

# A Review of the Navigation HCI Research During the 2000's

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**Abstract**—Two of the common problems associated with navigation research in the field of human computer interaction (HCI) systems and human factors, are the relatively narrow view that the display is able to provide for a large information space, and the impact that a diversity of contexts has on the users' divided attention. In recent years, much research has been focused on the development of navigation presentation techniques to address the first problem, and the development of capturing the context with multimodal interaction in order to address the second challenge. However, the growing number of new terminologies and techniques that has been developed has caused considerable confusion for HCI researchers, consequently making the comparison of these techniques and the generalisation of empirical results of experiments very difficult, if not impossible. This article provides a taxonomy of current navigation research, which describes clearly the navigation research on desktop and non-desktop environments; it also helps to identify research domains that afford and promote the direction of navigation research. This review reveals gaps where navigation research has identified challenges but has not yet explored them.

**Index Terms**—Human Factors, Navigation, review

## I. INTRODUCTION

Over 500 years ago some of the most well-known feats of navigation were accomplished when Christopher Columbus sailed across the Atlantic Ocean. Even then, he knew that navigation tasks could be practiced beforehand in order to find an easier route. During Columbus's era, navigation was understood as moving from one place to another and finding one's way in a real physical environment. Hundreds of years later, navigation now also signifies something else for those of us who live with hypermedia applications, search information within large databases, listen to driving instructions on a SatNav device in our cars, and locate local sights as pedestrians using mobile tourist guides.

Navigation has also been the focus of a huge amount of scientific research over the past decades. For example, in 1948, Tolman (1948) argued that navigating is to some extent a personal ability or skill, and a human being creates a personal cognitive map in order to be able to navigate better in the world. Lynch (1960) explored to what extent these cognitive maps could support navigation in Chicago during the 1960s. In this type of navigation research, the focus is on *wayfinding*, i.e., searching and finding a route from point A to point B. Thus, studies on wayfinding not only cover the wayfinding task in real environments, they are also the focus of navigation research in three-dimensional virtual environments; (see for example

Vinson, 1999, Cliburn et al., 2007). In virtual environments, users are exploring great quantities of information and one of the navigation challenges lies in how to support users in order to enable them to find what they are searching for. Three-dimensional virtual environments are also an example of a certain kind of large information space with interconnected and massive amounts of digital files or documents. Research on how to navigate in large information systems seems to focus on how to support document navigation for example, how to move with perspective-drag technique (Guiard et al., 2007) or scroll and zoom between documents; see Mehra et al. (2006). As stated, navigation research has an extensive and broad field of interesting starting points. However, in order to understand navigation research and to be able to take steps forward in the future, researchers should be able to place their own scientific contributions within the wider context of research into human computer interaction. This review of navigation research in the 2000s draws upon the bigger picture of scientific navigation research. The primary objective of this study is to capture an overview of navigation research being conducted in the human computer interaction research field for the period of 2000 to 2007.

Why cover this wider field of navigation research and not just focus on, for example, navigation research on mobile devices? The argument for taking the wider view is two-fold. First, it is assumed that navigation research shares some general characteristics whether it concerns mobile or desktop environments. One example of this similarity uses the concept of a landmark. A 'landmark' is defined by Lynch (1960) as an external point-reference, which a user (an observer) does not enter. Landmarks are physical objects, and they may be local or distant, or even mobile; they may include a storefront, a tower, or the sun. The impact of using landmarks to support navigation has been explored, for example, when studying auditory landmarks in mobile navigation (Baus et al., 2007), designing guidelines for landmarks to support navigation in virtual environments (Tory et al., 2004), developing dynamic landmark placement as a navigation aid in virtual worlds (Cliburn et al., 2007), and analyzing the navigability of Web applications for improving blind usability (Takagi, Saito, Fukuda and Asakawa, 2007). Therefore, it can be assumed that there might be other interesting similarities concerning navigation research across various environments and conducted with different devices. Second, the differences that, for example, desktop and non-desktop navigation research may possess could reveal something critical. For example, until recently multimodal interaction was the focus of navigation research mainly in desktop navigation; see e.g Wall and Brewster (2006). Thus, Jöst et al (2005) explore the influence of social and situational

contexts on multimodal interaction; they stated that multimodality can enhance the usability of navigation tasks for mobile pedestrians as well. Finally, even if navigation research in human computer interaction has been conducted in desktop environments for longer than in non-desktop environments, it is still interesting to examine how some of the key concepts used, that is, navigation, landmarks, and wayfinding, have counterparts in navigation in a real physical environment. When reviewing navigation research both within the desktop and non-desktop research, it assumed that the possible shift that occurs between these two areas can be acknowledged.

This paper is organized into five main sections. Following the Introduction, the Methodology section introduces the steps of the reviewing process. The third section focuses on the characteristics of the navigation research from the 2000s studied in this paper, categorized according to the technology and keywords focus of the research and key concepts. Section four describes the key results and possible gaps that should be taken into account in future research agendas in the field of navigation research. The fifth section discusses the implications of this description for the research of navigation in the field of human computer interaction.

II. METHODOLOGY

The main aim of this review is to describe the path for future research of navigation for any researcher in the field of human computer interaction. The research questions in this study are as follows:

1. What is the focus of navigation research in the field of human computer interaction?
2. What types of results has navigation research in the 2000s accomplished?
3. What are the main challenges and directions to fill in for future research?

The published navigation research articles were examined in the following stages:

To identifying the relevant articles, the first three steps were taken (see Swanson and Ramiller, 1993) 1) *selecting/searching articles for review* 2) *filtering relevant articles* and 3) *identifying content and structure*. In addition, in order to analyze the content, the following four steps were taken: 4) *evaluating the content and structure* 5) *grouping according to the objectives* 6) *clustering and validating* and finally 7) *triangulating* (see Patton, 2002).

The research method conducted for this study was content analysis. In previous studies reviewing HCI research and research methods, see e.g. (Kjeldskov and Graham, 2003); there are only a few, if any, reviews of navigation research. In this study, the articles published from 2000 to the end of 2007 were included from five HCI-related conferences and three journals. The selected articles were blind-reviewed and were published in:

1. SIGCHI conference on human factors in computing systems (CHI)
2. Nordic conference on human computer interaction (NordiCHI)
3. Human computer interaction with mobile devices and services (MobileHCI)
4. International conference Intelligent User Interfaces (IUI)

TABLE I.  
CONFERENCE PROCEEDINGS AND JOURNALS STUDIED

Conference or journal	Title	Abstract	Keywords	Total
CHI 2000-2007	11	51	30	58
NordiCHI 2002-2007	1	5	4	6
MobileHCI 2004-2006	5	21	13	23
IUI 2000-2007	7	20	20	29
HUMAN-COMPUTER INTERACTION 2000-2007	5	4	1	5
TOCHI 2000-2007	2	13	7	14
PUC 2000-2007	4	11	4	14
Total	35	125	79	149

5. Human Computer Interaction
6. ACM Transactions on Computer Human Interaction (TOCHI)
7. Personal and Ubiquitous Computing (PUC)

All the articles have been peer-reviewed and the journals and conferences selected have an established reputation as the main publications for HCI research. Out of more than 200 articles consulted, 149 were kept for more detailed analysis.

The articles were selected using the following criteria:

1. navigation is mentioned in the title, or
2. in the abstract, or
3. as one of the keywords.

The total number of articles found is summarized in Table 1. Where overlap was found between the articles, that is, where navigation is mentioned in the title and in the abstract/keywords, or navigation is mentioned in the abstract and in the keywords, those articles were removed. The total number of selected articles was 149.

III. CHARACTERISTICS OF NAVIGATION RESEARCH

Navigation is the process of moving through an environment, either virtual or real. Thus, there are different kinds of navigation; it can, for example, be goal-directive or explorative (Darken and Sibert, 1996). Wayfinding is an essential part of navigation. The tasks of wayfinding can be categorized as naïve search, primed search, and exploration. Purposeful movement during navigation improves with increased spatial knowledge of the environment. Spatial knowledge can be described as three-level information: landmark knowledge, procedural knowledge and survey knowledge. (Darken and Sibert, 1996). Based on the articles reviewed for this study, navigation research can be roughly categorized into research on navigation *within* information systems, such as in databases, web pages, other digital documents and three-dimensional virtual environments; and on navigation *with* information systems, such as mobile guidance systems or wearable maps. Furthermore, navigation research can focus on 1) *navigation with information systems designed for desktop computers* or 2) *navigation with information systems designed for non-desktop computers* or 3) *navigation in real physical environments with non-desktop computers*. The two latter types of research include mobile computers, large displays, wearable computers and embedded technology. The objects, that is, navigators, are usually human beings but in recent research, studies on robots navigating

in real physical environments (Amant and Christian, 2003) have been explored as well.

Navigation research can be divided into several categories according to the technology that is used when users are completing the navigation task. Based on the articles reviewed, navigation research during the 2000s can be classified in the following ways:

1. Navigation in information systems with desktop computers
2. Navigation in 3D virtual environments with desktop computers and other type devices (e.g. haptic)
3. Navigation in information systems with mobile devices
4. Navigation in information systems with wearable devices
5. Navigation in information systems with embedded technology

Even with technology-based classification, which seems to be clear and well-restricted, there are some cases that are not easy to categorize according to the technology. For example, research on multi-device environments and social interaction are not so well suited to this type of technology-driven classification.

The primary motivations for navigation can be exploring or searching for information or completing a wayfinding task in all of these five cases, that is, when human beings are 1) navigating in information systems with desktop computers, 2) navigating in three-dimensional virtual environments, 3) navigating in information systems with mobile computers, 4) navigating with wearable computers, and 5) navigating with embedded technology. However, the wayfinding task in a real environment or context can focus only on mobile, wearable or embedded technology. Furthermore, these navigation studies with mobile, wearable and embedded technology can take place indoors or outdoors. The main difference between navigation with desktop and mobile, wearable and embedded computers is that the latter is designed to be carried out by pedestrians or vehicle drivers. In these cases, the navigation may not be the primary task of the users to the same extent that it could be when users are navigating with the desktop computers at their offices. In the first and second categories (see Table 2), there are similarities in research, for example, exploring orientation issues see (Tory et al., 2004). Moreover, in the last four categories there can also be similarities found in research, particularly if the focus is on wayfinding tasks. Wayfinding tasks are one of the key issues both when choosing the viewpoint in the research of three-dimensional virtual environments, and when providing instructions for finding the correct route for pedestrians or vehicle drivers.

In the research field of human computer-interaction, keyword classification systems reflect navigation research, which is currently more related to navigation in information systems. One of the most cited classifications is the ACM Computing Classification System (1998). According to this classification, navigation is part of the class H.5.4 Hypertext/Hypermedia, Navigation. However, if we analyze the empirical data of this review, the researchers themselves have taken a much broader view, describing their navigation research using the primary keywords of the ACM Classification system. They describe their research mainly using the ACM Classification

TABLE II.  
SUMMARY OF ARTICLES CATEGORISED BY TECHNOLOGY

	Total share of reviewed articles
Navigation in information systems with desktop computers	53 %
Navigation in 3D virtual environments with desktop computers and other devices	11 %
Navigation in information systems with mobile devices	31%
Navigation in information systems with wearable devices	2 %
Navigation in information systems with embedded technology	5%

system with primary keyword (53 % of the total papers) into the class H.5.2 User Interfaces. In addition, classes such as K Computing Milieux, C.3 Special-Purpose and application-based systems, Real-time and embedded systems, J. Computer Applications, and D Software, are used to describe the navigation research. Analyzing the five different research focuses (see Table 2) in general terms by ACM, it seems that navigation research with desktop computers covers all the areas, whereas the non-desktop navigation research still primarily focuses on issues of design and human factors, and less on experimentation and theory development. This is the case particularly with navigation research of wearable and embedded technology. It seems that research related to design, human factors, and performance is covered in all three technology-based navigation research domains. Even if studies are categorized with the technology-driven classification presented in the Table 2, more detailed analysis with key concepts, navigation research methods, and outcomes of the studies is needed. With better understanding of the concepts, methods used and the results of previous navigation research, more detailed explanation of prior research within the research stream is found and therefore arguments for future research trends and directions can be based on more solid ground.

A. *Navigation in information systems with desktop computers*

According to our data, current navigation research in the field of human computer interaction primarily concentrates on examining how users navigate within large information systems. This trend is easy to recognize by the amount of articles reviewed for this study, particularly from the CHI conference and the two HCI journals, TOCHI and Human Computer Studies. The total share of the articles reviewed in this study is 53%. This figure does not include navigation research into three-dimensional virtual environments. The main focus of navigation research (see Table 4) covers a wide range of issues from user-related issues to social navigation and multimodal interaction. It is clear that this type of navigation research has the longer research tradition compared with non-desktop navigation research, and therefore desktop navigation research covers a wider range of research topics. The key topics of user-related issues of research includes, for example, gender and age issues in addition to user adaptability, whereas the rest of research focuses on the impact of navigating with other users (social navigation), user interface design, navigation techniques (panning,

scrolling etc.), searching and browsing, filtering and recommending, and multimodal interaction. However, research into developing usability evaluation methods is also the current centre of attention of this type of navigation research.

The primary research methods for navigation research on desktop navigation are quantitative and experimental research methods. The data-gathering methods and data-analyzing methods are most often based on statistical analysis. Only a few, (see Wall and Brewster, 2006), if any, research investigations were conducted using qualitative methods. Main findings covers a wide range of navigation techniques, theoretical developments, design guidelines for user interfaces, usability evaluation methods, new systems for recommend users, and issues related to social navigation.

As a summary, navigation HCI research with desktop computers during the 2000s seems to explore how to develop techniques to navigate, how to present and search/browse information, what kind of differences there are between women and men navigators and users with different ages, in addition to the impact of other navigators. Moreover, how to evaluate usability of navigation is also an important research topic. As a result, system development, design guidelines and method in addition to theoretical development can be presented.

*B. Navigation in three-dimensional virtual environments*

A total of 11% of the articles reviewed concerned navigation research in three-dimensional virtual environments. The key focus of the research (see Table 5) is covering user-related issues, social navigation and viewpoint and orientation issues. However, evaluation methods, multimodal interaction and user interface issues are lacking this type of research based on the reviewed articles. The main research methods are quantitative, experimental methods, for example, task-based controlled laboratory tests.

The main findings of this type of navigation research includes, for example, the development of new navigation techniques, e.g., (Tan et al, 2001), choosing orientation (Tory et al., 2004), or viewpoint Tatemura (2000). Furthermore, user interface-related studies resulted in an intelligent navigation interface with a personalisable assisting mechanism (Li and Hsu, 2004), and more explicit or exaggerated representations of actions (Hindmarsh et al., 2000).

To summarize, navigation research of three-dimensional virtual environments during the 2000s covered how users orientate and choose a viewpoint, what kind of navigation techniques users have, how to present the information of an avatar, the impact of other navigators and the gender of a user. The navigation research related to virtual environments is resulting techniques of navigation, choosing viewpoint and orientation and mechanisms of representations.

*C. Navigation in information systems with mobile technology*

In relation to research on navigation in information systems with non-desktop computers, and particularly with mobile (or handheld devices), the total share is 31% of the all reviewed articles.

TABLE III.  
KEY CONCEPTS OF NAVIGATION IN INFORMATION SYSTEMS WITH DESKTOP COMPUTERS

Research focus	Concepts
Navigation techniques	panning, hop, scrolling, fisheye, click action, crossover effect, dynamic/ static peephole
Searching and browsing	faceted search, visual data browsing, interacting with search-engines
Social navigation	social affordance, socially translucent systems, social search, social markers
User-related issues	gender and age issues, user adaptability, web pages visited
Multimodal interaction	tactile interaction, speech recognition, multi-point interaction
Usability evaluation	evaluation of 3D techniques, cognitive walk-through, easy prototyping, interpretability, automatic checking tools
Information visualization	scalability of information visualisation
Filtering and recommending	content-based and collaborative filtering, personalization in e-commerce, resource adaptability,
User interface design	overview display, levels of detail, off-screen target selection, halo interface, reconnaissance agents, zoomable user interfaces with and without an overview
Other issues	task-based taxonomy, goal-directed behaviours, Hyperbolic Tree, user's success rates, page re-visitation, entry points in to video, effects of context information (structural and temporal), contextualising navigation, automatically build associations in different media

TABLE IV.  
KEY CONCEPTS OF NAVIGATION IN 3D VIRTUAL ENVIRONMENTS

Research focus	Concepts
Navigation techniques	a personalisable assisting mechanism, tracking system, Speed-coupled Flying with Orbiting
Orientation	performance differences for 3D orientation, spatial orientation tasks
Viewpoint	Semi-distorted views to support peripheral awareness; transition between local and global view, views blocked by obstacles
Social navigation	sensitive to the actions of others
Navigation task	spatial orientation task
User related issues	gender bias, gender-specific navigation,
Information visualization	explicit or exaggerated representations of actions provided by avatars

It is argued here that the main differences in navigation research between research on navigation in information systems and navigation with mobile devices in real environments is the impact of context. Tamminen et al.(2004) have stated that in mobile contexts, users' internal factors are different and external factors are dynamic and unpredictable. Furthermore, they argue that in relation to a mobile context, users solve navigation problems with social solutions, both national and within the mobile context, and there are temporal tensions, such as acceleration, declaration, hurrying, normal and waiting. Regarding the user interface issues, modality selection and interruption management are two of the main issues (Tamminen et al., 2004) in mobile navigation. According to the data of this study, the research focus of navigation research with mo-

mobile devices is on searching and exploring, multimodal interaction, user-related issues, user interface and navigation techniques (see Table 6). The key issues in user-related themes are limited to the impact of age and the urban environment.

Main findings of non-desktop navigation research are related to interaction design, for example, Holland et al., (2002) and adaptability, e.g., Baus et al., (2002).

To summarize, navigation research with mobile technology during the 2000s explores navigation techniques, how to search and explore information, the possible impact of age and spatially-aware displays on navigation, in addition to how to design user interfaces and tailor the presentation information. In multimodal interaction, speech seems to be emphasized as the most popular modality.

*D. Navigation in information systems with wearable and with embedded technology*

In the research field of HCI, navigation with wearable computers is not yet in the mainstream of the current research. Of the reviewed articles, the total share was less than 2% of all the articles. The main focus of the research concentrates on interaction and user interface topics. The key concepts of research (see Table 7) involves primarily how simple interaction with wearable computers can be conducted. Other research interests include studies on positioning and measuring.

The main findings include issues such as presenting a platform or a prototype for wearable computing, or a map application, see for example, Raghunath and Narayanaswami (2002), Rantanen et al., (2002). Navigation HCI research during the 2000s is at an early phase. The amount of published articles are as yet very few and the topics concentrated on issues such as basic interaction and the design of user interfaces in this type of navigation research.

The embedded technology in this study is defined as including large displays, outdoors or indoors, ubiquitous and pervasive systems. The total share of this type of navigation research in this study is 5%. The main focus of this type of research seems to focus on navigation techniques and displays (see Table 8). In other words, issues such as the adaptability of displays and tangible displays, besides the design of sizes and visual angles of displays, are highlighted in the navigation research.

The main findings relate to the design issues of the displays, such as size [24], adaptability and choosing the visual angle, or comparing physical and virtual navigation, for example, (Ball et al., 2007).

*E. Special case: Navigation in a real physical environment with mobile/ wearable/embedded technology*

Of the reviewed articles in this study, navigation with mobile devices includes special cases, for example, where the users' actions involves navigation tasks in a real environment with a mobile system particularly designed for support navigation and wayfinding in a real environment. It is argued here that in most cases of this type of navigation, the role of navigation in the information system is the secondary task, whereas the primary task is the navigation (by walking, driving a car, or a bike) in a real physical

TABLE V.  
KEY CONCEPTS OF NAVIGATION IN INFORMATION SYSTEMS WITH MOBILE COMPUTERS

Research focus	Concepts
Navigation techniques	static and dynamic peephole navigation
Searching and exploring	navigating web pages, effective browsing, tailoring information
Multimodal interaction	voice response
User-related issues	age, urban people
User interface	inconsistent UIs, speech-based UI, an expressive representation for location
Context	spatially aware displays
Other	improving productivity and efficiency, personalised service, hybrid system, decision-theoretic handheld system

TABLE VI.  
KEY CONCEPTS OF NAVIGATION IN INFORMATION SYSTEMS WITH WEARABLE COMPUTERS

Research focus	Concepts
Interaction	Automatic emergency message
User interface	Navigation aids, a map application, a visualisation method
Other	Communication, positioning, measuring the human and the environment, a wearable computing platform on a wrist

TABLE VII.  
KEY CONCEPTS OF THE ARTICLES CONCERNING NAVIGATION IN INFORMATION SYSTEMS WITH EMBEDDED COMPUTERS

Research focus	Concepts
Design factors	display size, visual angle constant
Multimodal interaction	tangible displays
User interface	adaptive displays
Navigation technique	Physical vs. virtual navigation, spatial orientation, directional signs
Other	user performance

environment. This is not the case when users are navigating, for example, with desktop computers in virtual environments. The possible misunderstanding and uncertainty with navigation concepts between these research fields may be apparent. Therefore, it is suggested here that we should clarify whether the research is about virtual navigation (in an information system with desktop/mobile/embedded technology) or (real) navigation (in a real environment with technology). In most cases, this may be obvious, but above all, when the research into virtual navigation is seeking and developing novel methods and concepts based on the principles of real navigation, for example, when using landmarks and utilizing navigation strategies, the potential for misinterpretation is real.

When exploring navigation HCI research that focuses on supporting navigation tasks with mobile technology, Table 9 describes how that navigation research focuses on issues of context (indoor, outdoor, in-vehicle, pedestrian). The user-related key concepts seem to focus on the impact of visual ability and the impact of indoor or outdoor navigation, as well as whether the navigators are acting as a driver or a pedestrian.

TABLE VIII.  
KEY CONCEPTS OF THE ARTICLES

Research focus	Concepts
Wayfinding	Wayfinding strategies, route guidance, situated navigation, navigation task
Indoor	Hybrid system
Outdoor	Wayfinding, context awareness
Pedestrian navigation	Navigation assistance, perceptible landmarks, uncertain predictions
User interface	Wearable adjustable 3D version of the map application, the maintenance of forward/ up correspondence, spatially aware display, adaptive route directions
In-vehicle navigation	Driving performance and listening synthetic and natural speech, speech-based UI, mismatch between the complexity of maps and the attention demands of driving
Embedded technology	Scalability of information visualisation, target acquisition, tangible user interface that facilitates retrieval of historical stories in a tourist spot. Orientation, movement, relative positions of physical, mental rotation tasks
User-related issues	Visually-impaired people
Interaction	One-handed thumb
Other	Eyes-free navigation, environmental factors

To summarize, navigation HCI research to support real navigation tasks is for the most part divided into indoor or outdoor navigation and/or into pedestrian navigation and in-vehicle navigation.

#### IV. CONCLUSIONS

The main results of navigation research between 2000 and 2007 tend to contribute mainly by providing novel systems, guidelines e.g., Tan et al. (2006), for designers' user interface design, e.g., Raghunath and Narayanaswami (2002), McGrenere et al. (2007), systems or prototypes of systems, e.g. Holland et al. (2002), Cheverst et al. (2002), Yee (2003), Rantanen et al. (2002), and novel evaluation methods e.g., Takagi et al., (2007). It is quite interesting how research on navigation, whether it is focusing on navigation within an information system, or wayfinding in a real physical environment, possesses some similarities. On a general level, such research focuses on navigation strategies, and navigation techniques connect different kinds of navigation research (see Table 10). However, there are clear differences as well. For example, research on social issues in mobile navigation is lacking. Most of the research presents a cross-sectional view about the navigation issues. There are not so many studies focusing on the theory development of navigation or longitudinal studies indicating the impact of using navigation systems in a real or virtual environment. Fewer studies are about the possible transformation of user actions when they are navigating or using navigation systems.

One of the almost totally missing research topics of navigation HCI concerns navigation with multi-device environments. Nevertheless, most users are already using multiple devices in their everyday life. This review covers the field of navigation research during the 2000s so far. Based on the analyzed data, there are plenty of challenges for researchers and several directions for their future work. A general proposal for future work includes sugges-

TABLE IX.  
TAXONOMY FOR THE RESEARCH FOCUS

	Research focus
Navigation in information systems with desktop computers	Evaluation methods, navigation techniques, multimodal interaction, social navigation
Navigation in 3D virtual environments with desktop computers and other devices	Social navigation, performance differences, orientation, viewpoint
Navigation in information systems with mobile devices	Searching, exploring, user interface, pedestrian navigation, in-vehicle navigation
Navigation in information systems with wearable devices	Navigation aids, communication, user interface
Navigation in information systems with embedded technology	Display size, adaptive displays, user performance

tions for conducting more qualitative research alongside quantitative research. For example, exploring the context and its impact on navigation with qualitative research methods, whether with desktop or mobile computers, may reveal critical factors about navigation. Furthermore, due to the fact that we are living and navigating in *multi-device* environments, much more research should be carried out on exploring what kinds of possible impact changing devices during a navigation task can cause. In additions, *longitudinal studies* of navigation are needed to better understand how navigation is possible when changing the technology that users are provided with.

For non-desktop navigation research, there are gaps to fill if we compare navigation research into desktop navigation. First, it is strongly emphasized here that describing who the users are and how the sample of users for the tests and evaluations were chosen could be mentioned more precisely. People do have different kind of navigation strategies or techniques, see for example Czrewinski et al., (2002) and Guiard et al. (2007), and therefore it is more than crucial that these *user-related issues* should be explored. Navigation in a variety of contexts (indoor, outdoor, pedestrian, in-vehicle) has been explored, but it does not describe for example what kind of impact gender or age has on mobile navigation. Therefore, possibilities how to adapt novel navigation systems according to user's profile should be explored. Second, what is missing almost totally from non-desktop navigation research, is research on evaluation methods. For non-desktop navigation research, as distinct from the desktop environment, the fact that navigation cannot be the primary task of a user as often it is in a desktop navigation, should be noted in the research as well. In other words, what are the main challenges when people are navigating in real environments? Furthermore, what kind of challenges people face if navigation guidance is not presented on the screen of mobile device but it is, for example, projected on different surfaces.

Finally, based on this review, due to the possible misunderstanding and uncertainty with navigation concepts between the research fields of navigation in information systems and navigation with information systems, it is suggested here that we should clarify whether the research is about *virtual navigation* or *navigation* in a real environment.

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