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Understanding Spatial Cognition for Designing Pedestrian Wayfinding Systems: development of practical guidance

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Abstract
Individuals react differently when moving in urban spaces, as their senses are distinctively activated. Their interpretations and how the built environment is perceived result in different meanings. When studying public spaces, it is of utmost importance to understand how residents and visitors construct images of the city, by perceiving and appropriating urban spaces. In particular, this is decisive when designing Pedestrian Wayfinding Systems (PWS) in urban areas.
Based on spatial cognition studies, this paper identifies and explores the main aspects influencing the design of wayfinding systems. The study is structured in three main parts. First, the article reviews literature on spatial cognition and human behaviors. Second, it analyzes some reference cases considered good practices for PWS, their implementation in contemporary public spaces, and their visual and aesthetic forms of expression. Third, it develops a practical guide for designing a PWS focused on end-users. More specifically, the research aims to support the municipality of Porto in defining the tender specifications for the development of a PWS, to be included in the future Integrated Signage and Information System.
Ultimately, this study proposes recommendations to improve pedestrian navigation in the urban context and help decision-makers, designers, and urban planners potentially create better wayfinding systems in the future.

Keywords. Spatial Cognition, Mental Mapping, Human Behavior, Wayfinding Systems, Urban design and Planning.

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1. Introduction

Nowadays, the power of images cannot be ignored, especially their influence on human perception and behavior in urban spaces. In this context, understanding the processes of image-making, as people experience the city, is essential in the design of better wayfinding systems for pedestrians. Thus, spatial cognition studies can provide important insights into the user's capacity to grasp key elements of the outside world and learn from their surroundings, allowing them to navigate and find their way in different environments.

Urban spaces are inherently related to the activities that people perform in them, and also to how they perceive and assimilate clues and signs of the urban landscape and build their mental maps. It is essential to fully acknowledge these aspects, transcribing individual and collective mental images into urban narratives, enabling a broader understanding of how this process constitutes a subject's relationship with the city and how members of a community appropriate the places they use. Spatial cognition knowledge can be applied in the areas of urban design and planning, encouraging individuals to become not only passive recipients, but also actors directly involved in decision-making related to the public domain. Engaging communities in designing and planning processes has been consensually recognized (Afdhal et al. 2022; Frantzeskaki, Niki and Rok 2018; Turnhout et al. 2020) to lead to more meaningful places, promoting a sense of belonging by bringing the population closer to the spaces they use, enhancing the sense of community, and responding more effectively to their needs and desires. Madden et al. (2000) argue that the current disciplinary and project-oriented approach to public space planning should be replaced by an alternative, location-oriented and community-based perspective. This paradigm shift enables active and continuous participation of the population in urban projects, drawing from the immeasurable value of existing local knowledge.

Thus, actors and agents responsible for urban design and planning, such as city planners and municipal authorities, are more committed to support and engage the population in creating and transforming their own spaces. Urban strategies around the world have been encouraging inclusive and collaborative approaches, cross-sectoral partnerships, and innovative solutions to achieve more sustainable, safe and attractive people-friendly spaces (Mach et al. 2020; Puerari et al. 2018; Shirvani et al. 2022). When it comes to the requalification of public spaces, urban policies have been strongly oriented to promote non-motorized mobility, such as walking and cycling.

In particular, walking is fundamental as long as it is pleasant, free, and accessible to everyone. In this context, pedestrian wayfinding systems (PWS) have been emerging as a new global trend in terms of active mobility. Hence, aspects, such as urban form, people's spatial behavior, and cognitive mapping (Couclelis et al. 1987), become essential study tools for the definition of environmental components that facilitate the orientation process. Eslami (2019) argued that measures of urban layout, e.g., integration, connectivity, visibility, and choice, can predict the movement patterns of individuals and enhance their experience within the built environment. This happens either in daily activities performed by its residents or in the first contact of visitors with the place. Hence, the analysis of the subjective and material dimensions that influence people's actions towards the city can help the development of navigation tools for pedestrians and improve their wayfinding performance. The goal is to encourage active pedestrian mobility in public spaces.

This article aims to explore the main aspects influencing the design of PWS based on spatial cognition knowledge. First, we conduct a literature review on the subject. The second part of this study is the analysis of successful worldwide reference cases of PWS. Their success is mostly due to the application of mental mapping approaches in the design of PWS, with a positive impact in public spaces through innovative, mainly user-oriented mobility solutions. Finally, it addresses a request from the Porto municipality to make recommendations, comprised in a practical guide, on how the *Integrated Signage and Information Project* (ISIP) should be designed. The research was developed in close collaboration with the Division of Requalification of Public Space of the municipality of Porto.

2. Literature Overview

The importance of Gordon Cullen's series of essays and drawings for the Townscape Casebook, (1949), followed by his book *The Concise Townscape* (1961), and Kevin Lynch's famous *Image of the city* (1960) to urbanism literature are undeniable. Cullen's concept of "serial vision" is fundamental to understand the pedestrian experience in the urban space. He argues that images provoke emotive responses in the subjects, engaging them to explore the city. The changing views observed through bodily movements in the built environment allow the human mind to create imagery representations of places. Thus, how people perceive and interpret their surroundings influences pedestrian behavior.

Lynch (1960), in his well-known book, proposes an innovative method for addressing research questions related to city form and cognitive mapping, influencing different disciplines such as architecture, psychology, social geography, urban design and planning. Since then, Lynch's work has become a reference for research and intervention practices in public space (Osóch and Czaplińska 2019; Quercia 2016; Šakaja 2020; Stevens 2006), as it objectively explores the complex interaction between individuals and their immediate surroundings. Besides, it promotes a specific understanding of how people perceive and assimilate the components of the built environment, transforming them into imagery representations full of sensory information and meanings.

In his research, Lynch (1960) identified the spatial features of the urban space that people use to structure their mental maps, and classified them into five groups: paths, edges, districts, nodes, and landmarks. Also, for a city to be considered legible, these elements must be easily recognizable, both separately and as a set, and have a coherent pattern. As an example, when the form of a building reflects its function, there is legibility (Bentley 2015). Legibility emerges as an essential quality in the urban layout, facilitating its readiness, allowing people to construct a more accurate mental image of the real world.

Powerful images increase the likelihood of the user to build a clear and cohesive representation of the urban realm in their minds. The image's capacity to awaken the senses and generate meaning (practical or emotional) is essential to guide people moving in the built environment, facilitating a more complete and intense experience in the city. Thus, a well-formed city is memorable because it is legible (Lynch 1960). In this sense, personal representations of the urban fabric are fundamental for the navigation task.

2.1. Spatial Cognition and human behaviors

The word cognition can be described as the mental capacity to process and transform information into knowledge through personal and collective experiences and the senses (Angus and Christine 2010). Cognitive skills involve imagining, observing, feeling, thinking, remembering and perceiving (Gold 2004). Each individual has a different cognitive process due to material and subjective factors that affect how they interact with the world. Thus, the term "spatial cognition" emerges as a set of human cognitive skills linked to the acquisition and processing of spatial knowledge. This capacity involves the generation, storage, and retrieval of mental images, which, combined with motor and sensory systems, help people in the task of recognizing and finding their way around (Montello et al. 1999). Perception, sometimes mistaken for cognition, is the ability of the cognitive system. Its function is to capture enough social and physical information from the environment, so that the human brain can organize it, allowing the subject to make sense of their surroundings. That is to say, the concepts of cognition and perception, although distinct in meaning (the first one being much broader than the second), are both related to the human ability to acquire knowledge of the surrounding physical environment (Eslami 2019). In the scope of spatial knowledge, mental mapping and navigation, the two concepts have been used together in many studies since the late ’70s, with the increase of publications and citations in the social and environmental sciences (Thorndyke and Hayes-Roth 1982; Ishikawa and Montello 2006; Chrastil and Warren 2013).

Sensory experience is an essential step for people to learn from the urban context, assimilate its information, and understand mental images by giving them meanings. In this line of thought, **Figure 1** shows how environmental components impact on the users, establishing connections that suggest ideas and create emotions.

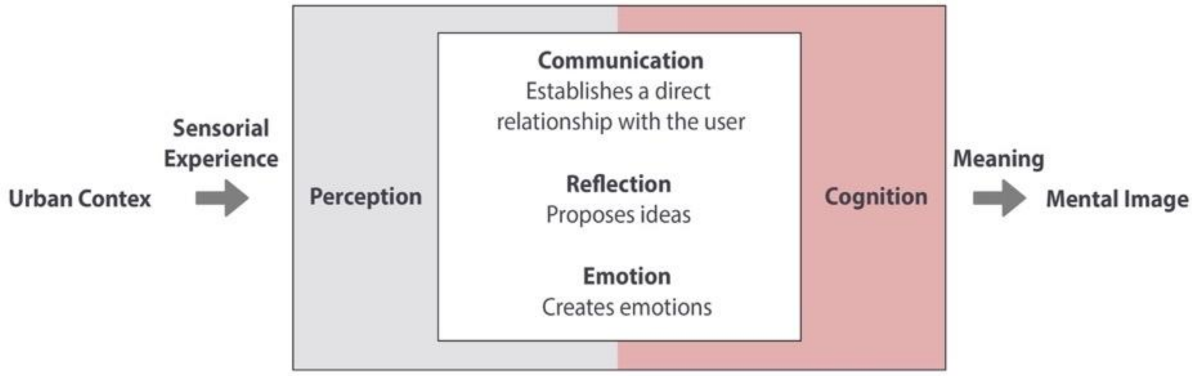

Figure 1: Process of creating mental images through sensorial experience in the urban context.

The environmental layout shapes human behavior at the cognitive level, thus influencing how one performs daily activities by, for example, choosing a route to a familiar place (Crucitti, Latora and Porta 2006; Hölscher et al. 2011; Mohamad and Said 2014; Peponis et al. 1998).

In this case, the tangible and intangible dimensions of the world intertwine, and the user or subject, through physiological perception, enters a subjective dimension. Through their cognitive abilities, they first process the information, and then understand how elements interact with each other and as a whole, as if they were contemplating a map comprising a range of mental images. In a way, human decisions and actions are the result of the emotions and meanings attributed to the components of the built environment (Balaban et al. 2017; Ferri and Popp 2022).

2.1.1.Main factors influencing people's choice and behavior

Images are complex places where the real, the imaginary, the symbolic, and the ideological intertwine, creating constellations of meanings. It is the prerogative of all images to awaken some emotion in the viewer. Nowadays, the image occupies a considerable space in contemporary society, becoming as important as other languages that are part of our daily lives. The image has the capacity to testify and expose the city.

In general, vision is not only related to the eyes. Some would say that it is also possible to see through other senses, as environmental experiences derive from stimuli that the subject perceives through the body as a whole. When reading spaces, the individual becomes capable of transforming elements, such as shape, volume and perspective, into raw materials for subjectivity. The representation of architecture and urbanism, even visual and symbolic, exposes how people relate aesthetically to their surroundings.

A mental image is a representation of reality, constructed by human cognition through the perception of stimuli at the place where the subject is. Through this image, they become aware of their relationship with their surroundings. As people move around the city, different meanings and importance are assigned to spatial elements within the urban context. This hierarchy changes due to the parameters of the perceived object in relation to the observer: its distance, size, color, shape, function, etc.

People become familiar with a given environment by exploring them through their senses (sight, sound, smell, taste, and touch). Searching strategies and cognitive mapping abilities are fundamental to achieve environmental familiarity. Daily activities, the arrangement of spatial elements, and the memories attached to them contribute to this factor. Multi-sensory spatial experiences are imperative for meaning-making, which improves knowledge acquisition and wayfinding performance (Böhme 2013; Dai and Zheng 2021; Hasse 2016; Wankhede and Wahurwagh 2016).

The image encompasses a series of cultural parameters and individual differences. Also, people apprehend and assimilate urban scenes in a personal way. This process is influenced by social structures and is sensitive to feelings, emotions, and ideas. According to Ishikawa and Montello (2006), people's cognitive maps and spatial behavior will always be different at some level due to individual singularities. Thus, emotional and sensorial responses play an important role in decision-making and route choice.

Environmental complexity is another factor that affects the cognitive ability of people to learn from space and navigate in the city. It is related to the morphology of the place, local specificities, position, characteristics, and articulation of urban elements, for example. Some authors argued that spatial cues in complex city settings can be unclear and confusing. Hence, the legibility of urban elements is crucial for users to become familiar with the environment and find their way (Iftikhar et al. 2020; Eslami 2019, Lynch 1960). Finally, the literature indicates that socio-demographic variables (such as income, ethnicity, gender and age) impact people's navigation preferences once they have distinct urban experiences and create different mental maps (Montello., et al. 1999; Tournier et al. 2016).

Factors	Description	Author/Year
Environment familiarity	Spatial cues, memories, daily activities	Dai and Zheng 2021; Iftikhar et al. 2020; Lynch 1960; Stea 2017; Hölscher et al. 2011; Eslami 2019; Golledge 2000; Xia et al. 2008.
Cultural and individual differences	Social structure, emotions, ideas, history, personality	Iftikhar et al. 2020; Ishikawa and Montello 2006; Mark and Frank 1996; Symonds et al. 2017.
Sensorial experience	Visual, touch, sound, smell and taste	Bille and Sorensen 2019; Dai and Zheng 2021; Wankhede and Wahurwagh 2016; Hasse 2016; Böhme 2013; Mark and Frank, 1996.
Environmental complexity	Morphology, local particularities, organization and relationship of urban elements in space, hierarchy and scale	Iftikhar et al. 2020; Lynch 1960; Hegarty et al. 2006; Pazzaglia 2003; Miller 1956; Raubal and Egenhofer 1998.
Socio-demographic characteristics	Income, ethnicity, gender, age, occupation, housing status, and level of education	Dai and Zheng 2021; Lynch 1960; Montello., et al. 1999; Hannes et al. 2006; Tournier et al. 2016.

Table 1: Main factors influencing people's behavior when navigating the built environment.

Table 1 addresses the most relevant factors cited in the literature on spatial cognition. They directly influence people's behavior when navigating the built environment, from the initial perception and assimilation to the choice of route to reach a destination. It is noteworthy that most factors are subjective and dependent on local specificities, and thus context-based and difficult to measure. Nevertheless, parameters, such as environmental complexity, are mainly dependent on the physical and material elements of the urban context.

2.2. Pedestrian Wayfinding System (PWS)

Based on the previous understanding of the individual mental representations of urban spaces, this section aims to further explore the task of navigating, more specifically wayfinding systems.

Kevin Lynch was the first author to use the term "wayfinding" in his book *Image of the city* (Lynch 1960). Ever since, it has been used in different areas of research and gained various definitions. It can be described as "a generic navigation task of traveling from one location to a specific destination" (Golledge 2000; Iftikhar et al. 2020; Ruddle and Lessels 2006). According to Montello (2005), the navigation in urban spaces is not an easy task, involving bodily movements around the immediate surroundings by using the motor and sensory systems, and a planned action towards a desirable destination (Chersi and Burgess 2015; Epstein et al. 2017).

Wayfinding is both the practical action of traveling to a familiar/unfamiliar destination, and just exploratory navigation (Golledge et al. 2000). It is the result of information processing (environment perception and cognitive mapping), decision-making (selection of reference points and path integration based on social aspects and spatial quality), and decision execution (behavioral action – movement toward a destination) (Hunter et al. 2016; Passini 1984). In other words, wayfinding is the interrelationship between "seeing" and "going" (Hillier 2003).

A pedestrian wayfinding system (PWS) encompasses a set of signs placed in the urban environment, to guide the movement of people on foot. Such programs consider all elements that constitute the city in terms of architecture, natural assets, private and public space distribution, configuration and quality of urban entities, etc. Even sensory cues (such as lighting and sound) play an essential role in the design of consistent and functional signage schemes.

Moreover, these systems can play a relevant role in promoting active mobility and thus contributing with benefits to local economy and city life (López-Lambas, Sánchez, J. and Alonso 2021; Salazar Miranda et al. 2021). More than just helping tourists to find major destinations, high-quality navigation tools change the behavior of users, promoting walkability for the city's residents and visitors (Jabbari, Ahmadi and Ramos 2022; Keliikoa et al. 2018; Yun, Kang, and Lee 2018). Therefore, a modal shift improves sustainability and public health, encouraging exploration, longer stays in public spaces, and pedestrian traffic. It also increases spatial knowledge and social interaction, which in turn contribute to building a more dynamic and livable environment.

In the last decade, pedestrian signage systems have been recognized in many cities around the world as an effective mechanism to encourage walkability (Candido 2017; Ryan and Hill 2022). When implemented consistently in an urban context, they can increase the number of journeys made on foot, as well as the time people stay in places, potentially spending more money and boosting local businesses. Clear and friendly information improves the navigator's experience in urban space and the spatial knowledge acquired. Mental images well established in the human mind contribute to the generation of more effective cognitive maps, ensuring greater freedom of movement due to increased environmental familiarity.

Wayfinding strategies help locals and tourists make the most of the city. In addition, a well-connected system that facilitates modal shifting during a journey (from walking to public transportation, for example) is more inclusive, as it allows more users to explore the city, projecting the city's image by making it more noticeable. **Figure 2** summarizes the links between the main direct and indirect benefits that pedestrian wayfinding systems can provide in urban contexts.

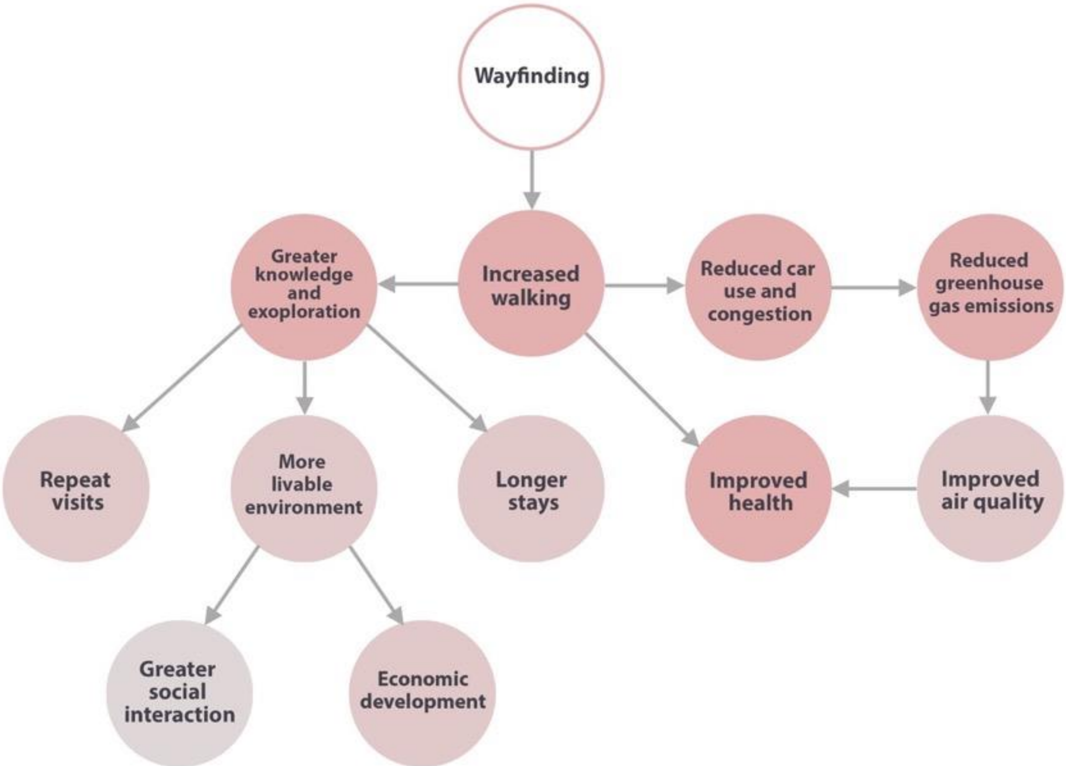

Figure 2: Benefits of implementing pedestrian wayfinding systems.

2.2.1. Implementation of PWS

PWS is a combination of coordinated signage systems (heads-up maps, directional signage, hand-held maps, etc.) with similar design, strategically located in the city and focused on encouraging people to walk. This approach was first developed in 2001 in Bristol, United Kingdom, as part of the Building Legible Cities project (Kelly 2001). Since then, it has been improved and applied by several cities in different countries, such as the United States, Australia, or Ireland. This phenomenon became standard practice for the benefit of pedestrians, recognizing their importance as indicators of public environment quality.

In March 2006, a study called Legible London (TfL and AIG 2007), conducted by the Applied Information Group under the supervision of a Steering Group established by the Central London Partnership (CLP), evaluated the benefits of implementing user-friendly guidance systems to improve walkability in the city. In addition, other related research (Research Business International 2002 and MORI study for the London Borough of Islington 2005, for example) pointed out that although most routes were suitable for pedestrians, some needed to be promoted for walking (TfL and AIG 2007).

Data presented in the Legible London report confirms that a well-planned signage system makes visitors walk more around the city. It also increases the number of residents choosing walking routes for their daily tasks, leading them to visit places more often and discover new ones. In addition, using signage increases physical activity, improving human health and environmental quality, and encouraging economic growth (TfL and AIG 2007).

It is essential to deliver relevant information to travelers where needed. Hence, providing accessible, effective, and connected navigation helps other modes of transport to improve the user experience of the city, making tourist itineraries more attractive and facilitating displacements related to the daily life of the local population. Wayfinding systems intend to ensure the comfort and safety of these journeys, especially in complex environments such as dense urban areas, where some information about the space is required to facilitate the journey.

Mental mapping is considered an internal tool for wayfinding (Vandenberg 2016). It is an individual and essential cognitive exercise that can lead to multiple interpretations of the same place (Gardony et al. 2013). The sequence of images people generate and store in their minds when exploring the city is crucial for defining route strategies. Hence, the repetition of elements in the urban space can optimize long-term memory, facilitating the wayfinding performance (Garling et al. 1981).

People use different navigation strategies to locate and orientate themselves in the city, generally combining more than one tool in the wayfinding task (Chang 2015; Eslami 2019; Iftikhar et al. 2020). The effectiveness of these tools is also a reflection of the urban configuration, as route planning depends on the quality of urban elements and the assimilation of information from the surrounding environment through cognitive abilities. Examples of navigation tools are physical maps, asking people for directions, Global Positioning Systems (GPS), and signage systems.

2.2.2. Approaches in designing and assessing Wayfinding Systems

Various studies have measured wayfinding performance in terms of time taken to reach a destination, distance traveled (m), speed (m/s), sense of direction, number of stops made, pointing error, and difficulty level, among other parameters (Eslami 2019; Khan and Kolay 2017). In this context, researchers developed techniques to qualify and quantify user performance in the wayfinding task, such as GPS tracking, think-aloud records, sketch mapping exercises, landmark recognition tests, questionaries, cognitive tests, post-test interviews, and environment analysis (using for example space syntax). According to the nature of the intended results, the investigator can combine two or more methods to obtain more accurate data. In addition, investigation techniques through immersion in Virtual Reality (VR) have gained prominence as an innovative way to evaluate strategies and performance in wayfinding systems. The use of technology to understand spatial cognition and assess wayfinding systems allows urban designers and planners to adjust the project in the virtual environment before implementing it in the real world.

The main purpose of a PWS is to improve the flow of pedestrians through active navigation, so they can better learn about places they visit or where they live. This awareness promotes the local economy, a sense of belonging, security and comfort, and the vitality of city spaces. However, built environments are dynamic and constantly changing. Thus, public participation in urban design and planning decisions is essential to create meaningful spaces that are responsive to the needs of community members and potential visitors. No matter how well planned and executed a wayfinding system is, it will only work if it makes sense to the people who walk the city. The local community needs to have an active voice in the changes made to their surroundings, so that it can relate to them and incorporate new urban elements into its mental images and maps.

Therefore, encouraging public participation in the design phase of future interventions in the city increases the probability of its success (Bianco 2016; Mahmoud and Takafumi 2011;

Vukmirovic and Gavrilović 2020). It is an opportunity for locals to express their opinion on the transformation of public space along with professionals. In this way, they learn about government procedures, budgeting, environmental issues, etc., thus reinforcing previous bonds and creating new emotional connections with the place.

Collaborative processes through community and stakeholder engagement also increase awareness on how to take care of the inhabited space, improving the quality of the urban domain (Goodspeed et al. 2023; Raynor, Andréanne and Tanja 2017). This possibility arises from individual and collective experiences in the city context and modes of sharing them, in particular by using imagery narratives, e.g., as mental images or cognitive maps.

Thus, co-designing processes, besides representing inclusive and democratic approaches, contribute to the creation of more meaningful and better cared-for spaces, reinforcing the sense of place and identity among insiders and outsiders (Hester 1990). Local knowledge is key to the planning and management of urban environments because the community must play an essential role in its development, and not just remain as observers in decisions made by city councils and urban planners.

2.3. Conceptual Framework

Based on the literature review, **Figure 3** brings together the main theoretical concepts in three groups: *urban form*, *navigation aids* and *spatial cognition*. These are interconnected and converge in the central group, *social and spatial interaction*, ranging from the act of perceiving to the wayfinding behavior.

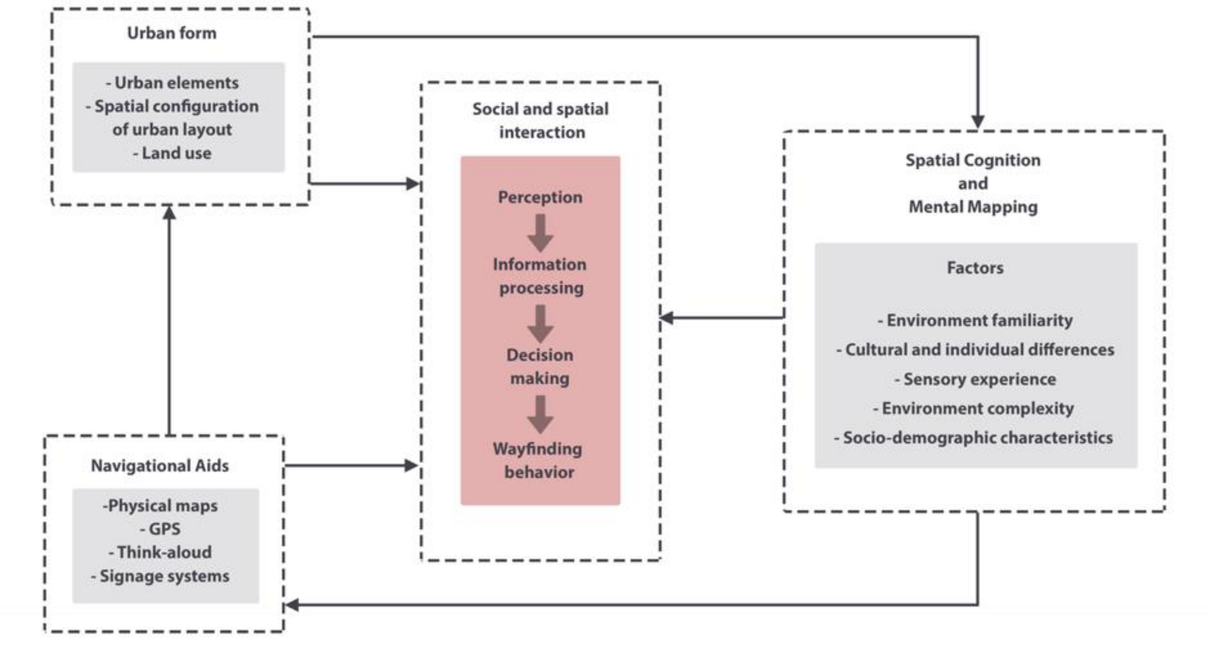

Figure 3: General conceptual framework.

The urban form and its components have a direct impact on the subjective and material factors (from Table 1) comprised in spatial cognition. Moreover, these factors influence the selection of the adequate navigation aids, for a better understanding of the urban form by users. Thus, it is a cycle that contributes to the improvement of the wayfinding performance.

3. Reference Cases

This section presents different case studies as references for designing and implementing pedestrian wayfinding systems. Five cities with PWS, recognized worldwide as good practices, were selected: Lisbon, Portugal; Dublin, Ireland; Brisbane, Australia; London, United Kingdom; and Seattle, United States. To better understand and identify what contributes to the success of these wayfinding systems, several aspects were analyzed regarding their development process, namely: the context of each program, the needs that led to the decision of adopting wayfinding strategies, and the process of planning and designing the signage. Thus, the five cities mentioned before are analyzed according to three categories: (1) project context, (2) design process and main features of the program, and (3) wayfinding system performance assessment.

The Nations Park case (1998) in **Lisbon** is an example of the implementation of this strategy in Portugal. The program aimed to create an image with a clear and unique identity for Expo'98. The directional signs in vibrant blue, red, and yellow colors stand out in the environment without interfering with other spatial elements (**Figure 4**). This characteristic helps navigators easily identify the signage and plan their journeys. In addition, each local designation is written in Portuguese and English, facilitating the orientation of foreign visitors to the area. This wayfinding system is objective and communicates only the essential content, so people don't spend much time searching for information.

Figure 4: Nations Park signage design.
Source: Larus Design. "Sinalética Expo'98" 1998.

The **Dublin** experience (2011) aimed to make the city a world-class pedestrian-friendly place, avoid street clusters and conflict with other transportation modes, reduce car use, increase walking journeys to work, and address infrastructural deficits. The on-street digital maps provide real-time navigation through tailored directions and other helpful information (**Figure 5**). This interactive feature encourages people to explore the city, increasing pedestrian flow. Also, the 3D representations of major destinations on the maps are an important characteristic of this scheme once it helps the users to locate themselves in the space, connect paths between landmarks and find their way in the city. Finally, the graphic identity and product design of this PWS are appealing to the public, promoting interactions with the system.

Figure 5: The Dublin Wayfinding Scheme.
Source: fwdesign limited. 2012.

Another example of good practice is the **Brisbane** PWS (2016). The program appeared in response to a growing multicultural population, to help immigrants, tourists and students in navigating the city. The family of signs has quickly become the primary source of information for pedestrian guidance in and around the city (**Figure 6**). The PWS elements create recognizable paths visually linked throughout the urban fabric. Despite their high contrast with the urban environment, the aesthetics of the signage provoke a visual impact on the observer, encouraging flows of active mobility without drastically interfering with the landscape.

The "walking man" cut into the panels fits into the environment dynamically and elegantly. The typography and scale of content allow the balancing of information in four different languages. In addition, the positioning of the panels follows the logic of the space, leaving clues in strategic places, guaranteeing the fluidity and coherence of the set.

Figure 6: Brisbane Multilingual Pedestrian Wayfinding.
Source: Driven X Design Awards Programs. 2020.

The **London** scheme (2018) sought to relieve pressure on the public transport system and change confusing existing signage. This program had as its central theme the cognitive science regarding mental mapping, that is, how walkers build mental images from their experience in urban space as they travel around the city. The content's sizes follow a hierarchy of names and places, connecting the particular to the general in a legible way. Although the PWS is only in English, the pictograms make it easy to recognize directions to major destinations and transport stations.

As shown in **Figure 7**, the maps are accessible at different scales, with 15-minute and 5-minute walk times, allowing the users to plan their trips effortlessly. The use of high-contrast colors differentiates the PWS from other spatial elements. Also, the yellow strip at the top with a walking man symbol makes the signs announce their function in the urban environment.

Figure 7: Legible London - Signage System.
Source: SEGD. 2009.

Seattle's PWS (2019) represents a response to the city's population growth due to the presence of high-tech companies and the University of Washington. The constant involvement of the community in the project makes it noteworthy, which was achieved through community meetings, workshops, public hearings, and prototype testing. The heads-up maps help users locate reference points in the environment and orientate themselves. The PWS simplifies the complexities of the urban environment through illustrations. Also, the signs contrast, large type sizes, and balance of content promote the legibility of the system. The program is a reflection of real journeys that people make, helping them to navigate without friction in every change of mode, regardless of their abilities, simply and predictably, through a unique set of elements and rules (colors, numbers, icons, names, etc.) easy to interpret and memorize (**Figure 8**).

Figure 8: Seamless Seattle - Core Sign Family.
Source: Seattle Department of Transportation (SDOT). 2019.

The cases of Lisbon and Brisbane invested in the high contrast of the PWS through the use of vibrant colors. The references from Dublin, London, and Seattle highlight the importance given to the detailing of the maps and technological innovations. Although the Nations Park example focused on the design of pictograms exclusively for the program, the use of internationally recognized symbols potentially facilitates the interpretation of the signs.

Each project presented in this section has a different spatial scale. Some municipalities implemented the scheme throughout the city, while others limited it to the most central and busiest areas. This fact obviously influences the financial resources used for each program, the entities involved in the design process, and the users' response to signage installation. It should also be noted that the lack of certain publicly available information has limited this research, which posed a challenge in the analysis of the reference cases presented in **Table 2**.

CITY	LISBON	DUBLIN	BRISBANE	LONDON	SEATTLE
PROJECT YEAR	1998	2011	2016	2018	2019
NAME	Nations Park Signage	The Dublin Wayfinding Scheme	Brisbane Multilingual Pedestrian Signage	Legible London	Seamless Seattle
AREA OF IMPLEMENTATION	50.000,00 m²	Central District	2.582.704,51 m² in central Brisbane	Oxford Street, Bond Street, Westminster/Camden, South Bank, Richmond and Twickenham, and West End	Citywide wayfinding system
BUDGET	N/A	€4,106,000	$80,000 AUD	N/A	Over $1,000,001
NUMBER OF SIGNS	60 signs	Total of 104 signs across the city, including 20 double-sided map panels	33 fingerpost signs	Removal of 46 existing objects and implementation of 19 new signs in 2007, and 23 more in 2008	N/A
LANGUAGE	Portuguese and English	English and Irish	English, Traditional Chinese, Japanese, Korean, and Arabic	English	English, together with a second language in areas where it has strong ties to a community, or a majority of residents speaks a language other than English
INSTITUTIONS	Commissioner: City Councils and the State Design: Pierluigi Cerri, Shigeo Fukuda, Henrique Cayatte Production: Larus	Commissioner: JC Decaux Ireland Partners: Dublin City Council, Department of Transport, Tourism & Sport, Dublin Tourism, national cultural institutions, and other civic interests Design: Fwdesign Production: Wood and Wood Signs	Commissioner: Brisbane City Council Design: Dotdash Production: Harlequin Signs and Plastics	Commissioner: Westminster City Council, New West End Company, Transport for London, Crown Estate, Greater London Authority Planning and Design: Applied Information Group (AIG) and Lacock Gullam Production: Woodhouse Installation: Westone	Commissioner: Seattle Department of Transportation (SDOT), King County Metro Sound Transit, Washington State Department of Transportation Design and planning: Applied Wayfinding with Alta Planning + Design Community engagement: 3 Square Blocks
INVOLVEMENT	N/A	Involvement of a group consisting of key stakeholders led by the City Council. Public engagement through semi-structured interviews and mental mapping studies with different organizations	Pilot testing on site	Stakeholder engagement through a meeting with members of the community, mental mapping studies, public hearings, and prototype testing	Rigorous and far-reaching engagement process with focus groups. Stakeholder involvement through community meetings, briefings, interviews, workshops, public hearings, mental mapping studies, and prototype testing

Table 2: Reference cases - review of studies.

4. Guidelines for Designing Pedestrian Wayfinding Systems

Based on the literature and reference cases, this section presents some principles to support the development of pedestrian wayfinding systems. According to the literature review, to better navigate spaces it is essential to have an understanding of the environment. Thus, a well-designed scheme can primarily help and facilitate essential activities of everyday life, such as going to work, school, leisure, commuting, or shopping. But more importantly, the signage and information program for pedestrians can become a vital tool for visitors in a different city, helping them explore, find amenities, and enjoy local resources such as tourist attractions and cultural events. Hence, any intervention on the urban realm that influences the movement of pedestrians should meet their needs first and foremost.

The design and planning of a wayfinding system must be people-centered irrespective of their abilities, encompassing a practical set of signs that simplify spatial relationships between the various uses and functions that exist in the built environment. An effective PWS has the potential to engage people in every sense, encouraging them to walk. Its main goal is to help navigators plan their journeys and orient themselves in the city in an easy way. Therefore, in addition to the system design, the program must take into account complementary aspects of the built environment, such as a water fountain, the floor texture, a bakery, or a coffee shop, as they can represent sensory markers in the user's mind. Stimulating cognitive skills will reinforce the generation of mental maps, giving the user the comfort to move around the city and the confidence to explore unknown areas.

According to our research, there are five core principles that should guide the development of a PWS:

(1) *Consistency* - the system must have a universal design. It is imperative that there is harmony between signage elements and the surrounding environment, to avoid visual

clutter and obstruction for pedestrians. Clarity of content at every touchpoint is also essential to create a simple and intuitive PWS.

(2) *Continuity* - the system must work as a network of progressive disclosure (just enough information where it is needed). Thus, the placement of signs should be predictable to users, allowing them to confirm their location during a trip or re-plan their journeys.

(3) *Connectivity* - the system must connect key points of the city through pedestrian routes and provide information about linkages with other transportation modes. In addition, when incorporating technology, the mapping and codes used for digital strategies should be the same as the signage on site.

(4) *Accessibility* - the system must be inclusive and accommodate all potential users, regardless of their physical or cognitive capacity, gender, age, education, income, ethnicity, etc.

(5) *Local Distinctiveness* - the system must stand out against road signs and other elements in the urban environment to be recognizable. Also, the design should be flexible and specific to distinctive areas of the city, without compromising the legibility of the system.

Based on these main principles, the development of the PWS should follow several sequential steps, described in the next sub-sections.

A successful pedestrian wayfinding system is intuitive and consistent, combining function and aesthetics into an efficient product design to provide a stress-free service. It should deliver a seamless experience to users, giving them the confidence to explore the city in the most comfortable way possible. Signage must provide the necessary information at the right time, reassuring people that they are moving towards their desired destination, but also facilitating the discovering of spaces to a certain degree. In summary, the PWS has to be inclusive, encourage mobility, and accommodate different levels of information without cluttering the environment.

4.1. Analysis of the Selected Area

The first step in developing a wayfinding strategy is to define the signage area. This geographical delimitation will help identify urban elements and their configuration in space. It is essential to learn how the physical components of the place affect movement, in order to provide the appropriate tools for pedestrians to navigate through a wide range of environments, regardless of their complexity. The shape and size of the signage area influence the number, location, and type of signs. **Table 3** exemplifies the aspects of the city's structure to consider when analyzing the dynamics of the site.

Aspects	Examples of characteristics to analyze
Urban development	Main drivers of city growth over time and historic phases
Topography and geography	Gradient, steps, stairs, and barrier shapes
Density of the built environment	Relationship between open spaces and built form
Street typology	Street hierarchy, walking routes, and type of street section
Points of interest	Landmarks, focal points, decision points, and historic locations
Movement	Understanding of different flows (pedestrians, vehicles, etc.)
Transit identity	Transportation modes available in the area

Table 3: Physical components of the selected area that affect user movement.

4.2. Community and Stakeholder Engagement for Co-Designing a PWS

The second step pertains to the moment when urban designers and planners must work alongside the different actors and stakeholders, including residents, government authorities, transport operators, and main business representatives. This partnership represents a crucial bonding between all of them to get maximum benefits from the new wayfinding system. In this regard, public involvement through community meetings is essential to engage people during the planning process, as well as to keep them informed from the beginning to the end of the project.

These events should encourage mental map drawing, landmark recognition tests, interviews, and questionaries to identify neighborhood limits, decision points, and landmarks, besides establishing appropriate naming and defining which content is most relevant for map production. In addition to public meetings, studies conducted *in loco* can provide data regarding the number of visitors to certain places or attractions, the density of movement during the day, etc. The goal is to design according to how people think and to what they need.

4.3. Pilot Testing

In the third step, pilot projects should be produced to assess the useability of the system and justify its implementation as a solution for the city. Prototype tests in the busiest and most complex transit centers of the urban fabric ensure a more comprehensive evaluation of the program elements. The feedback from this feasibility study concerning the number of trips, efficiency, difficulty levels, reliability, and speed allows changes in aspects of the PWS, or its refinement, before installing the final product in the public domain.

4.4. Developing Products for Pedestrians

The fourth step develops a set of products: signage family, signage layout, placement and accessibility.

4.4.1. Signage Family

The signage family must be consistent, with reliable information at every point of contact to consolidate local knowledge and develop environmental familiarity. For that, the scheme's components need to have the same design language based on a unique and concentrated mapping system. The formats must contemplate different scales of use with a coherent content hierarchy.

Figure 9 shows the types of signs of the core family (maxi-totem, mini-totem and fingerposts) and additional elements (transport totem, route marker and description, and sidewalk medallion). The scheme presents some estimated measurements of what would be ideal for the pedestrian viewing angle, as well as locating important information on the signs in an accessible way for people with reduced mobility. The measurements were determined based on the following references: Neufert et al. 2012; Teles 2007; TfL and AIG 2007; The State of Queensland (Department of Transport and Main Roads) 2020.

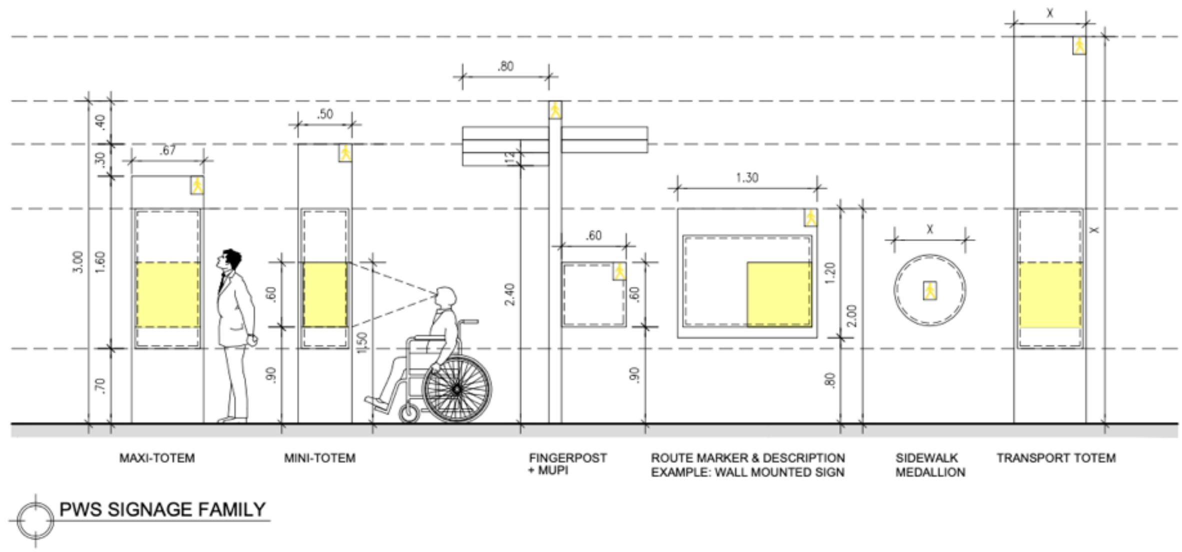

Figure 9: Family of signs for pedestrian wayfinding systems.

4.4.2. Signage Layout

The system's layout must be minimalist and functional, with common characteristics, to promote familiarity through repetition and simplification of environmental complexities. Thus, to create a friendly and practical design that combines aesthetics and usability, it is important to pay attention to details, such as colors, font, and symbols.

Table 4 provides general rules (TfL and AIG 2007; City of Toronto, 2016; SDOT, 2019; Driven X Design, 2020); The State of Queensland (Department of Transport and Main Roads) 2020) for the visual appearance of the scheme, regarding graphic design, text, and illustration contents, to ensure proper standardization. The careful balance of information in each sign is essential to reinforce legibility. Nevertheless, despite the defined pattern, the project needs to be flexible to reflect the city's identity and respect local distinctiveness.

General rules

Graphic design	Colors	Use of enough visual contrast
	Typography	Use of appropriate font style, size and height
	Pictograms	Use of internationally recognizable symbols
	Identifier	Use of a bright strip on the top of the sign with “the walker” pictogram, visible from distance
Text content	Name of suburbs, neighborhoods, places and streets (address), A-Z street finder, distance (m), walk times to key destinations (min), native and second language where needed, arrival points, heritage content, “you are here” and “walk this way” markers	
Illustration content	Heads-up maps with simplified 3D landmark representations; emphasis on steep slopes, steps, narrow or high pavements, pedestrian crossings, building, hill climb and civic and local amenities; traffic network diagram with the identification of the entrance of metro stations and bus stops; directional arrows; historic mapping	

Table 4: General rules to develop a signage visual identity.

It is important to note that the entities responsible for the program must select the content of the signs carefully, as the inclusion of too many symbols can clutter the map, reducing legibility.

4.4.3. Signage Placement

The number and location of the signage elements in the public realm must follow a logical arrangement to reduce clutter and improve awareness. It is necessary to provide just enough information to answer the user's questions where needed during their journey. That said, progressive disclosure at key locations can prevent distractions caused by potentially confusing content.

Sign installation must ensure visibility from key origin and destination points, at right angles to the direction of travel, in order to accommodate pedestrians, accounting for free movement and sufficient space for people with disabilities to perceive them. The location of the signage also depends on the density of environment flows within the urban context. These spaces have to be studied carefully before the position of the signs is decided.

4.4.4. Signage Accessibility

Finally, the wayfinding system must ensure accessibility regardless of environmental conditions and the navigator’s individual abilities, in terms of physical, cognitive, financial, and social capacity. Creating an equitable public domain is fundamental to removing possible physical and mental barriers in the built environment and developing an inclusive product design with adequate materials and dimensions. It is important to emphasize that the level of accessibility of a given area is directly related to its climatic and topographical characteristics. Also, it is necessary to assess the locations displayed on maps to guarantee that they have a safe infrastructure for pedestrians and are within acceptable walking distances.

5. Exploring the Future Signage System of Porto

Based on the principles and criteria defined in section 4, developed as a guide for the design of pedestrian wayfinding systems, this section 5 intends to illustrate their usefulness in a practical case. As explained in the introduction, the current research responds to a request of the municipality of Porto regarding development recommendations for a future city PWS. Thus, strategic recommendations to be incorporated in the Integrated Project of Signage and Information (IPSI) were presented and discussed with town planners, in order to support the design of the system and main aspects of the project, besides contributing to the requirements of the tender specifications. Some complementary studies are also recommended, to understand which spatial and cognitive factors influence people's decision to walk in urban spaces. This knowledge is essential for redefining Porto's signage and information plan, focusing on the comfort and safety of end-users.

To deliver a successful PWS, every change of mode or environment (physical or virtual) must be intuitive and effortless for the user. Accordingly, guidance system providers must collaborate to ensure the predictability of all program elements. It is essential to delineate routes that contemplate consolidated tourist sites. Nevertheless, the suggested pathways in the maps must also pass through streets with commerce and services that are challenging to find, or with underused spaces that have potential to promote social interactions. Moreover, in case of scarce financial resources, the city-wide PWS, government authorities, urban designers, and planners should identify and prioritize areas with the highest pedestrian flows and assess the level of existing infrastructure, to support walking comfortably and safely.

After identifying the most interesting destinations to users/walkers and after checking the conditions of route infrastructures, it is necessary to guarantee that there are suitable conditions along the paths for people to stay and enjoy the places they arrive at, as transformations in the urban environment will also change the way people navigate and use city spaces. The destination hierarchy of the IPSI should be adequate to the scale and complexity of the areas covered by the project, allowing users to create their own hierarchy in their mind maps.

In certain zones of the city of Porto, the Douro River is an important landmark. Like other natural elements of the landscape or the built environment, such as historical monuments or distinctive buildings, these landmarks can serve as a reference and a key destination, helping people in the wayfinding task. These focal points can also include streets or places people know as part of their daily journeys, such as transportation stations, parking lots, sports facilities, community centers, hospitals, and parks.

One of the goals of a PWS should be to support economic development. However, the reference points selected for the scheme should be defined through community and stakeholder engagement, considering the connectivity and legibility of the environment and not just based on commercial interests. Exploring the meaning of spaces from the perspective of both inhabitants and visitors can help define the content of the signs. In this sense, end-users must confirm the names of streets and places, so that architects and urbanists can include this information in the signage system.

Before starting the PWS project and preparing its installation, the public entities and private agencies involved need to agree on approval of designs, authorization for the manufacture of signs, and maintenance responsibilities. In addition, the installation plan must contain a schedule of activities, with diagrams, photos, or maps, and the specifications regarding the placement of the signs and their contents.

Each signage element must be selected and located to adapt to the characteristics of its surroundings (scale and angle, for example) and guarantee its harmony with the other components of the environment. Also, these elements must be accessible and perceptible to all people, regardless of their physical or cognitive abilities. The scheme in **Figure 10** describes the strategy for the development of a Pedestrian Wayfinding System for the city of Porto, although this scheme could be widely applied in other places or cities.

Figure 10: Indicative implementation plan.

In addition, it is imperative to perform an in-depth analysis of the project's impact on mobility in general, especially concerning its integration with other means of transport. Finally, the IPSI must ensure that every stage of the plan meets a high level of quality and detail, to achieve a refined and resolved design capable of addressing any demands that might arise in the future.

6. Conclusions and Recommendations

As explored in the literature review, factors related to human spatial cognition, such as environmental familiarity, cultural and individual differences, sensory experience, urban complexity, and sociodemographic variables, influence people's ability to find their way and navigate through space. Likewise, responsive behaviors such as searching, planning, and following routes not only depend on urban elements and their arrangement in the city, but on people's cognitive abilities to capture environmental information and create mental images full of meanings.

Wayfinding behavior is related to spatial cognition - people learn from the environment, process the information, and then choose the most suitable path to follow according to their needs. Users are the ones who assess the quality of environmental elements and define their hierarchy in mental maps. That said, wayfinding performance depends on the physical aspects of space and strategies based on individual experiences.

A person's physical and cognitive abilities influence how they perceive and appropriate their surrounding environment. Thereby, pedestrian wayfinding systems must be empathetic and responsive to the needs of all people, bolstering comfort, safety, and confidence when they walk around the city. People become much more receptive to active mobility once they are aware of its benefits. Hence, it is not only important to transform urban spaces, but also to enable a cultural change of mentalities and attitudes. Furthermore, users need to know which navigation tools are available and how they can be used. Ultimately, the goal is to promote route searching and cognitive mapping in order to improve environment familiarity.

One main conclusion of this paper refers to the importance of involving the public and stakeholders in co-designing interventions in the urban space, such as the implementation of pedestrian wayfinding systems. Participatory design and urban planning processes focused on end-users raise people's interest and awareness, encouraging them to explore the city while reinforcing the affective value they attach to places.

The research undertaken contributes with a practical guide for the development of Pedestrian Wayfinding Systems, based on the understanding of spatial cognition and analysis of reference cases. The criteria and principles presented were the basis for the recommendations to be included in the Integrated Project of Signage and Information (IPSI). Our study provided suggestions on how to think and design the system legibly and efficiently, and raised questions about responsibilities for the project maintenance in the future, especially regarding updating information and conservation of the signage's elements.

According to the knowledge revealed by this research, spatial cognition and wayfinding behavior involves a range of aspects and dimensions related to the user's perspective. Therefore, it is necessary to include this understanding in the PWS from the beginning of the project, so that the city's signage system can adapt and respond effectively to the demands of its inhabitants and visitors. It's essential to continue studying the way people perceive and understand these cues during navigation. Finally, exploring spatial cognition and preferences of users in PWS design can help improve the effectiveness of guidance tools, as well as overall program performance.

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