Human wayfinding behaviour and metrics in complex environments: A systematic literature review

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Abstract

Wayfinding requires a strong understanding of the relationship between human behaviour and environmental features. Previous wayfinding studies have focused on the relationship between human behaviour and environmental cues to deduce wayfinding metrics. In the domain of experimental psychology, human wayfinding behaviour has been explored in a number of environments; however, many complex settings are yet to be explored. Due to a lack of space, metropolitan city centres have morphed into complex environments with high-rise buildings. The legibility within a complex environment, such as a university campus in a dense urban area, is a matter of concern. Such campuses have a partial or complete visual absence of dedicated traditional cues for pedestrian navigation, such as distinguishable intersections, dedicated pathways, and information signage. As complex environments, these university campuses demand further exploration regarding human behaviour. This study presents a systematic review of various factors and techniques influential in analysing wayfinding behaviour. Factors such as environment complexity, wayfinding metrics, environmental familiarity, experimental settings, signage design, and cultural differences are critically discussed. This paper also discusses the technological contributions of virtual and augmented reality in the exploration of human wayfinding behaviour.

Keywords: Complex environments, navigation behaviour, wayfinding metrics, spatial factors, wayfinding technologies, wayfinding aids

1 Introduction

Searching for a specific location, building or environmental setting is a complex task. It requires understanding environmental cues in conjunction with cognitive strategies. This specific task of searching is known as wayfinding or spatial navigation. Wayfinding can be described as a generic navigation task of travelling from one location to a specific destination (Golledge 1999; Ruddle and Lessels 2006). The term 'wayfinding' was originally coined by Kevin Lynch in his book *Image of the City* (Lynch 1960), and has been developed by various definitions since. Wayfinding behaviour has been widely explored in terms of spatial influences, navigation aids, layout planning (Natapov et al. 2015), route planning, navigation performance, cross-cultural and individual differences. Wiener, Büchner, and Hölscher (2009) also tried to explain wayfinding taxonomy and metrics, spatial syntax and wayfinding aids with a number of experimental studies. Such studies have been performed in real as well as virtual environments (VE), with the addition of medical instruments to analyse human behaviour. The real-world investigations of human-environment interaction have been considered complex in nature in comparison to the laboratory-based experiments (Kuliga et al. 2017).

Studies have deduced that the task of navigation can be segregated into locomotion and wayfinding (Montello 2001, 2005). The term 'locomotion' has been defined as the tasks associated with walking, turning and avoiding obstacles. Wayfinding has been described as a comprehensive behaviour for searching, exploring and route planning from one location to another. Human information processing and cognitive behaviour are significant in wayfinding. The tasks require sensory and motor-related skills and use a substantial portion of the brain (Chersi and Burgess

2015; Epstein et al. 2017; Javadi et al. 2017). An investigation of multilevel wayfinding recommended that a building's wayfinding aids should include information about its cognitive and physical attributes (Kuliga et al. 2019). This argument was partially supported by Cheung (2006), who determined that during wayfinding, the personal strategies used to reach a destination are based on human spatial cognition and information processing.

Prior wayfinding studies have focused on individual behavioural patterns and environmental-spatial factors (Downs 2001; Downs and Stea 1973; Evans et al. 1980; Schneider and Taylor 1999). These studies suggested that human cognition and responsive behaviour are influential in route finding in both indoor and outdoor environments. These explorations have been extended and strengthened by incorporating information gathering, processing, spatial knowledge, route directions and performance calculations (Lovden et al. 2005). The process of gathering and processing information from an environment has been a point of interest since research on wayfinding began. This information processing is based on short-term and long-term memory storage. Short-term memory can store data in five to seven segments (Miller 1956), while long-term memory can be considered as the interconnection of memory nodes (Schneider and Shiffrin 1977). These nodes can be understood as storage folders where the data are stored and further processed to obtain useful information. The interconnection of these nodes has made the retrieval of information an effortless task. Therefore, information about a surrounding environment can be seen as pre-stored nodes and can be considered an important part of wayfinding behaviour.

An understanding of spatial configurations is also key to getting route information for effective wayfinding (Crucitti, Latora, and Porta 2006; Jiang, Claramunt, and Klarqvist 2000; Mohamad and Said 2014; Peponis et al. 1998). These configurations are instrumental in building up spatial knowledge (Ishikawa et al. 2008) and can decrease the probability of disorientation

during wayfinding. The methodology of space syntax, along with the spatial features, also aids the identification of routes through visibility and depth mapping (Jiang and Liu 2009; Li and Klippel 2012; Ratti 2004; Turner 2007). Space syntax is a combination of several techniques which theoretically analyse the relationship between human behaviour and the surrounding environment (Li and Klippel 2012). Through space syntax methodology, the ability to comprehend an indoor environment can be enhanced, which can substantially increase the usability of that environment (Ünlü et al. 2009).

The usage and effects of several wayfinding aids have been explored with reference to human wayfinding behaviour. Environmental cues including building information signage, directional signage and markings are important elements of wayfinding (O'Neill 1991; Passini 1984; Stevenson 1990). In addition, wayfinding research has explored the influence of landmarks (Pazzaglia and De Beni 2001), path recognition, environmental/building factors and egress models (Gwynne et al. 1999, 2000; Stahl 1982).

The effects of active exploration (Attree et al. 1996; Chrastil and Warren 2012) and passive exploration (Abu-Safieh 2011; Cao, Lin, and Li 2019) during wayfinding have also been explored and are considered critical in acquiring route and survey knowledge. Route knowledge can be obtained by travelling certain routes, whereas survey knowledge can be acquired through different experiences. Further investigations have supported these findings by proposing that gaining route knowledge (Aginsky et al. 1997; Golledge 1999; Shelton and McNamara 2004) and survey knowledge (Iaria et al. 2009; Liu et al. 2011) can improve wayfinding performance.

The acquisition of spatial knowledge is significant in human wayfinding behaviour, which is very intricate due to the diverse impacts of different environments. Multiple researchers have tried to explore human wayfinding behaviour based on individual differences such as age, gender,

education, professional background, technological awareness and cultural perspectives (Davies and Pederson 2001; Farr et al. 2012; Lesch 2008; Malinowski and Gillespie 2001; Montello and Sas 2006; Ng, Siu, and Chan 2013).

The fundamental objective of this research article is to encapsulate human wayfinding behaviour regarding a complex environment and the individual differences of wayfinders. The research was conducted in complex environments of university campuses situated in dense urban areas. Wayfinding problems exist in these complex spatial settings due to the presence of diffused pathways, multi-storey buildings, diffused facilities and a multi-cultural community, unlike other complex environments. In addition, the university campus attracts many new students every year, including international students, who are completely unfamiliar with the spatial layout of the campus. Therefore, it is important to find out the barriers to culturally consistent information design for wayfinding, with the aim of mitigating wayfinding problems for newly registered university students.

Several experimental techniques have been used to explore this topic over the last four to five decades. Before the emergence of technological substitutions, wayfinding research was performed by evaluating wayfinding tasks in real-world locations. Later, this shifted to virtual reality (VR)-based computer simulations and controlled lab environments that enabled better control of confounding variables.

Therefore, four research questions were formulated to guide a systematic literature review. This method was selected as the research questions were qualitative and exploratory in nature, and therefore required thorough qualitative literature research. The formulated research questions are as follows:

RQ1: What factors make university campus as a complex environment for wayfinding?

RQ2: What wayfinding metrics have been used for the complex environments?

RQ3: What are the impacts of culture, signage and unfamiliar environment on wayfinding behaviour?

RQ4: What experimental settings have been designed for wayfinding research?

2 Review methodology

2.1 Search criteria

To initiate the review process, five key phrases were formulated from the research questions: 'university campus wayfinding', 'cross-cultural wayfinding', 'virtual wayfinding', 'signage pictograms' and 'unfamiliar environment wayfinding'. After performing an initial search for the most relevant research articles, four databases were identified as suitable: Sage Journals, Science Direct (Elsevier), Springer Link Online and Taylor & Francis Online. The databases were searched for journal articles, reports and conference proceedings. Only articles available in English were considered valid for inclusion. The timeline for the search was 1st January 1990 to 31st January 2019. Most of the articles before 1990 were related only to wayfinding, its measuring metrics in city spaces and pedestrian navigation. Articles that were accepted but not published were also included in the review process.

2.2 Inclusion and exclusion criteria

The articles were checked for duplication, with repeated articles removed before the inclusion and exclusion criteria were finalised. The criteria were analysed in three stages. During the first stage, only articles related to the following key areas were included: complex environment wayfinding behaviour, signage-people understanding and wayfinding using VR-based simulations. From the articles selected during the first stage, those that addressed institutional wayfinding behaviour, university campus signages, signage design and wayfinding in VE were

included during the second stage. The third and final stage of the study included articles that examined wayfinding behaviour in real/virtual complex environments and signage information design in cross-cultural settings. Articles that did not fulfil the inclusion criteria were excluded from the study at each stage.

2.3 Results

During the search process, more than four thousand articles appeared based on the key phrases. Initially, a database of about eight hundred articles was established by excluding irrelevant articles. After performing the three-stage selection process based on inclusion and exclusion criteria, twenty-seven research articles were carefully chosen. The process of article selection and the number of included and excluded articles per stage are shown in Figure 1 as a prisma flow diagram (Moher et al. 2010).

[Figure 1 near here]

The search focused on articles concerned with public institutions situated in central urban areas with complex built and navigable environments, such as universities, hospitals and terminals. The articles were then further refined to those that examined educational institutions due to the particular spatial characteristics mentioned in the introduction. The articles used featured complex experimental locations and wayfinding that was performed in real time or in virtual conditions.

From the list of selected articles, four articles were related to institutional wayfinding (university campus). Two additional articles were selected for review based on their examination of cross-cultural aspects of wayfinding and navigation; these articles focused on the impacts of culture and individual differences on wayfinding behaviour. Six articles were related to wayfinding behaviour in VR-based simulations and VE. The articles related to computer simulations consisted of on-screen VE, VR and augmented reality (AR). Six articles were related to wayfinding aids and

cues, and examined the impacts of signage information design on human wayfinding behaviour. These articles studied graphics, language accessibility, colours, cross-cultural symbols and culturally consistent/universal pictograms. The remaining nine articles were related to wayfinding behaviour and performance according to familiarity with the environment, which has a substantial influence on human wayfinding behaviour.

Screened articles were critically discussed for effective outcomes and gaps to be addressed by future research. The articles were categorised in Table 1 based on content, research methodology, experimental techniques, use of technology, nature of subjects and findings.

[Table 1 near here]

3 Discussion

Wayfinding plays an important part in daily life, from commuting between cities to walking to destinations. It has become difficult in large developments (Meneghetti et al. 2017) as the buildings and spatial context become more complicated. A study by Allen (1999) described the three major types of wayfinding as exploratory navigation, travelling to a familiar destination and travelling to a novel destination. This study also described the various means of wayfinding, including roaming between landmarks and path integration. Some wayfinding tasks are quite well explored, such as path integration (Loomis et al. 1993), while others are more imprecise, such as cognitive mapping and schematic tasks (Kitchin 1994).

The basic purpose of wayfinding is to find the optimal route to reach a destination with the aid of environmental indicators and distance and survey knowledge (Cheung 2006; Siegel and White 1975). Survey knowledge acquired from maps or environmental aids may depend largely on the user's familiarity with a particular environment (Holscher et al. 2006). In addition to environmental familiarity, cognitive mapping and path searching strategies are

influential in wayfinding abilities. It has been suggested that wayfinding problems are caused by underdeveloped decision-making and problem-solving abilities, which should be examined in order to evaluate wayfinding performance for real-world applications (Rodrigues, Coelho, and Tavares 2018; Stern and Portugali 1999). There are a number of factors that influence wayfinding behaviour based on the interactions of humans with their surrounding environment. Significant elements taken from the existing literature are discussed hereunder.

3.1 University campus as a complex environment

The term 'complex environment' describes an environment in which spaces are not well defined for navigation. These are environments where navigational, spatial or geometric cues are unclear and confusing (Stankiewicz and Kalia 2007). Most spatial surroundings (both indoor and outdoor) can be described in this way, including public spaces, city centres, healthcare settings and educational institutions. Wayfinding in these complex environments can cause disorientation, which is linked to stress and frustration (Chang 2013; Haake, Smith, and Pick-Jr. 1984).

Wayfinding in university campuses has gained the interest of a number of researchers due to its complex nature and excessive roaming within the environment. Several studies (Afrooz, White, and Parolin 2018; Emo et al. 2014; Li and Klippel 2012; Meneghetti et al. 2017; Torres-Sospedra et al. 2015) mentioned in Table 1 used university settings as the environment for wayfinding research. Universities have many new students and visitors each year with a negligible level of environmental familiarity. Spatial design features are critical to the legibility of such complex environments, and are also crucial to users' wellbeing (Arthur and Passini 1992; Lynch 1960; Weisman 1981). When spatial aids do not adequately demonstrate the name and location of different facilities (Abu-Ghazzeh 1996), this leads to

disorientation, stress, frustration and time wasted.

The wayfinding research based on complex city settings cannot directly be applied to university settings, although they may share the same socioeconomic and environmental structure (Torres-Sospedra et al. 2015), as shown in Table 1. City settings have roads, walking paths, clear landmarks and environmental cues to guide users. In the complex university setting, the entire exterior is walkable and accessible, causing confusion in directed wayfinding. Several factors may exacerbate the complexity of this environment, particularly regarding universities situated in densely populated urban areas. In such settings, there is often a lack of discrete boundaries (Cheung 2006), complex layout planning (Hidayetoglu, Yildirim, and Cagatay 2010), a lack of efficient environmental cues, diffused walkable paths, shared social spaces, a heavy concentration of people, visual richness, complexity in gaining familiarity and a lack of functional space hierarchies. These are influential factors that reduce the legibility of campus environments.

3.2 Wayfinding metrics

Various studies have evaluated human wayfinding performance based on task performance criteria. These studies have measured the time taken to complete a task (Bowman, Johnson, and Hodges 2001; Elvins et al. 2001; Zhai et al. 1999), the distance travelled to the destination and the number of errors made during the task (Ruddle and Jones 2001; Witmer et al. 1996). Wayfinding behaviour has also been explored based on time and error classification (Bowman, Johnson, and Hodges 2001) and by observing the path followed (Darken and Sibert 1996). According to the mentioned key metrics, wayfinding behaviour has been further studied through asking participants to justify their actions. These justifications for selective behaviour have been studied through post-experiment questionnaires and think-

aloud protocols (Murray et al. 2000).

The combination of methodologies used for wayfinding evaluation of interior spaces has been described as space syntax (Hoeven and Nes 2014), as mentioned in Table 1. It is a set of particular methodologies and theories used for the quantification and interpretation of a building's spatial features and the settlements around it (Hillier, Hanson, and Graham 1987). Space syntax consists of three key methodologies involving convex spaces, isovist fields and axial lines. Convex space is defined as all those points joined to all other points within a space without crossing the boundary of the space (Hillier 1988), while isovist is the view of the user in a spatial environment from a specific perspective (Benedikt 1979). Axial lines are defined as the longest possible sightline within building structures or the interior spaces of a structure.

The study by Hoeven and Nes (2014) mentioned in Table 1 evaluated wayfinding in underground train stations in Belgium using space syntax and found it effective in analysing the space. Although the metrics for wayfinding may seem to be excluded from the described methodologies of space syntax (Ratti 2004), axial lines have a strong influence on wayfinding (Jiang and Liu 2009; Turner 2007). Another study (Davies and Peebles 2010) discussed the possible barriers to using space syntax for orientation in a three-dimensional spatial layout, because it relies on two-dimensional schematics. In addition, the space syntax methodologies cannot evaluate the impacts of spatial forms, decision point actions and the effectiveness of signage on real-time wayfinding behaviours (Tzeng and Huang 2009).

3.3 Cultural impacts

Culture, an inherently diverse element, is important in defining human wayfinding behaviour, because of the different understandings of spatial cues across different cultures (Karimi 2015; Tijus et al. 2007). Several researchers have investigated cross-cultural impacts

and influences in the fields of psychology, design and healthcare (Asghar, Torrens, and Harland 2018). Culture and human cognition are considered relative and important issues in the area of cross-cultural psychology. Cultural differences can affect cognitive behaviour for the abstraction and understanding of meaning (Asghar, Torrens, and Harland 2019). The differences in cognitive strategies to respond to the same situation may be defined as cultural differences. Cognitive strategies include an individual's manner of perception, memory and information delivery regarding a particular situation (Dornëy 2005). These cognitive strategies influence the decision-making skills of an individual. During wayfinding tasks, there are multiple decision points for determining the directions to the destination; therefore, wayfinding behaviour can differ based on different decision-making strategies. Moreover, the various interpretations of spatial cues due to cultural and individual differences may have a substantial impact on cognitive strategies (Brugger 1999; Foster and Afzalnia 2005). Therefore, cultural background has a significant influence on interpretative strategies, conception of meaning, cognitive decisions and comprehension of spatial cues.

3.4 Experimental settings (real-time and virtual)

Wayfinding research has been conducted in different scenarios and various environmental settings. Studies have explored spatial behaviour inside libraries and other spatial settings (Barclay and Scott 2012; Campbell-Hicks 2011; Li and Klippel 2012; Polger and Stempler 2014; Serfass 2011; Tzeng and Wang 2011; White 2010). Healthcare settings have been considered most appropriate for studies, as these spaces are complex and involve a time constraint. The standardisation of spatial cues in these settings has helped people to find their way in unfamiliar environments (Gakopoulos 2009; Lee et al. 2014; Rousek and Hallbeck 2011). Correspondingly, studies have tried to standardise spatial cues, specifically

wayfinding symbols and pictograms (Foster and Afzalnia 2005; Olmstead 1999). Such standardisation is an important parameter in understanding users' varied behaviour due to individual differences (Carrillo et al. 2014; Romera 2015).

Wayfinding experiments in real-time environments for evaluating behaviours have been accompanied by many confounding factors. These factors include diversion of attention, path association, reflections, crowd movements and weather conditions. It is quite difficult to achieve full control over the variables in real-time wayfinding experiments. Previous studies have suggested that computer VE can be considered an effective alternative to real-time wayfinding environments due to better control over confounding factors (Ahmad, Goldiez, and Hancock 2005; Cao, Lin, and Li 2019; Hoe et al. 2017; Vilar, Rebelo, and Noriega 2014).

VE have been used in research on spatial navigation for the last two decades. Multiple studies have used VE on a computer screen, such as desktop virtual reality (DVR) (Cubukcu and Nasar 2005; Omer and Goldblatt 2007) and AR systems (Hedley 2008; Lonergan and Hedley 2014). With the advent of technology, fully immersive VE have been developed for research on wayfinding. Head-mounted displays (HMD) have been used to display the fully immersive VE, allowing the user to have a 360-degree view of the experiment. Studies have used equipment such as the HTC vive in conjunction with the steam VR positioning system for wayfinding research (Cao, Lin, and Li 2019; Niehorster, Li, and Lappe 2017). Multiple studies have been conducted in VR with different variations of HMD for the exploration and evaluation of indoor and outdoor wayfinding (Creem-Regehr et al. 2015; Lingwood et al. 2015; Meng and Zhang 2014; Tang, Wu, and Lin 2009; Vilar et al. 2013).

VE can be used to study different emergencies, as they are quite complicated to conceive, control and perform in a real-time environment. Multiple mass egress models for

indoor wayfinding research have been proposed under fire, earthquake and other emergency scenarios. For experiments, these emergencies can only be produced in VE due to potential safety hazards.

3.5 Unfamiliar environment

Wayfinding in a familiar environment involves the search for a new location in an already known environment (Wiener, Büchner, and Hölscher 2009). Human actions and behaviours can be very different in known versus unfamiliar surroundings. Studies have supported this finding by repeating wayfinding experiments with different levels of environmental familiarity (Afrooz, White, and Parolin 2018; Garling, Book, and Lindenberg 1986; Tzeng and Huang 2009). Environmental familiarity allowed users to deduce the gathered information in a relaxed and flexible way (Iachini, Ruggiero, and Ruotolo 2009; Kirasic, Allen, and Siegel 1984; Marchette et al. 2011; Sholl, Kenny, and DellaPorta 2006), confident that they would not get lost. Similar interpretations have been derived from multiple studies (Afrooz, White, and Parolin 2018; Evans 1980; Garling 1989; Kinsley, Schoonover, and Spitler 2016; Lokka and Coltekin 2019) that people who are familiar with an environment rely more on the retrieval of information from memory, cognitive memory and previous mental mapping of the environment, rather than on the environmental information. Memory nodes and information retrieval from the long-term memory are quite influential in wayfinding planning and defining route strategies. These spatial planning actions can be optimised with repeated exposure to an environment (Garling et al. 1981).

Familiarity has an influence on real-time wayfinding environments, as well as on environmental cues such as signage. A study on signage suggested that people have different responses in virtual wayfinding experiments when different signage facilities are present

(Tang, Wu, and Lin 2009). Users performed better in the presence of familiar signage and interpreted signage comfortably. A few studies have also suggested that standardisation and consistency of spatial cues can play a significant role in enhancing spatial comprehension (Leonard, Verster, and Coetzee 2014; Rodrigues, Coelho, and Tavares 2018).

3.6 Wayfinding signage design

Several spatial factors affect wayfinding performance and behaviour, including information signage. Studies have investigated the role of wayfinding signage design in hospital settings (Rodrigues, Coelho, and Tavares 2018; Schuster 2012). These studies provided recommendations for textual and symbolic wayfinding information, while suggesting a need for standardisation. A study by Polger and Stempler (2014) provided recommendations regarding signage colours and symbolic information, particularly in library settings. Similarly, a study by Lee et al. (2014) investigated healthcare wayfinding symbols in the United States, South Korea and Turkey. These results found a strong relationship between a user's nationality and his or her comprehension of signage information. For effective delivery of information to the user, it was suggested that the user's perspective needed to be well understood. A study by Trisnawati and Sriwarno (2018) explored users' visual perception of wayfinding signage. This study used identification signs for toilets and found variations in understanding of the perceived signage information. The study also recommended understanding the user's perspective in terms of information comprehension before designing symbols for wayfinding signage.

4 Conclusion

Wayfinding has been explored in a number of environmental settings, including complex settings such as hospitals and public institutions. University campuses situated in city centres

present multiple wayfinding issues for new students and visitors, resulting in time wasted, stress and frustration. The studied literature identified these university campuses as complex environments for wayfinding, especially for users unfamiliar with them. Studies based on spatial syntax, wayfinding behaviour and wayfinding performance in complex settings have identified several causes for wayfinding issues. These causes include the user's individual and cultural differences, layout unfamiliarity and ineffective environmental information for wayfinding. Several studies have explored these wayfinding problems in real-time environments such as university libraries, hospitals and underground stations, though there is a need for further investigation. Multiple studies have investigated the effectiveness of wayfinding signage design in complex settings and found that the design is often inefficient in providing information and gaining visual attention. With the advancements in technology, studies have also tried to explore these issues in VE, using desktop monitors, AR and VR, which provide better control of confounding variables. The studies on textual and symbolic wayfinding information have recommended further investigation into varied user perception and comprehension due to individual and cultural differences. Culturally consistent information design can enhance users' understanding of environments and make further exploration easier.

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Table 1. Systematic review list of research articles

Authors	Study purpose	Study location	Methodology	Analysis techniques	Type & number of subjects studied	Findings
University campus wayfinding						
Meneghetti et al., 2017	Wayfinding performance (visuospatial factors)	School of psychology campus Padova, Italy	Analysis of individual differences and environment knowledge	Corsi blocks tasks, mental rotation test, sketch map pointing tasks	120 (93 F, 27 M), undergraduate students	Recall accuracy, visiospatial abilities, and cognitive abilities in wayfinding are strongly associated with environmental familiarity
Abu-Ghazzeh, 1996	To investigate the architectural legibility of the university	King Saud University, Saudi Arabia	The cognitive process of wayfinding	Real-time wayfinding using actions: asking people, using signs, reading buildings	30, aged 18, students unfamiliar with the environment	Better wayfinding information design and high visual access through vantage points can reduce spatial complexity

Li and Klippel, 2012	Used space syntax analysis for the wayfinding behaviour	Paterno Library, Pennsylvania State University, USA	Realtime finding of books on different library floors	Space syntax method, depth mapping, ICD (interconnection density), wayfinding time and distance	8, students unfamiliar with the environment	Confirmed the relationship between environment (visibility, connectivity, and layout complexity) and human wayfinding behaviour. Individual differences are also associated
Torres-Sospedra et al., 2015	Smart UJI platform apps checking	Jaume I University (UJI) campus, Valencia, Spain	Smart city and smart university facilities comparison	UJI application platform: smart UJI app, smart UI AR, 3D viewer, etc. using WAP	More than 20	Smart UJI app has been developed and tested for wayfinding on campus and proved helpful. App was also useful for planning and designing space
Cross-cultural						
Hoeven and Nes, 2014	Space syntax method in indoor wayfinding	Bockstael underground station,	Space syntax elements in underground station	Axial (all lines), orientability (point depth), isovist (all	No subjects, space analysis	Space syntax analyses revealed that underground train stations can be well organised spatially

		Brussels, Belgium		points), and depth (map)		It is an effective method for 2D spatial layout analysis
Filomena, Verstegen, and Manley, 2019	To compute the city of Boston using lynch parameters	Boston city centre and surrounding areas, USA	Colour coding the computational map with lynch parameters	Using nodes, paths, districts, landmarks, and edges	No subjects, city map analysis	Boston city has been computationally mapped based on lynch's parameters. The map presents nodes and districts for the reference of future urban designers
Virtual wayfinding						
Ahmad, Goldiez, and Hancock, 2005	Spatial performance with gender difference	Physical maze in an experimental setup	Real-time wayfinding in a maze with AR system	Battlefield augmented reality system	120 (60 F, 60 M), aged 17-37	Males outperformed females in AR wayfinding tasks. Similar gender impacts in real and virtual environments have been recorded
Lin, Cao, and Li, 2019	Stress level and exposures on wayfinding performance	Virtual museum lab experiment	Fire evacuation and smoke effects on wayfinding	Analysing time taken and distance travelled, HTC vive HMD	60, undergraduate/graduate students, Chinese	Repeated exposure to an environment can improve wayfinding performance under stress

Hidayetoglu, Yildirim, and Akalin, 2012	Effects of colours and lights on wayfinding performance	VR exp. in Selcuk University, Konya, Turkey	Different intensity of light with warm, cool, and neutral colours	Prepared videos with colour settings to ask about the remembrance of the place	120, undergraduate students, unfamiliar with the environment	Warm colours are good for landmark and wayfinding information, while cool colours are considered more navigable for spaces
Kim et al., 2015	To assess the user experience in wayfinding	UX based, university hospital	Locating different hospital facilities on levels	Used video camera for wayfinding behaviour and developed AR-based app	10 (5 F, 5 M), university students	The quantity of UX information was tested on the AR system for wayfinding and found that a certain balance of information is needed for easy wayfinding
Hoe et al., 2017	Training method for spatial visualization	Taiwan	Manual controller design for a training method	AR with Solidworks to design and analyse the effectiveness of this new training system	22 (14 F, 8 M), senior citizens	The study proposed an AR system for training mental rotational skills of the elderly. Used visual media as a tool of training
Schrom-Feiertag,	To analyse an indoor guiding system	VR (Vienna's main railway	Using BEGAZE® & visual analysis of	SMI (Senso Motoric Instruments) 3D gaze analysis	24 (12 F, 12 M), aged 22-75,	Used eye tracking for analysing gaze patterns during wayfinding. No significant

Settgast, and Seer, 2017		station), Vienna, Austria	wayfinding time, distance and signs	method, four-sided full VE, with Microsoft kinetics	unfamiliar with the environment	relationship between age and wayfinding. Identified points of interest in railway station
Signage pictograms						
Rodrigues, Coelho, and Tavares, 2018	Literature review on effective signs	Portugal	Searching databases: Science Direct, Scopus, and Springer	English studies related to healthcare wayfinding signs		Provided recommendations on signage text formatting, layout, symbols and pictograms in healthcare wayfinding
Lee et al., 2014	Compare the healthcare signs across countries	USA, South Korea, and Turkey	Comprehension, matching, and judgment tests of health symbols	Statistical analysis, symbols were presented on paper	180 (90 F, 90 M) aged 18-50+	Cross-cultural analysis of healthcare symbols for wayfinding. Suggests strong relationship between nationality and signage information
Trisnawati and Sriwarno, 2018	Measure visual perception of figures on toilet signages	Bandung Institute, Indonesia	Scale from 1-100, level of difficulty in sign understanding	Data collected using questionnaires while symbols were	36 (21 F, 15 M), undergraduate students, aged 18-22	Studied visual perception of human figures in signage. Recommended understanding

				presented on a projector		users' perspectives before designing symbols
Polger and Stempler, 2014	Library sign considering best practices and signage policy	Staten Island Library, city university, New York, USA	University library best signage placement policies	Data collection for evaluating sign policy through a questionnaire	75 library staff members	Provided recommendations for library signage design, including colour, symbols, and textual information
Schuster, 2012	Language accessibility of signs, linguistic landscape	Hadassah hospital, Jerusalem	Sample signs in a hospital using locations and sign interpretation	Analysis of 250 photos based on location, function, and language order		Provided framework for wayfinding information design based on language accessibility and linguistic landscape
Tzeng and Wang, 2011	Reliable model for university library sign system	Taiwan	Exploratory factor analysis for layout, display, and lighting	Data collection for evaluating models of library signs through a questionnaire	488 university students	Provided tool for library sign evaluation based on location, content, colour, font, sizing, light, form, and materials
Unfamiliar environment wayfinding						

Greenroyd et al., 2018	Signage strategies based on natural wayfinding metrics	Loughborough University	Space of signage placement with wayfinding metrics			Tool for analysing wayfinding decision points based on path's visual access, straightness, and width
Butler et al., 1993	Features an optimal new user wayfinding aid	Ball State University, Indiana	Real-time wayfinding with and without YAH maps	Data in the form of wayfinding time duration and correlating it with YAH map time	52 university students	Signs are more effective than YAH maps. Provided recommendations for signage design placements and information volume
Joy, Yien, and Chen, 2016	Evaluate healthcare symbols and their adoption	Taiwan	Most suitable symbols for healthcare system in Taiwan	Data collection for evaluating sign through a questionnaire	122, aged 15-75, different user exposures to healthcare symbols	Strong cultural influence on identification of signs and symbols. Factors are background knowledge and symbol categories
Afrooz, White, and Parolin, 2018	Memory recognition in active and	UNSW campus, Sydney	Real-time wayfinding in the campus for	Eye tracking, mirror image discrimination	108 (52 F, 56 M), aged 15-58	Recognition and recollected memory are important in wayfinding. City should have

	passive exploration		locations and signage	test, spatial ability questionnaire		eye-catching landmarks. Active exploration improves wayfinding abilities
Tzeng and Huang, 2009	Wayfinding spatial forms, decision points, and signages	Hospital outpatient services, Taiwan	Real-time wayfinding in an outdoor patient facility	Stop, search, decide, and legibility as behaviour content	24 (9 F, 15 M), college-level education	Orientation signage is most important, entrance signage can divide traffic, stop behaviours occur in closed form spaces
Erkan, 2018	Effect of gender, age, and education on wayfinding	Suleiman Demirel University, Turkey	Virtual wayfinding and behaviour analysis in architectural spaces	Individual differences in wayfinding. VR HMD and EEG for cognitive activity	343 (173 F, 170 M), aged 18-65	Ceiling height is an important factor in wayfinding. Height can effect cognition and behaviour
Jansen-Osmann and Wiedenbauer, 2004	Effect of colour on wayfinding tasks and strategies	Heinrich-Heine-University, Dusseldorf, Germany	Virtual wayfinding and behaviour analysis in a 3D maze	Virtual wayfinding tasks in grey and coloured maze	60 (20 second graders, 20 sixth graders, and 20 adults)	A colour coded wayfinding environment is good for children and adults. Not influential in building survey knowledge

Kinsley, Schoonover, and Spitler, 2016	Authentic experience of finding books in the library	Florida State University, USA	Locate 3 books in the library, with different levels of difficulty	GoPro for wayfinding behaviour, questionnaire, think aloud protocol	24 (12 F, 12 M), undergraduate students	Identified GoPro as an ethnographic tool of research. Captured detailed behaviour with first person view. Better to understand the behaviour
Lokka and Coltekin, 2019	Spatial knowledge for optimised route learning		Lab experiment, VE on videos on the screen	Short-term memory (visual, visuospatial, and spatial) and long-term memory test	42 (23 F, 19 M), university students	When optimising virtual environments for wayfinding, it is useful and preferable to mix them with reality

Figure **1.** Systematic review process