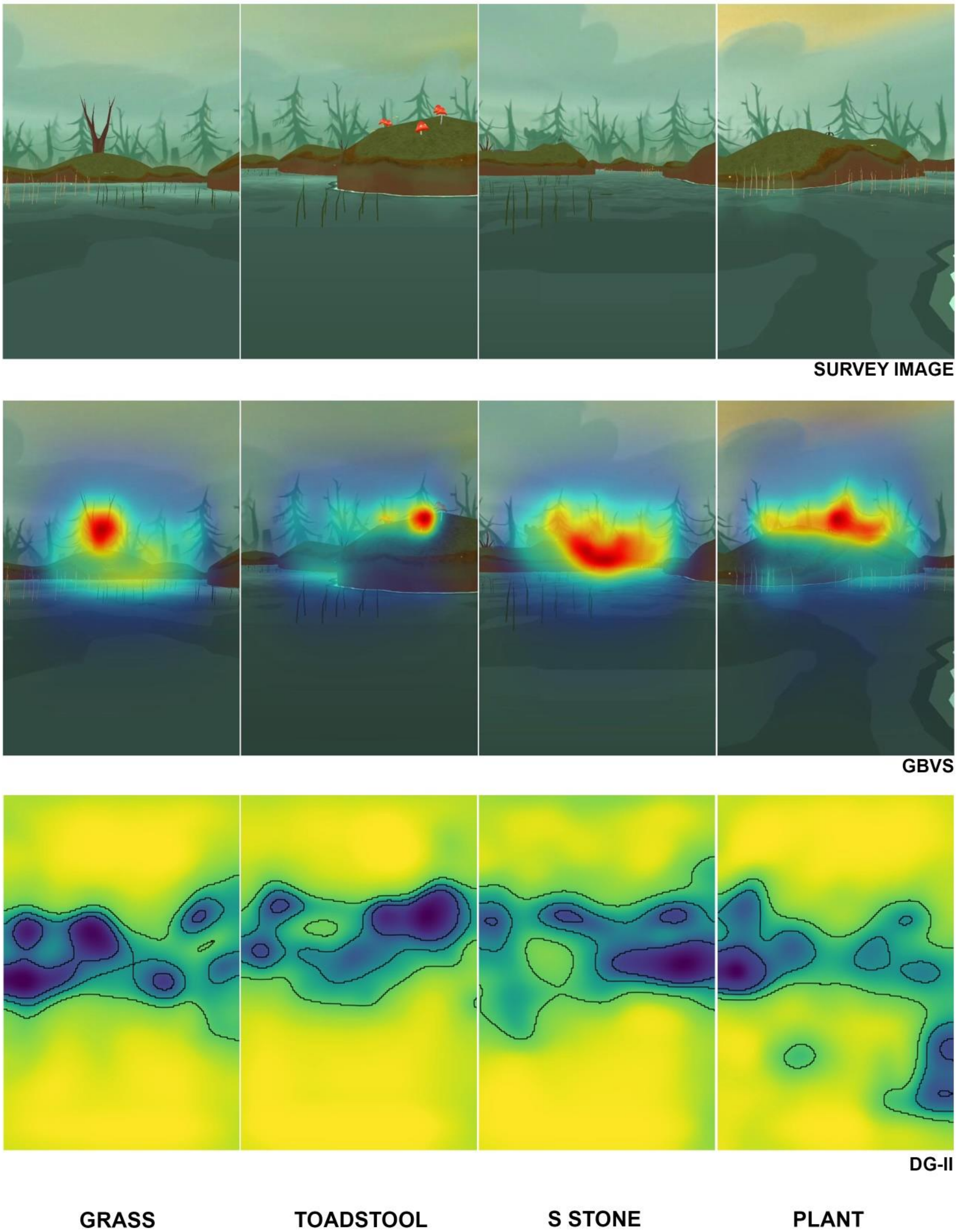


Figure A 8: Results of the Gbvs and DeepGaze II algorithms for level 32

Table A 3. Instructions for the structural saliency survey study

Hi! Thank you for participating in this study. It is part of Demet Yesiltepe's PhD research at the University of Northumbria in Newcastle, UK. If you agree to take part in this study, first you will be asked some standard demographic questions. Then you will complete a questionnaire (in the next sections) in which you will be shown 2 videos and some images. You will be asked questions about the videos you are shown. The whole questionnaire should take no longer than 10 minutes. Any responses to the questions that you give us will be held securely on password-protected computers, with data stored on a secure and encrypted server area. Anonymity will be maintained at all times. The project has been approved by the Ethics Committee of the University of Northumbria. If you have any questions, concerns or problems, you can contact me via email: demet.yesiltepe@northumbria.ac.uk. If you agree to participate by taking part in the study, please make sure that for the next few minutes nothing is likely to distract you from your computer (you might wish to consider turning off your computer's pop-ups or alerts, turning off your phone or putting it on silent etc). If you agree to participate by taking part in the study, please make sure that for the next few minutes nothing is likely to distract you from your computer. 1. I understand that my participation in this questionnaire is voluntary and that I am free to withdraw at any time without giving a reason and without detriment to myself. * • Yes, I understand

2. I agree to my responses being retained indefinitely for further research by the researchers related to the topic of the study. *
    - Yes, I understand
3. I understand that my data will remain confidential unless requested otherwise. *
    - Yes, I understand
4. I agree to take part in this questionnaire. *
    - Yes, I understand

*Required questions

Thank you again for participating.

Please follow all the steps below one by one.

Before we start, can you please answer the following questions?

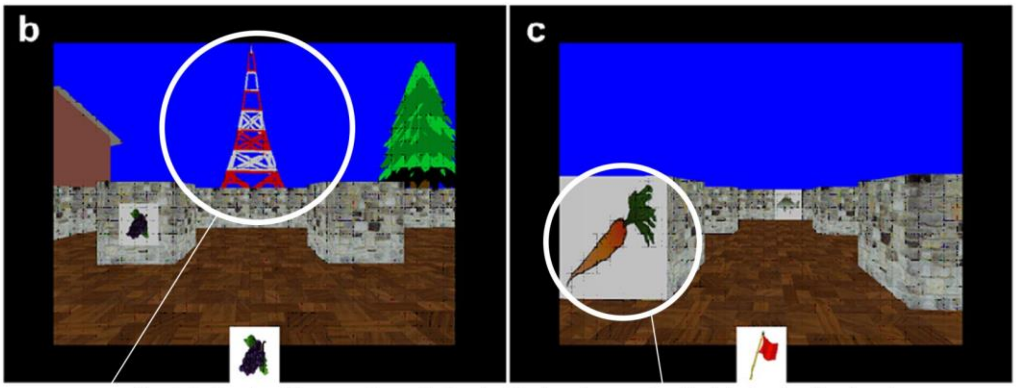
1. What gender are you? (F/M/O)
2. How old are you? (Open Ended)
3. What is your education level? (No formal education/high school/ college/ university)

Definition of Global and Local landmarks

There are two definitions you need to know for this study: global and local landmarks.

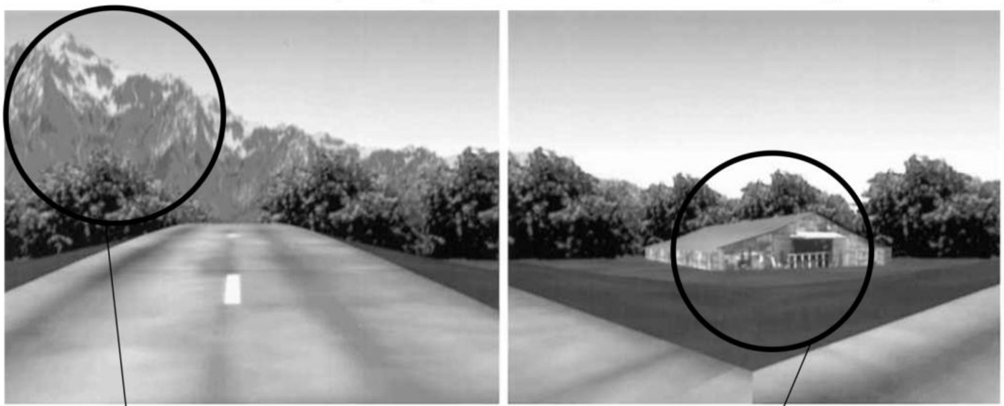
A global landmark is an object that can be seen from a large number of different places in an environment, (built or natural) but not necessarily from everywhere. A local landmark can be seen from close-up (they are typically memorable yet often of a smaller scale).

See the images below. Global landmarks can be seen from various points; whereas local landmarks can only be seen from close-up.



Lin et al., Gender differences in wayfinding in virtual environments with global or local landmarks

Global landmark example (tower) | Local landmark example (picture)



Steck and Mallot., The Role of Global and Local Landmarks in Virtual Environment Navigation

Global landmark example (mountain) | Local landmark example (house)

Experiment-I

Next you will be able to view the first video and will be asked to answer very short questions based on this video.

Please do not move to the next page before the video ends and please pay attention to the landscape through which the boat is moving.

(Video is inserted here)

In the series of questions below you will see a set of images of objects, all of which appeared somewhere in the video of the environment that you have just viewed (it does not matter if you do not recall seeing them. The video was simply to give you an idea of the context in which the objects appear).

Please, categorise each landmark as either a "global" (can be seen from many points) or as a "local" (can be seen from a limited area) landmark?

Experiment-II

The survey of the first video has been completed! Now, please start to view the second video and then answer the questions.

Please do not move to the next page before the video ends and pay attention to the landscape through which the boat is moving. Please do not go back to the previous page unless you would like to change your answers for the images.

(Video is inserted here)

In the series of questions below you will see a set of images of objects, all of which appeared somewhere in the video of the environment that you have just viewed (it does not matter if you do not recall seeing them. The video was simply to give you an idea of the context in which the objects appear).

Please, categorise each landmark as either a "global" (can be seen from many points) or as a "local" (can be seen from a limited area) landmark?

Table A 4: Instructions for the cognitive saliency survey study

Hi! Thank you for participating in this study. It is part of Demet Yesiltepe's PhD research at the University of Northumbria in Newcastle, UK.

For the context of the study, it is important for the survey to be taken by native English speakers. So please follow the next steps if you are a native speaker.

If you agree to take part in this study, first you will be asked some standard demographic questions. Then you will complete a questionnaire (in the next sections) in which you will be shown 2 videos. You will be asked one question for each video you are shown.

Any responses to the questions will be held securely on password-protected computers, with data stored on a secure and encrypted server area. Anonymity will be maintained at all times.

The project has been approved by the Ethics Committee of the University of Northumbria.

If you have any questions, concerns or problems, you can contact me via this email address: demet.yesiltepe@northumbria.ac.uk

If you agree to participate by taking part in the study, please make sure that for the next few minutes nothing is likely to distract you from your computer.

1. I understand that my participation in this questionnaire is voluntary and that I am free to withdraw at any time without giving a reason and without detriment to myself. *
   - Yes, I understand
2. I agree to my responses being retained indefinitely for further research by the researchers related to the topic of the study. *
   - Yes, I understand
3. I understand that my data will remain confidential unless requested otherwise. *
   - Yes, I understand
4. I agree to take part in this questionnaire. *
   - Yes, I understand

*Required questions

Thank you again for participating.

Please follow all the steps below one by one.

Before we start, can you please answer the following questions?

5. Are you a native English speaker?* (Y/N)
6. What gender are you? (F/M/O)
7. How old are you? (Open Ended)

Experiment-I

In this study, you will be asked to watch two videos that have been recorded in virtual environments. In these environments, you will see a boat navigating through a canal/river. The boat will travel to a series of destinations. Please watch these videos and pay attention to the landscape through which the boat is moving.

Now you will be able to view the first video and will be asked to answer a question based on this video. Please do not move to the next page before the video ends and pay attention to the landscape through which the boat is moving.

(Video is inserted here)

Survey

Which objects or landmarks did you see in the video? Please name them, and describe each of them in a couple of sentences (you can mention anything that comes to mind about them).

(Open ended question-long answer text)

Experiment-II

The survey of the first video has been completed! Now, please start to view the second video and then answer the question.

Please do not move to the next page before the video ends and pay attention to the landscape through which the boat is moving.

(Second video is inserted here)

Survey

Which objects or landmarks did you see in the video? Please name them, and describe each of them in a couple of sentences (you can mention anything that comes to mind about them).

(Open ended question-long answer text)

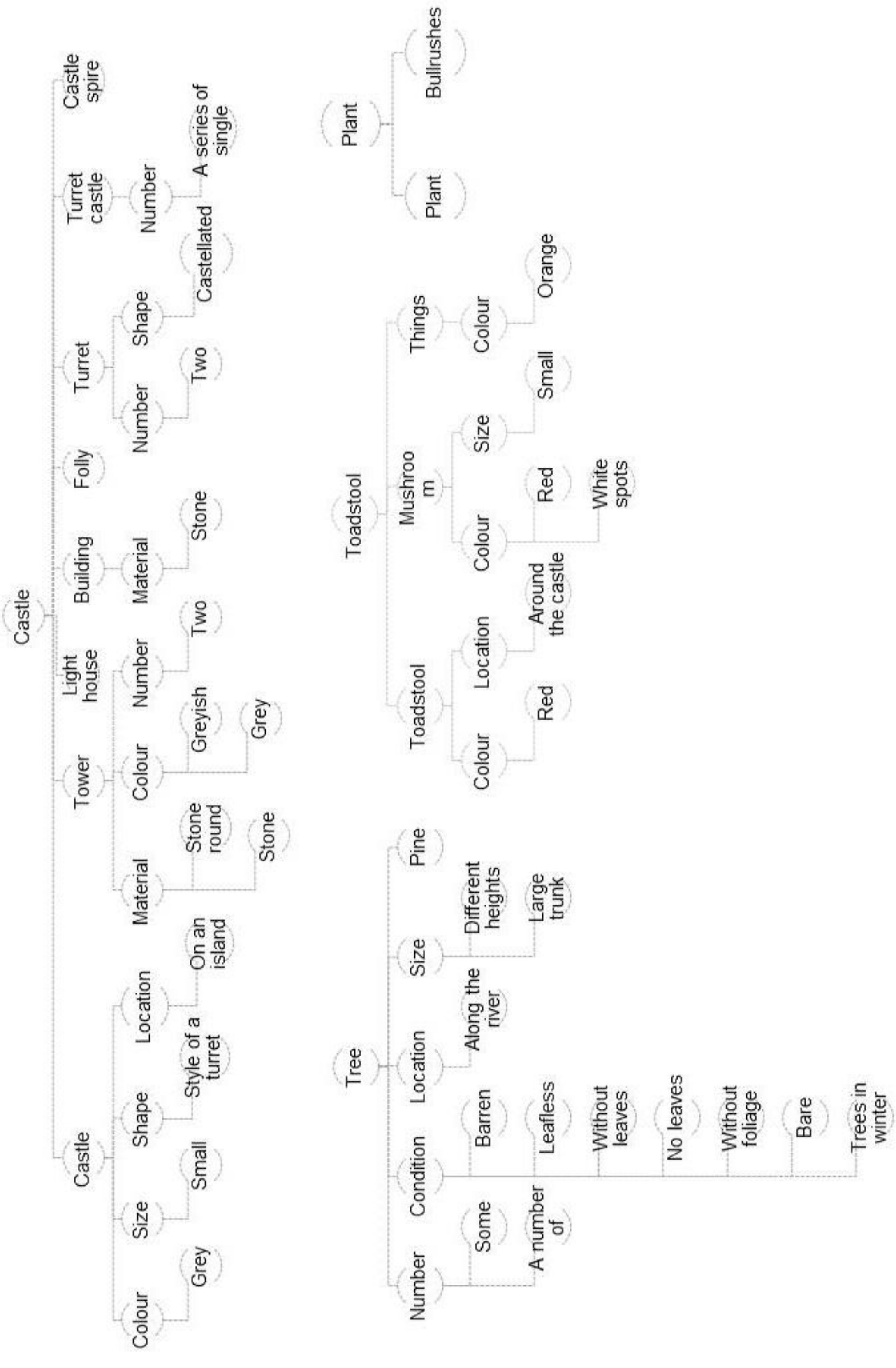


Figure A 9: The descriptions used by people for some of the landmarks in level 31

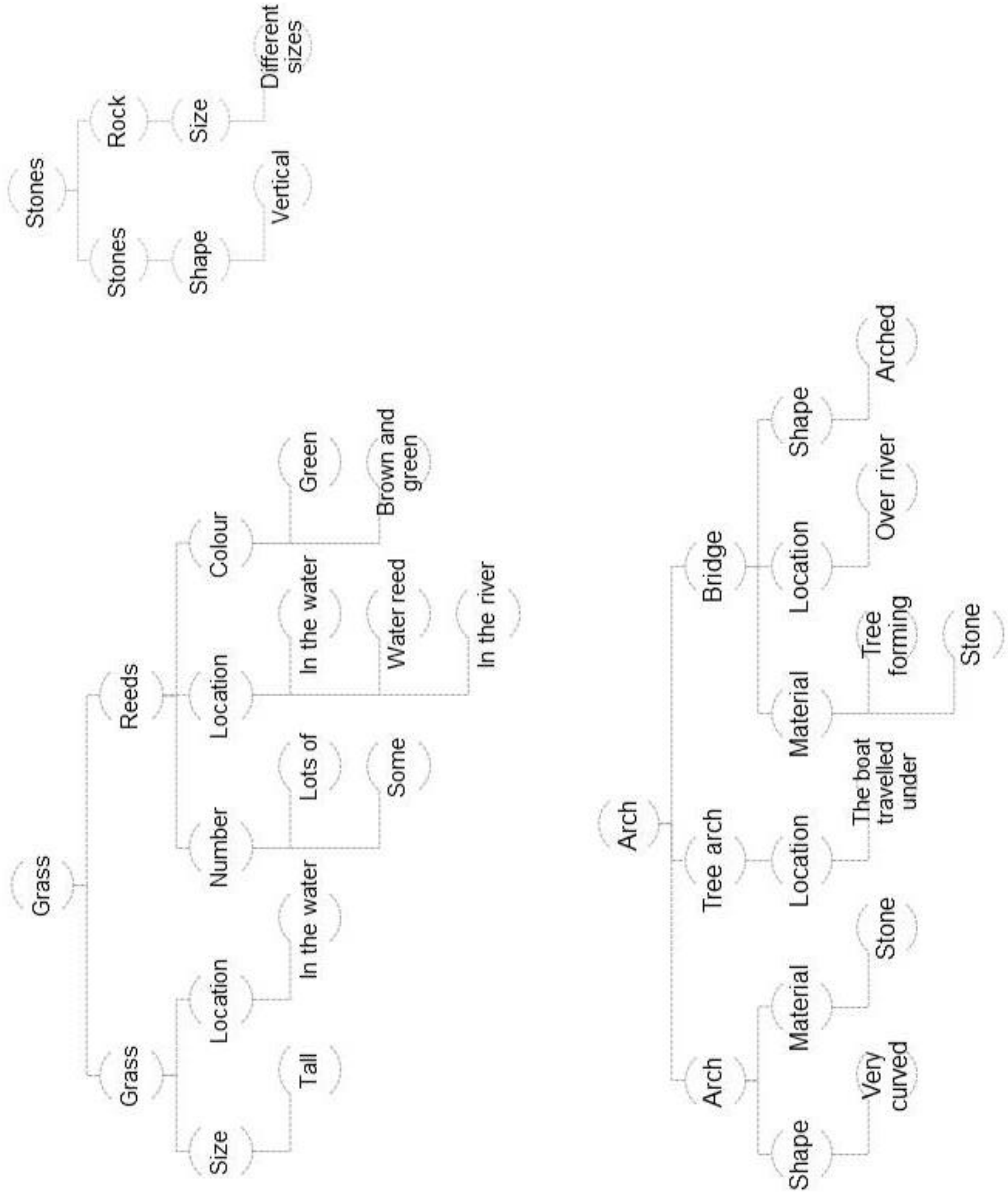


Figure A 10: The descriptions used by people for the rest of the landmarks in level 31

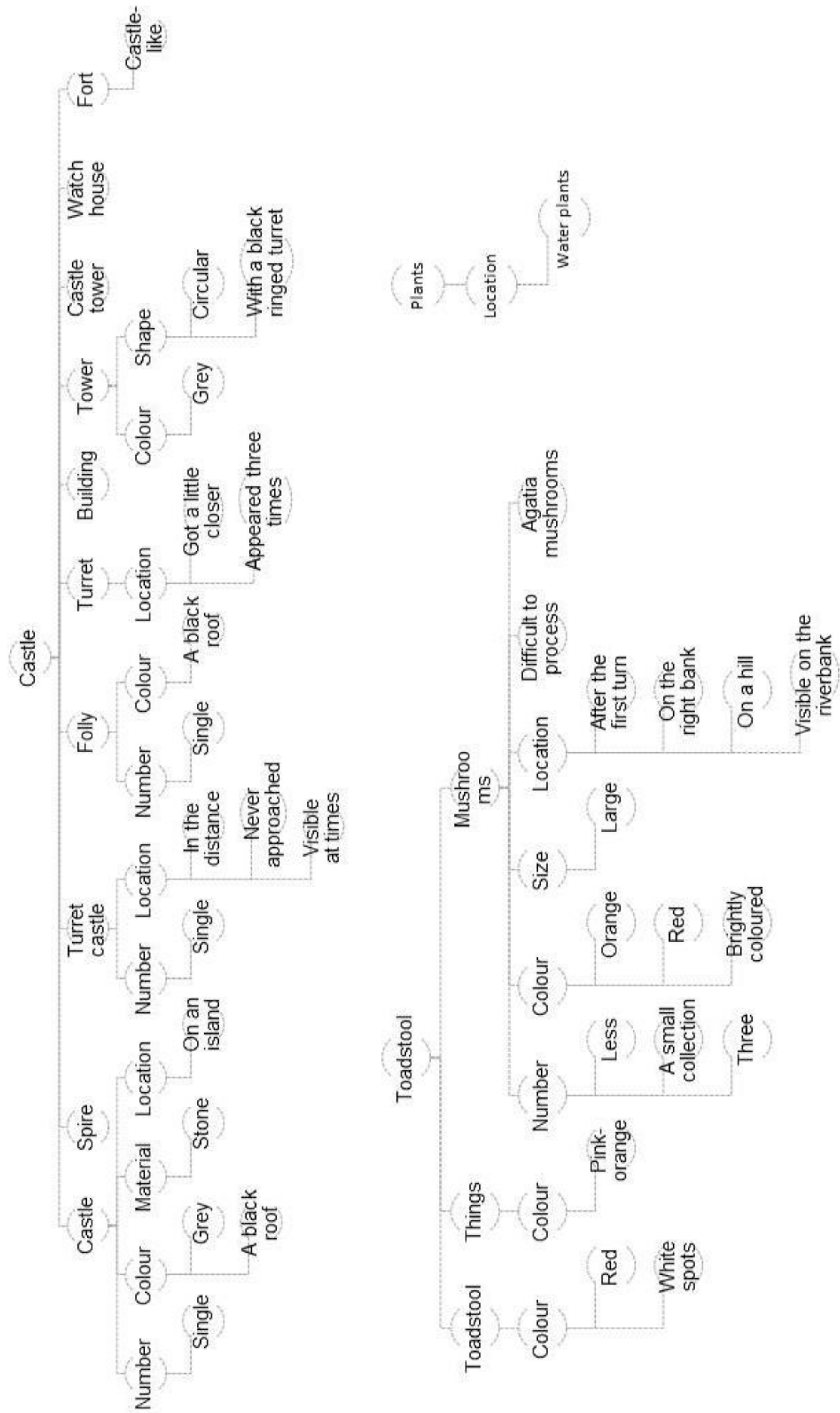


Figure A 11: The descriptions used by people for some of the landmarks in level 32

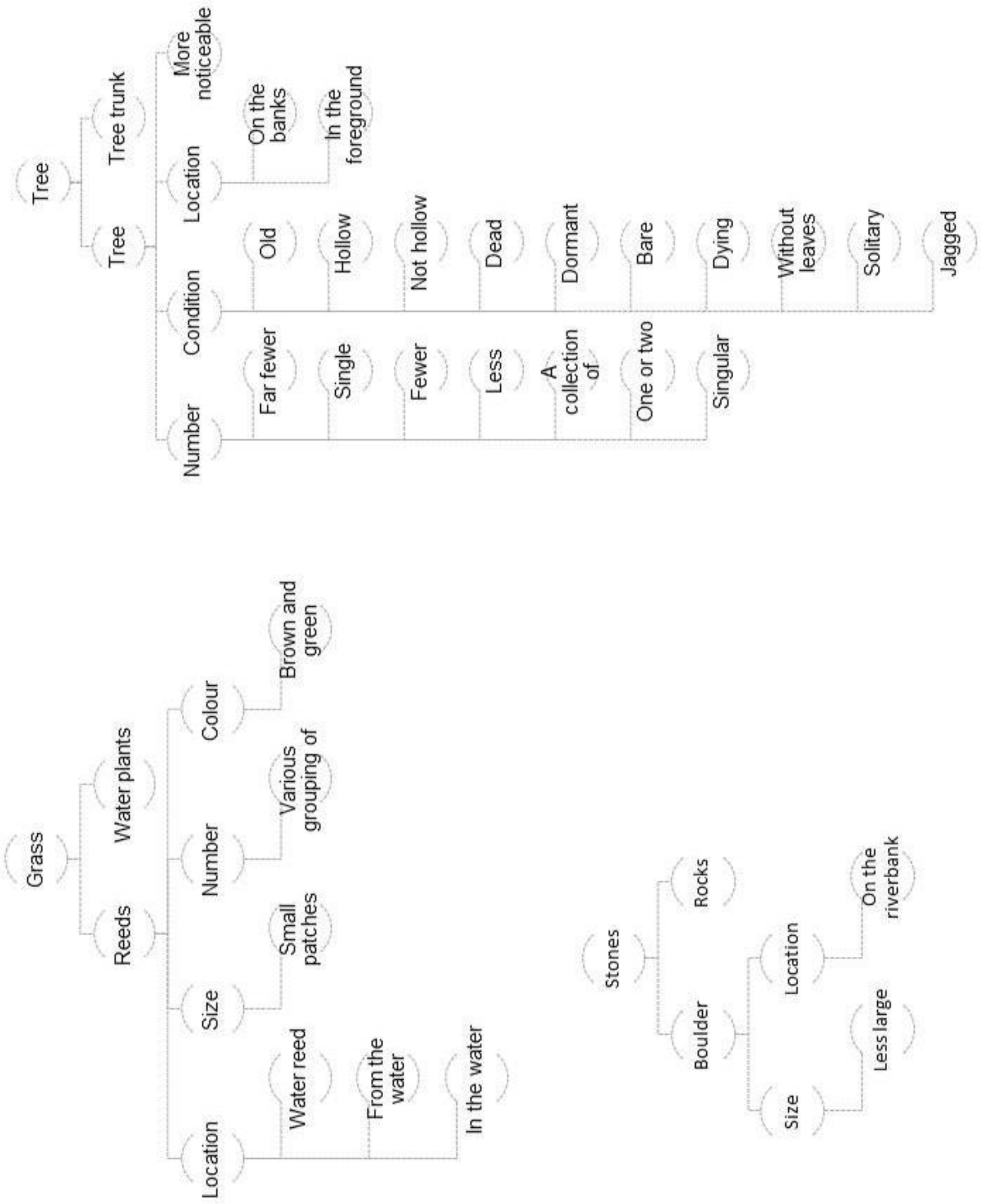


Figure A 12: The descriptions used by people for the rest of the landmarks in level 32