Northumbria University
NEWCASTLE

Abstract

This article focuses on the interactions between individual differences and building characteristics that may occur during multi-level wayfinding. Using the Seattle Central Library as our test case, we defined a series of within-floor and between-floor wayfinding tasks based on different building analyses of this uniquely designed structure. Tracking our 59 participants while they completed assigned tasks on-site, we examined their wayfinding performance across tasks and in relation to a variety of individual differences measures and wayfinding strategies. Both individual differences and spatial configuration, as well as the organization of the physical space, were related to the wayfinding challenges inherent to this library. We also found wayfinding differences based on other, non-spatial features, such as semantic expectations about destinations. Together, these results indicate that researchers and building planners must consider the interactions among building, human, and task characteristics in a more nuanced fashion.

Keywords: wayfinding, space syntax, spatial behavior, individual differences, building complexity.

Exploring individual differences and building complexity in wayfinding: the case of the Seattle Central Library

Large-scale, multi-level buildings, e.g., libraries, museums, shopping malls, and hospitals, can be hard to navigate (Dogu & Erkip, 2000; Eaton, 1991; Li & Klippel, 2012; Mandel, 2017), especially for first-time visitors (Baskaya, Wilson, & Özcan, 2004; Gärling, Lindberg, & Mäntylä, 1983; Haq & Zimring, 2003; Hölscher, Meilinger, Vrachliotis, Brösamle, & Knauff, 2006). One approach to a better understanding of the characteristics and conditions linked to multi-level wayfinding is to identify particularly challenging or unusual buildings and explore navigational behaviors within those settings.

The Seattle Central Library (SCL; designed by Koolhaas, Prince-Ramus, OMA, and LMN Architects, 2004; Image 1 and Figure 1), is a unique, award-winning structure (American Library Association, 2005; Lacayo, 2004) that is viewed simultaneously as architecturally important yet navigationally challenging (Mau, 2005; Murakami, 2006; Pogrebin, 2004). Researchers from various disciplines have found that, from the perspective of its users, this library's spatial configuration, aesthetics, and functionality are complex (Carlson, Hölscher, Shipley, & Dalton, 2010; Dovey, 2010; Fisher, Saxton, Edwards, & Mai, 2007; Mattern, 2007; Plank & Zisch, 2017; Seamon, 2017; Wang, 2017; Yaneva, 2009; Zook & Bafna, 2012). One architectural critic even noted that this library is "one of the most disorienting buildings one can imagine" (Dovey, 2017, p. 60).

In the present study, we examined navigational challenges in this multi-level building within the context of a theoretical framework for wayfinding complexity (Carlson et al., 2010; but also cf. Eaton, 1991; Golledge, 1999).

A framework for examining the complexity of multi-level wayfinding

Wayfinding is often framed as a process for active navigation through on-the-fly planning and reasoning. It involves making decisions to navigate to a destination that is not immediately in direct view because the destination and/or the path to it is not fully visible (Montello, 2005). Wayfinding includes self-localization within an environment, route identification and planning, continuous monitoring while on the route, and recognition of the destination upon arrival (Golledge, 1999). Accordingly, many factors, such as the building configuration, and the spatial and orientation skills of building users, or a combination of these, may determine whether wayfinding is successful.

Consequently, we based our work on a theoretical framework that posits that the difficulty of a wayfinding task is an interaction between the individual’s and the building’s characteristics (Carlson et al., 2010); including interactions among (1) the mental representations of the space (i.e., cognitive maps) that individuals acquire and use during wayfinding, (2) the building’s characteristics, and (3) the individual’s spatial skills and wayfinding strategies (Figure 2). We did not evaluate the framework; we used it as a context within which we could examine why some individuals find the SCL exhilarating while others consider it distressing (Carlson et al., 2010; Fisher et al., 2007; Murakami, 2006).

Building characteristics and mental representations (cognitive maps)

In unfamiliar buildings, wayfinders must learn the spatial configuration to acquire a mental representation of their surroundings (Allen, 1999; Arthur & Passini, 1992; Burgess, Jeffery, & O’Keefe, 1999; Downs & Stea, 2011; Golledge, 1999; Kitchin, 1994; O’Keefe & Nadel 1978; Tolman, 1948; Tversky, 1993). For multi-level wayfinding, this representation must also include how different floors relate to each other. However, although individuals can encode elevation information (Jeffery, Jovalekic, Verriotis, & Hayman, 2013; Lu & Ye, 2017), they may memorize multiple floors as a collection of separate floor layouts (layered two-dimensionally), rather than one cohesive 3-D model (Büchner, 2010; Montello & Pick 1993; Nardi, Newcombe, & Shipley, 2011; Tlauka, Wilson, Adams, Souter, & Young, 2007; Wilson, Foreman, Stanton, & Duffy, 2004). This stacked 2-D representation can influence wayfinders' expectations during their decision-making process.

A building's characteristics, such as its overall spatial configuration and local floor layouts, signage, architectural or aesthetic differentiation, and visual accessibility (i.e., how well a location is visually connected to the rest of the building) may facilitate or hinder the formation of a coherent mental representation (Arthur & Passini, 1992; Evans, 1980; Li & Klippel, 2012; Montello & Pick, 1993; O'Neill, 1991; Peponis, Zimring, & Choi, 1990; Weisman, 1981). For example, a building's layout complexity, signage, and visual connections between locations are associated with the success of finding destinations (Li & Klippel, 2012; O'Neill, 1991). At the same time, greater architectural variation allows the wayfinder to distinguish locations more readily (Evans, 1980; Weisman, 1981). The SCL has high spatial complexity, but substantial architectural and aesthetic variation, both within and between floors. This may aid the establishment of a mental representation of locations.

In addition, visual accessibility to vertical travel options and other areas means that more spatial information is available, such that the wayfinder needs less stored spatial knowledge to act (Haq & Zimring, 2003; Li & Klippel, 2012). The SCL design has strong visual connections between floors (i.e., an atrium, and glass walls that allow views to other floors), but only partial visual links to its vertical travel options. For example, yellow escalators that are visible from highly frequented areas reach specific sub-sets of floors while bypassing other, more secluded floors. In contrast, the staircases that connect floors bypassed by those escalators are located in more segregated, remote locations and are not obvious from these highly frequented areas. Therefore, we would expect that wayfinding is more difficult when visual accessibility to vertical travel options is limited. Furthermore, wayfinders tend to prefer navigating through areas that are both more visually accessible and have more connections to other parts of the building. Such areas can be termed 'central' in a building and through repeated use can become anchors for wayfinding (Batty, 2004, 2004b, 2017; Haq

& Zimring, 2003; Kuipers, Tecuci, & Stankiewicz, 2003; Peponis et al., 1990). Consequently, we might predict that wayfinding performance is better when start and destination locations are central in the building, and/or central within an individual floor.

The complexity of multi-level wayfinding can be further increased by the presence of multiple floor layouts. Changes in the layout from one floor to the next, *and* a misalignment of layouts in relation to adjacent floors, can pose a particular challenge when trying to develop a representation of the building. In Carlson et al.'s framework (2010), this concept is referred to as the 'correspondence' between a mental representation and building characteristics. When layouts change across floors, wayfinders can experience vertical disorientation and erroneous navigation (Carlson et al., 2010; Hölscher et al., 2006; Soeda, Kushiyama, & Ohno, 1997). Within the SCL, Floors 6 through 9 share relatively similar layouts but Floors 1 through 5, and 10, differ radically from each other. Moreover, many floors are misaligned in both orientation and shape. As such, the SCL design might encourage either highly disjointed or grossly incorrect mental representations that might have an impact on between-floor wayfinding. Thus, we would expect less success and reduced performance (e.g., longer routes, or more pauses) for between-floor tasks than for within-floor tasks.

Individual differences in spatial reasoning and wayfinding strategies

During the wayfinding process, the wayfinders' mental representations may also be affected by differences in their spatial-cognitive abilities. In Carlson et al.'s framework (2010), the 'completeness' intersection defines how strategies and skills influence which routes wayfinders take or prefer, as these aspects are associated with acquiring more or less complete mental representations (Figure 2).

Although studies about individual differences in spatial abilities and wayfinding in large-scale, real-world buildings have been limited (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Li & Klippel, 2016; Montello & Pick, 1993), it is widely accepted that spatial skills contribute to differences in navigational behavior (Allen, 1999; Hartley, Maguire, Spiers, & Burgess, 2003; Kozhevnikov & Hegarty, 2001; Montello & Pick, 1993; Vandenberg & Kuse, 1978; Wolbers & Hegarty, 2010). Here, we adopted a comprehensive approach to assess those differences in spatial abilities. We took the following steps to examine mental spatial transformations, self-perceptions, wayfinding strategies, and spatial preferences:

Mental spatial transformations. Spatial perspective-taking (i.e., the ability to imagine the world from different vantage points) and mental rotation (the capacity to imagine objects or arrays rotating about one or more axes) are distinct skills that vary widely across individuals (Kozhevnikov & Hegarty, 2001; Shelton & Zacks, 2015; Zacks & Michelon, 2005). Both types of skills are connected with environmental learning (Hegarty et al., 2006; Kozhevnikov, Motes, Rasch, & Blajenkova, 2006). For example, spatial perspective-taking is associated with various aspects of learning and navigating within an environment (Allen et al., 1996; Hegarty & Waller, 2004; Kozhevnikov & Hegarty, 2001), whereas mental rotation is linked to the spatial processing of complex environmental structures (Fields & Shelton, 2006; Hegarty & Waller, 2004; Shelton & Gabrieli, 2004).

For wayfinding in the SCL, we anticipated finding strong relationships among our wayfinding tasks and these mental spatial transformation skills. This was because the substantial visual variation and lack of structural alignment, especially when reasoning across floors, would increase the demands on participants to form, reason about, and manipulate mental representations of the space.

Self-perceptions: sense of direction and spatial anxiety. In addition to measurable abilities, people vary in their self-perceptions about space. We considered two aspects: how ‘good’ and how confident am I with spatial challenges, and how comfortable am I with these?

One’s sense of direction is a person’s self-reported ability to orient and navigate in space (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). It is positively related to various measures of environmental knowledge, e.g., direction-pointing, map-drawing, and estimates of distance (Allen, 1999; Hegarty et al., 2002), as well as to tasks that require survey knowledge (Hegarty et al., 2002; Kozlowski & Bryant, 1977). Spatial anxiety is the stress one might experience when required to reason about space (Lawton, 1994). Higher levels of anxiety are correlated with more navigational errors (Hund & Minarik, 2006).

Given the wide range of reactions to the SCL in terms of its wayfinding challenges (e.g., Dalton, Kuliga, & Hölscher, 2013), we anticipated that the building would tax the sense of direction and be particularly unnerving to those with high spatial anxiety. As such, we predicted that these self-perception measures would be correlated with wayfinding performance, especially in our most challenging tasks.

Wayfinding strategies & spatial preferences. Several types of wayfinding strategies in multi-level buildings have been identified (Allen, 1999; Golledge, 1999). For example, some wayfinders might first head toward the approximate area of a destination and then engage in a more detailed local search (Wiener, Schnee, & Mallot, 2004), whereas others might use salient points in an environment for reference (Hölscher et al., 2006; Tellevik, 1992). It is also likely that wayfinders follow intrinsic heuristics, such as using long sightlines (Frankenstein, 2015; Hochmair & Karlsson, 2005).

The ability and/or tendency to employ different wayfinding strategies depends upon individual differences in the types of spatial information that people seem to prefer when navigating (Lawton, 1994; Meneghetti, Pazzaglia, & De Beni, 2011; Pazzaglia & De Beni, 2001). Here, we measured spatial preferences for these three types: 1) egocentrically oriented route knowledge, based on previously experienced routes; 2) landmark knowledge, based on the spatial relations among salient objects (Pazzaglia & De Beni, 2001); and 3) survey knowledge, based on an integration of configurational spatial information, such as directions, distances, and relationships among objects (Meneghetti, Pazzaglia, & De Beni, 2011). These spatial preferences would likely interact with the building characteristics and the information that they afforded, thereby influencing which properties would be represented on a cognitive map. In Carlson et al.'s framework (2010), this corresponded to the 'compatibility' between a wayfinder's ability and preferences, and the building's characteristics (Figure 2).

Taking into account how spatial preferences for wayfinding strategies, and strategy *selection*, might be linked to building properties, we hypothesized that preferences for survey information (rather than route or landmark information) at the SCL were related to understanding its difficult overall configuration, as manifested in better wayfinding performance. Moreover, we proposed that the particular advantage/disadvantage of any preference would vary with the specific type of wayfinding tasks based on building characteristics for the areas through which a participant would be navigating.

Research aims and hypotheses

Based on our elaboration of the framework for wayfinding complexity (Carlson et al., 2010), we argued that aspects of this library and individual differences among wayfinders would predict performance. In particular, we designed this study to examine more closely the relationships among certain building characteristics (e.g., accessibility and floor navigation) and an individual's orientation skills and wayfinding strategies. We selected the SCL due to its architectural characteristics and began with a spatial analysis to develop appropriate wayfinding challenges that would address our manipulation of floor navigation (within- vs. between-floor) with a manipulation for accessibility (high vs. low). The tasks were designed to carry different wayfinding challenges, and to test the following hypotheses:

H1: Wayfinding performance between and within floors will be related to spatial analyses of accessibility in the following ways:

a. Performance will be better on within-floor tasks than on between-floor tasks.

b. Performance will be better if visual accessibility is higher.

c. Performance will be better when starts/destinations are located in central areas.

H2: Wayfinding performance between and within floors will be related to individual differences in spatial reasoning and wayfinding strategies in the following ways:

a. Performance will be better when spatial abilities (mental spatial transformations) and/or sense of direction are stronger.

b. Performance will be better when spatial anxiety is lower.

c. Performance will be better for wayfinders who show a preference for survey information (rather than route or landmark information).

d. Performance will be different in each specific type of wayfinding task, as the effects of skills, strategies, and self-perceptions mentioned in H2a-c will interact.

Method

Research design

Based on this framework, we established a 2 × 2 design, with the factors of floor (within/between) and accessibility (high/low), to test H1 and H2.

The within-floor versus between-floor factor was based on research that multi-level wayfinding is typically more difficult than wayfinding within a single floor (Hölscher et al., 2006; Li & Klippel, 2012; Soeda, Kushiyama, & Ohno, 1997). Research indicated that certain building characteristics (such as complex configurations, substantial visual variation, lack of structural alignment, and blocked visual access) might hinder the formation of a coherent mental representation of the building, thus making it harder to find certain destinations (Haq & Zimring, 2003; Li & Klippel, 2012; Weisman, 1981). We selected visual and spatial accessibility as the basis of our task classification to capture these factors. Thus, each task contained specific challenges that fit our floor × accessibility research design. This task classification was drawn from building analyses of SCL characteristics.

Building analyses to develop a wayfinding task classification

To define origin–destination pairs that fit the floor × accessibility manipulations, we first conducted a building walk-through, photograph-based evaluations, and qualitative interviews with key library stakeholders (anonymity requested). During the walk-through, we identified the visual accessibility of route options, signage, and vertical travel options, including stairs, ramps, and escalators; as well as changes in horizontal/vertical directions along a route and the saliency of wayfinding cues (e.g., the yellow escalators). These aspects are posited to be good proxies for wayfinding challenges (cf., Chang, 1998; Montello, 2014).

Second, we used a number of space syntax techniques that quantify an environment's spatial characteristics (Hillier & Hanson, 1984). Space syntax is highly predictive of movement flows, wayfinding decisions, and wayfinders' understanding of spatial environments (Dara-Abrams, 2006; Haq & Zimring, 2003; Li & Klippel, 2012; Montello, 2014; Penn, 2003; Peponis et al., 1990). This process i) divides a building into subspaces; ii) links all of these subspaces into a network and iii) derives quantitative measures that are either based on a small part of the whole network (local measures) or use the entire network (global measures) (Bafna, 2003; Hillier & Hanson, 1984). An analysis of both global and local spatial characteristics is then predictive of wayfinding performance (Li & Klippel, 2016). We implemented the following specific measures for spatial analysis:

Floor manipulation.

Overall building configuration: intelligibility. 'Intelligibility' is a space syntax measure for evaluating a building's legibility (the relationships between local spatial characteristics and global network measures). This measure expresses the ease and predictability of an environment in terms of wayfinding (Bafna, 2003; Dara-Abrams, 2006; Hillier, Burdett, Peponis, & Penn, 1987; Penn, 2003). As expected with a maze-like environment (cf., Zhang, Chiaradia, & Zhuang, 2013), intelligibility of the SCL is lower than that described for other facilities in previous wayfinding studies (cf., Haq & Zimring, 2003; Hölscher, Brösamle, & Vrachliotis 2012; Mavridou, 2012). This demonstrated the disorienting spatial complexity of our study site, making the SCL an excellent test case.

Within- and between-floor configuration: axial line analysis. In axial line analysis (Figure 3), the network's subspaces consist of lines of sight and movement that, when combined into a network, represent the navigable structure of a building (Bafna, 2003; Haq & Zimring, 2003; Hillier & Hanson, 1984). It reveals how wayfinding is related to a building's spatial layout, with unexplained variance often being associated with individual differences (Penn, 2003).

For examining global accessibility (i.e., the number of spatial connections to a location from the rest of the building), we applied a measure called integration, which describes how accessible one location is from all other locations in a building (Bafna, 2003). To gauge local accessibility (i.e., the number of spatial connections to a location from an adjacent and subset of the larger network) of within-floor spaces, we used 'axial line integration radius three', a proximal measure that excludes all spaces beyond three changes-of-direction (Bafna, 2003). The local integration measure enabled us to develop an initial set of starts/destinations in accessible and central, and in segregated and remote parts of the building within a floor. These were further refined as follows:

Accessibility manipulation.

Visibility graph and isovist analysis. In visibility graph analysis (VGA, Figure 3), the network's subspaces consist of mutually visible location-pairs (Turner, Doxa, O'Sullivan, & Penn, 2001; Turner & Penn, 1999). This allowed us to calculate measures that identify mutually visible locations across all floors. Using VGA, we again used the measure of integration (this indicates visual accessibility). For the SCL, Floor 5 was the most visually integrated while Floor 4 was the least.

The concept of integration can also facilitate further predictions of task difficulty for a set of origin–destination pairs. Such an approach has been described by Hölscher et al. (2012). Integrated spaces tend to be anchors for wayfinding (Haq & Zimring, 2003; Peponis et al., 1990) because a greater number of routes are more likely to pass through such integrated locations (Batty, 2004, 2004b, 2017). Thus, for a series of tasks, wayfinders will most likely have already been exposed to these more integrated locations as their tasks progress. Using this rationale, we developed a system of task classification. This approach involved assuming that (1) wayfinding from and to an integrated and visually accessible location would be easy because of high ('h') accessibility, and (2) navigating between any two segregated locations would be hard due to low ('l') accessibility. Along with our within-floor ('w') and between-floor ('b') manipulations, this analysis provided a classification for our wayfinding tasks: ('w/h'), ('w/l'), ('b/h'), and ('b/l').

Refinements. In addition, for each set of potential origin–destination pairs, we applied an isovist analysis (Benedikt, 1979; Benedikt & Burnham, 1985) to examine local visual accessibility at the starts and destinations (Figure 4). This was done only to ensure that destinations were never directly visible from the start locations (Montello, 2005).

We examined whether destinations were distinctive, memorable (Montello, 2017; Nothegger, Winter, & Raubal, 2004; Presson & Montello, 1988; Steck & Mallot, 2000), and unambiguous (Grice, 1975; Hölscher, Tenbrink, & Wiener, 2011). We ensured that they were unique locations and salient (our judgement) and that they were congruent with the building's signage (i.e., the names in the library's signage were replicated in our instructions).

We conducted a walk-through to confirm that the tasks met the floor (within/between) and accessibility (high/low) manipulations from a wayfinder's eye-level perspective.

Final wayfinding task classification based on spatial analyses

Incorporating the above space syntax analysis, we developed four core trials and two additional wayfinding tasks that addressed our manipulation of the floor navigation (within/between) with the manipulation of accessibility (high/low):

The four core tasks covered Floors 1 through to 7 (Table 1): the Children's Restrooms, 'CR' (w/h); Meeting Room Number Six, 'M6' (b/l); a book about Sherlock Holmes, 'SH' (w/l); and the section featuring Non-fiction DVDs, 'DVD' (b/h). These wayfinding trials, conducted with all participants, were the focus of the current analysis.

For the second data collection, we provided extra time to include two extra tasks covering Floors 7 to 10: the Aviation Room special collection, 'AR' (w/l); and the Music Practice Rooms, 'MPR' (b/h). Only the local group had this additional exposure to these two tasks. We always assigned those additional tasks to be finished after the four core trials were completed, to prevent contamination of the wayfinding solutions for the critical trials.

To fully disclose our protocol, the above section has mentioned all six wayfinding tasks. For statistical power and reading clarity, this article focuses only on the outcomes from the four core trials.

Types of tasks: challenges and demands in each wayfinding task

We designed each task to have specific demands and challenges, as follows:

The **CR within-floor/high accessibility (abbreviated as: w/h)** task entailed wayfinding from and to an accessible/central location. Relying on the established task classification, we expected this task to be easy.

The **M6 between-floor/low accessibility (b/l)** task called for wayfinding from a segregated, remote start to a segregated destination with low visual accessibility at the start. After changing floors, the destination on Floor 4 and the sign indicating room number '6' were already visible from the atrium on Floor 3. However, the shortest route, via a staircase, was not visible from this integrated area. Thus, if drawn toward the saliency of the escalators, participants would bypass the destination floor and subsequently have to find a way to descend from Floor 5. Relying on our classification, we expected this task to be hard.

As part of the **SH within-floor/low accessibility (w/l)** task, both the starting point (in the Teens' section of the library), and the destination (in the Mystery Fiction section) were located in segregated areas on Floor 3. Except for bookshelf information, no other relevant signage was nearby. As such, relying on our classification, we expected this task to be hard.

For the **DVD between-floor/high accessibility (b/h)** task, participants started in a highly accessible area on Floor 5 where visual information was abundant in the form of signage, a directory, and vertical travel options in direct sight. The destination was nearby, located exactly one floor above a wayfinder's start position. We expected this task to be easy.

Regardless of whether the task was to find specific media, a book, or a special collection, these types of tasks were associated with unique locations. Thus, reaching the intended position in front of a door or shelf would be considered successful wayfinding because those locations could be inferred and found only if the participant understood how the library building was spatially organized (cf., Montello, 2005).

The size of the target and its visual salience at the destinations were addressed as part of the floor manipulation: the CR and M6 destinations had entrance doors of similar size, and the SH and DVD destinations were bookshelves of similar height with similar visual salience, and both located within special sections. All destinations were functionally grouped within a larger semantic category or section (half a floor for only the children; half a floor for only the meeting rooms; special sections for Fiction and Non-fiction DVDs, or for mystery books).

Participants and recruitment

Participants were recruited on two separate occasions. The *conference* group comprised 31 persons who were invited for a one-day experiment as part of an academic conference. These participants were not residents of Seattle and were largely professionals in the field of cognitive or experimental psychology. To balance this potentially selective group with one that might better represent the general population, we assembled a second, *local*, sample of 36 volunteers recruited by advertising on a forum for events in the Seattle community (*Craisglist*, n.d.). For both groups, we focused on first-time visitors because we wanted individuals who would need to learn the structure of the building. We considered participants who self-reported that they had never visited the building before. To ensure the accuracy of these self-reports, during our post-study questionnaires, we asked again whether the given participant was previously familiar with the library. After the debriefing procedure, we informally inquired, once more, about familiarity with the building.

Using this threefold procedure, we identified and then excluded data of three potential participants who indeed appeared familiar with the building. Another five persons were dismissed due to technical issues. Thus, the reduced sample involved 31 volunteers in the local group (16 female; M_{age}=30.32; *SD*=12.10; 18-61 years old) plus 28 from the conference group (15 female, M_{age}=34.81; *SD*=12.44; 21-68 years old). This screening procedure resulted in a final sample size of 59 participants (31 female, M_{age}=32.41; *SD*=12.36; 18-68 years old).

Dependent variables

Wayfinding performance. We argued that shorter wayfinding times and distances, smaller deviations, less sign usage, and fewer pauses reflected a better wayfinding performance, which was measured in terms of the dependent variables wayfinding time (in min”sec’), distance (*d*, in meters), deviation (in percentage), sign usage (as frequency), and pauses (as frequency). We assumed that the performance was an indirect measure of the quality of one’s cognitive map and the wayfinding strategies individuals relied upon – and that it would be associated with specific characteristics of the SCL (Carlson et al., 2010).

The deviation was calculated as a percentage above an optimal, shortest path (PAO);

i.e., deviation/PAO = ($\frac{d\ covered - d\ shortest}{d\ shortest} * 100$). Deviation/PAO expresses superfluous distances (Büchner, 2010; Peponis et al., 1990; Ruddle, Payne, & Jones, 1997; Wiener et al., 2004). A value of zero meant that the wayfinder had stayed on the shortest path while a score of 200 represented twice the distance when the shortest path was subtracted.

We recorded sign usage during a task because we assumed that this component reflected a particular wayfinding strategy that confirmed the participant was still navigating the selected path. This was noted as a person glancing at a sign while moving past it (sign usage), as well as stopping to read a sign (pause + sign usage). Because we knew the locations of the signs, we separated pause and sign-usage frequencies *post-hoc*. Here, pauses were thought to reflect hesitations, uncertainty, and a participant's need for information.

The above behavioral mapping was conducted by four observers for the conference sample and one observer for the local sample, all of whom were closely trained with a protocol. The accompanying observers recorded a participant's wayfinding performance with a developer's version of the iPad app "PeopleWatcher" (Dalton, Dalton, & Hölscher, 2015). We cleaned the resulting data sets from the app, and summarized the data obtained for wayfinding time, distance, deviation/PAO, sign usage, and pauses during each task, using a custom-made script for *Matlab* (n.d.) before conducting statistical analysis in *SPSS 23* (n.d.).

Individual differences in spatial reasoning and strategies. We categorized the participants with respect to their skills in reasoning about spatial relations, sense of direction, wayfinding preferences, and spatial anxiety. This was accomplished through standardized questionnaires: the Mental Rotation Test (Vandenberg & Kuse, 1978), Spatial Perspective-taking Scale (Kozhevnikov & Hegarty, 2001), Santa Barbara Sense of Direction Scale (Hegarty et al., 2002), Questionnaire on Spatial Representation (Pazzaglia, Cornoldi, & De Beni, 2000), and Spatial Anxiety Scale (Lawton, 1994). These instruments were administered per the original authors' instructions and procedures (cf. online appendix). We also asked the participants to rank their wayfinding tasks from easiest to hardest (resulting in the dependent variable ‘ranked task difficulty’), and to describe, briefly, their wayfinding strategies in each task. Replaying the performance trajectories allowed us to consider variations in paths of the same length, to determine whether they might represent different approaches and error types.

Wayfinding task instructions

The sequence of the wayfinding tasks was fixed, with the destination of one task being linked to the start of the next. This sequence was circular, so that we could randomly select the first task for each participant. This produced four different orders for the four core trials (i.e., CR-M6-SH-DVD, M6-SH-DVD-CR, SH-DVD-CR-M6, and DVD-CR-M6-SH). For the local group, the final two trials were counterbalanced following each of these order (e.g., CR-M6-SH-DVD—AR-MPR, CR-M6-SH-DVD—MPR-AR, etc.). For each of the tasks, multiple routes with different distances to the destination, were available.

In keeping with our need for communicable locations, the instructions included a hint about whether the task was within or between floors. Instructing the participants to identify the shortest way, we cautioned them that they were not allowed to use the elevators or ask others for directions. This policy was enforced by the observer accompanying the participants to record behavior. We informed participants that the maximum time for each task completion was 10 minutes.

Procedure

For the conference group, participants were greeted offsite and escorted to the SCL by a study team member. Initially arriving in groups of four, each person was tested individually. During the trial period, participants were kept separate by following a different order for the tasks. For the local group, the observer welcomed each participant individually in a quiet nearby café. After providing consent for the study via a standardized form, each participant was guided to her or his randomly assigned starting point. The observer then read the respective task instructions and made sure that the participant understood the instruction to find the shortest way. Participants repeated which destination they were asked to find.

The wayfinding procedure was the same for the two groups. If a participant stated incorrectly that a destination had been reached, the observer asked her or him to continue the search. We did not use the words ‘error’ or ‘incorrect’ because this could have negatively affected a person’s self-perceptions during later tasks. If the participant verbally confirmed a correct destination, or if the time limit was reached, the observer stopped the recording. The observer then guided the participant to the next start location, using a pre-defined path and the elevators, in order to limit the amount of additional path information that the participant might incidentally acquire. The participant then received the instructions for the next task.

After completing her or his four tasks (conference group) or six tasks (local group), the participant completed a printed set of questionnaires in a room at either the conference venue (conference group) or the café (local group). The conference venue and the café had few or no other visitors, and background noise was very low.

We randomized the order of the questionnaires for each participant. Only the Spatial Perspective-taking Scale and the Mental Rotation Test were timed according to the advised procedures. The researcher informed participants that there would be no feedback about the results. All participants were fully debriefed about the study purpose; those from the local group received $30 each. The entire study procedure took two hours.

Results

Testing for differences between the two sample groups

We first tested whether we could justify merging the conference sample and the local sample to increase the statistical power for our analyses. A multivariate ANOVA for individual differences in spatial skills, self-perceptions, and spatial preferences indicated that locals and conference participants did not differ in spatial perspective-taking, mental rotation, sense of direction, spatial anxiety, and spatial preferences (Table 2). Results from a multivariate ANOVA for each of the six dependent performance variables demonstrated that the samples differed little (i.e., only the wayfinding time and pauses variables differed between groups, for two tasks: locals were less efficient in the SH w/l task; Table 3). Thus, we merged the samples, and examined only the 'stable' dependent variables of distance, deviation/PAO, sign usage, and ranked task difficulty. To increase power, we analyzed and present here only the data gained from the four core trials conducted with both groups.

Wayfinding performance in relation to the spatial analyses

Examining the floor and accessibility manipulation. The first hypothesis was that wayfinding performance between and within floors would be related to the spatial analyses of accessibility (H1). Our tasks were specifically designed to test the floor × accessibility-related expectations that navigating within floors (H1a), greater visual accessibility (H1b), and central destinations (H1c) would facilitate performance. According to this rationale, because those tasks were designed to have the above challenges, CR should have been the easiest task, followed by SH and DVD, with M6 being the hardest.

To test these assumptions, we ran separate repeated-measures ANOVAs with the manipulated within-subject factors floor (within/between) and accessibility (high/low) for each of the stable dependent variables that expressed performance (i.e., ranked task difficulty, distances, deviation/PAO, sign usage) for the four core trials. As shown in Table 4, the actual performance results differed from our preliminary expectations, as follows:

In the ratings of perceived difficulty, participants ranked the CR (w/h) task as the easiest, as predicted. However, the DVD (b/h) task was ranked as more difficult than all other tasks. Moreover, the *within*-floor SH (w/l) task was ranked as more difficult than the M6 (b/l) task. Therefore, the difficulty (from easy to hard) that we had predicted (CR < SH < DVD < M6) did not hold. Instead, participants ranked tasks as: CR < M6 < SH < DVD.

The same inconsistency with our predictions was evident in performance measures. Results for distances, as well as for sign usage indicated that the DVD task (b/h) was harder than predicted. That is, participants traversed longer distances in that task than for the M6 task (b/l), even though they used signage to the same extent for both of these *between*-floor tasks. The lowest deviation/PAO was found for the M6 task (b/l), rather than for CR (w/h), while the highest deviation/PAO came from a *within*-floor task (SH).

In summary, we did not find support for H1/H1a-c. These reversals in the floor and accessibility manipulations suggested that our building analysis did not fully capture the wayfinding complexity of the floor × accessibility manipulation as we had predicted. However, up to this point, it was possible that performance was mainly related to individual differences in spatial reasoning and wayfinding strategies, so that consistencies across tasks might indicate good versus less-efficient wayfinders. Thus, our next analysis was intended to evaluate the consistency of performance across tasks.

Consistency of wayfinding performance across tasks. To assess the consistency of wayfinding performance across tasks, we conducted Pearson's correlations.

First, we examined the relationships between pairs of different dependent variables that measured performance, separately for each task. Given that they were supposed to indicate performance, they were expected to be interrelated. Table 5 shows more sign usage was positively associated with a higher deviation/PAO, but only in the SH (w/l) and DVD (b/h) tasks. We noted that, for the 'unstable' pauses measure, more pauses were consistently and positively associated with higher deviations/PAO. We found no other correlations.

Second, we examined the consistency of behavior across tasks; i.e., the interrelationships of each single performance variable across all tasks (e.g., sign usage in one task with sign usage in another task). The use of signs was comparable in the M6 (b/l) and SH (w/l) tasks, while pauses indicating wayfinding uncertainty were similar in the SH (w/l) and DVD (b/h) tasks (Table 5). No other correlations were detected. Of particular note is the absence in the deviation/PAO across tasks that we had anticipated. This demonstrated that suboptimal decisions about efficient, shortest paths in one task were not related to behavior during another task. Consistent with Carlson et al.'s framework (2010), this suggested that categorizing wayfinders' performance as good versus less efficient was too simplistic.

Individual differences in spatial skills, self-perceptions, and spatial preferences. To test whether the individual differences in spatial skills (i.e., mental transformations, self-perceptions, and spatial preferences) were related to performance and interacted with the types of tasks (Table 5), we examined Pearson's correlations between the individual differences measures, in different sets. However, there were few significant correlations, as follows:

First, we evaluated whether performance improved when spatial abilities (mental spatial transformations) and/or sense of direction were stronger (H2a) and found that spatial perspective-taking was associated with fewer pauses in the SH and CR tasks. Mental rotations were associated with smaller deviations/PAO in the M6 task, but sense of direction was not associated with any of those measures.

We then investigated whether performance was better when spatial anxiety was lower (H2b) but identified no such relationship. However, when we analyzed whether performance was better when individuals preferred survey information over route or landmark information (H2c), we found that, indeed, shortcut/survey preferences (i.e., the route-survey score) were linked to smaller deviations/PAO in the DVD task (which proved more difficult than expected) while route preferences were linked to greater deviations/PAO in that task.

Consequently, we rejected H2/2a-c because the connection between individual differences and performance was linked to specific tasks rather than to general performance. However, this pattern of results provided partial support for H2d in that specific spatial skills and spatial preferences (but not self-perceptions) interacted with the task classification. In summary, because the relationships between performance-measures indicated contrasting associations with individual skill, we assumed that the specific tasks required different sets of skills. This meant that the results pattern was more nuanced than we had expected.

Taken together, based on all the correlations, we argue that distinct components of spatial ability addressed the requirements of specific tasks, rather than performance across all tasks. This is also in accord with Carlson et al.'s framework (2010), which stated that wayfinding experience would depend upon the confluence of the building, the mental representation (cognitive map) and spatial abilities, and are task-specific – and this is consistent with our hypothesis H2d.

Wayfinding strategies and error types

In exploring the reasons for this unexpected pattern in statistical results from the floor × accessibility manipulation, we examined the wayfinding tasks in more detail (Figures 5 and 6, and Table 6). Based on an custom coding-scheme, we captured sequences of events and counted how many participants used a certain strategy. This was necessary because the distance along two paths could statistically be the same, even though participants navigated different paths. We identified the following explanations for wayfinding complexity:

Within-floor tasks. As expected, the CR (w/h) task was easy because most participants correctly identified the children's section, in direct sight, and navigated directly towards the correct target direction. The only error was navigating in accordance with a misbelieved target of the adult restrooms, from which one could easily retrace and correct the error. In this sense, the high visual accessibility facilitated wayfinding.

However, in the SH (w/l) task, we noted that deviations/PAO were very high. Participants mainly followed bookshelf information, which is normally a useful strategy for finding such objects in a conventional library. When/if they realized that this strategy was not compatible with the non-traditional design of this building, they started wandering through integrated areas on the floor. In this sense, the SH task (w/l) was most closely aligned with our building analyses; i.e., wayfinders preferring routes through central areas (cf., Kuipers, Tecuci, & Stankiewicz, 2003). We reasoned that the segregation of the destination and the specific spatial organization were probable reasons why the SH task proved more difficult than we had expected and was even harder than the between-floor M6 task.

Between-floor tasks. In the M6 task (b/l), the view to the optimal shortest-route travel option was blocked, and so the most common wayfinding error was taking the salient yellow escalators and bypassing the correct floor. However, one reason why this task was easier than we anticipated was that, on Floor 5, wayfinders had options to correct their error by descending one floor in direct sight. Thus, even though the start and destination were in segregated, remote locations, participants did not rank this task as difficult. We suggest that one reason was the ease with which a person could correct a suboptimal decision.

The hardest task was that of Non-fiction DVDs (b/h). The suboptimal decision was that participants navigated to Floor 3 with the semantically related Fiction DVDs. However, their key challenge was that, on Floor 3, they did not receive feedback about whether the error was immediate (correct floor, wrong section) or widespread (incorrect floor *and* section). To compensate for this suboptimal decision to navigate to the Fiction DVDs on Floor 3, participants had to ascend four floors on a path that required several disorienting turns of direction. Reasoning *post-hoc*, the visual accessibility was high, but using semantic information from one's own expectations perhaps overshadowed the information present in the environment. Thus, semantic organization of the architectural programming (dividing Fiction from Non-fiction DVDs), *and* the complex recovery of this particular wayfinding error were potential reasons why participants experienced challenges. They also appeared to forget that their instructions had mentioned the exact destination floor, which possibly hinted at a severe memory load imposed by the complex structure (cf., Hölscher et al., 2009).

In summary, considering the effects of building characteristics, as reflected in our floor ×accessibility manipulation, along with individual differences and strategy outcomes, we made two tentative conclusions. First, each task had unique demands that taxed the skills and strategies of our wayfinders in different ways. Participants were good or poor *at specific tasks* rather than in their overall general performance; and this was associated with building characteristics, mental transformation components of spatial skills, survey-related preferences, and strategies compatible with a task's demands. This is consistent with the interactive approach postulated in Carlson et al.'s framework (2010). Second, non-spatial reasons also explained why participants got lost: we reasoned that semantic interpretations and related expectations about this library influenced making suboptimal decisions. In addition, the way participants ranked a task's difficulty reflected the fact that they assigned worse rankings when it was harder for them to recover from suboptimal decisions and errors.

Discussion

The purpose of this study was to evaluate a known to be disorienting structure, the Seattle Central Library, and to examine the relationships between certain building characteristics and an individual's orientation skills and strategies. Our wayfinding tasks were devised to address high/low accessibility by between-/within-floor wayfinding. We then analyzed wayfinding performance in relation to several individual difference measures.

When assessed across all tasks, our statistical and observational results were largely unpredicted. Instead, the key finding here was that individual wayfinders were good or poor depending on the specific task (but not in general), and that those outcomes depended upon their spatial abilities and strategies – but the interplay of strategies and spatial skills was complex and nuanced. It included non-spatial aspects, such as preconceptions and semantic expectations, the facility or difficulty in correcting a suboptimal wayfinding decision, specific task demands, adaptive strategies and skills, and other interactions. These interactions add refinements to the original Carlson et al. framework (2010).

By investigating the particular tasks in detail, and how their difficulties mapped onto this specific building, we could illustrate how the current findings might support the theoretical components defined by Carlson et al. (2010). These components appeared to be interdependent in terms of predicting wayfinding success. We had assumed that the characteristics of a building specified within that earlier framework referred to its *physical* attributes. Although these are important, we would argue on the basis of various data that building characteristics should also include its semantic organization and spatial configuration, the first of which is adequately measured via space syntax methodologies.

Theoretical contributions: defining the factors that contribute to wayfinding complexity

Our results suggest that definitions for the factors from the Carlson et al. (2010) framework could benefit from the following, more explicit, wording. The ‘building’ component should include not only physical attributes (as reflected in measures of spatial legibility and lines of sight) but also information about how a building is organized, both spatially and semantically. The ‘cognitive map’ component should cover cognitive selection processes that determine, e.g., which information to encode, as dictated by the constraints of a task. Finally, researchers should recognize that an individual wayfinder employs ‘skills and strategies’ differently for different contexts, rather than performing generally well or poor.

Future research should be conducted to improve our understanding of this interplay among building characteristics, user characteristics, task requirements, and individual expectations, as well as their triggers in multi-level buildings. For example, such studies could include state and trait variables (e.g., leisure exploration versus a time limit) as underlying motivational or intrinsic goals, dynamic experiences, and the interplay among specific components of individual spatial skills. Other factors embracing the components for wayfinding complexity in complex environments may be emotional influences, cultural differences, crowding and attention/depletion (etc.), which we did not examine here. To engage those facets and interactions, researchers might conduct controlled testing in a virtual simulation of the environment (i.e., reproducing each spatial complexity in isolation). This could shed light on the relative impact of building, building user, and contextual factors. Eye-tracking could enhance the understanding of visual attention and reliance upon signage.

Practical contributions

The SCL is hard to navigate for an uninitiated wayfinder because the building challenges our understanding or schema of what a library is. The unique characteristics of this building are likely to trigger a cognitive mismatch between intrinsic expectations of how a typical library ‘should’ look and the actual mental representation acquired from spatial learning (cf., Zook & Bafna, 2013). The library thereby plays with semantic expectations (see work by Frankenstein, 2015, about spatial features that trigger semantic knowledge, as well as notions that such conceptions and expectations should be central to an individual’s spatial behavior in built environments, as addressed by Barker (1968) and Canter (1977)). This disruption might explain why our participants experienced hardship during our most challenging tasks.

Consequently, our practical implications for building planners are clear: building users are incredibly diverse, and spatially and semantically complex structures can tax even the most-skilled wayfinders. It is worth considering, with more nuance, the traits of individual patrons; applying the ‘one size does *not* fit all’ approach that involves realizing the levels of competence, spatial reasoning, and strategies that users bring, including the perspective of a least-competent user.

The planners of the SCL anticipated types of building users to a certain degree, and their design evolved from a highly rationalistic programming (Ferré, 2004; Kubo & Pratt, 2005; Mattern, 2007; Yaneva, 2009). However, the desire to be unconventional, an interest in achieving an aesthetic experience, and a desire to change the definitions of a contemporary library, ultimately, likely were stronger than functional considerations. The SCL evokes spatial exploration and stimulating experiences *beyond* efficient, effective point-to-point navigation. As such, wayfinding can be distressing (Carlson et al., 2010; Murakami, 2006). Therefore, we suggest that it may be worth developing an integration of building evaluation methods that captures users' perspectives while ensuring that basic functional qualities, such as effective, efficient, and pleasant wayfinding, are not overshadowed by the wish to introduce unconventional architecture.

Limitations

Although we relied on systematic questions regarding participants' unfamiliarity (excluding three volunteers), we cannot rule out the possibility that some participants had preconceptions before entering the building. Even a rough knowledge of a general floor layout could have contributed to wayfinding performance. However, the wayfinding difficulties in *both* samples clearly discounted familiarity by members of either group.

Given that participants were randomly assigned to their start locations, it was difficult to account for individual spatial learning or levels of frustration being dependent upon their successes achieved on previously experienced paths. By necessity, these choices ensured experimental control. In addition, we did not allow the participants to use the elevators, ask others for directions, or walk in groups, all of which are typical behaviors in everyday wayfinding. Although our volunteers did not appear anxious during our observation periods, we cannot rule out the possibility that any nervousness that emerged after failing one task may have affected their abilities during subsequent tasks. We initially included classical cognitive measures, such 'pointing tasks' to previously visited locations to assess the coherence of the cognitive map. Since our study focused on wayfinding performance measures and first-time visitors, this was an exploratory, secondary measure for us. First-time visitors rely on their cognitive skills, information in their immediate environment, and expectations. We could not analyze the pointing data due to technical problems, but since we did not aim at formally testing Carlson et al.'s (2010) model, this does not affect our results.

We did not control the number of other visitors and associated operational noise but collected data during regular opening hours. However, this constraint added realism to the wayfinding tasks. We did not account for which exact information on signage the participants might have read because the library staff did not allow us to use eye-tracking or audio recordings during the study. Therefore, our assumptions about semantic expectations and strategies arose from *post-hoc* reasoning. Finally, we intentionally studied wayfinding in an architecturally unique building that combined several complexities, a situation not likely to occur in other buildings.

Conclusions

To summarize, our intent was to explore multi-level wayfinding in a real-world setting featuring a strong variety of visual and spatial features. Our results challenge the premise that any given individual can be readily and absolutely classified as a good or poor wayfinder. Instead, a wayfinder's performance may be good or less efficient as a function of the interplay among building, cognitive map, individual, and task. Relatedly, the observation that different persons can excel at different types of tasks has important implications for user-centered design. That is, 'one size will not fit all' suggests that designers must consider an environment that will allow success in light of multiple different strategies, solutions, or skills, and that those plans account for the incredible diversity among building users. Taken together, our research elevates the need to understand the challenges of wayfinding in light of a more comprehensive and interactive approach.

References

Allen, G. L., Kirasic, K. C., Dobson, S. H., Long, R. G., & Beck, S. (1996). Predicting environmental learning from spatial abilities: An indirect route. *Intelligence*, *22* (3), 327-355. doi: 10.1016/S0160-2896(96)90026-4

Allen, G. L. (1999). Spatial abilities, cognitive maps, and wayfinding. In R. G. Golledge (Ed.), *Wayfinding behavior: Cognitive mapping and other spatial processes* (pp. 46–80). Baltimore: Johns Hopkins University Press.

American Library Association (2005). *AIA/ALA Library Buildings Award* [award]. Retrieved from http://www.ala.org/llama/awards/aiaalalibrarybuildings

Arthur, P., & Passini, R. (1992). *Wayfinding: People, signs, and architecture.* New York: McGraw-Hill Book.

Bafna, S. (2003). Space Syntax: A brief introduction to its logic and analytical techniques. *Environment and Behavior, 35* (1), 17-29. doi: 10.1177/0013916502238863

Barker, R. G. (1968). *Ecological Psychology: Concepts and methods for studying the environment of human behavior.* Stanford: Stanford University Press.

Baskaya, A., Wilson, C., & Özcan, Y. Z. (2004). Wayfinding in an unfamiliar environment different spatial settings of two polyclinics. *Environment and Behavior, 36* (6), 839-867. doi: 1177/0013916504265445

Batty, M. (2004). A new theory of Space Syntax [working paper]. Retrieved from http://discovery.ucl.ac.uk/211/1/paper75.pdf

Batty, M. (2004b). Distance in Space Syntax [working paper]. Retrieved from http://discovery.ucl.ac.uk/206/1/paper80.pdf

Batty, M. (2017). Space Syntax and spatial interaction: Comparisons, integrations, applications [working paper]. Retrieved from https://www.ucl.ac.uk/bartlett/casa/sites/bartlett/files/working-paper-208.pdf

Benedikt, M. L., & Burnham, C. A. (1985). Perceiving architectural space: From optic arrays to Isovists. In W. H. Warren (Jr.) & R. E. Shaw (Eds.), *Persistence and change: Proceedings of the first international conference on event perception* (pp. 103-114). Hillsdale: Lawrence Erlbaum.

Benedikt, M. L. (1979). To take hold of space: Isovists and Isovist fields. *Environment and Planning B: Planning and Design, 6* (1), 47-65. doi: 10.1068/b060047

Büchner, S. (2010). *Environmental structure, mental representations and path choice heuristics – information processing in wayfinding* [unpublished doctoral dissertation]. Freiburg: University of Freiburg.

Burgess, N. E., Jeffery, K. J., & O'Keefe, J.E. (1999). *The hippocampal and parietal foundations of spatial cognition*. Oxford: Oxford University Press.

Canter, D. (1977). *The psychology of place.* New York: St. Martin Press.

Carlson, L. A., Hölscher, C., Shipley, T. F., & Dalton, R. C. (2010). Getting lost in buildings. *Current Directions in Psychological Science, 19* (5), 284-289. doi: 10.1177/0963721410383243

Chang, D. (1998). *Integrated multi-floor circulation systems in dense urban areas: The effects of complex spatial designs on multi floor pedestrian movement* [unpublished doctoral dissertation], London: University of London.

Craigslist (n.d.). [website]. Retrieved from https://seattle.craigslist.org/

Dalton, N., Dalton, R., & Hölscher, C. (2015). People Watcher: An app to record and analyzing spatial behavior of ubiquitous interaction technologies. In A. Gehring, A. Krüger, F. Alt, & N. Taylor (Eds.), *Proceedings of the fourth international symposium on pervasive displays* (pp.1-6). New York: ACM. doi: 10.1145/2757710.2757714

Dalton, R. C., Kuliga, S., & Hölscher, C. (2013). POE 2.0: Exploring the potential of social media for capturing unsolicited post occupancy evaluations. *Intelligent Buildings International, 5*(3), 62–180. doi: 10.1080/17508975.2013.800813

Dara-Abrams, D. (2006). Ground truthing Space Syntax. In K. F. Richter, & U. J. Rüetschi (Eds.), *The cognitive approach to modeling environments* (pp. 23-28). Freiburg/Bremen: Report series of the transregional collaborative research center SFB/TR 8 'Spatial Cognition' (Report No. 009-08/2006).

Dogu, U., & Erkip, F. (2000). Spatial factors affecting wayfinding and orientation: A case study in a shopping mall. *Environment and Behavior*, *32* (6), 731-755. doi: 10.1177/00139160021972775

Dovey, K. (2017). One way street. In R. C. Dalton, & C. Hölscher (Eds.), *Take one building: Interdisciplinary research perspectives of the Seattle Central Library* (pp. 53-66). New York: Routledge.

Downs, R. M., & Stea, D. (2011). Chapter 4.3 Cognitive maps and spatial behavior: Process and products. In M. Dodge, R. Kitchin & C. Perkins, *The map reader: Theories of mapping practice and cartographic representation* (pp. 312-317). New Jersey: John Wiley & Sons / Blackwell. doi: 10.1002/9780470979587.ch41

Eaton, G. (1991). Wayfinding in the library: Book searches and route uncertainty. *Reference Quarterly, 30* (4), 519-527. doi: 10.2307/25828878

Evans, G. W. (1980). Environmental cognition. *Psychological Bulletin*, *88* (2), 259–287. doi: 10.1006/jevp.1998.0089

Ferré, A., Hwang, I., Kubo, M., Prat, R., Sakamoto, T., Salazar, J., …, & Tetas, A. (2004). Verb Architecture Boogazine: Connection. The changing status of the city, of architecture, of urbanism. *The generation of activity, physically linking programs,* *people, and uses.* Barcelona: Actar.

Fields, A. W., & Shelton, A. L. (2006). Individual skill differences and large-scale environmental learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32* (3), 506-515. doi: 10.1037/0278-7393.32.3.506

Fisher, K. E., Saxton, M. L., Edwards, P. M., & Mai, J.-E. (2007). Seattle Public Library as a place: reconceptualizing space, community, and information at the Central Library. In J. E. Buschman, & G. J. Leckie (Eds.). The library as place: History, community, and culture (pp. 135-160). Westport: Libraries Unlimited.

Frankenstein, J. (2015). *Human spatial representations and spatial memory retrieval* [doctoral dissertation]. Diss. ETH No. 22980, Zurich: ETH Zürich. doi: 10.3929/ethz-a-010608257

Gärling, T., Lindberg, E., & Mäntylä, T. (1983). Orientation in buildings: Effects of familiarity, visual access, and orientation aids. *Journal of Applied Psychology, 68* (1), 177-186. doi: 10.1037/0021-9010.68.1.177

Golledge, R. G. (1999). Human wayfinding and cognitive maps. In R.G. Golledge (Ed.), *Wayfinding behavior: Cognitive mapping and other spatial processes*, (pp. 5-45). Baltimore: Johns Hopkins University Press.

Grice, H. P. (1975). Logic and conversation. In P. Cole & J. Morgan (Eds.). *Syntax and semantics 3: Speech acts (*pp. 41–58). New York: Academic Press.

Haq, S., & Zimring, C. (2003). Just down the road a piece: The development of topological knowledge of building layouts. *Environment and Behavior*, *35* (1), 132-160. doi: 10.1177/0013916502238868

Hartley, T., Maguire, E. A., Spiers, H. J., & Burgess, N. (2003). The well-worn route and the path less traveled: Distinct neural bases of route following and wayfinding in humans. *Neuron, 37* (5). 877-888. doi: 10.1016/S0896-6273(03)00095-3

Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial layout learning. *Intelligence, 34* (2), 151-176. doi: 10.1016/j.intell.2005.09.005

Hegarty, M., Richardson, A. E., Montello, D. R., Lovelace, K., & Subbiah, I. (2002). Development of a self-report measure of environmental spatial ability. *Intelligence, 30* (5), 425-447. doi: 10.1016/S0160-2896(02)00116-2

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence, 32* (2), 175-191. doi: 10.1016/j.intell.2003.12.001

Hillier, B., Burdett, R., Peponis, J., & Penn, A. (1987). Creating life: Or, does architecture determine anything? *Architecture and Behaviour, 3* (3), 233-250.

Hillier, B., & Hanson, J. (1984). *The social logic of space.* Cambridge: Cambridge University Press. doi.org/10.1017/CBO9780511597237

Hochmair, H., & Karlsson, V. (2005). *Investigation of preference between the least-angle strategy and the initial segment strategy for route selection in unknown environments.* In C. Freksa, M. Knauff, B. Krieg-Brueckner, B. Nebel, & T. Barkowsky (Eds.), Spatial cognition IV: Reasoning, action, interaction (pp. 79– 97). Berlin: Springer.

Hölscher, C., Meilinger, T., Vrachliotis, G., Brösamle, M., & Knauff, M. (2006). Up the down staircase: Wayfinding strategies in multi-floor buildings. *Journal of Environmental Psychology*, *26* (4), 284-299. doi: 10.1016/j.jenvp.2006.09.002

Hölscher, C., Büchner, S. J., Meilinger, T., & Strube, G. (2009). Adaptivity of wayfinding strategies in a multi-building ensemble: The effects of spatial structure, task requirements, and metric information. *Journal of Environmental Psychology, 29* (2), 208-219. doi: 10.1016/j.jenvp.2008.05.010

Hölscher, C., Tenbrink, T., & Wiener, J. M. (2011). Would you follow your own route description? Cognitive strategies in urban route planning. *Cognition, 121* (2), 228-247. doi: 10.1016/j.cognition.2011.06.005

Hölscher, C., Brösamle, M., & Vrachliotis, G. (2012). Challenges in multilevel wayfinding: A case study with the Space Syntax technique. E*nvironment and Planning B: Planning and Design, 39* (1), 63-82. doi: 10.1068/b34050t

Hund, A. M., & Minarik, J. L. (2006). Getting from here to there: Spatial anxiety, wayfinding strategies, direction type, and wayfinding efficiency. *Spatial Cognition and Computation, 6* (3), 179-201. doi: 10.1207/s15427633scc0603_1

Jeffery, K. J., Jovalekic, A., Verriotis, M., & Hayman, R. (2013). Navigating in a three-dimensional world. *Behavioral and Brain Sciences, 36* (5), 523-543. doi: 10.1017/S0140525X12002476

Kitchin, R. M. (1994). Cognitive maps: What are they and why study them. *Journal of Environmental Psychology, 14* (1), 1-19. doi: 10.1016/S0272-4944(05)80194-X

Koolhaas/Prince-Ramus/OMA/LMN Architects (2004). *Seattle Central Library* [building in Seattle, WA, U.S.A.].

Kozhevnikov, M., & Hegarty, M. (2001). A dissociation between object manipulation spatial ability and spatial orientation ability. *Memory & Cognition, 29* (5), 745-756 doi: 10.3758/BF03200477

Kozhevnikov, M., Motes, M. A., Rasch, B., & Blajenkova, O. (2006). Perspective-taking vs. mental rotation transformations and how they predict spatial navigation performance. *Applied Cognitive Psychology, 20* (3), 397-417. doi: 10.1002/acp.1192

Kozlowski, L. T., & Bryant, K. J. (1977). Sense of direction, spatial orientation, and cognitive maps. *Journal of Experimental Psychology: Human Perception and Performance, 3* (4), 590. doi: 10.1037/0096-1523.3.4.590

Kubo, M., & Pratt, R. (2005). *Seattle Public Library OMA/LMN*. Barcelona: Actar.

Kuipers, B., Tecuci, D. G., & Stankiewicz, B. J. (2003). The skeleton in the cognitive map: A computational and empirical exploration. *Environment and Behavior, 35 (*1), 81-106. doi: 10.1177/0013916502238866

Lacayo, R. (2004). *Architecture: One for the books.* The Time 100, Retrieved from http://www.time.com/time/magazine/article/0,9171,993920,00.html

Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles*, *30* (11), 765-779. doi: 10.1006/jevp.1996.0011

Li, R., & Klippel, A. (2012). Wayfinding in libraries: Can problems be predicted? *Journal of Map & Geography Libraries*, *8* (1), 21-38. doi: 10.1080/15420353.2011.622456

Li, R., & Klippel, A. (2016). Wayfinding behaviors in complex buildings: The impact of environmental legibility and familiarity. *Environment and Behavior, 48* (3), 482-510. doi: 10.1177/0013916514550243

Lu, Y. & Ye, Y. (2017). Can people memorize multifloor building as volumetric map? A study of multifloor atrium building. *Environment and Planning B: Urban Analytics and City Science, 0* (0), 1–18. doi: 10.1177/2399808317705659

Mandel, L.H. (2017). Wayfinding research in library and information studies: State of the field. *Evidence Based Library and Information* Pr*actice, 12* (2), 133-148. doi: 10.18438/B8395P

*Matlab (*n.d.). [software], Retrieved from https://www.mathworks.com/products/matlab.html

Mattern, S. (2007). Resonant texts: Sounds of the American public library. *Senses & Society, 2* (3), 277-302, doi: 10.2752/174589307X233521

Mau, B. (2005). *Life style.* London: Phaidon Press.

Mavridou, M. (2012). Perception of architectural and urban scale in an immersive virtual environment. *Environment and Planning B: Planning and Design, 39 (2),* 33-47. doi: 10.1068/b34049

Meneghetti C., Pazzaglia, F., De Beni, R. (2011). Spatial mental representations derived from survey and route descriptions: When individuals prefer extrinsic frame of reference. *Learning and Individual Differences*, *21* (2), 150–157, doi: 10.1016/j.lindif.2010.12.003

Montello, D. R. (2005). *Navigation.* Cambridge: Cambridge University Press.

Montello, D. R. (2014). Spatial Cognition and architectural space: Research perspectives. *Architectural Design, 84* (5), 74-79, doi: 10.1002/9781119162124.ch9

Montello, D. R. (2017). Landmarks are exaggerated. *Künstliche Intelligenz, 31* (2), 193–197. Retrieved from https://link.springer.com/article/10.1007/s13218-016-0473-5

Montello, D. R., & Pick, H. L. (1993). Integrating knowledge of vertically aligned large-scale spaces. *Environment and Behavior*, *25* (3), 457-484. doi: 10.1177/0013916593253002

Murakami, K. (2006). *Too many people getting lost in new downtown library.* SeattlePi, Retrieved from https://www.seattlepi.com/local/article/Too-many-people-getting-lost-in-new-downtown-1213582.php

Nardi, D., Newcombe, N. S. & Shipley, T. F. (2011). The world is not flat: Can people reorient using slope? *Journal of Experimental Psychology: Learning, Memory and Cognition 37*(2), 354–67. doi: 10.1037/a0021614

Nothegger, C., Winter, S., & Raubal, M. (2004). Selection of salient features for route directions. *Spatial Cognition and Computation, 4* (2), 113–136. doi: 10.1207/s15427633scc0402_1

O’Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map.* Oxford: Clarendon Press.

O’Neill, M. J. (1991). Effects of signage and floor plan configuration on wayfinding accuracy. *Environment and Behavior*, *23* (5), 553-574. doi: 10.1177/0013916591235002

Pazzaglia, F., Cornoldi, C., & De Beni, R. (2000). Differenze individuali nella rappresentazione dello spazio e nell'abilità di orientamento: Presentazione di un questionario autovalutativo. *Giornale Italiano di Psicologia*, *27* (3), 627-0. doi: 10.1421/310

Pazzaglia, F., & De Beni, R. (2001). Strategies of processing spatial information in survey and landmark-centred individuals. *European Journal of Cognitive Psychology, 13* (4), 493-508. doi: 10.1080/09541440125778

Penn, A. (2003). Space Syntax and spatial cognition: Or why the axial line? *Environment and Behavior, 35* (1), 30 - 65. doi: 10.1177/0013916502238864

Peponis, J., Zimring, C., & Choi, Y. K. (1990). Finding the building in wayfinding. *Environment and Behavior*, *22* (5), 555-590. doi: 10.1177/0013916590225001

Plank, C. & Zisch, F. (2017). Discovering Serendip[sic!]: Eye-tracking experiments in the Seattle Central Library as the beginning of a research adventure. In R. C. Dalton, & C. Hölscher (Eds.), *Take one building: Interdisciplinary research perspectives of the Seattle Central Library* (pp. 188-202). New York: Routledge.

Pogrebin, R. (2004). *Inside the year's best reviewed buildings* [website]. Retrieved from: http://www.nytimes.com/2004/12/26/arts/design/26pogr.html?_r=0

Presson, C.C., & Montello, D.R. (1988). Points of reference in spatial cognition: Stalking the elusive landmark. *British Journal of Developmental Psychology*, *6* (4), 378–381. doi: 10.1111/j.2044-835X.1988.tb01113.x

Ruddle, R., Payne, S. J., & Jones, D. M. (1997). Navigating buildings in "desk-top" virtual environments: Experimental investigations using extended navigational experience. *Journal of Experimental Psychology: Applied, 3* (2), 143–159. doi: 10.1037/1076-898X.3.2.143

Seamon, D. (2017). A phenomenological and hermeneutic reading of Rem Koolhaas's Seattle

Central Library: Buildings as lifeworlds and architectural texts. In R. C. Dalton, & C. Hölscher (Eds.), *Take One Building: Interdisciplinary Research Perspectives of the Seattle Central Library* (pp. 67-94). New York: Routledge.

Shelton, A. L., & Gabrieli, J. D. (2004). Neural correlates of individual differences in spatial learning strategies. *Neuropsychology, 18* (3), 442-449. doi: 10.1037/0894-4105.18.3.442

Shelton, A. L., & Zacks, J. M. (2015). Spatial transformations of scene stimuli: It's an upright world. In J. S. Gero (Ed.), *Studying visual and spatial reasoning for design creativity* (pp. 245-266). Dordrecht: Springer.

Soeda, M., Kushiyama, N., & Ohno, R. (1997). Wayfinding in cases with vertical motion. *Proceedings of MERA 97: International conference on environment-behavior studies*, 559–564.

SPSS (n.d.), IBM [software]. Retrieved from https://www.ibm.com/analytics/spss-statistics-software

Steck, S. D., & Mallot, H. A. (2000). The role of global and local landmarks in virtual environment navigation. *Presence: Teleoperators & Virtual Environments*, *9* (1), 69-83. doi: 10.1162/105474600566628

Tellevik, J. (1992). Influence of spatial exploration patterns of cognitive mapping by blindfolded sighted persons. *Journal of Visual Impairment & Blindness*, *86* (5), 221-224.

Tlauka, M., Wilson, P. N., Adams, M., Souter, C. & Young, A. H. (2007). An investigation into vertical bias effects. *Spatial Cognition and Computation*, *7* (4), 365–91. doi: 10.1080/13875860701684138

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review*, *55* (4), 189, doi: 10.1037/h0061626

Turner, A., & Penn, A. (1999). Making Isovists syntactic: Isovist integration analysis. In F. Holanda (Ed.), *Second international symposium on Space Syntax, Brasilia*. Retrieved from http://cvcl.mit.edu/SUNSeminar/ Turner_isovist_space_99.pdf.

Turner, A., Doxa, M., O'Sullivan, D., & Penn, A. (2001). From isovists to visibility graphs: A methodology for the analysis of architectural space. *Environment and Planning B: Planning and Design*, *28* (1), 103-121. doi: 10.1068/b2684.

Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In A. U. Frank, & W. Kuhn (Eds.), *Spatial information theory: A theoretical basis for GIS* (pp. 14-24). Berlin: Springer.

Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills, 69 (12)*, 915-270, doi: 10.2466/pms.1978.47.2.599

Wang, W. (2017). Epilogue: Drawing together multiple perspectives of the Seattle Central Library. In R. C. Dalton, & C. Hölscher (Eds.), *Take one building: Interdisciplinary research perspectives of the Seattle Central Library* (pp. 203-209). New York: Routledge.

Weisman, J. (1981). Evaluating architectural legibility way-finding in the built environment. *Environment and Behavior*, *13* (2), 189-204, doi: 10.1177/0013916581132004

Wiener, J. M., Schnee, A., & Mallot, H. A. (2004). Use and interaction of navigation strategies in regionalized environments. *Journal of Environmental Psychology, 24* (4), 475-493, doi: 10.1016/j.jenvp.2004.09.006

Wilson, P., Foreman, N., Stanton, D. & Duffy, H. (2004). Memory for targets in a multifloor simulated environment: Evidence for vertical asymmetry in spatial memory. *Memory and Cognition, 32* (2), 283–97. Retrieved from https://link.springer.com/article/10.3758/BF03196859

Wolbers, T., & Hegarty, M. (2010). What determines our navigational abilities? *Trends in Cognitive Sciences*, *14* (3), 138-146. doi: 10.1016/j.tics.2010.01.001

Yaneva, A. (2009). *Made by the Office for Metropolitan Architecture: An ethnography of design.* Rotterdam: nai010.

Zacks, J. M., & Michelon, P. (2005). Transformations of visuospatial images. *Behavioral and Cognitive Neuroscience Reviews*, *4* (2), 96-118, doi: 10.1177/1534582305281085

Zhang, L., Chiradia, A., & Zhuang, Y. (2013). *In the intelligibility maze of Space Syntax: A Space Syntax analysis of toy models, mazes and labyrinths*. In Y. O. Kim, H. T. Park, & K. W. Seo (Eds.), Proceedings of the 9th International Space Syntax Symposium (pp. 1-18), Seoul: Sejong University.

Zook, J. B., & Bafna, S. (2012). Imaginative Content and Building Form in the Seattle Central Public Library. In M. Greene, J. Reyes, & A. Castro (Eds.), *Proceedings: Eighth International Space Syntax Symposium* (pp. 1-24), Santiago de Chile: PUC.

Figure 1. Seattle Central Library.

Note. Exterior of the Seattle Central Library, designed by Rem Koolhaas and Joshua Prince-Ramus of Office of Metropolitan Architects (OMA) and Loschky, Marquardt, and Nesholm Architects (LMN); opened in 2004.

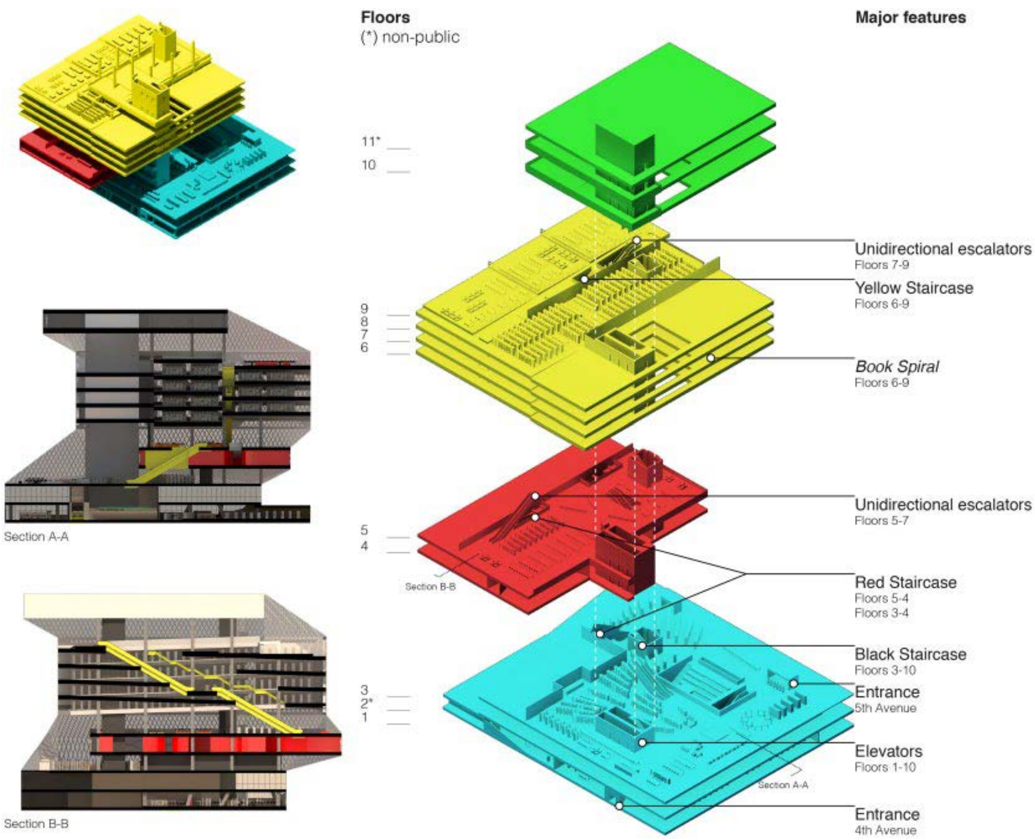

Figure 2. Spatial configuration of the Seattle Central Library.

Note. Spatial configuration, two section cuts, and all vertical transfer options and entrances. The colors indicate shifted floor plates.

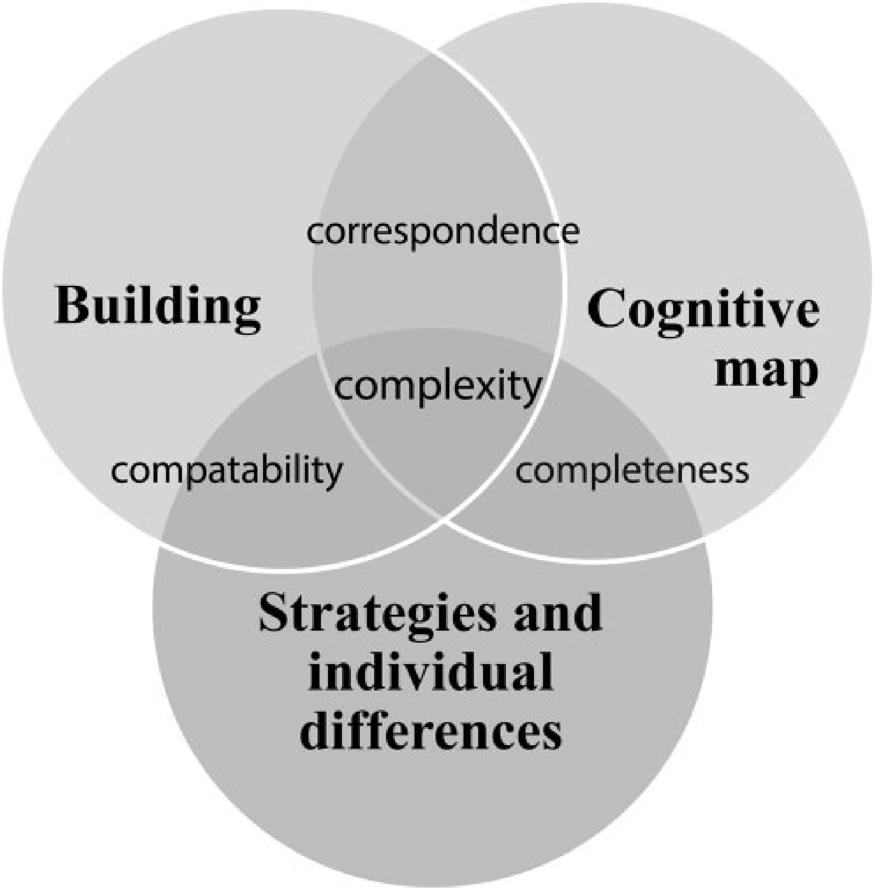

Figure 3. Framework proposed by Carlson, Hölscher, Shipley, and Dalton (2010) for complexities in multilevel wayfinding.

Note. Reprinted with permission from Carlson et al. (2010). This theoretical framework comprises three major components that define multilevel wayfinding complexities: features/ characteristics of building, mental representation/cognitive map of the wayfinder, and individual differences in spatial skills and wayfinding strategies. The framework also includes interactions among these components, labeled correspondence, completeness, and compatibility (each described in depth in Carlson et al. (2010), and in the context of our study in the introduction of this article). In our discussion section, we suggest refinements and extensions for this framework based on our results.

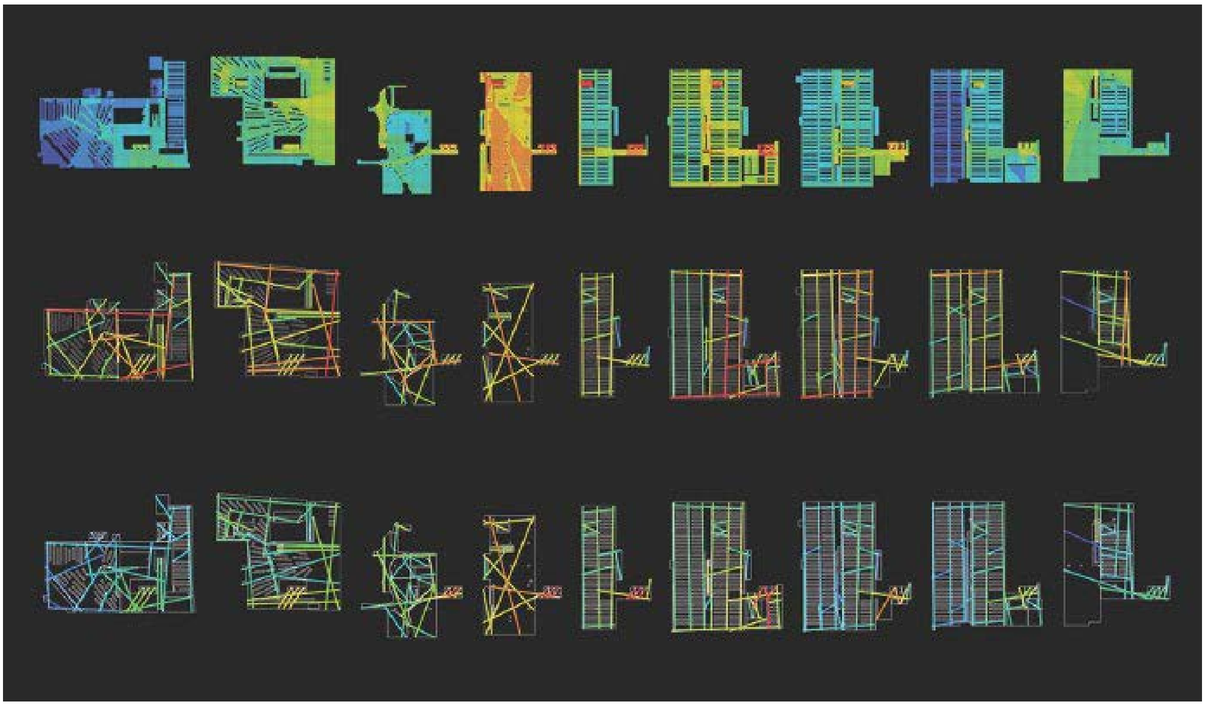

Figure 4. Building analyses: Space syntax.

Note. Analyses of the library's public floors (left to right: Floors 1 to 10 [excluding the inaccessible floors for staff, Floors 2 and 11]). In space syntax, local and global measures pertain to the amount of the network graph included in calculations (i.e., the whole or subgraph) and can be applied within floors or between floors. All analyses here consider each floor linked to adjacent floors via stairs/elevators. Vertical links are not shown for sake of clarity. Above: a visibility graph analysis shows the measure of integration, which is the relative visual accessibility of a location from all others in the building. Middle: an axial line analysis shows axial integration radius three, which is a calculation of the local accessibility of an axial line only including lines 3 or fewer line-connections away. Below: an axial line analysis shows axial integration, a measure expressing how reachable an axial line is, from all other lines/locations in the building. For all analyses, red/yellow colors express more accessible, central areas, whereas blue/green colors indicate more segregated, remote areas.

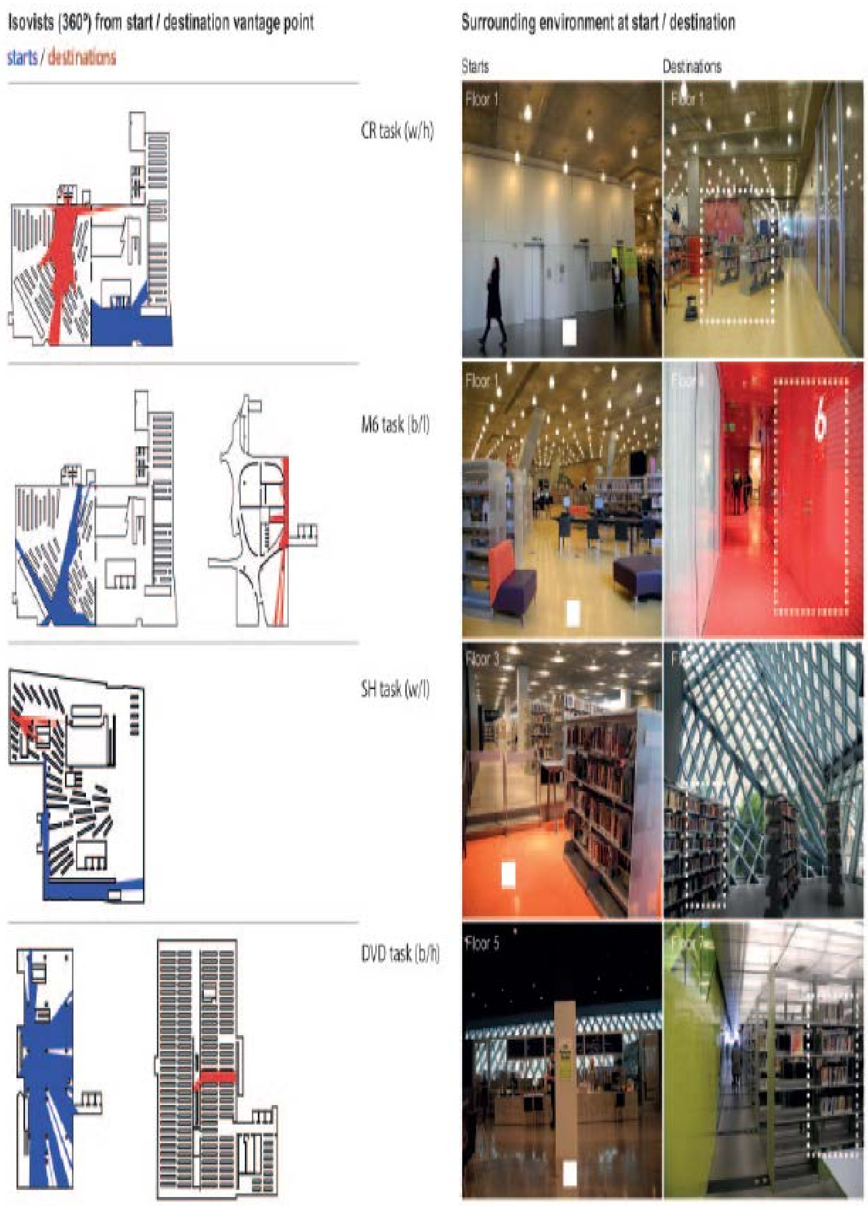

Figure 5. Start and destinations of four core wayfinding tasks.

Note. Left: field of views, called isovists, were computed to ensure that a destination (in red) was never in direct view from start location (blue). They expressed an exact 360° field of vision that wayfinders had available from each start point and when standing at destination. Isovist analysis does not capture low furniture that may block movement or visual access. Right: photos of views close to starts (white boxes) and destinations (dotted boxes), but not exact isovist locations. The four wayfinding tasks reflected specific wayfinding challenges that tackled the study’s Floor × Accessibility manipulation. CR = Children’s Restrooms; w/h

= within-floor/high accessibility; M6 = Meeting Room No. 6; b/l = between-floor/low accessibility; SH = book about Sherlock Holmes; w/l = within-floor/low accessibility; DVD = Nonfiction DVD; b/h = between-floor/high accessibility.

Table 1. Wayfinding Task Classification, Based on Changes in Floors and Degree of Accessibility.

Independent variables				Wayfinding tasks	
Merged group (*N* = 59)	Floor	Accessibility	Expected difficulty	Task	Optimal shortest path and strategy
	Within (Floor 1)	High	Easy	Children's Restrooms (CR)	Look around to identify children's section nearby and walk toward it. Then identify children's restrooms nearby
	Between (Floor 1—Floor 4)	Low	Hard	Meeting Room No. 6 (M6)	Understand the global spatial configuration. Resist the urge to use salient wayfinding options (yellow escalators)
	Within (Floor 3)	Low	Hard	Sherlock Holmes book by Arthur Conan Doyle in the Mystery section (SH)	First identify the correct section (Mystery), then search locally, but not in central areas on the floor
	Between (Floor 5—Floor 7)	High	Easy	Nonfiction DVDs (DVD)	Look around to identify local signage. Use salient escalator to ascend, and see destination in a direct line of sight

Note. Wayfinding task classification with the manipulated independent variables floor (within/between) and difficulty (high/low) and indicating the expected task difficulty and strategy to identify the shortest, optimal route option.

Table 2. Individual Differences Between the Groups.

Individual differences	Group	Minimum (rounded)	Maximum (rounded)	M_{all} (*SD*)	M_{male} (*SD*)	M_{female} (*SD*)
Spatial skills (mental transformations)						
Spatial perspective-taking (absolute directional errors)	Conference	93	173	154.80 (18.20)	149.62 (23.95)	159.29 (10.05)
	Locals	83	171	153.15 (19.02)	153.31 (14.51)	153.02 (22.73)
Mental rotation (score out of 40)	Conference	3	39	19.82 (10.39)	21.54 (11.57)	18.33 (9.40)
	Locals	8	35	17.91 (7.35)	20.48 (9.23)	15.67 (4.36)
Self-perceptions						
Sense of direction (score out of 100)	Conference	29	99	68.61 (17.70)	70.00 (14.05)	67.40 (20.78)
	Locals	32	100	69.63 (17.52)	73.86 (14.95)	65.94 (19.20)
Spatial anxiety (score out of 40)	Conference	10	33	19.50 (6.57)	18.77 (5.46)	20.13 (7.53)
	Locals	9	30	20.40 (5.78)	18.28 (6.04)	22.25 (5.00)
Spatial preferences (scale 1-10)						
Route	Conference	2	9	6.14 (1.82)	5.77 (1.73)	6.47 (1.88)
	Locals	3	10	6.83 (1.74)	7.21 (1.81)	6.50 (1.67)
Survey	Conference	2	10	6.96 (2.17)	6.85 (1.95)	7.07 (2.04)
	Locals	3	10	6.93 (2.42)	7.50 (2.18)	6.44 (2.58)
Landmark	Conference	5	10	8.29 (1.49)	8.00 (1.08)	8.53 (1.77)
	Locals	4	10	7.83 (1.88)	8.21 (2.01)	7.50 (1.75)
Survey-Route	Conference	–6	8	0.82 (3.14)	1.08 (2.84)	0.60 (3.46)
	Locals	–4	6	0.16 (2.56)	0.29 (2.97)	–0.06 (2.23)

Note. Multivariate ANOVA for the two spatial skill measures (mental transformations: spatial perspective-taking and mental rotation) and individual differences (self-perceptions: sense of direction and spatial anxiety) and spatial preferences (preferences for route, survey, landmark, or survey/shortcut representations). Note that the "Survey-Route" score is a subtraction score that shows the relative tendency to use survey versus route information: Negative scores indicate participants who prefer route information more than survey information; positive scores indicate participants who prefer shortcut information to route information; and scores near zero indicate a balanced preference. The ANOVA indicated no statistically significant differences between the conference and locals, $F(7, 50) = 0.76$; Wilks's $\Lambda = 0.90$; $\eta_p^2 = .10$; $p = .63$, not significant; or between men and women, $F(7, 48) = 1.01$; Wilks's $\Lambda = 0.87$; $\eta_p^2 = .13$; $p = .44$; not significant. Consequently, we merged the two groups as planned.

Table 3. Dependent Variables Calculated for Participants From Conference and Local Groups.

Dependent variables	Task comparison	Wayfinding tasks				
Performance	Test of performance differences between samples	Group	CR (w/h)	SH (w/l)	DVD (b/h)	M6 (b/l)
*Wayfinding Time (min's")	$F(4, 52) = 4.19$; Wilks's $\Lambda = .76$;	Conference	0'46"	4'04"*	5'08"	4'16"
	$\eta_p^2 = .24$; *$p = .005$	Locals	1'13"	5'49"*	5'41"	4'25"
Ranked task difficulty (out of 4 tasks)	$F(4, 49) = 2.58$; Wilks's $\Lambda = .83$;	Conference	1.00	3.00	3.42	2.50
	$\eta_p^2 = .17$; $p = .05$	Locals	1.48	2.96	3.29	2.27
Distances (meters)	$F(4, 53) = 1.84$; '$\Lambda = .88$;	Conference	60.17	193.63	246.65	264.98
	$\eta_p^2 = .12$; $p = .13$	Locals	78.68	214.09	301.78	259.51
Deviation/PAO (percentage)	$F(4, 52) = 1.73$; Wilks's $\Lambda = .88$;	Conference	33.96	346.68	246.47	28.16
	$\eta_p^2 = .12$; $p = .16$	Locals	74.54	358.24	325.24	25.73
*Pauses (frequency)	$F(4, 54) = 6.11$; Wilks's $\Lambda = .68$;	Conference	0.11	2.68*	2.25	0.93
	$\eta_p = .31$; *$p < .001$	Locals	0.45	7.26*	4.32	1.00
Sign usage (frequency)	$F(4, 53) = 3.05$; Wilks's $\Lambda = .81$;	Conference	0.57	1.93	2.46	3.21
	$\eta_p^2 = .19$; $p = .02$ (>.01)	Locals	0.37	1.20	2.47	1.77

Note. Results of separate *multivariate ANOVAs* (reported in the table) for each of the six dependent variables (alpha adjusted to $p < .0125$ for four task comparisons). Asterisks show differences between the two groups in the measures wayfinding time and pauses (due to differences in the *SH w/l* task). Consequently, we merged the two groups, as planned. CR = Children's Restrooms; w/h = within-floor/high accessibility; SH = book about Sherlock Holmes; w/l = within-floor/low accessibility; DVD = Nonfiction DVD; b/h = between-floor/high accessibility; M6 = Meeting Room No. 6; b/l = between-floor/low accessibility; PAO = percentage above an optimal, shortest path.

Table 4. Task Difficulty Based on Measures of Wayfinding Performance.

Dependent variables	Repeated-measures ANOVA	*df*	*F*	Wilks's Λ	Effect size (η_p^2)	Significance	Wayfinding performance (tasks sorted from easy to difficult based on the data)
Ranked task difficulty (out of 4 tasks)	Floor	53	37.12	.59	.41	***p* < .001**	w/h CR ($M = 1.25$, $SD = 0.66$)
	Accessibility		9.60	.85	.15	***p* = .003**	b/l M6 ($M = 2.38$, $SD = 0.83$)
	Floor × Accessibility		138.31	.27	.72	***p* < .001**	w/l SH ($M = 2.98$; $SD = 0.81$) b/h DVD ($M = 3.35$, $SD = 0.76$)
Deviation/PAO (percentage)	Floor	57	4.90	.92	.09	$p = .03$ ($p > .125$)	b/l M6 ($M = 26.91$, $SD = 25.27$) w/h CR ($M = 54.95$, $SD = 67.39$)
	Accessibility		0.76	.99	.01	$p = .38$	b/h DVD ($M = 287.14$, $SD = 211.24$)
	Floor × Accessibility		199.88	.22	.78	***p* < .001**	w/l SH ($M = 352.66$, $SD = 232.31$)
Distances (meters)	Floor	57	106.75	.35	.65	***p* < .001**	w/h CR ($M = 69.74$, $SD = 30.47$)
	Accessibility		23.27	.71	.29	***p* < .001**	w/l SH ($M = 204.21$, $SD = 104.31$)
	Floor × Accessibility		41.02	.58	.41	***p* < .001**	b/l M6 ($M = 262.16$, $SD = 53.04$) b/h DVD ($M = 275.17$, $SD = 150.99$)
Sign usage (frequency)	Floor	57	56.98	.50	.50	***p* < .001**	w/h CR ($M = 0.47$, $SD = 0.63$)
	Accessibility		6.29	.90	.09	$p = .02$ ($p > .125$)	w/l SH ($M = 1.55$, $SD = 1.89$) b/l M6 ($M = 2.47$, $SD = 1.63$)
	Floor × Accessibility		13.33	.81	.19	***p* = .001**	b/h DVD ($M = 2.47$, $SD = 1.81$)

Note. Results of separate *repeated-measures ANOVAs* (alpha adjusted to $p < .0125$ for four task comparisons) with the manipulated within-subject factors Floor (within/between) and Accessibility (high/low) for each of the dependent variables that did not differ between groups for the merged group ($N = 59$). The dependent variables "wayfinding time" and "pauses" were excluded from this analysis. w/h = within-floor/high accessibility; CR = Children's Restrooms; b/l = between-floor/low accessibility; M6 = Meeting Room No. 6; w/l = within-floor/low accessibility; SH = book about Sherlock Holmes; b/h = between-floor/high accessibility; DVD = Nonfiction DVD; PAO = percentage above an optimal, shortest path. Asterisks and bold text indicates significance.

Table 5. Correlations Among Performance Variables.

	CR (w/h)	SH (w/l)	M6 (b/l)	DVD (b/h)
Pearson correlations between the different dependent variables that measured performance in each task				
Pauses × Deviation/PAO	+.72* ($p < .001$)	+.42* ($p = .001$)	+.34* ($p = .009$)	+.70* ($p < .001$)
Sign Usage × Deviation/PAO	—	+.62* ($p < .001$)	+.25 ($p = .05$)	+.49* ($p < .001$)
Sign Usage × Pauses	—	—	—	+.33* ($p = .01$)
Pearson correlations of each performance variable across all wayfinding tasks				
Sign Usage × Sign Usage	Only M6 and SH Sign usage: +.35* ($p = .007$)			
Pauses × Pauses	SH and DVD pauses: +.40* ($p = .002$)			
Pearson correlations between individual skills and task performance measures				
Spatial Perspective Taking × Pauses	Only in CR task: –.38* ($p = .003$), and SH task: –.32* ($p = .01$)			
Mental Rotation × Deviations/PAO	Only in M6 task –.27 ($p = .04 > .125$)			
Route × Deviation/PAO	Only in DVD task: +.42* ($p = .001$)			
[Survey-Route] × Deviation/PAO	Only in DVD task –.31 ($p = .02$)			

Note. For Pearson correlations, all performance measures were considered except for ranked task difficulty because those data did not have proper distributions for examining correlations for the merged sample. Alpha was adjusted to $p < .125$ for four task comparisons. Results that are close to significance, but not statistically significant, are also displayed. CR = Children's Restrooms; w/h = within-floor/high accessibility; SH = book about Sherlock Holmes; w/l = within-floor/low accessibility; DVD = Nonfiction DVD; b/h = between-floor/high accessibility; M6 = Meeting Room No. 6; b/l = between-floor/low accessibility; PAO = percentage above an optimal, shortest path.

Figure 6. Individual wayfinding trajectories in within-floor tasks.

Note. Left: axial line analysis. Blue and green tones represent more segregated and remote areas; red and yellow indicate more accessible and central areas. Starts are displayed as blue dot; destinations as red cross. A white line (left) indicates the predefined shortest optimal path. Right: the wayfinding path trajectories (blue: conference; red: locals) in the within-floor tasks (CR, M6). The trajectories justify merging samples as planned, as the trajectories and error types in the tasks are very similar. CR= Children’s Restrooms; M6 = Meeting Room No. 6.

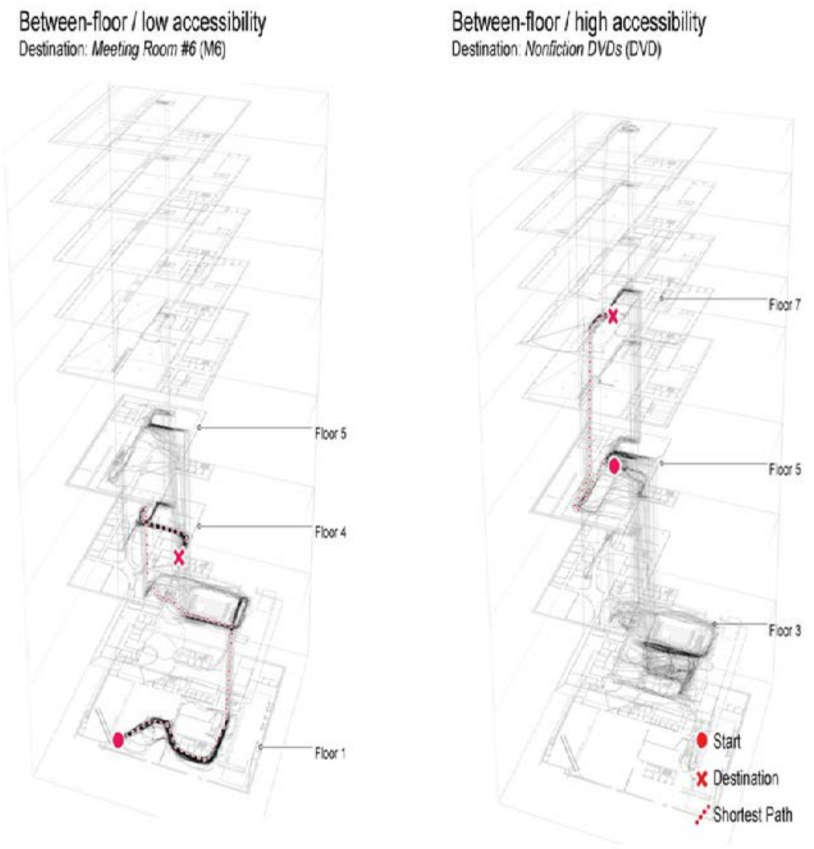

Figure 7. 3-D-trajectory visualization of paths in the between-floor tasks.

Note. Three-dimensional visualization of the wayfinding trajectories for the between-floor tasks (M6, DVD). The figure indicates routes that participants took, as well as an optimal, shortest path (dotted line). The dot represents the start, the cross the destination.

Table 6. Summary of Wayfinding Strategies per Task.

Task (*N* = 59)	Expected difficulty	Outcome	Optimal shortest path (frequency)	Recovery from an error/suboptimal decision	Summary of the wayfinding strategy observation and spatial skill analysis
CR (w/h) (Floor 1)	Easy	Easy	47	Easy	Error type: semantic interpretation that children's restrooms would be located with the adults' restrooms Error recovery: easy (retracing the path a few steps and walking behind the auditorium to the destination) Skills that help: spatial perspective-taking
M6 (b/l) (Floor 1 to Floor 5)	Hard	Easy	12	Easy	Error type: using salient yellow escalators as wayfinding cues (instead of optimal, but staircases) and bypassing the destination floor Error recovery: easy (on Floor 5: identifying another option by which to descend) Skills that help: mental rotation skills
SH (w/l) (Floor 3)	Hard	Hard	9	Hard	Error type: reading bookshelf information and searching in central rather than remote areas; challenge with spatial organization Error recovery: difficult (lack of understanding that a separate section for mystery books was housed in a remote area) Skills that help: spatial perspective-taking
DVD (b/h) (Floor 5 to Floor 7)	Easy	Very Hard	16	Hard	Error type: searching centrally on Floor 3, not realizing that this was the wrong floor and incorrect section; challenge with spatial organization: semantic interpretation by participants that Nonfiction DVDs would logically be located in the same area as the Fiction DVDs Error recovery: hard (realizing that one was on the wrong floor and in the wrong section, and then deciding to ascend four floors) Skills that help: shortcut/survey preferences (on the contrary, route preferences were linked to needing more wayfinding time)

Note. Left: expected and actual task difficulties based on a post hoc observations of the wayfinding performance. Right: notion of the observed strategies versus optimal strategies and error types, as well as on spatial skills correlated with a specific task. CR = Children's Restrooms; w/h = within-floor/high accessibility; M6 = Meeting Room No. 6; b/l = between-floor/low accessibility; SH = book about Sherlock Holmes; w/l = within-floor/low accessibility; DVD = Nonfiction DVD; b/h = between-floor/high accessibility; PAO = percentage above an optimal, shortest path.