Up the down staircase: Wayfinding strategies in multi-level buildings

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Abstract

The intention of this article is to create a link between human spatial cognition research and architectural design. We conducted an empirical study with human subjects in a complex multi-level building and compared thinking aloud protocols and performance measures of experienced and inexperienced participants in different wayfinding tasks. Three specific strategies for navigation in multi-level buildings were compared. The central point strategy relies on well-known parts of the building; the direction strategy relies on routes that first head towards the horizontal position of the goal, while the floor strategy relies on routes that first head towards the vertical position of the goal. We show that the floor strategy was preferred by experienced participants over the other strategies and was overall tied to better wayfinding performance. Route knowledge showed a greater impact on wayfinding performance compared to survey knowledge. A cognitive-architectural analysis of the building revealed seven possible causes for navigation problems. Especially the staircase design was identified as a major wayfinding obstacle. Finally we address the benefits of cognitive approaches for the architectural design process and describe some open issues for further research.
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To experience architectural space truthfully it is necessary to perambulate and stride the building.
Le Corbusier (1962, p. 30)

1. Introduction

Many people have problems finding their way around public buildings such as airports, hospitals, offices or university buildings. The problem may partially lie in their spatio-cognitive abilities, but also in an architecture that only rudimentarily accounts for human spatial cognition. We aim to make progress towards linking architectural design and human spatial cognition research. The paper begins with an overview of relevant previous work on wayfinding cognition. In the main part of the paper we report on an empirical investigation in which 12 partici-

pants solved wayfinding problems in a complex multi-level building. Half of the participants were very familiar with the building; the other half were visiting the site the first time. The results reveal distinct differences in the navigation strategies of familiar and unfamiliar participants in their strategy choice. We discuss how these strategy and performance differences may relate to route- and survey-based knowledge and to reference frames. We provide a detailed architectural analysis of the building and discuss the generalizability of our findings for architectural design, human spatial cognition research, and indoor-wayfinding.

1.1. Environmental features and wayfinding difficulties

What are the environmental features that can lead to navigation breakdowns? A pioneering study on indoor navigation was conducted by Best (1970), who first identified fundamental aspects of a building's route network, like choice points, directional changes and distances as relevant

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predictors of wayfinding difficulties in complex buildings. Numerous studies, especially in the environmental psychology community, have since investigated the reasons for wayfinding difficulties. For instance, Weisman (1981) identifies four general classes of environmental variables that shape wayfinding situations: visual access, the degree of architectural differentiation, the use of signs and room numbers, and floorplan configuration. Further studies pointed to the impact of layout complexity on both wayfinding performance and cognitive mapping (Gärling, Böök, & Lindberg, 1986; O'Neill, 1991a, 1991b). Recent studies have been conducted in airports (e.g., Raubal, 2002), shopping malls (Dogu & Erkip, 2000) and universities (Abu-Obeid, 1998; Butler, Acquino, Hissong, & Scott, 1993).

Another essential point seems to be the familiarity with the building. Gärling, Lindberg, and Mäntylä (1983) point out that familiarity with a building has substantial impact on wayfinding performance. So does visual access within the building: If large parts of the building are immediately visible and mutual intervisibility (vistas) connects the parts of the building, people have to rely less on stored spatial knowledge and can rely on information directly available in their field of vision, a notion inspired by Gibson (1979). A disadvantage of these lines of research is that floorplan complexity and configuration as well as visual access have been defined rather informally in the literature discussed above (e.g., by subjective ratings). The concept of *isovists* (Benedikt, 1979) provides a much more precise mathematical framework for capturing local properties of visible spaces as viewshed polygons, which correspond with psychological measurements of environmental perception (Stamps, 2002). The Space Syntax movement (Hillier & Hanson, 1984) has introduced formalized, graph-based accounts of layout configurations into architectural analysis. Calculations based on these representations express the connective structure of rooms and circulation areas in a building and are strongly associated with route choices of hospital visitors both in unguided exploration and in directed search tasks wayfinding behavior (Peponis, Zimring, & Choi, 1990; Haq & Zimring, 2003). Yet research along this methodology is generally based on correlations of building layout and aggregate movement patterns, thus providing no immediate understanding of individual cognitive processes (Penn, 2003).

1.2. Wayfinding in three-dimensional structures

One drawback of almost all controlled studies into wayfinding performance and building complexity is that they have limited themselves to investigating movement and orientation in the horizontal plane of isolated floor levels (with notable exceptions like Hunt, 1984; Moeser, 1988). Soeda, Kushiyama, and Ohno (1997) observed wayfinding performance in tasks involving vertical level changes. They found people losing their orientation due to vertical travel, supporting more informal results of Passini (1992). Soeda et al. (1997) identified another challenge of

multi-level buildings: Wayfinders assume that the topology of the floorplans of different levels is identical, an assumption that can lead to severe wayfinding difficulties.

In Section 2.2 of the paper we provide a building analysis revealing that our setting could be similarly prone to challenges based on multi-level properties. Therefore, our investigations into both the navigation performance of test participants as well as their mental processes explicitly focus on the above-mentioned aspects. Montello and Pick (1993), although not investigating wayfinding behavior directly, present evidence that humans have trouble correctly aligning vertical spaces in pointing tasks. We also expect wayfinders to have trouble integrating survey knowledge of different floors. Properly connecting mental floorplans at transition points like staircases or elevators may also be further impaired by difficulties of maintaining one's heading due to the rapid direction changes involved in stair climbing.

1.3. Wayfinding strategies for complex buildings

Authors like Weisman (1981) or Lawton (1996) have analyzed wayfinding strategies as to what degree they rely on different types of knowledge. Spatial knowledge is commonly distinguished into three levels (Siegel & White, 1975). In the context of this study it can be assumed that finding destinations inside the building requires all three types of spatial knowledge: landmarks identify one's own position and relevant navigational choice points, route knowledge connects distinguishable landmarks, while survey knowledge integrates routes and guides high-level decisions for route selection and general direction. Pazzaglia and De Beni (2001) found evidence that people differ in their general preference for relying on different types of spatial knowledge, especially landmarks vs. survey knowledge. Lawton (1996) implies that people's wayfinding strategies gradually progress from route-based orientation to survey-based strategies, yet could not clearly tie this evolution to a performance improvement. Yet it has become clear in recent years (Montello, 1998; Montello, Waller, Hegarty, & Richardson, 2004) that strict developmental stages from landmark, to route and then survey knowledge are not realistic and that the representations rather develop in parallel, so that navigators can build up initial survey representations early on.

In a building with a complex network like in our study, the general notion of survey knowledge—in the sense of correct positional information about the metric spatial position of destinations—representing the most advanced and valuable information may not hold. In fact, knowing the routes through the maze of levels and vertical and horizontal corridors can be even more important, especially since seemingly direct routes may be blocked by dead-ends in the building, an aspect not taken into account by direction-based navigation planning.

A number of different wayfinding strategies have been described for two-dimensional (outdoor) settings. Both

Hochmair and Frank (2002) and Conroy Dalton (2003), Conroy (2001) have described *least-angle strategies*: People try to minimize their global deviation from the direction of the goal position, and at the same time avoid local direction deviations at junctions, thus maintaining a straight heading wherever possible. Wiener, Schnee, and Mallot (2004) were able to show that navigators in a virtual outdoor environment rely on *region-based strategies* of *fine-to-coarse* planning with a hierarchical planning approach: The environment is cognitively segmented into regions which guide navigation decisions.

But how do people incorporate their available knowledge in wayfinding strategies in the three-dimensional case of multi-level buildings? We propose a distinction of three strategies for finding one's way, even in cases when the wayfinder does not have fully developed knowledge about the spatial setting:

1. The *central point strategy* of finding one's way by sticking as much as possible to well-known parts of the building, like the main entry hall and main connecting corridors, even if this requires considerable detours.
2. The *direction strategy* of choosing routes that head towards and lead to the *horizontal* position of the goal as directly as possible, irrespective of level-changes.
3. The *floor strategy* of first finding one's way to the floor of the destination, irrespective of the horizontal position of the goal.

Mapping these strategies to other accounts, the least-angle strategies can be directly related to the direction strategy in our classification. In a more abstract sense, the region-based "fine-to-coarse" strategy of—ceteris paribus—preferring paths that quickly bring one into the region of a destination, is compatible with the floor strategy, if you assume floor levels as organizing principles in the mental representation of multi-level buildings (cf. Montello & Pick, 1993). The idea of a route *skeleton* proposed by Kuipers, Tecuci, and Stankiewicz (2003) corresponds to the central-point strategy. Kuipers et al. showed that over time, human as well as artificial navigators learn a set of central paths ('the skeleton') in an environment. This centrality can be predicted based on the number of boundary relations involved in its segments, but we can also assume that architects mark certain paths as central by architectural features like entries or ornamentation. Also, the notion of a frame of reference which relates to the main orientation of an environment unless sticking to the orientation the environment was initially experienced (e.g., McNamara & Valiquette, 2004) might be interpreted in the sense of a central point strategy. The main corridors correspond to main orientation of the building and they are the first parts of the building to be experienced. If the whole building is encoded with respect to this reference frame as proposed by McNamara, using theses corridors like in the central point strategy should be easier for participants. Yet it is not a priori clear whether or not a reliance on central points and paths will have more positive or negative impact on navigation performance, especially in our setting.

1.4. Knowledge about the environment

The application of the strategies defined above clearly requires access to information about the building. Allen (1999, p. 51) provides a taxonomy of wayfinding means and tasks relative to available knowledge about the environment. With an environment as complex as the building in our setting, the relevant types of knowledge can become quite intertwined. To address this, we look into the knowledge requirements from three perspectives:

First, the overall familiarity of the wayfinders with the building is controlled for by comparing a group of visitors unfamiliar with the building to a group of repeat visitors. Second, survey knowledge about the building is identified for each participant in a pointing task. And third, in a self-report measure of environmental ability the competence to build up environmental knowledge is assessed.

This design, combined with verbal reports and task performance measures, will allow us to address the following research questions as well as methodological concerns:

1. Which strategies do wayfinders employ for navigating in the third dimension?
2. How does familiarity with the building affect performance and the choice of navigation strategies?
3. What is the role of survey knowledge for multi-level wayfinding performance?
4. Which cognitive processes can be identified in verbal reports of wayfinding tasks and how do they relate to performance?

2. Methods

The majority of experimental studies on human wayfinding behavior and related cognitive competencies are based on direct observation of navigator behavior. We agree with Passini (1992) that the collection of wayfinding behavior data can successfully be complemented with verbal reports of task-concurrent thoughts to get a comprehensive picture, especially in exploratory studies. Hence, we introduce verbal reports of wayfinders as an additional data source. The *thinking aloud method* of collecting verbalizations concurrent with task performance is an established method for tapping into those cognitive processes that can be verbally accessed (Ericsson & Simon, 1993). Passini (1992) based his seminal qualitative investigations into wayfinding processes on the extensive analysis of individual wayfinding episodes and the verbal comments of his test participants. Our study aims at a somewhat more formalized approach to qualitative verbal data by quantifying occurrences of verbal reports and comparing these with behavioral measures like time, distance, pointing accuracy and objective route choice since verbal reports of,
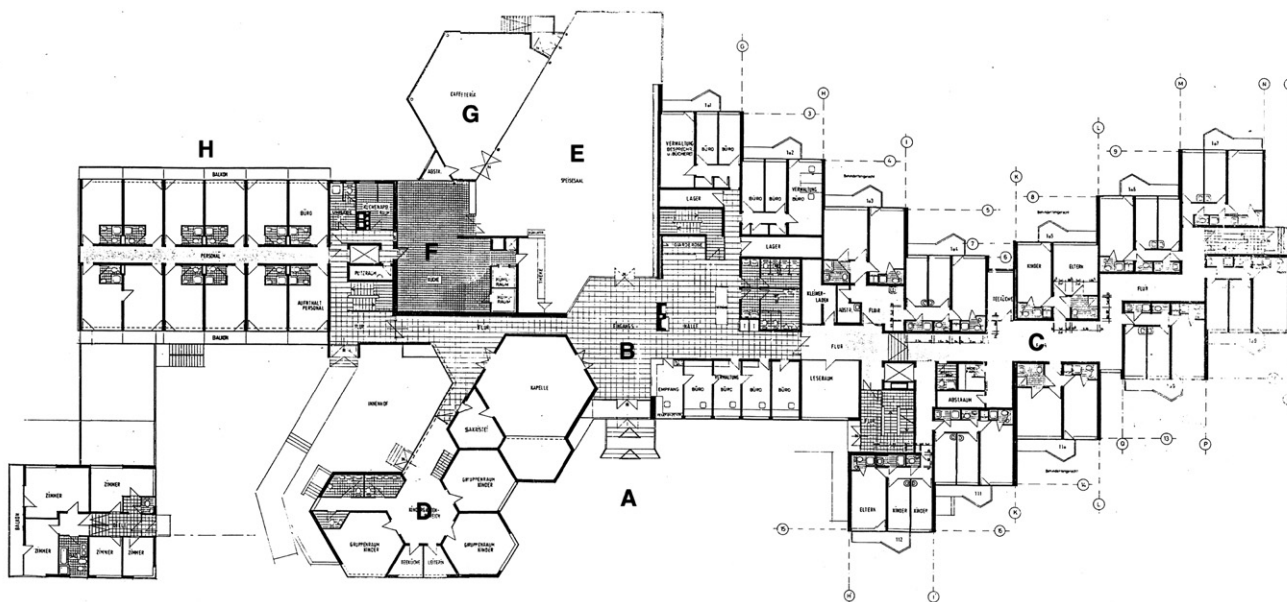
Fig. 1. Ground plan: (A) public entrance, (B) entrance hall, (C) living quarters, (D) commons—communication and leisure area, (E) dining-room, (F) kitchen, (G) coffee bar and (H) lecture rooms.

for example, strategic decisions alone may not be sufficiently reliable. In multi-level buildings with complex floorplans involving inconsistencies and dead-end routes, planning processes and adequate route choice strategies should be very important for wayfinding success. Therefore, our thinking aloud analysis of cognitive processes focuses on the degree of planning, the type of environmental information perused (signs, visual access, etc.) and strategic reasoning.

2.1. Participants

Participants were attendees of an annual summer school for human and machine intelligence which takes place at the Heinrich-Lübke Haus, a conference center in Günne, near Düsseldorf, Germany. Seven women and five men were asked if they would volunteer in a wayfinding experiment. Six of them were familiar with the building.[1] They had previously visited the 1-week conference at least two times and therefore knew the building well. The six participants unfamiliar with the building (three of them were women) visited this years' conference for the first time. Their sessions took place within the first 3 days after their arrival. All participants were in their mid-twenties to mid-thirties and were all native German speakers.

2.2. Building analysis

The conference center was built in 1970. We explore the ground floor (level 0) of the multi-functional building to

exemplify the general characteristics and spatial organization of the layout (see Fig. 1). The common layout consists of various simple geometrical elements that are arranged in a complex and multi-faceted architectural setting. In the theory of architectural design, building structures can be formally understood from diverse points of view, as a group of voids or solids (Mitchell, 1990). Consequently, this building is subdivided into a well-designed group of solids with void space between them. Additionally, each group of solids implies various functions, e.g., the living quarters (C) have a quadratic design style and the communication area (D) a hexagonal design style. With this in mind the building can be architecturally categorized as an "indoor city" (Uzzell, 1995) as it is composed of a small ensemble of units and a large public circulation area. The main path of walking through the building is an axial one rather than a cyclical one, which means one has to pass the central point (B) frequently when traveling between areas.

Changing floors in the building exemplifies its spatial complexity and vertical impenetrability. As one can see in Fig. 2 the layout of the hallways on every floor seems to be one and the same, but is actually different for each floor. For example, the configuration of the ground floor (level 0) and the basement (level −1) differs significantly. As a result of this counter-intuitive layout, the user has to repeatedly look for a new and unknown route on every level.

2.3. Procedure

In this building, the participants' task was to find six locations. The participants were filmed with a camera and had to verbalize their thoughts. Between wayfinding tasks

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[1]Due to technical reasons, performance on task1 (anchor) was only analyzed for five of the six familiar participants.

Fig. 2. The floors of the building with circulation areas. Stairways are illustrated as vertical connections. Starting points and goals of the navigation tasks are marked by numbers. First, participants had to reach point "1" (anchor), from there point "2" (room 308) and so on.

they had to point to four locations they had previously visited in order to assess their survey knowledge. The whole experiment lasted about 45 min including the instruction, as well as an interview and debriefing after the experiment.

First, the participants were instructed to think aloud while performing the wayfinding tasks and not to pay attention to the camera. During the whole experiment they were not allowed to use floor maps or ask other people for advice, but they were allowed to use signs or to look out of the window for orientation as long as they stayed inside. For most task instructions the experimenter just mentioned the goal such as "Find room number 308".

All participants received the tasks in the same order, as each destination point is the start location for the following task, making randomization unfeasible. Throughout this paper, navigation tasks are identified by numbers, pointing tasks by capital letters:

1. From outside the building, the participants were shown a wooden *anchor* sculpture inside the living quarters. They had to find it from the main entrance without leaving the building again.
2. The goal was to find *room 308*.
3. Participants had to navigate to the *bowling alley*. It was located in the basement of the building, where the locations for all leisure activities were to be found.

4. The *swimming pool* could also be found there.
A. From the swimming pool the participants had to point to the *anchor*, the destination of the first task.
B. After moving a few meters away from the swimming pool the participants were asked to point to the *forecourt* in front of the main entrance.
5. The participants had to navigate their way to the *lecture room number four*.
C. From a point close to the lecture rooms, the participants had to point to the *bowling alley*.
6. The final navigation task's destination was the *billiard table*.
D. From the billiard table they had to point back to the *lecture rooms*.

2.4. Dependent measures

2.4.1. Objective measures—performance

For each task, the shortest route as well as a list of reasonable route alternatives was determined beforehand. Reasonable routes are defined as neither containing cycles nor dead ends or obvious detours. Each observed route alternative was categorized for its compatibility with the three wayfinding strategies (central point, direction and floor strategy; see Section 1.4) and employed as the behavioral measure of strategy use. This categorization was based on the navigation decisions at each choice point, which could be compatible, neutral or incompatible with each of the three strategies. Two raters had to come to an agreement regarding the categorization.

Navigation performance was measured with six variables: (1) time to complete the task, taken from the video; (2) stops; (3) getting lost, i.e., number of times participants left a *reasonable route alternative* and showed detour behavior; (4) distance covered; (5) distance covered divided by length of the shortest possible route. (This parameter expresses the proportion of superfluous way independent of task length. E.g., a value of 1.35 can be interpreted as walking 35% farther than necessary); (6) speed (distance covered divided by the time to reach the goal).

2.4.2. Subjective measures—verbal protocols

The second group of measures classified the participants' verbal comments. To "quantify" the qualitative data the analyses were completed in three steps. First, prior to the analyses, a coding schema for classifying the verbal comments was developed according to Krippendorff (1980). The initial coding scheme was developed based on a pilot session to determine what types of verbalizations can be related to categories of theoretical interest. Second, the walked route for each participant and each task was drawn into the plans of the building. This was used to determine distances of routes and superfluous way after getting lost (see above). Third, the verbal codes and stops were written beside this drawn route at the location they were mentioned. This was done by two independent raters in a step-by-step fashion. The coding scheme was

incrementally refined so that categories could be reliably recognized by the two raters, based on the video sequences of four participants. This process was repeated until a sufficient inter-rater reliability with a kappa value of 0.7 ("substantial" reliability according to Landis & Koch, 1977) was reached. To reduce coding error, every participant was coded twice and in case of disagreement one consensual rating was achieved. In addition to the verbalization categories, the participants' remarks about their strategies were collected for every task.

Out of the mentioned strategies for each task, the preferred one was identified by the raters where possible. Four subjectively preferred strategies could be identified: The already described direction, floor and central point strategy (see Section 1.4) and, in addition to that, the "route is well-known" strategy when participants mentioned walking a route completely familiar to them (see also, Hochmair & Raubal, 2002).

2.4.3. Survey knowledge

From their current position the participant had to point his/her arm in the direction of a location previously visited during this experiment. The pointing arm was filmed from several perspectives, so that the pointing direction could be clearly identified afterwards. The position of the participant and the pointing direction were transferred from the video to a map. On this basis, the angular deviation from the correct direction was determined. Taking into account that the pointing error is to the right (negative angle) or to the left (positive angle), the mean is a measure of the systematic error, specific to each pointing task. The unsystematic error can be measured by the standard deviation (cf. Wang & Spelke, 2000).

2.4.4. Sense of direction

The subjective sense of directions was measured by the Freiburg version of the Santa Barbara Sense of Direction Scale-FSBSOD (FSBSOD—Freiburg Version of the Santa Barbara Sense of Directions Scale, 2004; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). It consists of 15 questions concerning spatial ability e.g. "I am very good at giving directions". After leaving the conference the participants were asked via e-mail to fill out an online questionnaire. This procedure inhibited direct influences from the task performed in the experimental session on the self-ratings (cf. Hegarty et al., 2002).

3. Results

First, general aspects of the process of navigation as expressed in the verbalization and their interrelations to performance are presented and the tasks are compared according to these measures. Second, for the central part of the analysis we look at the impact of wayfinding strategies. Finally, the influence of familiarity and survey knowledge on verbalized cognitive processes, navigation strategies and task performance is presented.

In the two rightmost columns of Table 1 the average performance and standard deviation per task are shown (see footnote 1). The participants needed almost 2 min to cover the average 100 m distance which is 36% more than the shortest possible way. They stopped about once per task and lost their way 0.3 times.

The verbalizsations mentioned during these tasks are shown in Table 2. About 40% of all verbalizations were reflections mainly about the building. A total of 22% refer to partial planning, 12% to landmark checks during plan execution (like "here is the fire place") and 9% to usage of signs. Remaining categories each make up for 5% or less of the utterances.

3.1. Tasks

Do the wayfinding tasks cover a broad range of difficulty? To answer this question, performance was compared between tasks in an ANOVA for each dependent measure. The tasks differed in all performance measures (see Table 1, all six $F(5, 65) > 3.0$, $p < 0.016$, $\eta^2 > 0.19$). The most difficult task was finding an anchor shown from outside of the building. The participants stopped and got lost most often and they covered the longest distance at the lowest average speed.[2] Both in the anchor task and in the bowling alley task—the second most difficult task—the covered distance was 70% longer than in the shortest possible route. In the bowling alley task (task 3, Fig. 2) many alternative routes were available. Here stopping and getting lost happened second most often, and speed was the second lowest. By the same variables, the billiard task (task 6) can be considered third in its degree of difficulty. The easiest task was the pool task (task 4). No-one got lost, there was no superfluous distance covered, stops were least frequent and therefore the speed was highest. So there was a clear variation in task difficulty as intended.

3.2. Strategies

Most of the participants voiced remarks concerning the strategy they used to find their goal. Sometimes they switched their strategy during a task, but in 61 cases a preferred strategy could be identified by the raters.

Different strategies were chosen in different tasks (not shown here, $\chi^2 (15, N = 61) = 56.9$, $p < 0.001$, $w = 0.97$). In the easiest task, the swimming pool task, all identified strategies relied on the well-known route. In the two most difficult tasks (anchor and bowling alley), many participants chose a direction strategy. For these tasks, the precise

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[2]Stops and getting lost can be considered dependent of length of the task, but normalizing them on navigation time or the shortest possible way did not produce a different pattern of results and so the average per task, which is easier to interpret, was taken. From a theoretical point of view, this parameter is also favourable, as the number of intersections, number of turns, etc., are more important for difficulty than mere length of the route.

Table 1
Average performance in each task and the average performance and standard deviation across all tasks

	Anchor	Room 308	Bowling alley	Swimming pool	Lecture room 4	Billiard table	M	S.D.
Time (s)	226	78	159	34	103	81	112	78
Stops (n)	2.8	0.4	1.7	0.3	0.5	0.9	1.1	1.80
Getting lost (n)	0.7	0.1	0.5	0.0	0.3	0.2	0.3	0.57
Distance (m)	168	84	127	40	113	87	102	58
Way/shortest way	1.68	1.24	1.71	1.00	1.08	1.50	1.36	0.59
Speed (m/s)	0.74	1.08	0.81	1.28	1.12	1.10	1.03	0.29

Table 2
The verbalization categories and their frequency and proportion across all tasks

Verbalization category	Description	Frequency (n)	Proportion (%)
Complete plan†	A complete plan covers a path from the current location to the destination of the current task	13	3
Partial plan*	A non-complete plan contains uncertainty and/or covers only parts of a complete path	87	22
Search	Systematic number-based search, e.g., to find a room	17	4
Correct reflection	Reflections about the building that are *correct*	18	5
False reflection	Reflections about the building that are *incorrect*	7	2
Reflection*	General reflections and assumptions, not only about the building	130	33
Alternatives*	Consideration of more than one possible route to the goal	16	4
Failed plan†	Failure of a pursued plan	11	3
Identify landmark	Recognition of a known landmark in sight	48	12
Outside orientation	Use of the outside space for orientation	14	4
Sign	Participants mention a sign in sight	34	9
Sum		395	100

Notes: An asterisk* marks a significant difference in average frequency between tasks ($p < 0.05$), a cross† marks a statistical trend ($p < 0.10$).

goal location was largely unknown for the participants. Contrarily, in the also often unknown task 2 (Room 308), the floor strategy was chosen most frequently. Assuming that the floor strategy is efficient, its application might explain the good results in this task.

To test this, performance according to the preferred strategy has to be considered. As strategy choice was dependent on the tasks and the tasks differ in difficulty, the influence of the tasks had to be partialed out, i.e. controlled statistically as a covariate in an ANOVA. So the benefit of the strategies could be compared independently of the tasks. As shown in Table 3 best performance was achieved when walking a well-known route (except stops all five $F(3, 56) > 3.1$, $p < 0.035$, $\eta^2 > 0.14$). Not surprisingly, here the absolute and relative distance as well as time was shortest, speed highest and getting lost occurred least often. When using the direction strategy or the central point strategy, the absolute and relative distance as well as time measures indicated the worst performance. With a central point strategy participants to some extent walked known (sub-)routes and therefore could walk quite fast without getting lost. But as the routes were longer than in other strategies, it took longer to reach the goal. With the direction strategy participants got lost more often and reorientation takes time, so that average speed dropped. The same amount of time was needed to reach the goal as in the central point strategy, even though the distance was shorter. The floor strategy resulted in better performance with respect to *both*

Table 3
Average performance per task solved with the preferred strategy

Partialed out means	Central point strategy	Direction strategy	Floor strategy	Route is well-known
Time (s)*	140	145	113	67
Stops (n)	1.05	1.50	1.62	0.18
Getting lost (n)*	0.23	0.69	0.35	0.03
Distance (m)*	142	119	97	68
Way/shortest way*	1.86	1.38	1.33	1.06
Speed (m/s)*	1.04	0.86	0.96	1.29

Notes: The influence of task difficulty is partialed out.

distance and time, thus avoiding the relative deficits of the central point and direction strategy.

The differences between the strategies can also be identified in the navigation process itself, manifested in the verbalizations (see Fig. 3, all described differences $F(3, 56) > 2.9$, $p < 0.044$, $\eta^2 > 0.13$). Again, walking a known route was quite different from the other strategies: participants most often planned their route completely, while overall fewer verbalizations of other processes were uttered when this strategy was used. Presumably these participants just relied on their readily stored (route) knowledge and did not need further reasoning. Participants using a central point strategy most often searched systematically, used
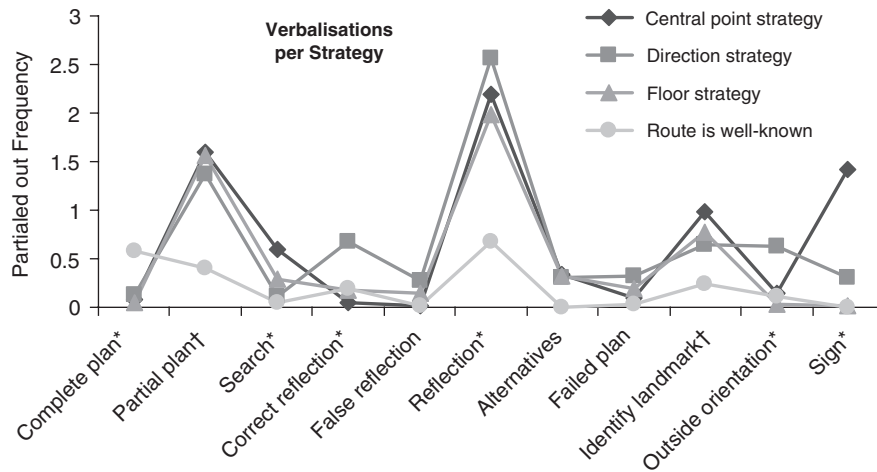
Fig. 3. Average verbalizations per task solved with the preferred strategy. The influence of task difficulty is partialed out.

signs most often and tended to identify landmarks most often $(F(3, 56) = 2.58, p = 0.062, \eta^2 = 0.12)$ as well as planned their route only partially $(F(3, 56) = 2.56, p = 0.059, \eta^2 = 0.12)$. Participants using a direction strategy mentioned the highest number of correct reflections and general reflections.

Strategy choice can be determined by objective route choice and subjective mentioned strategies. How closely are they related? Very similar results according to both performance measures and verbalizations were found when the selected route alternative was considered instead of the subjective mentioning of a strategy. In addition, the subjective and objective strategy indicators are directly connected. Even if a well-known route cannot be assigned to a specific route, subjective direction, floor and central point strategy are highly correlated with the objective choice of route: Route choices according to a certain strategy go along with mentioning this strategy significantly more often $(N = 59$; direction strategy: $\chi^2(1) = 11.8, p = 0.001, w = 0.45$; floor strategy: $\chi^2(1) = 8.11, p = 0.004, w = 0.37$; central point strategy: $\chi^2(1) = 21.1, p < 0.001, w = 0.60$).

3.3. The role of familiarity

Because of their greater knowledge about the building, familiar participants are assumed to show better performance—is this true? Indeed, familiar participants performed better (see Table 4). They got lost less often, covered a shorter distance (absolute & relative), with greater speed, and therefore reached the goal more quickly (all six $t(10) > 2.23, p < 0.05, ES > 0.77$).

Familiar participants performed better in reaching a goal. But can this difference be traced back to different processes during navigation? As shown in Fig. 4 they more often completely planned their route (unless stated otherwise, all $t(10) > 2.26, p < 0.048, ES > 1.30$), whereas unfamiliar participants tended towards more partial planning $(t(10) = 1.91, p = 0.085, ES = 1.10)$. There was a trend for

Table 4
Means and standard deviations of the performance with different degree of familiarity

Performance	Unfamiliar		Familiar	
	M	S.D.	M	S.D.
Time (s)*	128	22	95	21
Stops (n)	1.36	0.69	0.78	0.80
Getting lost (n)*	0.42	0.17	0.17	0.21
Distance (m)*	115	16	89	17
Way/shortest way*	1.55	0.22	1.17	0.16
Speed (m/s)*	0.96	0.06	1.10	0.09

unfamiliar participants to utter more reflections $(t(10) = 1.92, p = 0.084, ES = 1.09)$ and to identify more landmarks $(t(10) = 2.13, p = 0.059, ES = 1.21)$. Unfamiliar participants also needed to search more as well as to orient themselves more towards signs and the outside of the building.

Familiar participants were able to rely on their (route-related) knowledge for execution whereas unfamiliar participants needed to process more local information from the building and from outside. Can this difference also be found in the choice of strategies? Indeed, familiar and unfamiliar participants differed in their preferred strategies (see Fig. 5, $\chi^2(3, N = 61) = 19.0, p < 0.001, w = 0.56$). Participants unfamiliar with the building most often chose the central point strategy and almost never walked a well-known route, whereas participants who knew the building almost never chose a central point strategy and most often either walked a well-known route or used a floor strategy. The direction strategy was equally used by both groups.

3.4. Survey knowledge

If survey knowledge is the crucial factor for the good navigation performance, pointing performance should
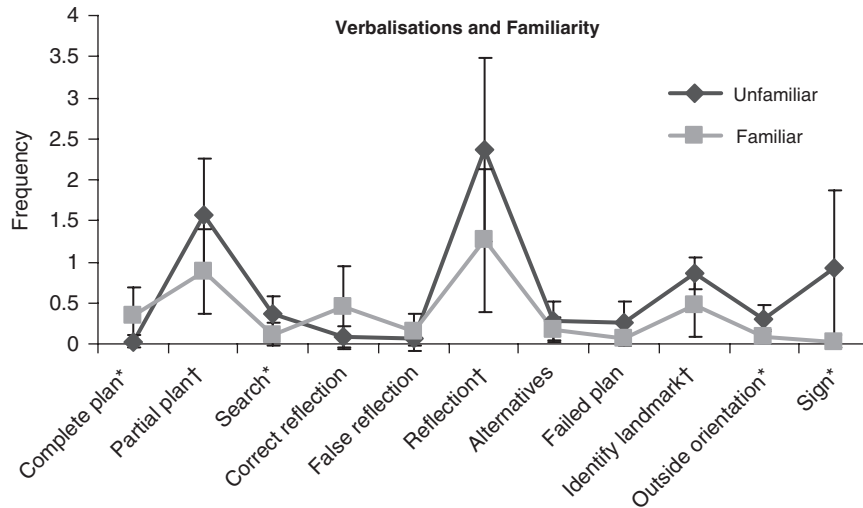
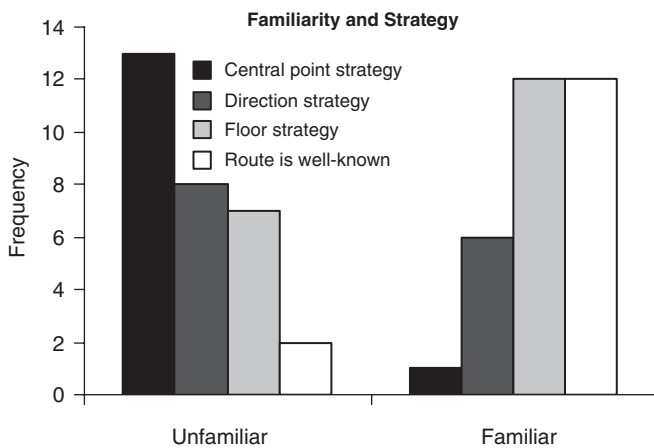Fig. 4. Means and standard deviations of verbalizations as a function of familiarity.

Fig. 5. Frequencies of strategy selection as a function of familiarity.
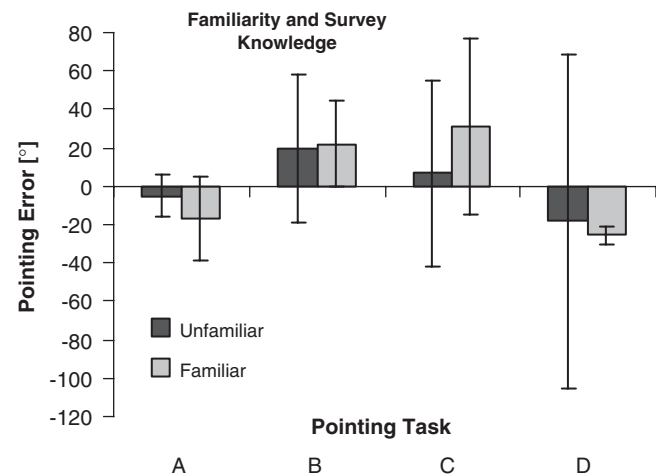

Fig. 6. Pointing errors in the four pointing tasks in familiar and unfamiliar participants. Pointing to the left of the correct direction resulted in a positive error, pointing to the right in a negative one. The systematic pointing error is displayed in the mean deviation from the right pointing direction, the unsystematic error in the standard deviation.

differ due to familiarity. But in the four pointing tasks no difference could be found in the systematic error expressed in the mean pointing error (although these tests are not orthogonal, see Fig. 6, all four $t(10) > 1.21$, $p > 0.252$, median ES = 0.32). For the unsystematic error expressed in the standard deviation, there was a trend in pointing task A for a smaller pointing error in unfamiliar participants $(F(5, 5) = 3.90, p < 0.10)$ and there was a smaller pointing error in familiar participants D $(F(5, 5) = 388, p < 0.001)$. So, except for task D, no indication of better survey knowledge due to familiarity was found.[3]

To obtain a more direct and sensitive test for the influence of survey knowledge on navigation, the sample was bisected into good vs. bad pointers according to their average absolute pointing error across the four tasks. However, in this analysis also no differences could be

revealed for navigation performance measures (all six $t(10) > 1.30$, $p > 0.221$, median ES = 0.11). Even among the eleven verbalization categories only a single difference was found: good pointers uttered more correct reflections $(t(10) = 2.60, p = 0.026, ES = 0.90)$. Survey knowledge did not explain differences in performance and verbalization.

3.5. Sense of direction

Nine out of twelve participants completed the online questionnaire. While for the behavioral measures reported above we did not find any gender differences, women did consider themselves to have a poorer sense of direction than men did $(t(6.84) = 2.703, p = 0.031, ES = 1.65)$ in the self-rating questionnaire. Good pointers achieved higher questionnaire scores $(t(7) = 3.423, p = 0.011, ES = 2.20)$.

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[3]An additional analysis of absolute pointing error as a combined measure of systematic and unsystematic error revealed the same pattern of results.

No differences in sense of direction due to familiarity were found ($t(7) = 0.939$, $p = 0.379$, ES = 0.61). No significant correlations between average performance of a participant and her/his sense of direction could be found ($n = 9$, all six $r < 0.50$, $p > 0.173$). Participants with a good sense of direction rating uttered more correct reflections ($n = 9$, $r = 0.76$, $p = 0.018$) and tended to utter less references to landmarks ($n = 9$, $r = 0.60$, $p = 0.089$; all other verbalizations $r < 0.53$, $p > 0.141$). No correlation between sense of direction and the strategic preferences of a participant (as measured by the number of tasks he or she tackled with each of the available strategies) could be revealed (all three $r < 0.25$, $p > 0.531$). Overall, the SBSOD scores revealed as little relation to navigation performance in our setting as the survey knowledge measured with the pointing tasks (Section 3.4).

4. Discussion of empirical results

The present study was conducted to explore wayfinding strategies in a complex indoor environment and their relations to the user's knowledge. The experiment provides quantitative behavioral and verbal data, as well as the opportunity to observe deficits of the building with respect to wayfinding usability. In the next sections we first discuss the main quantitative results. Then we link the experimental data collection to architectural design. We analyse seven "hotspots" of the building and explain why they make it so hard to find a way through the building.

Our study follows a strategy of methodological triangulation by combining verbal data and behavioral observation to collect a large data set from each participant to adequately reflect the complexity and variability of navigation behavior in a real life setting. Each participant had to complete a battery of six wayfinding tasks over a range of spatial sub-settings and covering a considerable span of difficulty (as demonstrated in Section 3.1). This measure was taken to increase the ecological validity and generalizability of our findings. Due to this approach, the number of participants of our study may appear relatively limited. Yet the statistical results do show that our sample size was adequate for the setting. At the heart of the empirical part of our paper lies the analysis of strategies (Section 3.2) and experience (Section 3.3). The tests revealed the expected significant results and we report the corresponding effect sizes (Cohen, 1988) for all tests in addition to the significance values. Obtaining significance despite a small sample size is generally only possible with substantial underlying effect sizes. The effect sizes (w, η^2 and ES scores, see above) for all tests reported as significant correspond to at least "large effect sizes" according to Cohen (1988). Furthermore, the statistical analyses reported on parametric statistics were replicated with nonparametric tests as well, yielding the same pattern of results (Siegel & Castellan, 1988). We have reported the parametric measures prominently, since for part of the analysis we needed to statistically control for task difficulty, a feature not available with nonparametric testing.

The main finding of our study is that different indoor wayfinding strategies could be identified on a subjective and an objective level and that these strategies correspond to specific differences in cognitive processes and performance measures. The shortest and fastest way to reach a goal was to walk a well-known route. If that was not possible—e.g., because the goal or part of the way to it was unknown—the floor strategy was the best alternative in our scenario. Walking via a central point or going directly in the assumed direction of the goal led to clearly worse performance.

The second finding is that participants familiar with the building more often relied on their knowledge and they walked a well-known route that they had completely planned in advance. In doing so they navigated faster than unfamiliar participants taking the same route. If that was not possible, they chose another efficient strategy, the floor strategy, leading to shorter navigation distances and times. With their knowledge familiar participants did not have to collect as much information from their surroundings as unfamiliar participants, who had to search and look at signs as well as looking outside. This led to a clearly better performance.[4] In a task new even to participants familiar with the building, differences vanished.

Our third finding is related to the impact of survey knowledge. In this study survey knowledge did not correspond to wayfinding performance and a clear superiority of familiar participants with respect to survey knowledge could not be established. The errors in task D is surprising as this was the only pointing task which could be solved by path integration: the participants just had to remember the direction of the starting point of their last navigation task. As this was not possible in the other tasks one would expect the best results in task D, not the worst ones. But taking into account that this was the only task where the parts of the building the participants pointed from and to did not lie at a right angle to each other but at $60°$ (see Fig. 7, left), the systematic error can be explained. A person remembering a $90°$ angle instead of the correct $60°$ one would locate him/herself standing on the start of the (dotted) arrow to the right and not at the start of the arrow to the left. From this position the mean pointing direction would be quite accurate. Similar results are found in pointing (e.g., Thorndyke & Hayes-Roth, 1982) and in map drawing (e.g., Gillner & Mallot, 1998).

We also found that complete planning is associated with good performance, while reflecting, partial planning and re-planning is tied to poor performance. Verbal reports alone must be interpreted with caution as they are restricted to consciously accessible aspects of cognitive processes (Ericsson & Simon, 1993). Thus it is important to note that in our study we have identified wayfinding

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[4]A similar comparison between women and men did not reveal any gender differences.

strategies on a *subjective* and an *objective* level with converging results: The shortest and fastest way to reach a goal is by using one's knowledge to walk a well-known route, as most familiar participants do. If that is not possible, for example because the goal is unknown, the wayfinder has to rely on one of three heuristic strategies (floor, direction or central point strategy) to find her goal. In such a situation familiar participants dominantly choose the floor strategy, that turns out to be the best alternative in our scenario. Walking via a central point—like most unfamiliar participants do—is clearly less efficient, and going directly in the assumed goal direction leads to higher levels of navigation errors. Consequently both the direction and the central point strategy proved less favorable in our scenario.

Survey knowledge—as measured by pointing performance—could not account for the wayfinding differences, as even with familiar participants systematic errors in survey knowledge prevail. Overall, unfamiliar participants verbalize more. Assuming that this requires more (cognitive) resources and therefore makes unfamiliar participants slower could explain their poor performance. But referring to the strategies, one reason for poor performance is unfamiliar participants taking long and winding routes like in the central point strategy or getting lost as in the direction strategy. Slowness alone cannot account for that.

According to the classical view of Siegel and White (1975) one would expect the familiar participants' wayfinding advantage to be based on clearly more elaborate survey knowledge compared to unfamiliar participants. Although the classical view with its strict developmental steps is not shared anymore (Montello et al., 2004), e.g. we are able to build up survey knowledge from a map (e.g. Moeser, 1988) and photo slides rather quickly (Holding & Holding, 1989), familiarity *does* facilitate the acquisition of survey knowledge (Montello et al., 2004). Why could the familiarity difference not be explained by survey knowledge? Is it the small number of participants, since in this part of the analysis the pattern of effect sizes is less clear cut? For other variables of theoretical merit reliable effects could be found in our study, and for the pointing variables even the direction of the differences often is not in favour of familiar participants.

Maybe measuring pointing *after* the navigation task is the reason. Previously existing differences in survey knowledge could account for the better navigation performance in familiar participants. But by walking the routes unfamiliar participants were able to acquire this survey knowledge, reduce the difference and perform equally well in the pointing task afterwards. To test that, pointing performance would have to be measured before navigating a route. But also individual differences in sense of direction (FSBSOD)—known to be related with tasks requiring survey knowledge—did not correlate reliably with performance (Hegarty et al., 2002; Kozlowski & Bryant, 1977). This might be due to the even smaller number of participants, but still sense of direction was interrelated with inter-individual pointing performance and higher scores for males, who are known to perform better in tasks requiring survey knowledge. Therefore it is also possible that survey knowledge is not as much of a key issue in reaching a goal as route knowledge is. Meilinger and Knauff (submitted) were able to show that in an outdoor setting available and memorized survey knowledge (in the form of maps) did not lead to better performance in finding a novel route compared to bare route knowledge (in the form of verbal descriptions). Relying on a direction strategy led to worse performance. Indoors, this may be even more pronounced, since dead-ends and limited connectedness of floors and paths make survey and direction-related knowledge even less useful here. Further support for our tentative view is provided by the fact that the strategy exclusively dependent on survey knowledge— the direction strategy—is accompanied with getting lost and relatively bad performance. Also, searching systematically is not associated with bad performance and the two tasks including systematic search are solved quite well. Overall the failure of survey knowledge to show any clear correspondence with wayfinding performance at least casts a shadow of doubt on its predominant relevance for indoor navigation.

Yet we must bear in mind that the building in this study may also have some characteristics limiting the generalizability of the results, especially with respect to survey knowledge. Gaining a survey representation of the individual floors is not overly complex, as there is always one core route per floor. But the pointing tasks in this building require the integration of survey knowledge across levels. Even with the study by Montello and Pick (1993), it is an open question, whether people actually possess an integrated 3D representation of a building, or if this needs to be computed on the fly in a potentially error-prone manner, because the survey representations of floors are stored independently. This integration of survey representations across floors may still be difficult even for the experienced visitors of the building. As pointed out in Section 1.2, the current study is one of very few attempts to approach this 3D integration challenge. We believe that our analysis of strategies characteristic for 3D navigation provides some initial access to the issue of representing 3D space:

The advantage of the floor strategy can be interpreted as a result of a hierarchical planning process. Ants are known to store 3D movements in form of a horizontal projection (Wohlgemuth, Ronacher, & Wehner, 2001). Human performance declines if they have to use pitch rotations to explore a VR labyrinth (Vidal, Amorim, & Berthoz, 2004). Therefore we might store the different levels of a building separately in memory rather than construct a 3D mental model of the building. This makes navigational decisions more difficult that require an integration of vertical and horizontal aspects. The floor strategy avoids this integration bottleneck with a hierarchical route planning heuristic: First we change to the corresponding
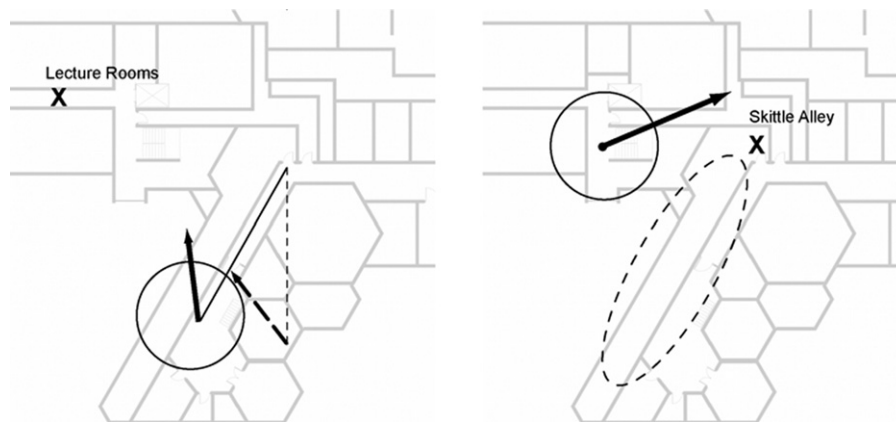
Fig. 7. Starting (circle) and goal point (cross) in pointing task D (left). The mean pointing direction is marked with the arrow in the circle. If you assume that the participants remembered a right angle between the parts of the building and not the correct 60°, pointing from the assumed place (dotted line and arrow) is quite accurate. Pointing performance for task C is shown on the right side.

vertical level and once we have reached it, the fine planning is reduced to a two-dimensional problem space. In terms of Wiener et al.'s (2004) fine-to-coarse planning our *floor strategy* can thus be interpreted as a 3D variant of the cognitively efficient regionalization strategy.

As a design consequence, the floor strategy, which is most efficient for unknown goals in multi-level buildings, should be supported by easy transitions between the floors. Also, the systematic search is to be taken into account with systematic room numbers or informative signs.

5. Cognitive-architectural analysis

Architecture deals with the design, construction and conceptualization of built space. It greatly influences the comprehension and knowledge of orientation and navigation systems. Akin (2002) clarifies that the architect aims to construct buildings as complex systems of numerous architectural dimensions. To develop an adequate and satisfactory compromise is an essentially spatial task. Architectural space is not generated on a blank sheet, but constantly in respect to the present environment and consequently in a high-dimensional decision space (Bertel, Freksa, & Vrachliotis, 2004).

More than 40 years ago Le Corbusier emphasized the idea of movement as a central theme in the theory of architectural design—see the epigraph to this paper. We agree that the perception of a built environment must be described as a dynamic process of movement caused by the fact that we do not experience the spatial layout of a building as a static structure. We discover architectural shapes and layouts literally step-by-step. Thus, from a user's perspective several points of environmental ability, legibility (Lynch, 1960) and imageability (Passini, 1992) are essential to understand and interpret building layouts, e.g., landmarks, routes, paths and walkways, and to differentiate shapes and forms, configured space and building topology, and the close relation between inside and outside space. "The idea or image of a building is as important as

the building itself" characterized David Stea (1974, p. 157) as the connection between architectural space and its mental image.

Understanding a building from its inside structure and spatial organization requires making one's way through the building. Thus, in theories of building design, the idea of architectural experience and the meanings of walkways have a very close relationship. From a Space Syntax's point of view walkways seems to be the most fundamental aspect of architectural space, not only for investigating pedestrian movement in designed environments but also for general exploring, discovering and learning about architectural settings. In order to provide useful spatial points of reference, the differentiation and discrimination of shapes is the most central property in planning an architectural setting. Although symmetry and similarity are very well-known features in the history of architecture, they contrast with the indispensable need of distinguishing multi-faceted environments. Symmetrical architectural settings are principally one of the foremost difficulties in spatial problem-solving processes (Remolina & Kuipers, 2004). Yet, they can be helpful in interpreting vertical information of space, e.g., for spatial reasoning within multi-level buildings (Montello & Pick, 1993).

5.1. Analysis of usability hotspots in the conference facility

Overall, we believe the functional dilemma of the building for wayfinding is prominently caused by the problematic arrangement of complex decision points, their linking paths, the position and design of stairways, vertical incongruence of floors, incomprehensible signage, and too few possibilities for monitoring interior and exterior landmarks. Consequently, the building as a whole gives the impression of a three-dimensional maze. In the following, we focus on seven "hotspots" of the building and describe their disadvantages from a cognitive-architectural point of view.

5.1.1. Hotspot 1: Entrance hall

The entrance hall is indiscernible. For public buildings the entrance hall symbolizes the most important point in the layout. The public entrance (see Fig. 1A) as well as the large entrance hall (Fig. 1B), the two central points of the conference center, are comparatively indiscernible, although they are centrally positioned in the general configuration of the building. The essential function of the entrance hall is to be readable as such and to cognitively structure the route network, especially for unfamiliar visitors, who clearly rely on central-point-based strategies, as we have discussed earlier (cf. McNamara & Valiquette, 2004). However, this function is not properly met, which imposes a usability deficit on the building as a whole. For the user entering the entrance hall, there is an immense lack of survey as well as little visual access to areas relevant for the legibility of the spatial situation of the building (see Fig. 8, providing the *isovist* from the center of the entrance hall). The entrance hall doesn't make the navigation choices visible to the user; especially the stairways are invisible from the entrance hall.

5.1.2. Hotspot 2: Survey places

The building lacks survey places. Especially within complex spatial settings architects and designers have to create places of survey and overview to allow users to build well-integrated spatial knowledge. Visibility is one of the most important qualities of architectural spaces and consequently fundamental to the general understanding of built environments. Even on the ground floor of this conference center there are not enough areas of open space to familiarize oneself with the environment, neither with the interior space (e.g., visual axis) nor with the exterior surroundings (e.g., inside–outside relationship). A striking example of this is the basement with its leisure facilities. It was compared to an area in the entrance hall paralleled in size and alternatives. Far from giving a good overview, the entrance hall is still better than the basement. And indeed comparing these two areas, there were significantly more stops in the basement (16 vs. 6: $t(10) = 3.079$, $p = 0.01$), yet no differences in the frequency of getting lost (these are more closely related to dead ends and stairways design, see below).

5.1.3. Hotspot 3: Floors

The layout of the floors is incongruent. In the planning of complex buildings architects have to pay attention to the uncomplicated and insightful organization of floors. The floors of the conference center give the impression of matching one another, but in fact the hallways are considerably different (see Fig. 2). From wayfinding research and a building usability point of view, this (a) prompts improper assumptions in the users about the route networks and (b) hampers the mental alignment of levels. Pointing task C (bowling alley, see Fig. 7, right) illustrates the problem: Although the bowling alley is directly ahead and extends to the right, participants systematically point left, presumably because they misalign their current position with respect to the floor below, due to inconsistent hallways (ground floor vs. basement) in this area.

5.1.4. Hotspot 4: Dead ends

Dead ends make wayfinding difficult. It is very important in architecture and particularly for public buildings such as universities, hospitals or conference centers to pay attention to always provide an alternative route to any navigational decision. Dead ends block the user's exploration activity and are extremely difficult to operate within the mental representation of the building in respect to the levels above and vertical information in general. But there are several locations that can be characterized as "dead space", "dead ends" or "blind alleys" (Figs. 1 and 2). For example, the public area surrounded by the living quarters leads to a dark and uncomfortable corridor. Users will not expect the stairways at the end of the corridor (far right in Figs. 1 and 2) and thus miss relevant route choices and feel lost in dead ends. We observed a total of 17 episodes of getting lost in our experiment. Five of these episodes (29%) were directly caused by the fact that the participant was stuck in one of the two dead ends in the basement (the far right and far left parts of the basement level in Fig. 2).
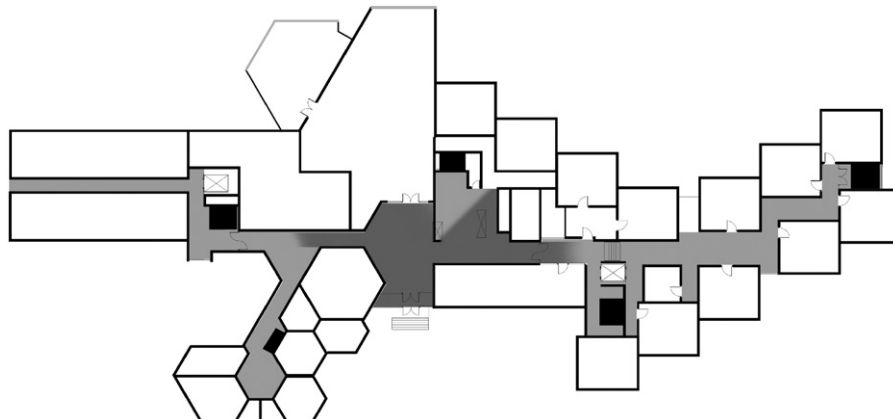

Fig. 8. Location of stairways (black boxes) and isovist (area of visual access) from the main entrances hall (darker gray shaded area in center).

5.1.5. Hotspot 5: Interior building structure

The interior building structure is not distinguishable. To understand a building layout both the exterior and the interior structure of a public building has to be effortlessly understood. Looking at the floor plan (see Fig. 1), the dissimilarity of geometrical shapes and architectural forms would appear to be helpful for the users to orientate themselves. But in fact, when actually navigating in the building, the different subsections are no longer readily recognizable for the wayfinder, leading to a lack of visual differentiation.

5.1.6. Hotspot 6: Public and private space

There is too little differentiation of public and private space. When planning multi-functional public buildings architects have to bear in mind to separate private or personal space from public space. This rule serves the purpose of integrating two disparate spatial systems within one building. There are a lot of mistaken public and private areas within the conference center, which results in disorientating the user and the production of unnecessary dead ends. Therefore, public spaces have to be clearly indicated both by architectural layout and signage.

5.1.7. Hotspot 7: Stairways

Here lies the main disadvantage of the building. In architecture, a stairway should serve as visual focus and spatial connector. In the Heinrich-Lübke Haus they do not fulfill this criterion. In general, stairways should help integrating vertical information while exploring multilevel buildings and they should ease experiencing the layout spatially with respect to the building as a whole. Stairways are architectural design elements in their own right and not just technical components of the building for going up or down. They function as a significant circulation node as well as a vertical interconnection between different levels of the building and thus enable the movement flow between the levels of the building.

During vertical motion, well-designed stairways can provide access to various perspectives of the interior organization of the building and thus facilitate its legibility. Also, investing time into the design of stairways has yet another facet: Individual floor plans may be readily changed to suit specific tenant requirements, but the facilities for pedestrian circulation between the floors in the building are fixed.

Vertical circulation is one of the most important aspects of good building design in architecture. So, when planning the design of staircases architects generally have to take into account two key design parameters. First the constructional and representational form of its appearance have to be highlighted with respect to the function of the building and second the position of the stairway has to be optimized in relation to the user's activity within the layout.

Ideally, stairways of a building represent its functional framework and accordingly, architects speak about the spatial nerve tract of the building (i.e., Scamozzi, 1615; Vasari, 1946). As we have discussed for Hotspot 1, the positions of the five small stairways in the conference center are not evenly dispersed and not perceptively placed (see Fig. 8). Furthermore, there is no main stairway that functions as the user's visual focus while exploring the building. The frequently used stairway near the entrance hall is particularly counter-intuitively located (see Figs. 1 and 8). Consequently, not only the impractical location of the entrance hall but also the stairway has a negative effect on the building's usability. Users do not readily perceive a main stairway to the upper floors.

Using the foremost stairway (near the entrance hall), there are a lot of spatial twists and turns without an opportunity for controlling one's location. This deficit is at least partly due to the complete lack of visual access to the outside, which would help to improve spatial updating. Additionally, the number of rotations within the stairway plays a great role for the user's stability of his cognitive map of the building (see Fig. 9). As this staircase is offset from the main axis and not directly accessible from the entrance hall, a total of seven turns is necessary when moving between the main corridors of two levels. Frequently, users reported being very disoriented after using this stairway. Six of the seventeen episodes of getting lost (35%) are identified as disorientation observed directly after leaving the stairway, sometimes even before reaching the proper destination level. An illustration of a typical episode of getting lost due to the stairway is illustrated in Fig. 9.

Taken together, the analyses revealed that—except for global building characteristics—the staircases are the single
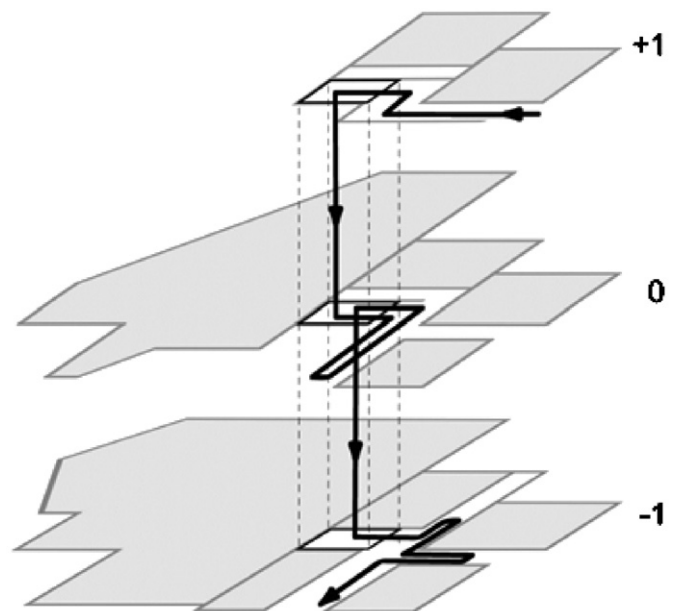

Fig. 9. Closeup of the most central staircase, located closest to the entrance hall. The black line illustrates a participant's movement from level +1 to the basement, including path deviations related to disorientating properties of the stairways.

most clearly identified cause of wayfinding problems in our setting. Further research into the consequences of rotations in vertical movement is clearly called for (see also Richardson, Montello, & Hegarty, 1999).

6. Future research

Providing guidelines for improving wayfinding friendliness and usability (Werner & Long, 2003) is clearly a practical goal of our research. For instance, the benefits of the floor strategy identified in the present experiment warrant further investigations. What are the specific factors that contribute to the familiar participants' preference for this strategy and what are the relationships to configurational features of the floor layouts? It also remains to be seen in further studies to what extent variations in task characteristics (e.g., goal concreteness) shape strategy preferences and performance in 3D settings. We will also need to check whether the results of our study generalize to buildings with less complicated layouts across floors. It remains to be tested in subsequent studies, how the 3D navigation strategies are related to the important theoretical concept of "frame of reference" (cf. McNamara & Valiquette, 2004) in more detail. Werner and Long (2003) have provided a basis with their identification of local mismatches of reference frames in a building and this should be extended to the multi-level case.

Based on the present study we hope to intensify the cooperation of cognitive scientists and architectural designers. In the future, we will develop specific methods to support usability from the early planning stages on, in order to avoid costly design mistakes. Besides using virtual reality techniques for testing layout prototypes, we envision augmenting Space-Syntax-type layout analysis with the techniques presented here to identify usability deficits. Our study has demonstrated the general usefulness of verbal data for systematic statistical analyses of cognitive processes in wayfinding—at least if they are combined with objective wayfinding measures.

Helping to understand the cognitive strategies of building users is a valuable contribution of cognitive science to architectural planning.

Acknowledgements

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