Spatial Knowledge Acquisition in Large-Scale Environments

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The research emphasizes the critical role of spatial cognition in understanding urban travel behaviors. It discusses how individuals' spatial experiences and cognitive maps shape their perception and interaction with their surroundings, influencing navigation, route planning, and travel decisions. The emergence of small electric vehicles (SEVs) is highlighted as a sustainable urban transport option, necessitating an understanding of spatial cognition for effective integration. Affordance and spatial learning stages are explored, elucidating how the physical environment and individual experiences contribute to spatial knowledge acquisition. The research explores the relationship between spatial experience and travel attitudes, emphasizing the influence of the cognitive built environment on travel motivations. It discusses the importance of spatial knowledge in trip planning and activity-travel patterns, especially in the context of SEVs and their constraints. Various techniques for investigating cognitive maps are reviewed, underscoring the significance of understanding spatial cognition for improving transportation modeling and enhancing urban mobility. Overall, the research provides a comprehensive overview of spatial cognition's impact on travel behaviors and its implications for urban transport planning.

Keywords: sustainable mobility ; electric vehicle ; spatial cognition ; cognitive map ; environment

1. Introduction

Spatial cognition plays a crucial role in travel behaviors, encompassing aspects such as wayfinding, navigation, and route selection [1][2]. Individuals' spatial cognition both influences and is influenced by their spatial experiences, collectively shaping how they perceive and interact with their environment. The majority of research in transportation studies has focused on car drivers, given the dominant role of automobiles in cities [3]. Comprehending the role of spatial cognition is vital for predicting urban traffic flow. Despite some attempts to integrate human cognitive factors into transportation modeling, the understanding of the impact of spatial experience and varying levels of spatial knowledge remains limited [4][5][6]. It is regarded that a more thorough comprehension of how mode experiences shape individual spatial cognition could improve transport modeling significantly by creating fundamentally different matrices of activity opportunities [3]. Moreover, studies have examined the impact of different transport modes on travelers' spatial knowledge [7]. Integrating a comprehensive understanding of how mode experiences shape individuals' "cognitive maps" can enhance transport modeling by generating distinct matrices of activity opportunities [3]. Cognitive maps, as mental representations of experienced external environments, shape how people interact with and navigate through their surroundings, making them essential in studying spatial cognition in travel behavior.

In recent years, the emergence of small electric vehicles (SEVs) has been facilitated by advancements in energy-charging services. An SEV offers an affordable and sustainable transport alternative that can contribute to urban sustainability, ecofriendly landscapes, and the mitigation of traffic congestion. It bridges the flexibility gap between private and public transportation modes, adapting to dynamic changes in demand and mobility preferences [8]. Urban administrators have encouraged the use of SEVs as an effective and a sustainable means of transport, providing a viable substitute for personal car trips [9].

SEV serves a role akin to active modes, fostering connectivity between travelers and their environment while promoting social and cultural cohesion [10]. Meanwhile, it offers the flexibility of a motorized vehicle for spatial exploration. Studies on user intentions toward new mobility services have explored functional/instrumental and experiential/hedonic values [11][12]. In certain developed urban contexts, an SEV is viewed more as entertainment than a significant transportation mode [13]. Although experiential/hedonic values are known to influence user adoption [14], the impact of spatial experiences on urban travel remains unclear.

Spatial abilities for navigation and wayfinding are particularly important for SEV users, especially with the emergence of battery-swapping solutions to address charging concerns and limited EV range [15][16]. The mechanism of battery sharing is expected to reshape EV users' urban travel patterns, which are closely tied to their cognitive urban form and charging demand. Users' spatial cognition affects their behaviors, including knowledge acquisition, route planning, and their perception of distance to manage residual power before reaching the next charging spot. Consequently, concerns about residual power may restrict users' travel range despite the increased mobility provided by SEVs. It is worth noting that while technologies like GPS have improved city navigation, cognitive maps play a role in predicting access to potential opportunities when making travel decisions [2]. In other words, individuals' decisions to travel or stay are influenced by their perception of distances to destinations [17].

2. Spatial Knowledge Acquisition

Cognitive mapping is closely intertwined with spatial knowledge acquisition. It refers to the mental process through which individuals acquire, store, recall, and manipulate information about the attributes and relative locations of their spatial environment [18]. As individuals interact with and receive information from their surroundings, they develop spatial knowledge by understanding the relationships and features of the environment [19]. There has been extensive research on spatial knowledge acquisition, including several review articles [20][21][22].

Previous research has focused on how people remember and represent medium-scale and large-scale environments (i.e., neighborhood and city scales) [19][23][24][25][26][27]. Lynch's influential work identified five elements—nodes, paths, districts, landmarks, and edges—that shape individuals' mental representation of a city [19], providing a framework for understanding the structure of cognitive maps. Appleyard examined the influence of social meanings on the cognitive representations of neighborhoods and cities, finding that visibility, personal use, and the significance of physical characteristics affect inhabitants' perceptions [24][25]. He also addressed the role of symbolism in the environment, emphasizing the importance of environmental meaning and symbolism in human experience [28][29]. According to Moore (1979), developmental changes occur in perceiving large-scale environments, shifting from social and physical conceptions to symbolic ones [27].

2.1. Affordance and Cognitive Mapping

Physical environments exert a profound influence on human behavior through the concept of affordance, originally introduced by perception psychologist James J. Gibson [30][31]. Affordance refers to the opportunities and possibilities that the environment offers to individuals. Lazarus (1991) explored the link between an animal's needs and the environment, highlighting the preconscious appraisal of affordance [32]. In the domain of architecture, affordance is a framework for understanding the relationship between environment and its occupants, particularly in terms of form and function [33]. Cognitive affordance plays a starring role in interaction design, particularly for users with limited experience, by supporting thinking and learning processes [34].

Marcus, Giusti, and Barthel (2016) extended the concept to urban design, suggesting its relevance to sustainable urbanism and emphasizing the constant interaction between individuals and their situated cognition [35]. The everyday environment was regarded as playing the role of the interface in which a person learns when personal abilities are enabled by situational opportunities (i.e., affordances). In the dynamic interaction between a person and the built environment, the designed features may have varying social meanings for different users. In the context of road environments, road users progressively develop spatial abilities to actualize the potential affordances of the environment through their everyday experiences. These potential affordances can be obtained from road space (e.g., traffic conditions, infrastructure design), surrounding architectural features, natural sights, etc.

2.2. Spatial Learning

The acquisition of spatial knowledge, named spatial learning, involves three stages: landmark, route, and survey [26][36]. Landmarks are prominent features of cognitive maps, providing basic location information. Route knowledge allows individuals to link locations during travel but lacks an overall understanding of spatial organization. At the survey level, individuals acquire a comprehensive understanding of the environment, recognizing relative directions and distances among multiple locations. Individual spatial experiences, particularly within their activity space, influence spatial knowledge. The anchor-point theory suggests that people have the most extensive knowledge of areas around their homes and workplaces [37]. To obtain comprehensive knowledge, the anchor points have active roles in organizing spatial relations in cognitive maps [38]. Spatial learning leads to the development of a survey map that recognizes relative directions and distances among multiple locations, resulting in both quantitative and qualitative improvements in spatial knowledge [22][39].

3. Spatial Experience and Urban Travels

The relationship between spatial experience and transport users' attitudes has received limited attention in the literature. However, insights from architectural research suggest that the design of space, particularly in small-scale environments, conveys different social symbols and influences spatial behaviors [40][41]. For large-scale environments, studies have explored the effects of visual design and the presence of vegetation on spatial memory [42]. Furthermore, research has highlighted the connection between road users' perception of the built environment and their travel motivations. Mirzaei et al. (2018) found that the characteristics of the built environment influenced utilitarian and hedonic walking, with pedestrians' perceived value impacting their walking behaviors [43]. In the context of SEVs, which share similarities with active transport modes, understanding the hedonic motivations underlying mobility trips is crucial, as they may differ significantly from motivations associated with car driving. Additionally, in terms of travelers' instrumental attitudes, having better spatial knowledge can support EV users in navigating charging spots and effectively managing battery power by accurately perceiving distances.

Planning a trip involves consulting cognitive maps of large-scale environments to facilitate movement and navigation, leading to trip plans that minimize travel time or utilize shortcuts and alternative routes [1][44]. Previous research has examined the influence of spatial knowledge on various aspects of trip planning, including trip purposes, routes' complexity, and destination diversity. Spatial knowledge assists in considering route and activity choices, shaping the activity-travel level. Studies on cyclists have indicated the stabilization of spatial learning after multiple trips, which is related to activity patterns and route dynamics [45]. Comparative studies among car drivers, cyclists, and walkers have revealed differences in trip-chaining behaviors and daily activity patterns, highlighting the role of higher mobility and spatial knowledge in enabling individuals to plan and execute complex trips involving multiple destinations [46][47]. However, the specific trip-chaining behavior with SEVs is understudied. Investigating how SEV users engage in trip chaining, considering the sequence and purpose of multiple stops, is crucial for understanding their travel behaviors. Moreover, the trip-chaining behavior is influenced by the residual power of EVs, which imposes constraints on the duration and sequence of stops. Therefore, understanding the interaction between users' spatial cognition and the constraints posed by EVs in trip chaining is vital for comprehending users' activity-travel patterns.

4. Techniques for Investigating Cognitive Maps

Various methods have been employed to study human spatial knowledge, including traditional approaches such as sketch maps, route descriptions, and distance estimates [48][49]. In the field of cognitive psychology, multidimensional scaling (MDS) and Pathfinder networks have been widely applied to quantify similarity judgements [50][51], with MDS being particularly prevalent for distance or direction judgements [52][53][54].

Previous studies have evaluated the accuracy of MDS-derived maps compared to sketch maps [55][56][57], demonstrating that sketch maps can generate accurate representations of spatial relations similar to MDS in familiar environments. Sketch maps provide a flexible means for respondents to express their unique perspectives and knowledge of specific environments, encompassing landmarks, routes, and points of interest. In contrast, as a technique for generating coordinate spaces from distance data, MDS must assign a set of landmarks (i.e., reference points) to compare the accuracy of MDS-derived maps among individuals. However, as previously discussed, the assigned landmarks could have different social meanings among individuals, potentially influencing map accuracy [24][25].

Lynch's (1960) key elements have been widely used when studying cognitive maps for structuring large-scale spaces [58][59][60]. Techniques have been developed to aid in accurately representing spatial properties in mental maps and enhancing the recall of spatial layouts [61][62]. Sketch maps can be analyzed qualitatively or quantitatively. A qualitative analysis involves identifying clusters of features or paths, interpreting the meanings of depicted features, and considering context to investigate whether there are shared meanings of symbols among the participants. Recent qualitative research has examined the relationship between socioeconomic status and the scale of sketch maps [63], the effects of transport modes and GPS usage on city images [64], and the utilization of location-based media (LBM) for spatial experience [65]. On the other hand, a quantitative analysis often employs statistical methods to examine spatial patterns and relationships, such as measuring distances between landmarks, calculating the landmark density, or identifying clusters of similar features [66][67][68]. However, a potential limitation arises in terms of the amount of information that respondents intend to present, making quantitative information incomparable between different periods and among individuals.

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