CHAPTER FIVE

Human factors in pedestrian planning

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Abstract

The goals of this chapter are to provide: (1) an overview of the various human factors in pedestrian planning research, and (2) an understanding of how these human factors affect pedestrian behaviors relevant for pedestrian planning research. The interdisciplinary field of human factors combines engineering, psychology, and physiology to study the relationship between humans and technology from a system's perspective. Pedestrian planning research is also an interdisciplinary field at the intersection of engineering, transport, architecture, psychology, and sociology. It studies how pedestrians perform in specific contexts – such as at crossings, in travel choices, during wayfinding, and in egress – in both routine and emergency situations. Both fields share a focus on efficiency and safety, and therefore complement each other well. However, despite this, engineers who practice pedestrian planning and design or use technologies that can monitor or interact with pedestrians, do not typically have extensive experience in human factors. Consequently, such pedestrian

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systems rarely incorporate deep understanding of human behavior, some of which can be counterintuitive. To address these limitations, this chapter first introduces a framework to understand human factors in pedestrian planning research, including the dimensions: (1) observable versus non-observable behaviors, (2) conscious versus unconscious behaviors, (3) physical versus psychological crowds, (4) routine versus emergency situations, and (5) urban versus rural environments. Next, the most common human factors in pedestrian planning research and their influence on operational, tactical, and strategical pedestrian behaviors are considered at three levels: (1) individual, (2) social, and (3) environmental human factors.

1. Introduction to human factors in pedestrian planning research

Different research activities and perspectives within pedestrian planning for outdoor environments are described in other chapters of this book, such as data collection, pedestrian modelling and simulation, crowd management strategies, and travel choice behavior. Pedestrian planning comprises both the design of pedestrian-friendly infrastructure and its management (see Chapter 4). To do this effectively and safely, we need to understand human behavior. Hence, this chapter will discuss human factors in pedestrian planning research.

Human factors science studies the relationship between humans and technology from a system's perspective to increase performance and safety (Meister, 2008). Essentially, it concerns the interactions between humans and their physical environment, and the psychological and behavioral implications of this (Shorrock and Williams, 2017). Human factors science is interdisciplinary – and a sub-discipline of psychology, engineering, and physiology – with two interrelated domains of application: behavioral (human) and physical (technology) (Meister, 2008).

Human factors is a mature discipline with a history of extensive research across these broad areas (Blaga et al., 2025; Carayon et al., 2015; Fisk et al., 2009; Kolus et al., 2018; Wiegmann and Shappell, 2016). Furthermore, human factors research can be divided into fundamental and applied approaches, which either develop theories and principles applicable to the general population and various situations or which are very specific to particular populations and specific situations, respectively (Wickens et al., 2004). Research methods include experiments, such as laboratory or field studies with different participant groups, and descriptive research, such as observational studies, surveys, accident analyses, and meta-analyses (Wickens et al., 2004).

Pedestrian planning research is an interdisciplinary field at the intersection of engineering, transport, architecture, psychology, and sociology that focuses on designing and managing pedestrian-friendly infrastructure (Challenger et al., 2010b; see also Chapter 4). Pedestrian behaviors are studied in different environments and situations, where pedestrians continuously interact with their surroundings and other people (Timmermans, 2009), and under different circumstances, such as travelling behaviors (Vale and Pereira, 2016), travelling choice behaviors (Ben-Elia and Avineri, 2015), ingress and egress (Hu and Bode, 2023), wayfinding (Alinaghi et al., in press), large gatherings (Kundu et al., 2023), emergency situations (Van der Wal et al., 2021b), and increasingly interactions with electric cars, bikes, and scooters, and autonomous vehicles (Schneider et al., 2020).

Pedestrian planning is also a mature discipline with a history of extensive research in these areas (Duives et al., 2013; Fruin, 1971; Stoker et al., 2015; Vanumu et al., 2017; Wijermans et al., 2016). Research methods in this field include empirical research, such as laboratory or field studies and surveys, and modelling and simulation of pedestrian and evacuation dynamics (Haghani, 2020a; 2020b; Haghani and Sarvi, 2018; Martinez-Gil et al., 2018; Thompson et al., 2013).

Three important sources for data collection in pedestrian planning research were identified in Chapter 4: (1) data on the environment and infrastructure, (2) data on the use of the infrastructure (traffic), and (3) data on the pedestrians (e.g., personal characteristics and physiological data). Different research methods are used to collect data about pedestrian behaviors, with a systematic review by Feng et al. (2021) identifying four main categories: (1) field observations, (2) controlled experiments, (3) virtual reality (VR) experiments, and (4) surveys. Field observations have been performed via video recordings, camera-based monitoring systems, Wi-Fi and Bluetooth sensors, GPS traces, GSM data, and social media. Controlled experiments have been used for normal and emergency evacuation conditions, while VR is a separate, immersive approach for experiments. Finally, traditional surveys can be administered to pedestrians and experts. Each research method has advantages and disadvantages, so a balanced and complementary multi-method approach is preferable (Robinson, 2016). The richness and quality of data is typically higher in experiments than in surveys, but the latter can collect data from more participants. Higher levels of research control can be achieved with experiments (VR and traditional) than with field observations, but the latter examine the real-world and offer higher ecological validity. While field observations typically have higher ecological validity than experiments, VR experiments are more realistic than traditional experiments (Bhagavathula et al., 2018) and enable additional factors such as social identity to be examined (Drury et al., 2009c). However, due to the abundance of smartphone videos of emergencies available, video-based field observations can now be conducted across multiple contexts enabling key factors to be identified systematically with more rigor than before (Van der Wal et al., 2021b).

Despite the extensive research conducted within both human factors and pedestrian behavior fields, more integration is required to harness the benefits. The human factors discipline still has a relatively low exposure among engineers (Black et al., 2023) who practice pedestrian planning and design or use technologies that can monitor or interact with pedestrians. Consequently, many models of pedestrian behavior designed by engineers and computer scientists still treat humans as molecules in fluid, obeying laws of motion with perfect rationality and efficiency (Zhang et al., 2023). Human behavior is less predictable, however, as other concerns can override efficiency of movement and many people also travel in groups, so future pedestrian research should be underpinned by a more realistic understanding of how people actually behave (Templeton et al., 2015). Consequently, pedestrian systems often show little or no understanding of human capabilities or needs, such as wayfinding, nor acknowledge human failures and errors, such as in evacuation (Challenger et al., 2010b). These tasks require understanding environmental cues, responding to other pedestrians, spatial navigation, and decision-making processes. It is therefore important that these elements are studied as aspects of complex systems from a human factors or socio-technical systems perspective (Meister, 2008). Moreover, pedestrians must be studied at micro, meso, and macro levels, as individuals, small groups, and large crowds, respectively, with heterogeneous membership (Bellomo et al., 2023). All these considerations require a system's perspective, as introduced in this chapter.

The goal of this chapter is to provide an overview of the various human factors in pedestrian planning research and demonstrate how they affect pedestrian behaviors relevant to pedestrian planning research. To do so, we adopt a system's perspective, viewing people as embedded in a wider social and physical environment that influences their behavior (Clegg et al., 2017). We distinguish three levels of human factors for pedestrian behaviors: individual, social, and environmental human factors (see Table 1). The individual human factors refer to personal pedestrian characteristics, such as age, gender, personality and risk perception. The social human

Table 1 Three human factors levels for pedestrian behaviors relevant to pedestrian planning research.

Human factors level	Common categories/ themes of human factors found in pedestrian research	Human factors examples found in pedestrian research and human factors research
Individual	Personal pedestrian characteristics (mainly physical factors)	Age, gender, body weight, body height, alcohol
	Subjective/psychological factors	Perceptions, attitudes, self-identity as a safe person, gap acceptance, memory, information-processing, decision-making, attention, object-recognition, sensory skills
	Functional limitations and disabilities (physical and psychological factors)	Needing assisted mobility devices, medical disabilities
Social	Social and cultural factors	Ethnicity, nationality, group size, crowd type, culture, mood
Environmental	Infrastructural and environmental characteristics	Gradient, city size, indoor/ outdoor, time of day, weather, temperature, lighting, smell, music, nudging, traffic characteristics, road environment, traffic volume, vehicle size, vehicle speed
	Trip characteristics	Trip purpose

factors refer to social and cultural pedestrian characteristics, such as type of crowd group size, culture and mood. The environmental human factors refer to infrastructural and environmental factors experienced by pedestrians, such as weather, light, smell, music and nudging. We arrived at this distinction by examining the most common human factors in general pedestrian research that are specifically applicable to pedestrian planning research, focusing on efficiency, safety, and comfort. We then distinguished these three human factors levels: individual, social, environmental. We will now discuss the common human factors identified in pedestrian research.

Multiple human factors influencing pedestrian behaviors have been researched. Bosina and Weidmann (2017) provided an overview of the most important influences found on walking speed, including personal characteristics (age, gender, body weight, body height), and cultural and social factors (ethnicity, nationality, group size), trip characteristics (trip purpose), and infrastructural and environmental characteristics (gradient, city size, in/outdoor, time of day, weather, temperature). Chapter 3 provides further empirical data about pedestrian flow, including walking speed. Tiwari (2020) also identified key human factors in the pedestrian safety literature during the last century, including pedestrian characteristics (gap acceptance, sensory and cognitive skills, gender, age), pedestrian behaviors (crossing behavior, route choice behavior, risk-taking behavior), subjective factors (perceptions, attitudes), and environmental factors (traffic characteristics, road environment). Moreover, other human factors specific to pedestrian roadway crossing behaviors are: attitudes, perceived behavioral control, cognitive ability, vehicle size, vehicle speed, traffic volume, road layout, time of day, weather, age, gender, alcohol, self-identity as a safe person, and perceived control (Balk et al., 2014; Wilmut and Purcell, 2022). Another common human factor in general pedestrian research is that of functional limitations (Jeong et al., 2018; Schwartz et al., 2022). Research examining pre-existing pedestrian disabilities in road traffic injuries categorized them either as medical (e.g. ADHD, Alzheimer's, hearing loss, visual impairment) or requiring the use of an assisted mobility device (Schwartz et al., 2022).

Each of these human factors emerge from a different discipline, including cognitive psychology (sensory and cognitive skills, trip purpose, perceptions), neuropsychology (medical factors such as ADHD, Alzheimer's, visual impairments), social psychology (age, gender, group dynamics, affect, attitudes), cultural psychology (culture), personality psychology (risk-taking behavior), ergonomics (functional limitations needing mobility assistive tools), transport studies (road gradient, city size, road environment), and human factors (environmental factors such as temperature and weather). Therefore, we need to understand pedestrian behaviors from multiple perspectives, which we will discuss in Section 2.

Pedestrian behaviors are complex, as they represent a dynamic process of continuous interactions with the environment and other people, some volitional from decision-making and others unplanned and emergent

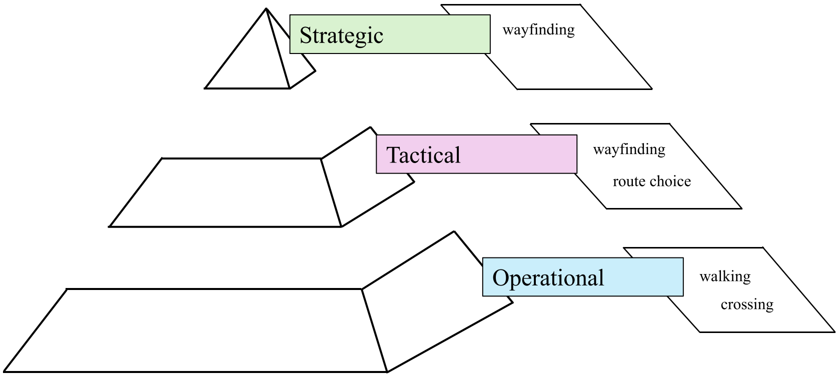

Fig. 1 Pedestrian behaviors relevant to pedestrian planning addressed in this chapter.

(Moussaïd et al., 2011). The human factors discussed in this chapter can therefore address different levels of pedestrian behaviors, namely operational, tactical and strategical behaviors. Examples of these pedestrian behaviors relevant to pedestrian planning are wayfinding (strategical/tactical), route choice (tactical), crossing behaviors (operational), and walking (operational), as shown in Fig. 1.

Next, in Section 2, we propose our framework for understanding the human factors of pedestrian behaviors relevant to pedestrian planning research. This framework explains five dimensions that are important to understand the human factors of pedestrian behaviors in pedestrian planning research, including: (1) observable versus non-observable behaviors, (2) conscious versus unconscious behaviors, (3) psychological versus physical crowds, (4) routine versus emergency situations, and (5) urban versus rural environments. Then, in Section 3, we discuss the different human factors in pedestrian behaviors, across the three levels: (1) individual, (2) social, and (3) environmental.

2. Framework for human factors in pedestrian planning research

In this section, we discuss the five behavioral dimensions of importance for understanding pedestrian behaviors in pedestrian planning research. These dimensions describe perspectives needed to gain a deeper psychological and behavioral understanding of pedestrian planning. The dimensions are rooted in the different disciplines from which human factors originates, as the examples below demonstrate.

Human factors' foundations in cognitive psychology and cognitive engineering can be seen in research determining the effects of cognition on pedestrian behavior, such as the effect of memory, information-processing, and culture on wayfinding, or the effect of attention on crossing behavior (Afrooz et al., 2018; Karimi, 2015; Simmons et al., 2020; Tijus et al., 2007). Cognitive engineering's influences can also be seen in pedestrian planning research, such as when cognitive work analysis is used to design footpaths (Stevens and Salmon, 2014).

Research on the effects of personality traits, such as risk-taking behaviors at crossings, have their root in personality psychology (Herrero-Fernández et al., 2016). Research on functional limitations and the need for mobility assistive tools stems from ergonomics (Jeong et al., 2018; Schwartz et al., 2022). Influence from (psycho)biological approaches in human factors can be seen in research examining the effects of stress, biomechanics, or neurological disorders on walking behavior (Hall, 2022; Richards et al., 2023; Robinson and Leach, 2018). Human factors research in pedestrian planning underpinned by social and cultural psychology can be seen in examples such as the effects of group size on walking speed or evacuation decision-making (Cuesta et al., 2021; Haghani et al., 2019; Nguyen et al., 2019; Von Krüchten and Schadschneider, 2017). The distinction between physical and psychological crowd also stems from social psychology and sociology (Drury and Reicher, 2020). Furthermore, in sociology and social psychology, the view on crowds and collective behavior has evolved from one of an irrational crowd driven by urges, needs, and impulses in the 19th and early 20th century, to one of collective behavior driven by emergent norms or social identities from the mid 20th century onwards (Drury and Reicher, 2020; Freud, 1921; 1922; Le Bon, 1895; 1896; Mackay, 1852; Martin, 1920; McDougall, 1920; Turner and Killian, 1987).

Finally, influences from environmental psychology can be seen in human factors research determining the effects of odor, sounds, temperature, or weather on pedestrian behaviors (Abusaada and Elshater, 2020; Ba et al., 2020; Berggård and Johansson, 2010; Ma et al., 2019).

2.1 Observable versus non-observable behaviors

The first dimension for understanding pedestrian behaviors originates from psychology: introspective psychology versus behaviorism. Between the 1910s and 1930s, behaviorists, such as J.B. Watson and B.F. Skinner, argued that psychology should be a science of observable and measurable behaviors, and that mental states and cognitive processes were irrelevant or inaccessible (Schneider and Morris, 1987). This behaviorist stance protested against the historical origins of psychology which are now referred to as introspective psychology (Danziger, 1980). Introspective psychology addresses various practices of introspection that can be summarized as experimental psychologists, such as E.B. Titchener and W. Wundt, developing systematic procedures for internal perceptions or observations of thinking, memory, and complex feelings (Danziger, 1980).

Today, we can still see both schools of thought in practices and approaches. In engineering fields, however, the non-observable behaviors are underrepresented. Even though pedestrian planning research includes human factors, we often only see observable behaviors included, such as walking speed, walking behaviors, route choice, while the influence of the brain, from a cognitive or neurobiological perspective, is often overlooked (Mondschein and Moga, 2018; Thagard, 2016). Pedestrian planning research rarely examines non-observable pedestrian behaviors, most likely because of a lack of understanding of human psychology in this research field (Balk et al., 2014; Erkan, 2024; Papadimitriou et al., 2016; Wilmut and Purcell, 2022). Therefore, more integration between human factors research and pedestrian planning research is needed.

2.2 Conscious versus unconscious behaviors

The second dimension examines behaviors that are the result of (un)conscious processes and decisions. Many pedestrian behaviors in pedestrian planning research, especially at the tactical and operational levels, involve unconscious thinking. For example, route choice, crossing roads, following signs, following people, and avoiding collisions are mostly achieved through automatic, unconscious thinking (Chan et al., 2024; Gruden et al., 2021; Harms et al., 2019; Karthika et al., 2022). Consequently, pedestrian planning researchers must understand the difference between conscious and unconscious thinking, in order to design efficient and safe infrastructure.

A foundational theory to distinguish conscious and unconscious thinking proposes, for instance, that there are two cognitive systems involved in decision-making: System 1 and System 2 (Kahneman, 2011; Stanovich and West, 2000). System 1 is an automatic, fast, effortless, and emotional system in which intuitive and immediate responses are generated (Gilhooly et al., 2022; Kahneman, 2011); there is, however, no voluntary control (Kahneman, 2011). This system is, in evolutionary terms, assumed to be relatively old, and one through which people find decisions difficult to explain (Gilhooly et al., 2022). Conversely, System 2 is assumed to be evolutionarily recent and operates relatively slowly and sequentially (Gilhooly et al., 2022; Kahneman, 2011). It is unemotional, limited by working memory capacity, permits abstract reasoning and hypothetical thinking, and people can explain their decisions (Gilhooly et al., 2022). The processes of System 2 are often associated with the subjective experience of agency, choice and focused attention (Kahneman, 2011). Most decisions are made by System 1, at an unconscious level (Kahneman, 2011). Therefore, route or travel choices might not be deliberate, conscious choices. However, in (experimental) studies, it is often assumed that an exit or route choice is a conscious and deliberate choice of an individual, although the researchers only observe the displayed behavior, not the underlying cognitive processes (Kinateder et al., 2014; Zhu and Shi, 2016). Also, commuting to work or travel to school, for example, is usually frequently practiced and therefore route choices might not be deliberate and conscious choices, unless something happens along the familiar route (accident, closed road) and pedestrians have to deviate from their 'normal' route (Stern and Portugali, 1999). In Section 3.1.5 decision-making and choices will be discussed further.

Another model of unconscious decision-making that overlaps with pedestrian behaviors is nudge theory. Rooted in behavioral economics, nudge theory suggests subtle policy shifts can significantly influence people's choices without restricting freedom (Thaler and Sunstein, 2008). Nudges alter the context in which decisions are made, but are not mandates so people can still make choices (Mertens et al., 2022; Thaler and Sunstein, 2008). In pedestrian planning research, this approach focuses on designing urban environments that encourage walking and improve safety (Wernbacher et al., 2020). Examples include strategic placement of crosswalks, enhanced visibility of pedestrian zones, or using visual cues to promote active commuting (Buikstra, 2021; Fuest et al., 2023; Karlsen and Andersen, 2019). By creating supportive infrastructure, planners can 'nudge' individuals towards healthier, more sustainable transportation options. This theory emphasizes the importance of understanding human behavior in urban design, ultimately fostering better public spaces and promoting a more walkable community.

2.3 Psychological versus physical crowds

The third dimension for understanding pedestrian behaviors distinguishes between psychological and physical crowds. Before explaining this distinction, we will first explain the terminology around pedestrians and crowds.

When pedestrians are studied collectively, the field can also be broadly categorized as crowd behavior, with which it shares much research (Challenger et al., 2010b), as we discuss below. Although crowds are easy to recognize, they are challenging to define. Indeed, given the diversity of crowds, it is preferable to define types of crowds rather than provide a specific definition. Accordingly, an early typology suggested 11 different crowd types, of which ambulatory and escaping crowds are of particular relevance to pedestrians (Berlonghi, 1995). However, this typology was not exhaustive and contained overlaps, so more recent research sought to identify key characteristics of crowds. Challenger et al. (2010a) identified five such characteristics, namely: (1) size, (2) density, (3) time, (4) novelty, and (5) collectivity.

Examining the Challenger et al. (2010a) characteristics, size and density interact, so a larger collection of people positioned far apart may not constitute a crowd, but a smaller collection of people positioned more closely may do. Typically, smaller crowds exceed the size of groups, so may start at around 20 people (e.g., West et al., 1998), and would typically comprise hundreds or thousands of people; although much larger crowds of 3.5 million have been reported at music concerts (BBC, 2006). Crowd densities have been studied extensively and safety guidelines exist. For instance, the UK's guide to sporting venues specifies maximum densities of 4 people/m^2 when sitting and 4.7 people/m^2 when standing (Sports Grounds Safety Authority, 2018). However, safe crowd densities when moving are considerably lower, with observed densities of 0.4 to 0.8 people/m^2 in busy urban environments (Do et al., 2016) and just 0.16 people/m^2 if pandemic infection is a concern (Echeverría-Huarte et al., 2021).

Turning to the characteristic of time, some crowds are transient (e.g., an entrance queue), while others may exist for several hours (e.g., a festival), and while some crowds exist for long periods their membership changes frequently as people arrive and depart (e.g., a transport terminal) (Challenger et al., 2010b).

Novelty refers to whether crowds exhibit collective emergent behavior at the macro-level arising inductively from the micro-level interactions of crowd members in ways that are not necessarily planned (Van der Wal et al., 2021a).

All four of these characteristics can affect, and be affected by, the fifth characteristic of collectivity. Collectivity is a key characteristic in crowd definitions (Challenger et al., 2010a), as it affects the behavior of the crowd and its members. In this respect, physical crowds can be distinguished from psychological crowds. Physical crowds are those where members simply happen to be in the same space at the same time but do not share a collective identity, whereas psychological crowds do perceive themselves as sharing a collective (social) identity (Reicher, 2011). Essentially, in a psychological crowd, people shift from their personal identity to a shared social identity, categorizing themselves as 'we' or 'us' rather than 'I' or 'me' in relation to other individuals in the crowd (Templeton and Drury, 2018). The collectivity or social identity experienced by the crowd will interact with the other four characteristics used above to define crowds (Challenger et al., 2010a). For the design of pedestrian-friendly infrastructure and its management, it is relevant to take these characteristics into account.

Returning to the characteristics we used to define crowds earlier (Challenger et al., 2010a), these affect the extent to which crowds are more or less likely to be physical or psychological. For crowds in which members have no prior shared social identity, psychological crowds will be more likely to arise from members spending longer time periods together, in close proximity, and in smaller groups, as each of these factors will provide more opportunities to interact and establish social connections. However, in crowds in which members do have a prior shared social identity, then larger crowds are likely to intensify the emotional reactions, particularly in close proximity when there is sufficient time for the social identity to amplify in response to events. Furthermore, members of such crowds with prior shared social identities are likely to seek out events related to that identity, such as sporting events, festivals, or protests, which tend to be longer in duration. Finally, novel emergent behavior can occur in both physical crowds and psychological crowds but is more likely to be spontaneous and random in the former case and more planned and structured in the latter case.

Note that while members of psychological crowds may know each other prior to the event, this is not a prerequisite as collective identities can emerge during the event itself (Reicher et al., 2004). For instance, supporters of a music band or sporting team may share that identity despite having never met (Robinson et al., 2023). Furthermore, the treatment of the crowd by safety management professionals such as police can generate or change social identities fluidly (Stott and Radburn, 2020).

Finally, note that physical and psychological crowds are not discrete categories, and it is possible for either type of crowd to transform into the other type, either whole or in part. For instance, a physical crowd of commuting train passengers may develop a shared social identity as they talk among themselves about an incident such as a delayed train, thereby becoming a psychological crowd of stranded passengers. Conversely, a psychological crowd of supporters leaving a football match may become more focused on navigating their journey home on public transport, thereby becoming a physical crowd of passengers. However, it is more likely that most crowds will comprise some members acting more like a physical crowd and some acting more like a psychological crowd. For instance, research has found that in pedestrian crowds, many people are moving in smaller groups, such as friends, colleagues, or family units (Moussaïd et al., 2010).

2.4 Routine versus emergency situations

This fourth dimension concerns the situation pedestrians are in, as this will affect their behavior. In pedestrian planning research and practice, careful planning and design can prevent or mitigate emergencies. Relevant areas here include risk assessment, crowd management, designing evacuation routes, designing clear signage, and public communication. Unfortunately, though, some incidents will always happen. Moreover, there are still misunderstandings and ambiguous terms used in crowd science that can prevent effective pedestrian planning (Haghani et al., 2019). Therefore, it is important to understand pedestrian behaviors in both routine and emergency situations, to more effectively prepare for emergencies, and some examples are provided below.

In routine conditions, self-organization behavior leads to pedestrians walking in an orderly fashion (Templeton et al., 2018). Compared to a physical crowd, pedestrians in a psychological crowd are more able to coordinate with each other (Templeton et al., 2018). In emergency situations, this means people will usually also evacuate in an orderly way (Drury et al., 2009a, 2009b, 2009c). Only rarely, in dire circumstances, do people get stuck or crushed walking to or exiting an area because too many people try to go or leave via the same route at the same time. This was, for instance, the case at the Love Parade in 2010, at Mount Meron in 2021 and at the Halloween celebration in Seoul in 2022 (Helbing and Mukerji, 2012; Sharma et al., 2023; Yogev and Levenkron, 2023).

In routine conditions, walking behavior can vary from walking alone to walking in groups, either with or without a purpose in each case (e.g., commuting versus a leisurely stroll, respectively), and walking speeds will probably differ between these situations (e.g., if people are commuting in ‘rush hour’). In emergency situations, psychobiological aspects should also be considered (Robinson and Leach, 2018), as the experience of stress could affect cognitive functioning and therefore also pedestrian (walking) behavior.

Furthermore, routine conditions can sometimes quickly change to emergency conditions, which, in a crowded space with many pedestrians, could lead to a crowd disaster. Generally, there are two causes of crowd disasters. First, as Still (2022) notes, they can occur when the density of the crowd increases to dangerous levels due to the influx of too many people into a constrained place, such as when a street or doorway becomes narrower, or where an obstacle blocks a corridor or route. Either way, the density increases and people are pushed together, with pedestrians no longer having control of their movements and being unable to walk or escape. However, although crushes occur because of crowd dynamics, this does not mean that the crowd is to blame for the disaster. Rather, a crowd disaster is usually caused by a cascade of errors and factors in combination with poor or absent crowd management (Challenger et al., 2010b).

Another cause of crowd disasters are sudden incidents in crowded places, such as a terrorist attack (e.g., Paris, 2015) or mass shooting (e.g., Las Vegas, 2017) (Van der Wal et al., 2021b). Here, pedestrians in the crowd usually try to escape the danger by walking or running away, or when people are trying to hide from terrorists or shooters (Van der Wal et al., 2021b).

Early sociological research revealed that the notion of 'crowd panic' in emergency situations was not supported (Quarantelli, 1954). Indeed, recent research has indicated that the concept of crowd panic is now considered outdated and inaccurate (Auf der Heide, 2004; Clarke, 2002; Quarantelli, 2008). Specifically, most sociological and social psychological researchers who have investigated whether panic is common in emergencies agree that, while in individual cases it could happen, it is generally considered a myth arising from misunderstandings of behavior that has more accurate alternative explanations (Drury et al., 2013; Gantt and Gantt, 2012; Keating, 1982; Quarantelli, 2008).

2.5 Urban versus rural environments

The fifth dimension concerns the environment pedestrians travel through. A key determinant of pedestrian behavior is whether the environment is urban or rural (Azmi et al., 2012). Urban and rural environments can differ substantially in terms of the extent to which routes are restricted and wayfinding information is provided, which in turn affect pedestrian behavior.

Urban environments such as cities have structured routes for pedestrians to follow, in the form of pavements, sidewalks, underpasses, and footbridges (Zhu et al., 2023). These structured routes exist for several reasons. First, pedestrians need to be separated from the large volumes of road traffic that exist in cities, for their own safety. Second, buildings or the built environment function as barriers, both to movement and also visually, so guidance is required. For instance, it is often difficult to see more than one or two blocks ahead in a city and very rare to see the natural horizon unless in an elevated location. For these reasons, cities usually provide many resources to support effective wayfinding, both explicitly and deliberately, such as signs and maps, and implicitly and coincidentally, such as famous landmarks (Yesiltepe et al., 2021). Furthermore, pedestrians in urban environments often walk indoors, such as in shopping malls, department stores, leisure facilities, and transport terminals.

In rural environments, there are generally far fewer people and vehicles, and buildings are usually more spaced out. Consequently, there are far fewer human barriers to movement, but there may be natural barriers instead, such as rivers, vegetation, cliffs, and mountains. Due to the relative remoteness of rural environments and the lower populations, there are far fewer if any wayfinding resources (Yesiltepe et al., 2021). So, pedestrians in such environments (including 'hikers') must carefully consider their routes and have plans for emergencies, such as becoming lost, sustaining injuries, or encountering natural disasters (Mykletun et al., 2021).

2.6 Integrated framework of human factors in pedestrian planning

Our framework for understanding human factors in pedestrian planning is shown in Fig. 2. On the left, the five dimensions are shown, as explained above in Section 2, through which the human factors can be understood. The arrows do not connect specific dimensions and human factors, as each of the dimensions can have an effect on each human factor. We divided the human factors into three levels: individual, social, and environmental. Next, the human factors can influence different levels of pedestrian behaviors, shown as levels of a pyramid: strategical, tactical, and operational. Again, the arrows do not connect specific human factors to specific pedestrian behaviors, as each human factor level can influence any of the pedestrian behaviors.

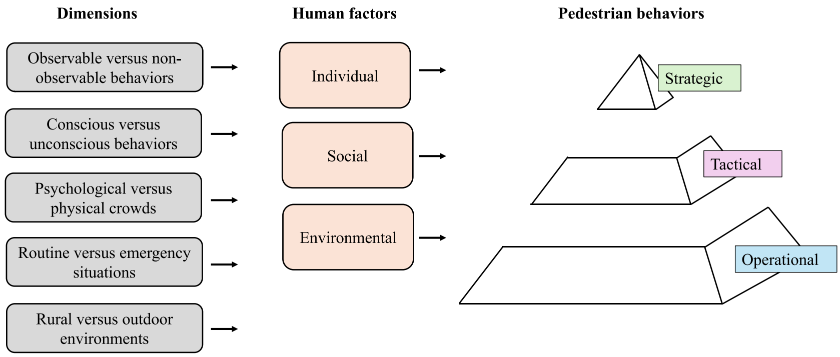

Fig. 2 The framework for understanding human factors in pedestrian behaviors, relevant to pedestrian planning research.

3. Human factors in pedestrian planning

In this section, we discuss various human factors in pedestrian planning, providing a broad overview, as shown in Fig. 3. We have chosen to structure this chapter from the perspective of different human factor levels and topics. Each human factor can influence different pedestrian planning actions. For example, age can affect walking speed and road crossing behavior, while group size can influence walking speed and evacuation decision-making. For readers interested in specific pedestrian behaviors, such as route choice, and the relevant human factor (Fig. 3) can be of help.

3.1 Human factors at individual level

In this section, the following human factors at an individual level are addressed: age, gender, personality traits, sensation and perception, decision-making and heuristics, risk perception, attention, and memory and information-processing.

3.1.1 Age

In adults, the walking speed of both females and males generally declines with age (Ye et al., 2012). On average, compared with young pedestrians, middle-aged pedestrians walk 6–8 % slower and old pedestrians walk 18–24 % slower (Ye et al., 2012).

From a safety perspective, children and the elderly are typically more at risk at road crossings, even though they typically behave more cautiously than other adults (Arnold and Bennett, 1990). The increased risk for older

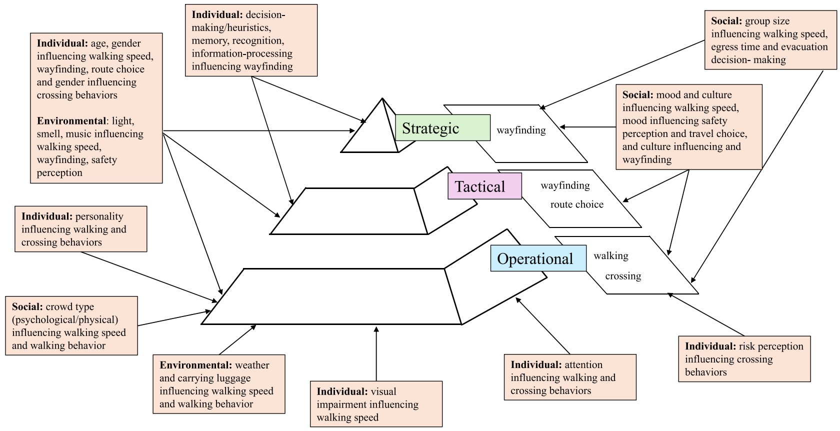

Fig. 3 Human factors addressed in this chapter and the pedestrian behaviors they affect.

adults is influenced by declines in cognitive, perceptual, and motor abilities, along with the complexity of the crossing task and environmental factors (Arnold and Bennett, 1990; Wilmut and Purcell, 2022). It can be harder for older adults to focus on and interpret their surroundings, judge vehicle speeds, decide when to cross, and initiate the crossing (Wilmut and Purcell, 2022). Older adults find non-signalized roads riskier due to the lack of regulated crossing times, making it harder to judge when it is safe to cross (Wilmut and Purcell, 2022). Young adult pedestrians have also been found to take more risks than older pedestrians, such as crossing during a red light and engaging in more distracting behaviors, like using a mobile phone while crossing the road (Bendak et al., 2021).

Age influences wayfinding as well. Spatial navigation deteriorates with age (Head and Isom, 2010). While navigating familiar environments tends to remain consistent with age, the ability to handle unfamiliar settings declines over time (Colombo et al., 2017). There is hardly any research on wayfinding in children, such as on how cognitive processes contribute to wayfinding (Yang and Merrill, 2022). Existing current research shows there is overlap in findings with adults, such as personal factors like affect, motivation and personality influencing their navigational skills (Yang and Merrill, 2022).

3.1.2 Gender

Gender has a significant impact on walking speed, with males walking 5–7 % faster than females for young and middle-aged pedestrians (Ye et al., 2012). However, there is no significant difference between the speed of elderly males and elderly females (Ye et al., 2012).

There are more male pedestrian fatalities than female fatalities across all age groups (National Highway Traffic Safety Administration NHTSA, 2023). Research generally reveals that males take more risks than females when crossing roads, and walk faster, which seems to be correlated with risk perception and personality (Bendak et al., 2021; Herrero-Fernández et al., 2016; Zhu et al., 2013).

Gender differences in spatial orientation have been linked to both cognitive and personality factors. In terms of cognition, research suggests that men and women tend to rely on different environmental cues and types of spatial information when navigating their surroundings (Wolbers and Hegarty, 2010). Spatial orientation typically involves two main frameworks: the egocentric (body-centered) and the allocentric (environment-centered) approaches (Klatzky et al., 1998). The egocentric framework involves determining one's position in space using internal cues, while the allocentric framework refers to spatial orientation that is independent of the individual's current location and instead focuses on the relationships between external landmarks. Studies have shown that men are generally more inclined to use allocentric strategies, while women are more likely to rely on egocentric strategies (Lawton, 1994; Lawton and Kallai, 2002). Gender can also have an effect on emotions during wayfinding skills. A recent study showed that gender serves as a predictor of both the use of effective wayfinding strategies and the experience of wayfinding-related fear (Mendez-Lopez et al., 2020). However, factors such as outdoor wayfinding experience, fear associated with wayfinding, and emotional difficulties did not mediate the link between gender and effective wayfinding ability (Mendez-Lopez et al., 2020).

3.1.3 Personality traits

Personality is the set of enduring psychological traits that influence an individual's behavior and interactions with their physical and social environments (Larsen et al., 2017). Research examining personality has identified a five-factor model (the 'Big Five') comprising the traits of extraversion, agreeableness, conscientiousness, emotional stability, and openness, on which people differ (Costa and McCrae, 1992; Larsen et al., 2017).

Several studies have identified relationships between personality traits and walking behavior. Lower neuroticism and higher conscientiousness (Stephan et al., 2018), extraversion, and openness are related to faster walking speeds (Stephan et al., 2018; Tolea et al., 2010). Chapter 6 also discusses how personality can influence travel choice behavior. Finally, research also indicates that people higher in agreeableness, conscientiousness, and emotional stability are more likely to conform to social influence (DeYoung et al., 2002), suggesting that they may be more susceptible to conform to social identity-related behaviors and norms in psychological crowds (Challenger et al., 2010b).

3.1.4 Sensation and perception

Perception is the process that transforms sensory input into an understanding of the world around us. Studying perception helps us understand how physical reality is converted into mental experiences and sheds light on behaviors such as navigation and recognition (Gilhooly et al., 2022). Perception lies on a spectrum between sensation, where physical energy is converted into brain signals, and cognition, where mental representations and goals guide reasoning and behavior planning (Gilhooly et al., 2022).

The importance of sensation and perception to pedestrian walking behavior is best explained by the following example. Consider a pedestrian who is given directions to the other side of the city while in a dark and noisy environment. In this case, the directions must be heard and understood by the pedestrian, and he/she has to be able to see and identify the relevant landmarks en route. If the pedestrian fails in one of these aspects, he/she may also fail in the other.

Furthermore, the perception of an environment involves both the recognition of individual objects and the overall character formed by all the objects collectively (Gilhooly et al., 2022). Object recognition is important for wayfinding. Learning a route requires more than just memorizing the number of turns, for instance; it involves understanding the angles of turns, key environmental features at decision points, and other notable surroundings along the path (e.g., landmarks visible from the route that aid orientation) (Golledge, 1999; Yesiltepe et al., 2021). Even if pedestrians deviate from the original path, they can still navigate successfully by recognizing nearby landmarks that confirm they are moving in the right direction (Golledge, 1999).

Visual impairment can also have an effect on pedestrian behaviors. Globally, at least 2.2 billion people are visually impaired, with leading causes including refractive errors and cataracts (World Health Organization, 2023a). There are dangers for visually impaired pedestrians as they often cannot sense aerial and suspended obstacles in front of them when walking (such as tree branches, half-open iron rolling doors, and signs), which may result in collisions and serious injuries (Sáez et al., 2015). Peat and Higgins (2023) examined the safety of visually impaired pedestrians in relation to quiet motor vehicles, like electric and hybrid cars. They concluded that crossing roads when quiet vehicles are present is dangerous for pedestrians with visual impairments, as they rely on vehicular sounds for safe crossings. Another danger lies in the existing characteristics of busy cities, where chaos and loud noises can reduce spatial perception for blind individuals, like their impact on sighted children (Tesoriere et al., 2018). Finally, policies aimed at enhancing walkability cannot be universally applied across all cities. Consider, for instance, the historic centers of certain Italian cities distinguished by narrow streets and steep inclines (Campisi et al., 2019). These features also pose challenges for orientation among blind or visually impaired individuals, particularly in unfamiliar or complex environments.

Increasingly, technology can provide support to visually impaired pedestrians, for example in navigation, orientation, and obstacle avoidance (Paiva and Gupta, 2020). In outdoor environments, several technological solutions exist to assist visually impaired pedestrians, including equipment such as digital cameras, mobile apps, Bluetooth, and radio frequency identification (RFID), which help them navigate outdoors, detect moving objects, or judge direction and distance.

3.1.5 Decision-making and heuristics

In Section 2.2, we considered the two cognitive systems involved in decision-making: System 1 and System 2 (Kahneman, 2011; Stanovich and West, 2000). System 1 is an automatic, fast system in which intuitive and immediate responses are generated, while System 2 operates relatively slowly and sequentially (Gilhooly et al., 2022; Kahneman, 2011). According to Kahneman (2011), most decisions are made at an unconscious level by System 1. However, System 1 is sensitive to heuristics, which are cognitive strategies or shortcuts people use to make judgments quickly and efficiently (Kahneman et al., 2021). This should be taken into account in pedestrian planning research because decision-making and heuristics have a significant effect on wayfinding. For example, your perceived position and orientation are utilized to determine your navigation direction or to favor continuing your route in an asymmetrical way (Hochmair and Frank, 2000; Van Tilburg and Igou, 2014). Within wayfinding, the availability heuristic also plays a role as pedestrians may choose a certain route because they walked it recently and therefore remember it. This also explains why in emergency situations people usually evacuate via a familiar route (Sime, 1983; 1985). Sometimes these heuristics lead to biases, however, which are systematic and predictable errors in judgment (Kahneman et al., 2021), such as choosing a familiar route over a shorter, unfamiliar route.

3.1.6 Risk perception

In young adult pedestrians, risky behavior at crossings is positively associated with impulsiveness and negatively associated with the personality trait conscientiousness (Bendak et al., 2021; Herrero-Fernández et al., 2016). Furthermore, males score higher on impulsiveness and lower on conscientiousness than females, which may partially explain their riskier behaviors (Herrero-Fernández et al., 2016). Risk perception also influences crossing behaviors, where people that perceive higher risks are less likely to engage in risky crossing behaviors (Hou et al., 2022). Risk perception seems to be related to worrying as well, as pedestrians that have a higher risk perception, worry more (AlKheder et al., 2022; Kummeneje and Rundmo, 2019).

3.1.7 Attention

Attention is the mental process of concentrating effort on a stimulus or a mental event (Radvansky and Ashcraft, 2014). While walking, pedestrians must pay attention to their environment (external attention) but also process thoughts and motivations (internal attention). Failures in attention can occur in two key ways: change blindness and inattentional blindness. Change blindness is when substantial differences between two nearly identical scenes are not noticed when presented sequentially (Gilhooly et al., 2022). Inattentional blindness is the failure to notice a clearly visible target due to attention being diverted from the target (Gilhooly et al., 2022).

In interactions with other pedestrians and other road users in vehicles, inattentional blindness can cause serious incidents and accidents. There were an estimated 1.19 million road traffic deaths in 2021 worldwide, with pedestrians representing 23 % of these fatalities (World Health Organization, 2023b).

Laboratory and field experiments indicate that pedestrians are distracted by cell phone use while walking, whether talking or texting, and this increases the risk of accidents, especially on the streets (Sobrinho-Junior et al., 2022). Furthermore, in laboratory settings, cell phone use impairs auditory and visual attention (Haga et al., 2015). A meta-analysis of 14 experimental studies and eight observational studies concluded that both cell phone conversation and texting increased the rates of collisions and close calls, while texting also decreased rates of looking left and right prior to and/or while crossing the street (Simmons et al., 2020). In object-detection field experiments, only 20 % of walking pedestrians engaged in phone calls detected the objects compared to 74 % in the control condition

(Alejalil and Davoodi, 2017). Furthermore, pedestrians talking on the phone tend to reduce and control their walking speed by adjusting their stride length or frequency (Alsaleh et al., 2018).

3.1.8 Memory and information-processing

Various cognitive abilities, such as memory and information-processing, have been found to influence pedestrian behaviors such as wayfinding (Erkan, 2024; Golledge, 2003). Recognition and recollected memory are important in wayfinding, so eye-catching landmarks can help improve wayfinding performance (Afrooz et al., 2018). A study examining the cognitive process of wayfinding found that high visual access and better wayfinding information can reduce the spatial complexity, and thus improve wayfinding (Abu-Ghazzeh, 1996). Recall accuracy, and visuospatial and cognitive abilities in wayfinding behaviors are strongly associated with environmental familiarity (Meneghetti et al., 2017).

If pedestrians use the same environment frequently, they will become more familiar with it, improving their wayfinding. With repeated use, maps and location apps are no longer required, as people develop their own mental maps of locations and routes (Li and Klippel, 2016). For instance, people develop cognitive scripts for familiar routes, which are enduring and instinctive, such as the same route home from work every day (Donald and Canter, 1992). While generally useful and effective, in emergency situations these cognitive scripts remain, sometimes with tragic consequences, such as attempting to evacuate via the familiar entrance rather than the nearest exit in emergencies (Grosshandler et al., 2005).

3.2 Human factors at social level

In this section, the following human factors at a social level are addressed: group size, type of crowd, emotions and mood, and culture.

3.2.1 Group size

Pedestrians often walk in groups of two or more people, in the company of family, friends, or colleagues rather than alone (McPhail and Wohlstein, 1982; Moussaïd et al., 2010; Nicolas and Hassan, 2023). Indeed, 70 % of observed pedestrians in a commercial street were found to be walking in such groups (Moussaïd et al., 2010), and 68 % of crowds in other diverse contexts (e.g., train stations, fairs, sport events, hospitals) comprise groups of at least two pedestrians (Nicolas and Hassan, 2023). Furthermore, even when not moving in groups, most pedestrians encounter other people while moving through built and natural environments, who if sufficiently large in number and densely located would constitute a crowd (Challenger et al., 2010a).

Social groups and their sizes can influence walking speed and walking patterns. An increase in the group size, namely groups of two, three, or four, will decrease the walking speed of the crowd, particularly at higher densities (Giannoulaki and Christoforou, 2024; Moussaïd et al., 2010). Groups also walk in reverse V-shape patterns, which are efficient for communication but inefficient for movement (Moussaïd et al., 2010; Sobhana and Verma, 2024).

Moreover, the existence of social groups seems to increase the egress times of pedestrian crowds, although the evidence for this effect is inconclusive (Hu and Bode, 2023). In Bode et al. (2015), Haghani et al. (2019), Köster et al. (2011), and Bode (2016), the existence of social groups in the crowd did increase the egress time, while in Xie et al. (2020) and Hu et al. (2021) it did not. However, the low number of replication studies and variability in measurements can explain seemingly conflicting results across these studies (Hu and Bode, 2023). When analyzing the social groups themselves, not their effect on the total crowd, different results have again been found. Laboratory studies of evacuation dynamics have shown that small groups (two or three people) evacuate slower than individuals (Bode et al., 2015; Lu et al., 2017), while larger groups (four or more people) evacuate faster than individuals or smaller groups (Cuesta et al., 2021; Haghani et al., 2019; Von Krüchten and Schadschneider, 2017).

Group size also influence decision-making. Group size can influence orientation decisions during wayfinding both positively as negatively (Dalton et al., 2019). Group size also influences evacuation decision-making. In a laboratory study, evacuation decisions for large groups (of 25 people) were more successful than for individuals and smaller groups (of five people) with a majority vote, and less successful than groups with a leader or consensus-reaching strategy (Nguyen et al., 2019). The preferred or perceived group decision strategies also differ between studies, such as a leader-follower strategy in Haghani et al. (2019) and a consensus or majority decision strategy in Cuesta et al. (2021). Other variables may also influence group decision-making, like members' physical distance or exit knowledge, and physical attributes making it challenging to evacuate (Aguirre et al., 2011a). Furthermore, a minority of informed crowd members can lead others to a particular destination without verbal communication, so decision-making may not necessarily be explicit and verbal (Dyer et al., 2008).

3.2.2 Type of crowd (psychological or physical)

As discussed in Section 2.3, the behaviors of pedestrians in a physical crowd might be different than the pedestrian behaviors in a psychological crowd. For instance, pedestrians in a psychological crowd walk slower than pedestrians in a physical crowd (Templeton et al., 2018). One explanation for this behavior is that pedestrians in a psychological crowd are more inclined to talk to each other compared to those in a physical crowd. It seems that pedestrians are also more open to talking to strangers in a psychological crowd than a physical crowd (Drury et al., 2015).

Pedestrians in a psychological crowd also stay closer together compared to pedestrians in a physical crowd (Novelli et al., 2013; Templeton et al., 2018). In emergency situations, psychological groups might therefore try to stay together, resulting in more fatalities. In The Station nightclub fire in 2003, for instance, it was found that groups with interpersonal relationships had higher fatalities than those without (Aguirre et al., 2011b). Furthermore, groups within a psychological crowd typically contain more members than groups within a physical crowd, and in a psychological crowd they do not divide into smaller groups (Templeton et al., 2018).

Finally, pedestrians in a psychological crowd share the same group norms (i.e., values and rules) that will shape common behaviors, such as selecting preferred routes or shortcuts, and following other members of their group. For emergency situations, there is considerable evidence of mutual helping among strangers and sometimes individuals even risk their own safety to help strangers (Aguirre et al., 2011b; Drury and Cocking, 2007).

3.2.3 Emotions and mood

Emotions and mood can influence pedestrian behaviors, such as walking speed, travel choice and safety perception. The difference between emotion and mood is that moods are less specific, less intense and less likely to be provoked or triggered by a particular stimulus or event, while emotions are triggered by a stimulus and have a clear starting point (Robbins et al., 2010).

Chapter 6 discusses how travel choice behaviors can be influenced by mood and other factors including socio-demographics factors, economic factors, personality characteristics, physical abilities, mood, habits, and social and environmental factors. In Balaban et al. (2017), results indicated that wayfinding and recognition performance were highest when landmarks with negative emotional content were used. Compared to neutral and positive landmarks, recognition of negatively laden landmarks remained relatively stable over time.

Mood can also affect walking speed (De Silva et al., 2017; Franěk and Režný, 2017). Franěk and Režný (2017) explored how priming with images of different environments influenced walking speed in urban settings. They found that participants who viewed photographs of vegetation walked more slowly, especially in naturally rich sections of the route. While nature-based photographs slowed walking speed, photographs with shopping malls did not significantly increase it, suggesting that nature positively impacts walking behavior. Negatively perceived streetlighting and atmosphere of the environment can also affect walking speed and safety perception negatively (De Silva et al., 2017).

3.2.4 Culture

Culture is defined as the collective programming of the mind that distinguishes the members of one group or category of people from others (Hofstede et al., 2010). Moreover, culture is learned, not innate, derived from one's social environment rather than from one's genes (Hofstede et al., 2010).

Culture can influence wayfinding behavior, because of different understandings of spatial cues across different cultures (Karimi, 2015; Tijus et al., 2007). Lee et al. (2014) and Joy Lo et al. (2016) both found a strong cultural effect on the identification of healthcare symbols for wayfinding in healthcare facilities. Joy Lo et al. (2016) found universal healthcare symbols for wayfinding, designed in the United States, can be interpreted differently based on a person's nationality, in this study Taiwanese. Similarly, Lee et al. (2014) found differences in the understanding of universal healthcare symbols between American, Korean, and Turkish people.

Culture can also influence walking speed. Bornstein and Bornstein (1976) found that walking speed is not only dependent on city size, but also on cultural differences. People have cognitive and behavioral adaptations to increases in social stimulation, depending on the country they live in, resulting in different behavioral norms (e.g., increases or decreases in walking speed) (Bornstein and Bornstein, 1976). Cultural influences on walking speed have been researched for many years, with results finding key factors such as social status, cultural environment, and size of settlement area (Bosina and Weidmann, 2017). Essentially, successful and busy people walk faster compared to unemployed people (Jahoda et al., 1933), those living in colder climates walk faster compared to warmer climates (Bosina and Weidmann, 2017), and those living in larger cities walk faster compared to smaller cities (Bornstein, 1979; Walmsley and Lewis, 1989).

3.3 Human factors at environmental level

In this section, the following human factors at an environmental level are addressed: weather, light, smell and music, nudging and biophilia, road crossings, and carrying luggage.

3.3.1 Weather

Weather conditions influence pedestrian behavior and should be considered when planning events or designing urban environments. Precipitation such as rain and snow can make walking surfaces slippery and hazardous, particularly when conditions are icy (Schepers et al., 2017). In such adverse conditions, pedestrians will walk more slowly and may take less direct routes to avoid hazards such as puddles. The risk of slips, trips, and falls is also much greater, particularly on ice (Berggård and Johansson, 2010), so pedestrians will require more space to balance and so that if they do fall, other pedestrians are not impacted. During heavy rainfall, there is also the risk of flooding, as rivers and streams may burst their banks, and flash flooding where water appears in unlikely areas (Musolino et al., 2022). Here, warning signs and temporary barriers can help reroute pedestrians away from the most hazardous areas.

Furthermore, during rain and snowfall, pedestrians will frequently be wearing hooded clothes and using umbrellas, both of which can be hazardous. For instance, hoods can reduce peripheral vision and hearing (Network Rail, 2013) which makes crossing roads and navigating busy pedestrian areas more challenging. Umbrellas can also substantially reduce visibility in all directions, take up considerable space, and their sharp edges which are usually at head level constitute a safety hazard (Carothers, 1978). In falling rain and snow, particularly when blown sideways by wind, pedestrians are also likely to be looking downwards which reduces visibility further. Snow and ice on the ground can obscure the boundaries between roads and pavements, making road crossings more hazardous, particularly when vehicles will also have reduced visibility and longer stopping distances (Japan Automobile Federation JAF, n.d).

Sunny and warmer conditions are generally safer for pedestrians but also present their own hazards. For pedestrians walking long distances or attending events of long duration, high temperatures can lead to health conditions such as dehydration and heat stroke (Jay et al., 2021). While extreme cold can also pose health hazards, people are generally less likely to spend extended periods outdoors. At sunrise and sunset, the sun low on the horizon can create glare and reflections off mirrored surfaces, which can reduce visibility and increase accidents (Ma et al., 2019). In general, nighttime and other dark conditions are more hazardous for pedestrians as they are much less visible to vehicle drivers (Tyrrell et al., 2016). To counter this, in darkness, particularly when walking in less illuminated rural areas, pedestrians should wear highly visible reflective clothing where possible (Seidu et al., 2024). Finally, vehicles in countries or regions with seasons of high darkness sometimes have lights that are permanently activated, to improve their detection by pedestrians and reduce accidents (Krajicek and Schears, 2010).

3.3.2 Light, smell and music

Environmental factors such as light, color, smell and sound can influence pedestrian behaviors (Moser and Uzzell, 2003).

The design of city smell environments, or 'smellscapes' is a separate research field in environmental psychology (Henshaw, 2014). The odor in urban environments can have an effect on placemaking and emotions (Henshaw, 2014; Xiao et al., 2020).

Outdoor lighting can have an effect on perception and pedestrian behavior. In Rahm and Johansson (2021), results showed that lighting with higher uniformity and horizontal illuminance improved perceptual performance (facial expression recognition and sign reading), and that these methods effectively assessed lighting impacts across age groups.

Chapter 13 presents a literature review on crowd management strategies and other factors influencing crowd behaviors such as pedestrian walking speed, flow, and wayfinding. Guiding mechanisms such as lighting and (dynamic) signage and gates influence the crowd dynamics. Other influencing factors include personal characteristics, such as age and gender, social factors such as group formation, and infrastructure such as hallways and stairs. In Van Beek et al. (2024), it was determined that pedestrians have the tendency to follow a path with green lights and avoid a path with red light.

Different types of music can influence walking behavior in an outdoor urban environment. Results in Franěk et al. (2014) showed that while music affected walking tempo – motivational music increasing speed and non-motivational slowing it down – precise synchronization with the beat was rare, and music partially masked the influence of the surrounding environment, with individual personality traits also playing a role. Franěk and Režný (2021) examined how visual environmental features influence walking speed. This study found that walking speed was lower in sections with high natural characteristics and a high environmental preference.

Noise here was perceived as less annoying than in sections with lower natural characteristics. Other studies have found similar results, whereby noise (traffic sounds) made pedestrians walk faster and relaxing sounds (nature sounds) make pedestrians walk slower (Kweon et al., 2021).

3.3.3 Nudging and biophilia

Nudge theory (Thaler and Sunstein, 2008) proposes that environmental features can be designed, structured, and presented in particular ways to subtly encourage people to behave in a desired way while retaining autonomy over their decisions. Consequently, nudge theory has also sometimes been referred to as choice architecture (Thaler et al., 2013). The principles of nudge theory have been widely applied in the design of pedestrian infrastructure. On escalators in transport terminals, for instance, brightly colored footprints are often painted on the steps to indicate appropriate behavior (Xie, 2013). Specifically, two footprints together on each step, or side of a step, indicates pedestrians should stand still, while single left and right footprints alternating between steps indicate pedestrians should walk. Similarly, in transport terminals, large information boards are generally only located in open atrium areas, partly so that pedestrians and passengers stopping to read them do not block narrow corridors designed for walking (e.g., BNSS, n.d.). Consideration and adoption of such principles by pedestrian planners can therefore help influence pedestrians to behave and move in a safer and more efficient way through urban environments.

Biophilia theory proposes that people are innately attracted to natural surroundings such as foliage and water features, as these calming environments boost wellbeing and help people relax (e.g., Milliken et al., 2023). Principles of biophilia theory have therefore been adopted by city planners to design environments for pedestrians that incorporate natural features such as trees, parks, and fountains (Beatley, 2011). Specifically, in transport terminals, architects and builders have incorporated living walls of foliage, designs that maximize natural light, and calming water features to reduce the stress of busy and rushed commutes for pedestrians and passengers (Roös et al., 2016). As well as mitigating pedestrian frustrations that may lead to antisocial behavior, such natural features may also encourage pedestrians to congregate and meet in appropriate places such as open atriums and parks, rather than on congested walking routes that may block other pedestrians.

3.3.4 Road crossings

Locations where pedestrians must interact with vehicles are particularly hazardous and must be carefully managed. Adequate road crossing facilities must be provided, such as traffic lights and pedestrian crossings. Jaywalking, or crossing outside of designated areas, is also legally prohibited in some countries but can be discouraged through safety notices and availability of sufficient pedestrian crossings (Anik et al., 2021). For areas where high speed vehicles operate, such as motorways, freeways, and train tracks, pedestrian crossings can be physically separated from vehicles routes to improve safety, by providing footbridges and underpasses for pedestrians to use (Zhu et al., 2023). Recently, the increase in smaller electrically-powered vehicles such as scooters and e-bikes has introduced more hazards for pedestrians, alongside regular pedal bikes, with accidents increasing (Savitsky et al., 2021). Furthermore, such vehicles are frequently used on pavements and in other pedestrian areas, despite their high speed (Anke et al., 2023). Finally, pedestrians should only use pavements and footpaths, but if walking on a road is unavoidable they should face the oncoming traffic so they can be alerted for danger (Luoma and Peltola, 2013).

Balk et al. (2014) examined more than 70,000 pedestrian crossings at 20 different locations to analyze the environmental factors that influence pedestrian crossing behaviors. They found that trip originators, trip destination, and perceived affordances influence pedestrian flow and crossing behaviors. Trip originators are the areas where pedestrians begin trips and trip destinations are where they end trips. Affordances refer to the quality of the environment, determining how it can be used, perceptions of which lead pedestrians to take action. Affordances can be inaccurately perceived, however, such as at night, when pedestrians frequently overestimate the distance at which drivers are able to see them (Tyrrell et al., 2004).

Age, gender, alcohol consumption, self-identity (as a safe or careful pedestrian), and perceived control (part of the theory of planned behavior) influence road crossing behaviors also (Balk et al., 2014). Road crossing is considered a cognitively difficult task for which children may not have fully developed all the required abilities and the elderly might experience greater demands on their declining physical and cognitive resources (Arnold and Bennett, 1990). Among pedestrians, there are more male fatalities than female fatalities and 49 % of these involve alcohol consumption (National Highway Traffic Safety Administration NHTSA, 2023). People identifying as safe pedestrians are less likely to cross at a potentially risky location

(Evans and Norman, 2003; Holland et al., 2009). However, the more pedestrians perceive having behavioral control, the more likely they are to cross roads (Evans and Norman, 1998; 2003).

3.3.5 Carrying luggage

Carrying small, medium, or large luggage or a trolley-case significantly decreases walking speed (Ye et al., 2012). Compared with no luggage, small luggage reduces walking speed by 2–3 %, medium luggage by 5–8 %, large luggage by 10–14 %, and a trolley-case reduces speed by 3–8 % (Ye et al., 2012).

Pedestrians carrying luggage and equipment may also be hazardous for other people. This is particularly true in transport terminals, where passengers may be carrying large luggage which can reduce space in, or block, confined spaces such as entrances, exits, elevators, and escalators (Larue et al., 2021). Furthermore, luggage or other people that are below lines of sight in crowded spaces, such as wheeled cases or pushchairs, may constitute trips hazards if people believe the space is empty and attempt to step into it when overtaking.

4. Summary

In conclusion, this chapter highlights the intersection of human factors and pedestrian research, emphasizing the need for a comprehensive understanding of how these factors influence pedestrian behaviors in pedestrian planning research. By integrating the fields of engineering, psychology, physiology, transport, architecture, and sociology, we can better understand pedestrian behavior in various contexts, from routine activities like wayfinding and crossing streets to emergency situations such as evacuation due to an incident. Despite the shared focus on efficiency and safety between human factors and pedestrian research, a significant gap remains in the practical application of this knowledge within pedestrian planning and design. Engineers and designers often lack the necessary experience in human factors, leading to systems that do not fully account for the complexities of human behavior.

This chapter addressed these limitations by presenting a framework to categorize human factors in pedestrian planning research, comprising five dimensions of observable versus non-observable behaviors, conscious versus unconscious behaviors, physical versus psychological crowds, routine versus emergency situations, and urban versus rural environments. These five dimensions inform the three levels of human factors we distinguished: individual, social, and environmental.

The key issues discussed for individual-level human factors were age, gender, personality traits, sensation and perception, decision-making and heuristics, risk perception, attention, memory and information-processing. In summary, adult walking speed decreases with age, while males walk faster than females in young and middle-aged groups (Ye et al., 2012). Personality traits can also influence walking speed and conformity to social norms (Stephan et al., 2018; Tolea et al., 2010). Heuristics influence route choices, especially in emergencies (Sime, 1983; 1985), while familiarity with the environment improves wayfinding and reduces reliance on maps (Li and Klippel, 2016). Visually impaired pedestrians face significant challenges, particularly with quiet vehicles like electric cars (Peat and Higgins, 2023). Males tend to be more impulsive and less conscientious, leading to riskier behaviors (Herrero-Fernández et al., 2016). Challenging noisy or dark environments can impact the ability to follow directions and identify landmarks (Afrooz et al., 2018; Yesiltepe et al., 2021), while attention is also crucial for pedestrian safety (Simmons et al., 2020; Sobrinho-Junior et al., 2022).

For the social-level human factors, we considered how group size can influence walking speed, walking patterns, evacuation times, and (evacuation) decision-making (Dalton et al., 2019; Giannoulaki and Christoforou, 2024; Hu and Bode, 2023; Moussaïd et al., 2010; Nguyen et al., 2019). Distinguishing between physical and psychological crowds is also relevant for pedestrian planning because pedestrian behaviors might be different in these type of crowds, both in routine and emergency situations (Drury and Cocking, 2007; Templeton et al., 2018). Emotions and mood can also influence the walking speed, travel choice and safety perceptions of pedestrians (Balaban et al., 2017; De Silva et al., 2017; Franěk and Režný, 2017). Different cultural interpretations of spatial cues and symbols can affect navigation (Karimi, 2015; Tijus et al., 2007), for instance.

For the environmental-level human factors, we addressed how adverse weather conditions like rain, snow, and ice slow pedestrians and increase the risk of slips and falls (Schepers et al., 2017). We also discussed how light, odor and music can influence pedestrian behaviors (Moser and Uzzell, 2003). Nudges (Thaler and Sunstein, 2008) can be used to subtly encourage pedestrians to behave in a desired way or move in a safer and more efficient way through urban environments. Furthermore, principles of biophilia theory can help city planners to design environments for pedestrians that mitigate antisocial behavior, for instance. Pedestrian crossing behaviors are influenced by various factors, including age, gender, alcohol consumption, and perceived control (Anik et al., 2021). Furthermore, safe crossings require proper facilities and awareness of environmental affordances. Finally, we considered how carrying luggage can reduce walking speed and create hazards in crowded areas (Ye et al., 2012).

Our aim was to provide a deeper understanding of the human factors involved in pedestrian behavior. We invite pedestrian planners to utilize our framework as a resource for identifying relevant human factors and exploring them in greater depth. To this end, the chapter provides a broad overview as a starting point. Ultimately, by adopting an interdisciplinary approach and integrating a deeper understanding of human behavior into pedestrian systems, pedestrian planners, policymakers and designers can better implement targeted interventions that align infrastructure with human capabilities and limitations.

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