Original Paper

Reducing Information Uncertainty in Hospital Wayfinding for People With Specific Needs: Findings From a Qualitative, Multimethod Study

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Abstract

Background: Hospital wayfinding is a well-documented source of patient stress, yet people with sensory, cognitive, or mobility-related needs face additional information barriers that generic wayfinding research rarely resolves. Information uncertainty, rather than a simple lack of signage, has recently been proposed as a unifying construct for locating and diagnosing these barriers across the patient journey.

Objective: This study empirically applies a Stage-Touchpoint-Uncertainty coding framework across 2 structurally contrasting hospitals to identify the elements that constitute information uncertainty during hospital navigation, how patients with specific needs perceive and prioritize these elements, and how the resulting uncertainty peaks can inform the prioritization of wayfinding interventions.

Methods: We conducted a qualitative, multimethod study with 4 rounds of data collection between May 2024 and July 2025 at 2 university hospitals that differ in scale and spatial organization (hospital A: more than 1000 beds, decentralized multipavilion campus; hospital B: 890-bed comprehensive center with a historic core). Methods comprised expert accessibility walkthroughs, website accessibility and usability testing with users with severe visual impairment, user walkthroughs with mobile eye-tracking and think-aloud protocols, and focus groups homogeneous by impairment type (hearing, developmental/learning, physical/mobility, and older adults) to evaluate candidate signage designs. In total, 38 participants took part (36 research participants and 2 accessibility experts who conducted the heuristic walkthroughs). The mean age of user-walkthrough and focus-group participants was 38.0 (range 21-75) years; age was not recorded for experts or website-testing participants.

Results: Coding organized observations into a Stage-Touchpoint-Uncertainty matrix spanning 5 consolidated journey stages, from digital prearrival search through physical navigation to exit. Four recurring uncertainty mechanisms emerged: absence, where a needed cue is simply missing; equivocality, where cues are present but fail to converge on one meaning; perceptual degradation, where a cue is legible in principle but difficult to see or read; and cognitive-translation demand, where a legible cue still requires additional mental work to act on. Absence characterized the earliest stages, involving digital search and entry, whereas equivocality became dominant once participants were navigating the building physically and remained the most frequently coded pattern through exit. Priorities also diverged by impairment group and data source: participants with visual impairment prioritized the digital retrievability of information, whereas focus-group participants with developmental/learning impairments

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prioritized redundant multichannel coding, and those with physical/mobility impairments prioritized functional-eligibility information.

Conclusions: Information uncertainty in hospital wayfinding is best understood along 2 axes—the stage of the journey at which it occurs and the mechanism that produces it. Together, these axes support wayfinding interventions that target specific stages and are tailored to specific types of breakdown, with potential transferability to comparable hospital settings beyond the 2 studied here. Breakdowns corroborated across multiple sources and impairment groups should be prioritized first.

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KEYWORDS

wayfinding; hospital accessibility; information uncertainty; patient journey mapping; usability testing; universal design; assistive technology; disability

Introduction

Background

Wayfinding is a key part of the patient experience. It is 2-fold in nature, representing both a design element and a medical problem. Well-designed wayfinding systems in hospitals offer numerous benefits, including reduced stress and anxiety for patients and visitors [1,2]. Effective wayfinding can save costs by decreasing missed appointments, minimizing staff time spent giving directions, and improving overall efficiency [1,3], as well as reducing complaints [4]. Implementing clear signage with symbols and pictograms can enhance patient outcomes and staff satisfaction [3]. Digital wayfinding systems can further improve the user experience by providing interactive guidance and reducing task complexity [5,6]. A holistic approach to wayfinding design, incorporating multiple communication channels and considering the broader health care journey, can empower health seekers and improve their overall experience [7,8]. Ultimately, well-designed wayfinding systems contribute to a more comfortable and user-friendly hospital environment [9]. Several studies point out that supporting wayfinding also involves paying attention to digital tools, such as information on hospital websites, digital navigation systems, and other specialized applications [10,11]. However, digital touchpoints introduce distinct accessibility challenges of their own. Usability testing of health-related digital systems with assistive technology users has repeatedly identified structural and navigational barriers that persist even on well-resourced digital touchpoints, suggesting that digital wayfinding tools cannot be assumed to be accessible by default [12].

Wayfinding in Hospitals in the Context of Specific Patient Needs

In recent years, several studies have addressed the issue of wayfinding in hospitals [13]. Researchers continue to examine how various groups navigate and orient themselves in physical environments, with a strong emphasis on both their strategies and effectiveness. However, the diverse needs of users, including those with special needs, must be taken into account in both research and design [6]. To address the challenges that arise from differences in spatial perception, studies have focused on diverse populations, such as older adults [14,15], children [16], and individuals with specific needs, including those with visual impairments [17], mobility impairments [18], autism [16], dementia [19,20], and other disabilities, to identify solutions that improve their wayfinding experiences. Methodologically, understanding how these populations navigate has increasingly relied on eye-tracking and think-aloud protocols, which allow researchers to capture attentional and behavioral evidence of navigation difficulties in situ rather than relying solely on retrospective self-reports. However, these approaches remain underused in naturalistic, real-world settings compared with controlled laboratory settings [21].

Information Uncertainty in Wayfinding

Previous studies conceptualized wayfinding as spatial problem-solving involving information processing, decision-making, and plan execution [22]. Uncertainty in wayfinding can arise from multiple factors, such as environmental complexity, the legibility and effectiveness of navigational aids, and individual differences in spatial cognition. Information uncertainty may result from gaps in information that patients experience in hospital settings [23]. Uncertainty significantly influences wayfinding by affecting both cognitive processes and navigational behaviors [24,25]. A thorough understanding of the sources of information uncertainty and how they influence both cognitive and behavioral aspects of navigation is essential for designing effective wayfinding systems and built environments.

Patient Journeys as a Method for Mapping Patients' Experience

Patient journey mapping is an emerging method for understanding and improving patient experiences in health care systems [26]. It provides valuable insights into wayfinding challenges in complex hospital environments [7]. This approach can inform clinic placement, signage design, and resource allocation to enhance patient experience and operational efficiency [27] and optimize signage placement [28]. Studies have shown that patients benefit from simple building layouts, nature-themed visual displays in diagnostic settings, and a variety of social spaces during treatment, including when navigating health care facilities [29]. Building on a replicable Stage-Touchpoint-Uncertainty framework [30], this study applies the framework empirically across 2 hospitals and 4 data-collection methods, focusing specifically on patients with diverse impairment-related needs. The framework operationalizes information uncertainty in hospital wayfinding through a 7-stage patient journey model spanning digital and physical touchpoints. It also codes observable, time-stamped

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indicators of uncertainty rather than relying solely on retrospective self-report.

Patient journey mapping has also been proposed as a boundary object that helps multidisciplinary teams reconcile competing priorities in service design by externalizing tacit knowledge about the patient experience for stakeholders outside the clinical field [31,32]. Digital applications of journey mapping in hospital settings—for instance, mobile tools guiding patients through the perioperative period—illustrate both the potential of structuring the patient journey around discrete stages and the persistent challenge of tailoring these structures to individual variations in needs [33].

Research Questions

While previous studies have emphasized the importance of understanding patient experience as a driver of health care service improvement, they have also highlighted the methodological challenge of capturing this experience holistically across the complex trajectory of hospital care [23]. Building on this line of inquiry, our study seeks to further unpack the patient journey by focusing on the constituent elements (touchpoints) that shape the hospital wayfinding experience. In doing so, we aim to address 3 research questions: (1) What elements constitute information uncertainty in the patient's experience during navigation and interaction with hospital services? (2) How are these elements perceived and prioritized by patients with specific needs? and (3) How can the uncertainty peaks identified across the patient journey inform the design and prioritization of wayfinding interventions for people with specific needs?

Taken together, these strands of literature suggest that information uncertainty in hospital wayfinding is shaped jointly by physical and digital touchpoints, the user's specific perceptual and cognitive profile, and the methodological lens used to observe it. However, few studies have combined field-based behavioral methods, website accessibility testing, and evaluative design methods within a single, cross-impairment framework.

Methods

Study Design and Hospital Settings

This study applies the patient journey framework for mapping information uncertainty in hospital wayfinding [30] to 2 university hospitals that differ in scale and spatial organization. We adopted a qualitative, multimethod design with methodological triangulation across 4 rounds of data collection between May 2024 and July 2025. The design combines expert heuristic walkthroughs, accessibility and usability testing of the hospital website, user walkthroughs with mobile eye-tracking accompanied by think-aloud protocols and posttask interviews, and focus groups evaluating candidate signage designs. Each method captures a different layer of the wayfinding experience—professional assessment, digital interaction, embodied use, and deliberative evaluation—consistent with our conceptualization of wayfinding as a sociotechnical, cross-channel information behavior [34,35].

Data were collected at 2 large hospitals selected for their contrasting wayfinding contexts. Hospital A has more than 1000 beds and is organized as a sprawling, multipavilion campus on a hillside site. Approximately 25 departments and 7 clinics are distributed across numerous freestanding historic pavilion buildings dating from the hospital's original construction between 1926 and 1934. These buildings are connected by outdoor pathways and later infill buildings rather than a single unified structure, resulting in a decentralized, low-legibility spatial layout typical of large teaching hospitals that have grown incrementally. Hospital B is an 890-bed university hospital comprising 39 specialized departments and designated as a comprehensive cardiovascular, cerebrovascular, and oncology center. It is organized around a historic core in the old town district, with the first building completed in 1868 and several pavilions added later for cardiac surgery, intensive care, and dialysis. This spatial organization reflects historical growth on a constrained inner-city site and the partial relocation of departments to a newer campus.

Ethical Considerations

The study protocol was reviewed and approved by the Ethics Committee of Masaryk University (approval number EKV-2022-121) in accordance with relevant laws and institutional guidelines. All participants provided written informed consent before each session and received a financial reward of approximately €20 (US $22.45).

Analytical Framework

The analysis applies the Stage-Touchpoint-Uncertainty coding scheme [30]. The journey stages, spanning digital and physical contexts, were consolidated into 5 groups:

- Prearrival (digital orientation): hospital website, department page, and route-planning tools
- Entry and initial orientation: vestibule/lobby, reception/volunteer desk, and first decision node
- En route navigation: corridors, junctions, vertical circulation, and confirmation cues
- Destination interface: department front of house (doors, counters, and check-in)
- Exit and postvisit: Return path, payment and administration, discharge, and follow-up information

For each stage, the analysis enumerates 2 classes of wayfinding touchpoints: digital (web pages, map widgets, PDF maps, contact information, and accessibility notes) and physical (exterior totems, building identifiers, building numbers, directories, directional signs, confirmation signs, landmarks, floor graphics, elevator call panels, and door labels). Social and organizational touchpoints (reception desks and ad hoc staff guidance) are outside the scope of this study, as the analytical focus is on the artifactual layer of wayfinding. Help-seeking interactions with other people and the use of personal devices were not allowed during walkthroughs.

The unit of analysis is a stage-bounded interaction with a wayfinding touchpoint—an observable episode in which a participant engages with a digital or physical cue at a specific journey stage (eg, entry and initial orientation: "reads lobby directory for 18 s and selects elevator A"). Each unit is coded along 5 indicator families: task state, operationalizing the microprocess of wayfinding [22,23]; uncertainty markers,

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directly observable in eye-tracking and audio data [24,25]; touchpoint qualities, translating environmental communication principles into codable variables [3,28]; accessibility factors, surfacing equity-relevant issues across digital and physical channels [11,17]; and context modifiers, reducing attribution error when failures are driven by the environment rather than the cue itself [4].

Coded units are aggregated into a Stage-Touchpoint-Uncertainty matrix that overlays task states and quality flags by stage, enabling the identification of uncertainty peaks, recurring breakdown patterns, and impairment-specific issues across participants and sites. As the number of coded events differs across stages and hospitals for reasons related to route length and structure rather than uncertainty severity (see the "Data Sources and Procedures" section), an uncertainty peak is defined here not as a raw event-count maximum but as a stage-mechanism combination corroborated by multiple independent data sources or affecting a majority of participants within that stage. The 4-mechanism typology (absence, equivocality, perceptual, and cognitive-translation) used throughout this paper was applied as an interpretive classification by the coding team to each stage-touchpoint pattern, rather than logged as a discrete, systematically quantified code for every individual event.

Data Sources and Procedures

Overview

The study comprised 4 rounds of data collection, summarized in Table 2. Each round is described below.

Expert Walkthroughs

In May 2024, 2 accessibility and inclusion experts (E1, experts with mobility impairment, and E2, experts with visual impairment) conducted heuristic walkthroughs of hospital A to establish a baseline of design weaknesses before user testing. The protocol included 3 approach routes to the hospital (from public transport and the parking lot), 3 routes between buildings within the hospital complex, and 1 indoor route. Each route comprised several destination departments arranged in sequence. The experts documented their observations through structured field notes, photographs, and short postwalk debriefs with the research team. Findings from this round informed the design of subsequent user walkthroughs and provided a heuristic comparison layer for triangulation.

Conducting expert-led field walkthroughs of the physical hospital environment follows established practice in accessibility assessment of the built environment, commonly termed an access audit. Access audits typically involve a structured assessment of a building along the journey of a user with disability, from arrival at the site to every area they might reasonably need to access. This approach is reflected in our protocol, which combined 2 approach routes (from public transport and the parking lot), 3 interbuilding routes, and 1 indoor route. This journey-based approach is consistent with the broader conceptualization of accessibility as a relational property rather than a fixed attribute of the building alone. Iwarsson and Ståhl [36] proposed an instrumental definition of accessibility that integrates personal and environmental components, arguing that accessibility must be analyzed through the interaction between the 2 rather than through the environment in isolation. This framing justified our selection of 2 experts with complementary profiles (ie, with mobility/visual impairment) rather than a single generalist auditor, as each expert's assessment reflects a different facet of the person-environment relationship that a single evaluator could not fully represent. Consistent with standard access-audit methodology, an access audit evaluates how well an environment and its service delivery meet the needs of existing and potential users by assessing features against predetermined criteria, thereby identifying physical barriers that may compromise access to services. This approach underpinned our experts' structured field notes and photographic documentation, which subsequently served as the heuristic baseline against which findings from later user walkthroughs were contextualized.

Website Accessibility and Usability Testing

In September 2024, the hospital A website was tested for digital accessibility and usability with 4 users with severe visual impairment (2 women and 2 men) of varying ages. The testers used different assistive technologies—JAWS (Freedom Scientific), NVDA (NV Access), VoiceOver (Apple Inc), and ZoomText (Ai Squared/Freedom Scientific)—with moderate to advanced proficiency. Selecting users with high assistive technology proficiency was a deliberate sampling strategy to minimize confounding arising from limited technology skills, allowing observed breakdowns to be attributed primarily to the website rather than to user competence.

Testing was conducted manually with experienced screen reader users rather than through automated conformance checking, following a methodological distinction established in a foundational comparative study of web accessibility evaluation methods. Mankoff et al [37] compared a laboratory study involving users with blindness with an automated tool, expert reviews conducted by designers with and without a screen reader, and remote testing. Focusing on techniques for evaluating accessibility for users with blindness, they found that multiple developers using a screen reader were the most consistently successful at identifying different classes of accessibility problems, although they identified only around half of the known problems [37]. This finding supports our decision to prioritize testing with real assistive technology users (JAWS, NVDA, VoiceOver, and ZoomText) over an automated audit, while also tempering expectations that a single testing round would be exhaustive. We address this limitation through triangulation with expert walkthroughs and user walkthroughs at the physical site.

Testers completed 10 task scenarios reflecting common prearrival information needs, such as locating a specific clinic, identifying the correct entrance, and finding parking and accessibility information. The sessions were unmoderated, and screen and audio recordings were captured throughout. Participants were asked to think aloud during testing and complete a structured report afterward.

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User Walkthroughs With Mobile Eye-Tracking

Between June 2025 and July 2025, participants completed accompanied walkthroughs of hospital A and hospital B. Routes at hospital A were traversed within a single large, multistory pavilion (building 3), accessed via 2 elevators and 2 stairwells across 6 floors (basement to fourth floor). All participants completed the same fixed sequence of 5 destination tasks: (1) the electroencephalogram unit within the neurology outpatient clinic; (2) the ENT (ear-nose-throat; otorhinolaryngology) outpatient clinic; (3) the specialized examination rooms of the ophthalmology department; (4) the urology department office; and (5) exiting the building via a route not previously used during the session. An additional brief directional probe ("Which direction is the phoniatrics unit?") was administered to assess signage-reading accuracy independently of overall wayfinding performance. Routes at hospital B spanned multiple interconnected buildings and, for most participants, followed a fixed sequence of 5-6 destination tasks: the gynecology department, the patient admissions office, the neurology outpatient clinic, an exterior building-identification task, the computed tomography scanning facility, and a return to the main reception. The exit tasks were tailored to the physical characteristics, spatial organization, and available patient through-routes of each site rather than scripted identically. Hospital A's walkthrough took place within a single multistory pavilion, making an exit via a previously unused route a meaningful test of independent orientation. By contrast, hospital B's decentralized, multibuilding layout meant that a return to the shared main reception better reflected the through-routes available to patients navigating that site.

The decision to conduct eye-tracking in situ using mobile rather than stationary equipment reflects a well-established methodological concern in spatial cognition research regarding the ecological validity of eye-tracking data. Mobile eye-tracking enables participants to move unrestrictedly through real environments, allowing researchers to examine the relationship between visual behavior and the characteristics of the physical environment [38] in ways that static, screen-based stimuli cannot. Concurrent think-aloud protocols were added specifically to address a known interpretive limitation of gaze data collected in complex, multicue environments, such as hospital corridors and junctions, where several plausible fixation targets (signs, doors, and landmarks) may be visible simultaneously, and gaze position alone cannot disambiguate participant intent.

Participants met the researchers at the main entrance of each hospital, where informed consent, financial compensation, and eye-tracking calibration were completed. Eye movements were recorded using SMI Eye Tracking Glasses 2, while concurrent audio captured think-aloud comments. Participants then navigated to a sequence of target destinations, each of which was communicated orally and provided on paper. One researcher accompanied each participant to prevent interference with hospital operations but did not provide directions or evaluative feedback during the task. Participants with hearing impairment who used sign language were additionally accompanied by an interpreter who was briefed in advance not to assist with navigation. Eye-tracking video served primarily to time-stamp and disambiguate moments of uncertainty identified in the concurrent think-aloud audio and posttask interviews rather than to provide independent quantitative gaze metrics (eg, fixation counts or dwell time). No systematic quantitative eye-tracking analysis is reported.

After the final destination was reached, the researcher conducted a semistructured posttask interview covering both general impressions of the wayfinding system and specific aspects of the participant's experience, including decisions made at junctions, sources of confusion, observed breakdowns, and instances of help-seeking. Each walkthrough, including the interview, lasted approximately 45 minutes.

Focus Groups

The team conducted 4 rounds of focus groups to evaluate 3 candidate navigation design proposals developed by external design studios. Group sizes ranged from 2 to 8 participants, and the groups were homogeneous by impairment type—hearing (n=8), developmental/learning (n=5), mobility (n=2), and older adults (n=4)—enabling each cohort to focus on needs specific to its modality. The focus groups evaluated candidate signage designs developed independently of the walkthrough findings. They were not used to validate or member-check specific breakdowns identified during the user walkthroughs but served as an independent evaluative data source.

Each session followed a 4-part protocol covering (1) pictogram comprehensibility, (2) the interior signage system, (3) the exterior signage system, and (4) the main complex map. Participants completed a short, structured scoring sheet indicating studio preference for each category and each pictogram and listing 5 descriptive adjectives for each design, followed by open deliberation. Focus groups involving participants with hearing impairment who used sign language were additionally supported by an interpreter. Sessions were audio-recorded, and the scoring sheets were retained as supplementary structured data.

Structuring focus groups to be homogeneous by impairment type follows long-standing guidance on focus-group composition in qualitative health research. Kitzinger's [39] foundational methodological paper on focus groups provides specific guidance on group composition, and homogeneous grouping is recommended because it allows group dynamics to surface shared, modality-specific concerns that might otherwise be diluted or reframed in a mixed group. This choice is further supported by participatory disability research, which argues that people with disabilities should evaluate design solutions directly rather than be represented by proxies. Bennett and Rosner [40] examined how empathy-based design activities, in which designers attempt to understand people with disabilities on their behalf, can serve as a powerful but potentially problematic substitute for direct engagement with the people the design is intended to serve. This argument is consistent with the disability rights principle "nothing about us without us" [41]. Our 4-group, impairment-specific approach operationalizes this principle by giving each cohort direct evaluative authority over the candidate signage systems rather than filtering its perspectives through a single mixed panel.

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Participants

A total of 38 participants were included in the analysis across the 4 data sources (Table 1): 36 research participants who were involved in website testing, user walkthroughs, and focus groups, and 2 accessibility experts who conducted the heuristic walkthroughs. These individuals were counted together because Table 1 organizes participation by data source rather than by role. Of the 15 participants originally recruited for the user walkthroughs, 13 were retained for coding: 1 session was excluded because of failed eye-tracking calibration, attributed to the participant's eyeglasses, and 1 recording was lost due to a technical fault. Table 1 presents the characteristics of the 13 user-walkthrough participants retained for coding. All walkthrough-based analyses reported in the "Results" and "Discussion" sections, including the 451 coded stage-touchpoint events, are based on these same 13 participants. Participants were recruited through the university's participant database, personal contacts, and interest groups representing people with specific needs. The sole exclusion criterion was prior familiarity with the layout of hospital A or hospital B. Familiarity was assessed alongside self-reported orientation skills and experience with unfamiliar environments using an online intake questionnaire.

To capture the heterogeneity of patient experiences and address concerns related to equity, inclusion, and access within health care systems, recruitment deliberately prioritized diversity across 3 axes: impairment type (visual, hearing, mobility, cognitive, neurodevelopmental, and learning), age, and assistive technology use. The resulting sample included participants with hearing impairment, visual impairment, dyslexia, dyscalculia, attention-deficit/hyperactivity disorder, autism spectrum disorder, mobility limitations, lung fibrosis, and cognitive impairment, distributed across the 4 data sources, as shown in Table 1.

Table 1. Participant characteristics by data collection method.[a]

Characteristic	Expert walkthroughs (n=2)	Website testing (n=4)	User walkthroughs (n=13)	Focus groups (n=19)	Total (N=38)
Gender, n (%)					
Male	2 (100)	2 (50)	7 (54)	8 (42)	19 (50)
Female	0 (0)	2 (50)	6 (46)	11 (58)	19 (50)
Age, mean (range)[b]	N/A[c]	N/A	32.7 (21-61)	41.6 (21-75)	38.0 (21-75)
Hospital, n (%)					
Hospital A	2 (100)	4 (100)	6 (46)	N/A	12 (32)
Hospital B	0 (0)	0 (0)	7 (54)	N/A	7 (18)
Participant cohort/impairment category, n (%)					
Visual	1 (50)	4 (100)	0 (0)	0 (0)	5 (13)
Hearing	0 (0)	0 (0)	5 (38)	8 (42)	13 (34)
Physical (mobility or chronic condition)	1 (50)	0 (0)	0 (0)	2 (11)	3 (8)
Cognitive/neurodevelopmental (cognitive, learning, attention-deficit/hyperactivity disorder, or autism spectrum disorder)	0 (0)	0 (0)	9 (69)	5 (26)	14 (37)
Older adults[d]	0 (0)	0 (0)	0 (0)	4 (21)	4 (11)

[a]Percentages are of column N. Counts exceed column N in User walkthroughs because 1 participant (P6) had co-occurring impairments spanning 2 categories (hearing and cognitive/neurodevelopmental) and is counted in both.

[b]The reported overall mean age (38.0 years) is calculated across the user-walkthrough (mean 32.7) and focus-group (mean 41.6) participants only; age was not recorded for expert-walkthrough or website-testing participants.

[c]N/A: not applicable.

[d]"Older adults" reflects a dedicated focus group recruited by age rather than by a specific impairment.

Data Analysis

All audio and screen-capture materials were uploaded to Condens.io (Condens Insights GmbH) and transcribed. Eye-tracking videos were reviewed alongside think-aloud audio to identify uncertainty events with temporal precision. Field notes from expert walkthroughs and structured scoring sheets from focus groups were imported as supplementary data sources.

Coding proceeded in 2 rounds, applying the framework described above. The first round used descriptive coding to identify individual barriers and elements of information uncertainty at the touchpoint level. The second round applied process coding to situate the identified elements within stages of the patient journey and capture sequences of action, decision, and recovery as they unfolded in context [42]. Coded units were entered into the Stage-Touchpoint-Uncertainty matrix. Aggregation by stage and impairment group supported the identification of uncertainty peaks, recurring breakdown patterns, and impairment-specific issues. Reports from focus groups and expert walkthroughs were used to triangulate and

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enrich the data from website testing and user walkthroughs. Two members (LZS and HG) of the research team conducted the 2 coding rounds, dividing the transcripts and cross-checking each other's coding. One coder coded a given portion of the transcripts while the other reviewed and checked the coding; these roles were reversed for the remaining portion. Thus, every transcript was coded by 1 team member and independently checked by the other. A third team member (KJ) adjudicated cases in which the coder and checker did not reach agreement. This coder-checker approach, appropriate for a small, closely coordinated coding team, followed established qualitative coding guidance [42] rather than a formal interrater reliability procedure.

Mapping of Data Sources to Journey Stages and Triangulation Logic

The 4 data sources contribute unevenly to the analysis across journey stages (Table 2). The prearrival stage is investigated through a single source—website accessibility testing—which yields behavioral observations and assistive technology evidence on digital touchpoints. The remaining stages, from arrival through exit, are investigated primarily through user walkthroughs with mobile eye-tracking and think-aloud protocols, complemented by posttask interviews. Expert walkthroughs, conducted earlier in the project, serve as a heuristic baseline against which user-derived evidence is contextualized rather than as a primary source of findings. Focus groups operate across stages, providing an evaluative layer focused on participants' preferences and prioritization of design alternatives.

Methodological triangulation operates along 2 axes. First, *within-stage triangulation*, where for the arrival-to-exit stages, 3 independent sources—expert heuristic evaluation, user walkthroughs with attentional and behavioral evidence, and posttask interviews providing reflective evidence—converge on the same touchpoints. This enables cross-validation of findings and identification of breakdowns that are observable in behavior, articulated by participants, *and* recognized by experts as design weaknesses. Second, *cross-source elaboration*, where focus groups add an evaluative dimension that the in situ methods cannot capture, allowing participants to articulate priorities and preferences in a deliberative setting within groups organized by impairment type. This layered approach follows the principle that information uncertainty in wayfinding is a multidimensional phenomenon [24,25] and that no single method can adequately capture both its behavioral and attitudinal manifestations (Figure 1).

The decision to combine 4 methodologically distinct data sources rather than rely on any single source reflects a deliberate application of methodological triangulation, understood as the use of multiple methods or data sources to develop a comprehensive understanding of a phenomenon and test the validity of findings through their convergence [43,44]. Denzin [43] and Patton [44] distinguish 4 types of triangulation—method, investigator, theory, and data-source triangulation. Our design draws on the first and last of these simultaneously: 4 different methods (expert walkthroughs, accessibility testing, eye-tracking walkthroughs, and focus groups) are applied to the same underlying phenomenon (information uncertainty in hospital wayfinding), while drawing on 4 structurally different data sources (expert judgment, assistive technology–mediated interaction, embodied in situ behavior, and deliberative group evaluation). This dual structure allows the same touchpoints to be examined from professional, behavioral, and attitudinal vantage points rather than from a single perspective.

The rationale for combining methods in this particular way, rather than using an arbitrary combination, follows directly from the known limitations of each method in isolation, as discussed above. Expert walkthroughs are efficient but reflect professional judgment rather than lived user experience; screen reader–based website testing captures functional barriers at digital touchpoints but provides no information about the physical environment; mobile eye-tracking captures embodied, real-time behavior but is resource-intensive and necessarily limited in the number of participants and routes it can cover; and focus groups capture considered, comparative preferences but are evaluative and hypothetical rather than based on observations in situ. Every research method has inherent strengths and weaknesses. Surveys can reach large populations but may miss deeper meanings, whereas interviews offer rich detail but can be shaped by how questions are framed. Combining complementary approaches allows the weaknesses of one method to be offset by the strengths of another. Structuring the 4 rounds around this principle of complementary offsetting, rather than redundancy, enables the Stage-Touchpoint-Uncertainty matrix to aggregate types of evidence that no single method could have produced independently. This approach is consistent with the broader methodological pluralism that characterizes contemporary hospital wayfinding research. Related work applying a design-research framework to the same domain demonstrates this pluralism, drawing on methods ranging from surveys and experiments to ethnographic and physiological approaches and combining techniques such as usability testing, eye-tracking, virtual reality prototyping, and participatory concept testing across diverse patient groups [45].

Finally, the temporal sequencing of the 4 rounds (expert walkthroughs → website testing → user walkthroughs → focus groups) reflects a further, often under-specified rationale for combining methods: triangulation involves not only combining methods but also using earlier rounds to inform and focus later ones, thereby developing a progressively more comprehensive understanding of the phenomenon under study. In our design, expert walkthroughs generated a baseline set of anticipated touchpoint issues; website testing and user walkthroughs then examined whether these anticipated issues occurred for specific user groups under real-world conditions; and focus groups, conducted last, allowed participants to evaluate candidate design responses to the issues identified in the preceding 3 rounds. This progressive logic justifies treating the 4 methods not as parallel, independent data collection exercises but as components of a single, cumulative research design.

We acknowledge an asymmetry in coverage: the prearrival stage is supported by a single data source and by testers from a single impairment category (visual impairment). Focus groups partially compensate for this asymmetry through their cross-stage

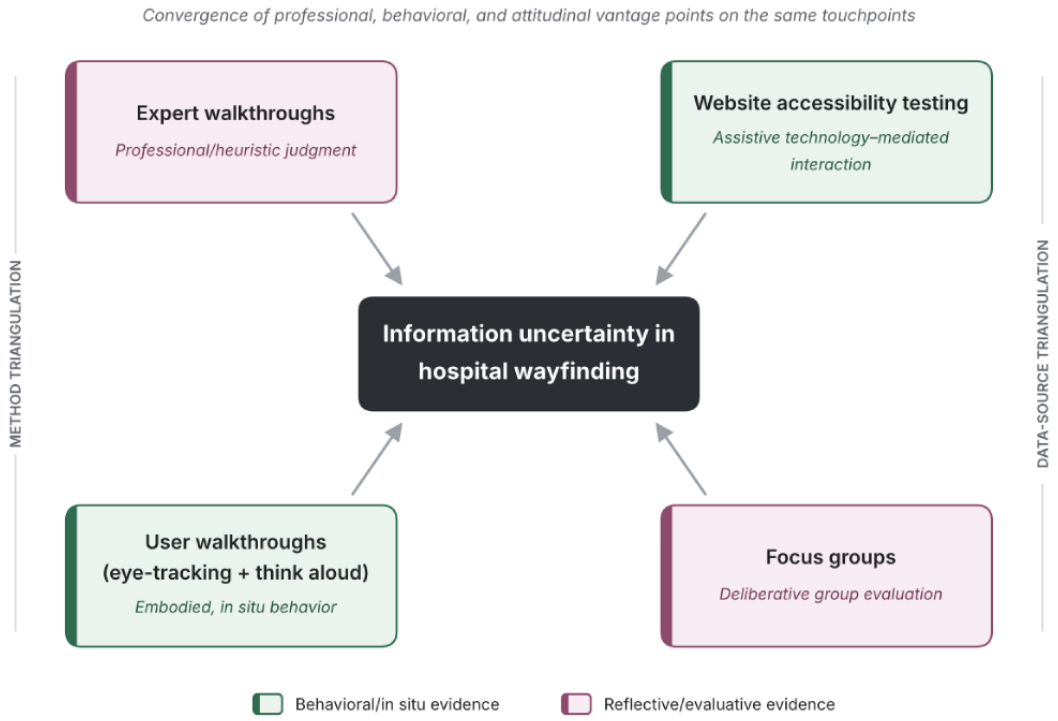
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contributions and inclusion of participants with hearing, mobility, developmental, and learning differences. A comprehensive, multiimpairment investigation of the digital prearrival stage remains a direction for future research and is identified as a limitation in the "Discussion" section.

Table 2. Mapping data sources to journey stages, evidence type, framework dimensions, and principal limitations.

Data source	Journey stages covered	Evidence type	Framework dimensions populated	Principal limitations
Expert walkthroughs (n=2)	Arrival → exit (hospital A)	Heuristic field notes and photographs	Touchpoint qualities and context modifiers	Single site; expert perspective only; and no behavioral data
Website accessibility testing (n=4)	Prearrival	Screen capture, think-aloud audio, and task completion notes	Touchpoint qualities and accessibility factors	Single impairment category (visual) and single site
User walkthroughs with mobile eye-tracking (n=8 at A and n=7 at B)	Arrival → exit (hospitals A and B)	Eye-tracking video, think-aloud audio, and posttask interviews	Task state, uncertainty markers, touchpoint qualities, and context modifiers	Limited prearrival coverage, observer presence, and 1-shot exposure to site
Focus groups (4 groups; n=19)	Cross-stage (evaluative)	Audio recordings and structured scoring sheets	Touchpoint qualities and accessibility factors	Hypothetical evaluation of designs rather than in situ use and single site

Figure 1. Triangulation logic: behavioral and reflective triangulation, and method and data source triangulation.



Results

Prearrival: Digital Orientation

The prearrival stage was investigated through accessibility testing of the hospital website with 4 testers with severe visual impairments using JAWS, NVDA, VoiceOver, and ZoomText across 10 task scenarios. Observations were coded into stage-touchpoint events (n=40), each characterized by the touchpoint engaged and the uncertainty trigger(s) it produced. The resulting touchpoint structure is summarized in Table 3.

Touchpoint-quality families (visibility, legibility, consistency, and accessibility) were not quantified for this stage. As every observation was mediated by a specific assistive technology, the same underlying breakdown could plausibly be attributed to different families depending on which technology exposed it. For instance, a missing cross-link may manifest as a discoverability problem for a screen reader user and as a magnification-specific problem for a ZoomText user. Quantifying these categories would imply a level of precision that the coding cannot support at this stage; therefore, the recurring qualitative patterns are reported instead.

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Several patterns recurred across multiple touchpoints. First, *information fragmentation*, that is, the data required to complete a single task were systematically split across pages (eg, clinic, accessibility, contact, and vaccination pages) without cross-links. This prompted backtracking by most testers and outright task failure or partial completion in several scenarios, notably those involving parking information for the maternity and emergency buildings, the disability-assistance service, and the route to the pediatric ward. Second, *avoidance strategies* were triggered whenever a primary touchpoint failed: testers resorted to the footer site map, external search engines, or Google Maps satellite imagery. This was particularly evident when seeking parking information, which was absent from the website for at least two of the buildings tested, indicating that the website did not reliably fulfill its informational function for this user group. Third, *full-text search proved unreliable* for semantically equivalent queries, returning no results or an unrelated result for at least two query pairs (eg, "COVID testing" vs "COVID test"), despite search being testers' first recourse once navigation failed. Fourth, information about a *disability-assistance service* for visitors was absent from every location where testers expected to find it—the home page, the "For patients" and "About the hospital" sections, and full-text search. Only a general "Patient Rights" page mentioned people with disabilities, without identifying a bookable service. Fifth, the building-accessibility page used the term *accessibility* ambiguously, leaving it unclear whether it referred to step-free access or merely physical reachability, and described entrances using cardinal directions that were not actionable on-site.

Several scenarios resulted in unresolved information needs that carried forward into the next stage. Patients who arrive without confirmed information about building entrances, parking, or internal routes enter the physical environment without the cognitive anchors that prearrival orientation is intended to provide [46]. This continuity is examined further in the following sections.

Table 3. Dominant touchpoints and uncertainty triggers in the prearrival stage.

Touchpoint	Uncertainty triggers	Impairment-specific notes
Centralized "Building accessibility" page	Ambiguous use of the term *accessibility*; entrance descriptions given via cardinal directions ("entry from the north") not actionable on-site; parking information completely absent for several buildings; no cross-link from department pages	All testers
Individual clinic and department pages	Missing route descriptions and department-specific access detail; no cross-link to the accessibility page	All testers
Full-text search	Semantically equivalent queries return no or unrelated results; not consistently available from every page	All testers
Main dropdown navigation	Hover-activated menu disappears outside viewport at magnification; subitems inaccessible without static fallback	ZoomText user only
Breadcrumb navigation	Incomplete paths (no intermediate categories); low-contrast gray text; does not branch, preventing stepwise return	ZoomText user only
Home page department list	Alphabetic list lacks clear heading structure, hindering discovery without prior familiarity	1 of 4 testers
Information about parking (cross-page)	Completely absent for several buildings; forces avoidance strategies (eg, Google Maps satellite view)	All testers
Information about disability assistance	Absent or buried in unrelated sections (the "Patient Rights" page)	All testers

Entry and Initial Orientation

Observations were coded into stage-touchpoint events (n=59), distributed unevenly between sites (11 at hospital A and 48 at hospital B). This difference reflects route structure rather than uncertainty severity: the hospital A route unfolds within a single multistory pavilion and therefore generates a single entry event per session, whereas the hospital B route crosses several freestanding buildings, each triggering a separate entry event (see Table 4).

Two patterns recurred across multiple participants. First, *map information gaps at the point of entry*: the general orientation maps available in hospital lobbies frequently lacked the specific department, floor level, or directional cue needed to plan a route. As one participant put it after repeatedly scanning the lobby map without locating the target department, "It's annoying that I don't know where this is. That means I have to go all the way back to the main entrance again" [P15, hospital B]. Another participant, unable to locate any relevant information on the map, decided to abandon it altogether: "I won't find anything here. I'll just have to go inside somewhere" [P10, hospital B]. Second, building-level identification was inconsistently supported at hospital B, where participants sometimes could not confirm which building they had entered: "This might have been marked here at some point, but..." [P13, hospital B]. The participant trailed off before consulting the map again, illustrating a breakdown that carried forward into the en route stage described below.

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Table 4. Dominant touchpoints and uncertainty triggers in the entry and initial orientation stage.

Touchpoint	Uncertainty triggers	Site/impairment-specific notes
General orientation map (lobby or entrance)	Lacks floor-level or directional detail; department not locatable on the map at all	Both sites
Paper/portable map	Consulted repeatedly at the entry point before committing to a direction	Both sites
Signage/building identifiers	Absent or insufficiently prominent building-level identification at entry	Both sites

En Route Navigation

Observations were coded into stage-touchpoint events (n=241; 67 at hospital A and 174 at hospital B). This is the most heavily represented stage in the dataset, reflecting the greater number and length of interbuilding segments at hospital B rather than differences in underlying uncertainty (see Table 5).

Several patterns recurred across sites and participants. First, *floor-numbering inconsistency* was the most consistently identified breakdown across the walkthrough data, affecting 8 of the 13 coded participants: “Honestly, it’s not clear to me whether I’m supposed to go up or down the stairs” [P13, hospital B]. A similar issue arose at hospital A: “I’m pissed that I have to take the elevator — there was no warning anywhere on the main sign about this” [P8, hospital A]. Second, *department-name overlap* led several participants to question whether differently worded signs referred to the same destination: “It says ‘patient reception’ here, but I don’t know — maybe it’s something else?” [P12, hospital B]. Third, at hospital B, *adjacent conflicting doorsignage* caused momentary confusion: “I don’t know if this is really the way through. They’re sending pretty mixed signals” [P13, hospital B]. Fourth, at hospital A, *elevator or door availability conflicted with posted signage*: “The elevator isn’t running, so now I don’t know — if I can only get there by elevator, and the elevator isn’t running, I don’t know how I’m supposed to get there” [P6, hospital A]. Another participant, finding that a door would not open from the side approached, exclaimed: “Damn it! So I have to go back up?” [P8, hospital A].

Table 5. Dominant touchpoints and uncertainty triggers in the en route navigation stage.

Touchpoint	Uncertainty triggers	Site/impairment-specific notes
Floor/level signage	Inconsistent floor-numbering conventions; color coding not aligned with numbering	Both sites
Department/room signage	Overlapping department names referring ambiguously to the same or different destinations	Both sites
Directional signage/general maps	Missing directional detail; information overload on large general maps	Hospital B
Door signage	Conflicting adjacent signs (“Do not open” next to “Exit”)	Both sites
Elevator panel/door	Elevator marked operational on signage but out of service on arrival; doors not opening from the approached side	Hospital A

Destination Interface

Observations were coded into stage-touchpoint events (n=84; 48 at hospital A and 36 at hospital B; Table 6).

Two patterns stood out. First, *terminology inconsistency at the point of arrival* was most pronounced at hospital A: the same clinical service was labeled inconsistently across signs approaching the same destination. One participant, confronted with a term she had not encountered elsewhere, explained: “I had no idea that outside regular hours this is already called the emergency service — that’s probably general knowledge I’m just missing” [P1, hospital A]. Another compared what she had seen inside the elevator with the signage at the corresponding floor exit: “In the elevator I saw something written a bit differently — there was nothing there about the acute ambulance...I’ll check again once the elevator arrives” [P1, hospital A]. At a signage board listing several overlapping department names simultaneously, a participant summarized the experience directly: “ENT ambulance — back entrance by the snack stand — that’s the exit — speech therapy...use the stairs only for floors 1, 3, 4...it’s total [chaos]” [P4, hospital A]. Second, at hospital B, breakdowns at this stage were more often attributable to physical legibility than to naming: “That’s a tiny sign, and faded on top of it” [P14, hospital B].

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Table 6. Dominant touchpoints and uncertainty triggers in the destination interface stage.

Touchpoint	Uncertainty triggers	Site/impairment-specific notes
Departmental/terminology signage	Same service labeled inconsistently across signs; in-patient-ward and ambulance labels adjacent and easily confused	Both sites
Elevator-car versus floor-exit signage	Information seen inside the elevator car differs from, or is absent at, the floor-exit signage	Hospital A
Printed schedule/opening-hours notices	Outdated or contradictory opening-hours information posted near the destination	Hospital A
Door/room signage	Small print, low-contrast, or faded signage at the final approach to the destination	Both sites

Exit and Postvisit

Following reclassification of the hospital B "return to reception" task to this stage, it now comprises 27 units across 10 of the 13 coded participants (12 units from 5 participants at hospital A and 15 units from 5 participants at hospital B). The 2 sites' exit tasks are not fully equivalent: hospital A asked participants to leave the building via a previously unused route, whereas hospital B asked participants to return to the main reception, a task that does not necessarily involve exiting the building. This difference should be interpreted as a difference in task demand rather than underlying site quality (Table 7).

Two site-specific patterns emerged. At hospital A, exit-related information was often available only inside the elevator: "I would have had to remember that. When we rode the elevator, I saw it there...and here's the building exit" [P1, hospital A]. At hospital B, breakdowns during the return to reception centered on wing/section disambiguation. Encountering a sign that contradicted the expected route, one participant reasoned aloud: "I don't think we can get through this way. I think we have to go around the outside" [P16, hospital B]. Another, mistaking a previously visited section for the target section, asked: "This is A1, that's fine — but we need B1. So where is it?" [P15, hospital B]. A third opted to retrace a familiar route: "I think I'd just go back the same way I came" [P11, hospital B].

Table 7. Dominant touchpoints and uncertainty triggers in the exit and postvisit stages.

Touchpoint	Uncertainty triggers	Site-specific notes
Elevator-car signage	Exit/bridge-route information available only inside the elevator, absent from floor-level signage at the exit itself	Hospital A
Unlabeled doors near restricted-looking areas	Doors near apparent staff-only areas, with no confirming sign	Hospital A
Printed schedule notices	Outdated schedule reused to infer a department's current location during exit	Hospital A
Evacuation signage/doors	Evacuation-route signage repurposed as a wayfinding aid; a usually-locked evacuation door found open	Hospital A
Building/wing signage	A previously visited section wrongly assumed to be the current target section	Hospital B
Door/exit signage	An explicit "not an exit" sign contradicting the participant's expected route	Hospital B

Cross-Source Synthesis: Stages, Uncertainty Types, and Convergence

Aggregating the 451 coded stage-touchpoint events across the 5 journey stages (prearrival, n=40; entry, n=59; en route, n=241; destination interface, n=84; and exit, n=27), together with the evaluative focus-group data, yielded 4 recurring types of uncertainty. These types were defined by what fails between a touchpoint and the patient's ability to act on it, rather than by where the failure occurs. *Absence-based* uncertainty denotes a needed cue that is missing at the point of need. *Equivocality-based* uncertainty denotes cues that are present—sometimes redundantly—but do not converge on a single, stable meaning. *Perceptual* uncertainty denotes an unambiguous cue that fails to reach the patient because the signal itself is degraded. *Cognitive-translation* uncertainty denotes a correct, legible, and unambiguous cue that nonetheless requires an additional internal operation before it can guide action.

Mapping every touchpoint-level finding onto this typology (Table 8) revealed a distribution not apparent in the stage-by-stage tables. Absence-based findings were concentrated in the digital prearrival and physical entry stages, whereas equivocality-based findings were the most frequently coded type in the en route, destination interface, and exit stages and across the dataset as a whole. As event counts reflect route length and structure as much as uncertainty severity (see the "Methods" section), this pattern is reported as a coding frequency rather than as evidence of relative severity. Two equivocality patterns were explicitly cross-stage. First, inconsistencies in information about vertical circulation recurred during the en route, destination-interface, and exit stages at hospital A, with information displayed inside elevator cars differing from or missing from floor-level signage. Second, inconsistent naming of services and locations occurred across multiple journey stages: entry (building identification), en route (overlapping department names), destination interface (inconsistent service labels), and exit (confusion over wings or

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sections). Perceptual uncertainty (small print, low-contrast, faded signage, and information-dense maps) was the least frequent type. Cognitive-translation uncertainty appeared at prearrival (cardinal-direction entrance descriptions) and in the focus-group data (nonviewer-oriented floor plans and color-only staircase coding).

The focus-group (evaluative) data triangulated the in situ findings rather than duplicating them. All focus groups—involving participants with hearing, developmental/learning, and physical/mobility impairments, as well as older adults—contributed coded data to this analysis. The strongest cross-source convergence concerned parking and vehicle information, which was corroborated across all impairment groups and the prearrival website-testing data. This was the most extensively triangulated finding in the dataset, appearing as absence at the digital prearrival stage and as equivocality at the physical, symbolic level on-site (eg, a parking-payment pictogram was independently misread as a bus by both an older-adult participant and a developmental/learning participant). Entrance/exit-pictogram ambiguity and the trade-off involving active/dynamic wheelchair symbols were also corroborated across all 4 groups, while water closet–pictogram ambiguity, floor-directory information density, the salience of the "you are here" marker, and campus-map color semantics were each corroborated across focus groups. Priorities also diverged in kind: participants with developmental/learning impairments emphasized redundant multichannel coding and completeness over minimalism; participants with physical/mobility impairments emphasized functional-eligibility information; older-adult participants relied heavily on everyday conventions from unrelated domains to decode pictograms (eg, interpreting a parking icon as a bus or a red cross as a traffic-light "stop" signal), were more sensitive to time pressure when viewing information-dense panels, and most often identified asking hospital staff as their preferred fallback strategy; and participants with hearing impairments emphasized the visual salience and contrast of symbols and the use of plain written language. Participants with visual impairment, whose website accessibility testing was reported under prearrival above, separately prioritized the digital retrievability of information.

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Table 8. Uncertainty types mapped across journey stages, with representative examples.

Uncertainty type	Prearrival	Entry	En route	Destination	Exit
Absence	Parking and disability-assistance information was absent from the hospital website and not linked from relevant department pages.	General and entrance maps and door signs repeatedly lacked department names or directional cues, forcing participants to return to the main information point for guidance.	Directional signs and supplementary maps were absent from stairwells and inter-building corridors, leaving participants without cues to confirm their floor or direction.	The destination building or department lacked clear arrival markers, leaving participants unsure whether they had reached their goal; corridors leading to the destination department lacked directional signage, forcing participants to guess which way to go.	N/A[a]
Equivocality	Ambiguous use of the term "accessibility," unresolved interpretations of parking and vehicle pictograms across 2 focus groups, and inconsistent terminology across website pages.	Building-identity uncertainty	Inconsistent floor numbering, conflicting door signs, discrepancies between indicated and actual elevator status, and overlapping department names.	Inconsistent service labels; discrepancies between elevator-car and floor signage; ambiguity in vehicle, water closet, and elevator pictograms; multiple overlapping department names on a single board; and outdated or contradictory opening-hours notices.	"Not an exit" signs conflicting with the expected route; confusion between A1 and B1; and evacuation signage repurposed for other directions.
Perceptual	Low-contrast breadcrumb text hindered stepwise navigation back through the website for a ZoomText user.	General map in the entrance hall with content positioned above comfortable eye level and information density that hindered rapid orientation.	Information overload on large maps, with equally sized bilingual text competing with the primary language and reducing legibility.	Door signage that was small, faded, or low in contrast.	N/A
Cognitive-translation	Cardinal-direction entrances	The entrance-door sign and the preceding instruction were each individually correct and legible, but required patients to mentally integrate the floor number and elevator/level instruction to construct a coherent route.	Floor plan not designed from the viewer's perspective; staircases distinguished by color alone, without text labels linking them to destination departments, making the coding difficult to interpret intuitively (focus-group finding).	"You are here" marker useful only when the map is correctly oriented; a mismatch between map orientation and the viewer's facing direction requires mental rotation to determine the correct route (focus-group finding).	N/A

[a]N/A: not applicable.

Discussion

Principal Findings

This study characterized information uncertainty in hospital wayfinding along 2 axes: *where* in the patient journey a breakdown occurs and *what kind* of breakdown it is. The journey-stage structure and the 4-type mechanism typology are complementary rather than competing: the stage locates a problem in a form that is administratively actionable (ie, identifies which team or physical or digital location must act), while the type specifies the appropriate remedy (adding missing content, standardizing terminology or adding a disambiguating channel, strengthening the signal, or reducing the cognitive translation demanded of the patient).

The stage structure was not merely an organizing convenience; it was a precondition for the study's 2 most consequential findings. First, the uncertainty mechanism differed across the journey, from absence-based deficits during digital prearrival search and physical entry to equivocality-based conflicts during on-site navigation, arrival, and exit. This finding describes variation across the care pathway that no single-touchpoint analysis could reveal. Second, tracking findings by stage revealed that an apparently scattered set of complaints could be explained by a small number of recurring cross-stage mechanisms. What might otherwise have been logged as 3 separate elevator complaints was, in fact, a single equivocality mechanism—information asymmetry between the elevator car and floor-level signage—recurring across 3 consecutive stages. Similarly, terminological drift was inherently a cross-stage phenomenon whose 4 stage-specific manifestations became apparent only because the analysis preserved the sequence of the journey rather than pooling all touchpoint events. The typology thus explains *why* particular touchpoints recur as problem areas, while the stage structure explains *where* each recurrence occurs along the pathway and who is responsible for addressing it. Across focus groups, the ability to locate the emergency department was considered categorically more urgent than the ability to locate other destinations. Participants explicitly linked psychological stress to situations in which even simple directional cues failed to provide useful guidance, suggesting an affective dimension of information uncertainty

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that the Stage-Touchpoint-Uncertainty framework, as applied here, does not explicitly model.

Regarding how patients with specific needs perceive and prioritize these mechanisms, evidence across data sources revealed clearly divergent priorities: digital retrievability of information for participants with visual impairment (website accessibility testing) and, among focus-group participants, redundant multichannel coding for the developmental/learning group and functional-eligibility information and standards-related concerns for the physical/mobility group. These differences indicate that a single wayfinding intervention is unlikely to serve all groups equally.

Comparison With Prior Work

The 2-axis structure operationalizes the distinction between locating a breakdown and diagnosing its mechanism more explicitly than the single-dimension Stage-Touchpoint-Uncertainty matrix from which it derives. The mechanism typology draws on Daft and Lengel's [47] foundational distinction between *uncertainty* (ie, the absence of information) and *equivocality* (ie, the presence of information that nonetheless admits multiple or conflicting interpretations). Their central claim that the more serious organizational problem is often a lack of clarity rather than a lack of data [47] maps directly onto our finding that equivocality, rather than absence, was the most frequently identified mechanism in the physical navigation stages. This finding reflects a qualitative coding-frequency pattern, not relative severity. To our knowledge, this distinction has not previously been applied at this level of granularity to patient wayfinding. Framing the recurring elevator and terminology findings as equivocality rather than as isolated site defects is consistent with treating wayfinding as a temporally and cross-channel distributed information behavior [34,35] and with the distributed-cognition premise that meaning is assembled across touchpoints rather than delivered complete by any one of them [48].

The predominance of equivocality over absence in the on-site data reinforces standardization arguments in the signage literature, including the reduction of environmental complexity through uniform color, typography, and symbol conventions across a signage system [49] and the specific emphasis on standardization in hospital wayfinding [50]. However, our findings extend these arguments by showing that inconsistency propagates across functionally sequential stages, rather than occurring only within a single sign type. The cognitive-translation type is supported by evidence that mental rotation of a map measurably increases cognitive load and reduces performance on orientation tasks [51]. This evidence provides a plausible cognitive basis for the difficulties associated with the nonoriented floor plans and cardinal-direction entrance descriptions observed in this study, rather than treating them as mere inconveniences. Finally, the divergent priorities across impairment groups are consistent with the universal-design literature's recognition that no single design serves all users equally, given persistent disagreement over how accessibility itself should be defined across groups [52]. They are also consistent with recent research in human-computer interaction, which argues that conflicting access needs are a substantive design consideration that requires careful deliberation rather than a technical problem that can simply be engineered away [53].

Practical Implications

The 2-axis structure translates directly into a division of labor among the teams responsible for hospital wayfinding, rather than a generic call for "better signage." Absence-type breakdowns are, by definition, content-management problems: the missing parking and disability-assistance information identified at prearrival requires a web-content solution—adding a persistent, cross-linked entry accessible from every relevant department page, not only from the centralized accessibility page—and no physical-plant intervention. Equivocality-type breakdowns require a different kind of fix: disambiguation and consistency across an existing set of cues, rather than the addition of new content. The ambiguous use of accessibility on the website should be resolved by separating step-free/wheelchair access from general reachability into 2 distinct, consistently labeled categories. The recurring asymmetry between elevator-car and floor-exit signage at hospital A, which surfaced independently at en route, destination, and exit, points to a single fix: synchronizing elevator-car and floor-level signage content. This would resolve 3 stage-level findings at once, illustrating why locating a breakdown by mechanism rather than by isolated touchpoint is practically, not just analytically, useful. Terminological drift across entry, en route, and destination similarly calls for a single controlled vocabulary for service and department names, maintained centrally and applied uniformly across digital and physical signage, consistent with standardization arguments in the signage literature [49,50]. Perceptual-type breakdowns (small print, low-contrast, and faded signage at final approach) require conventional print-production fixes, such as minimum contrast ratios and type sizes at the door or room level. Cognitive-translation breakdowns, by contrast, call for a different kind of redesign: replacing cardinal-direction entrance descriptions with landmark-anchored instructions that are actionable on arrival and orienting floor plans to the viewer's direction of travel rather than to an abstract north. These changes would reduce the internal translation step that our data suggest is otherwise demanded of the patient [46].

As impairment groups differed in the mechanisms they prioritized—digital retrievability, redundant multichannel coding, and functional-eligibility information—no single fix among those described above will serve every user group equally well. This reinforces the need to validate these corrections directly with the affected groups rather than assume they are sufficient once implemented [40,41,52,53]. We therefore recommend that hospital wayfinding teams use the stage-mechanism matrix presented here as a triage tool: the stage identifies which team is responsible for the fix (web content, facilities/signage, or elevator maintenance), while the mechanism type identifies the kind of fix required. This approach allows interventions corroborated across multiple sources and impairment groups—most clearly, those addressing parking and vehicle information—to be prioritized over findings supported by a single source.

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Strengths and Limitations

The principal strength of this study is methodological triangulation across 4 data sources and 2 structurally contrasting hospitals, allowing behavioral, digital-accessibility, and evaluative evidence to be considered together rather than in isolation. Several limitations qualify the findings. First, impairment status is reported unevenly: the focus-group findings are organized by impairment group, whereas the entry-through-exit walkthrough findings are not disaggregated by impairment category in this analysis, despite participants with hearing and cognitive/neurodevelopmental impairments forming the 2 largest walkthrough subgroups. Claims linking specific uncertainty types to specific impairment groups therefore remain provisional beyond the focus-group data. We deliberately did not attempt a quantitative or descriptive comparison between the walkthrough subgroups with hearing impairment and cognitive/neurodevelopmental impairments. In addition to their small and unequal sizes (n=4 and n=8, respectively), events for both subgroups were pooled across the 2 hospital sites, which, as noted below, differ substantially in scale, layout, and signage design. Any apparent difference between the 2 impairment groups could therefore not be cleanly separated from site-level differences in the volume and type of touchpoints encountered. A robust group comparison would require a larger sample stratified by both impairment group and site, which is beyond the scope of this study. Second, the elevator-equivocality patterns were documented at only 1 hospital site, so whether this pattern reflects a site-specific flaw or a general vertical-circulation problem cannot be determined. Third, the focus-group (symbol-level) and walkthrough (touchpoint-level) data operate at different levels of granularity and have not been fully cross-validated. Fourth, the 2 hospitals' exit tasks differed in demand, which should be considered when comparing findings. Fifth, the study covers 2 hospitals in 1 national context and may not generalize to facilities with different architectural or signage traditions. In addition, because the 2 hospitals differ in scale, layout, and available through-routes, as also reflected in their nonequivalent exit tasks, cross-site comparisons are limited to the typology of underlying uncertainty mechanisms (absence, equivocality, perceptual, and cognitive-translation) rather than direct comparisons of event frequencies between hospitals. Sixth, a researcher and, for participants using sign language, an interpreter accompanied each walkthrough participant. Although researchers did not provide directions or evaluative feedback, their presence may have influenced navigation behavior (a Hawthorne-type effect) relative to fully unaccompanied navigation. Seventh, eye-tracking data were used qualitatively to time stamp and disambiguate think-aloud utterances rather than analyzed as independent quantitative gaze metrics; a dedicated quantitative eye-tracking analysis was beyond the scope of this study. Eighth, focus-group comprehension of pictograms was tested within a fixed sequence of designs that itself supplied contextual cues (eg, adjacent icons and prior slides). Comprehension observed in these sessions likely overestimates comprehension of the same symbols encountered in isolation in the field.

Conclusions

Information uncertainty in hospital wayfinding is best understood along 2 axes: the journey stage at which a breakdown occurs and the underlying mechanism—missing information, conflicting information, degraded signal, or unmet cognitive-translation demand. The journey-stage structure remains essential because it allowed a scattered set of complaints to be consolidated into a few recurring cross-stage mechanisms and revealed that the type of uncertainty changes as patients move from digital prearrival search to physical navigation. The typology, in turn, replaces a generic call for "better signage" with a differentiated remedy for each mechanism. Together, the 2 axes support an intervention strategy that is sufficiently stage-specific to assign responsibility and potentially transferable to comparable settings beyond the 2 hospitals studied. This strategy prioritizes breakdowns corroborated across multiple sources and impairment groups—most clearly, those involving parking and vehicle information—over findings supported by a single source.

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Data Availability

The datasets generated and analyzed during this study (interview transcripts, eye-tracking recordings, and coded matrices) are not publicly available due to the potential identifiability of participants with rare impairment profiles and the terms of the informed consent obtained. Deidentified excerpts of the coded matrices may be made available by the corresponding author (LZS) upon reasonable request, subject to approval by the Ethics Committee of Masaryk University.

Generative AI Use

Generative AI was used to support the automated transcription of audio recordings (Condens.io) and the copyediting and visualization of sections of this manuscript (Claude; Anthropic) under direct author supervision. All AI-assisted output was

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reviewed, verified against source data, and edited by the authors, who take full responsibility for the accuracy and integrity of the content. Generative AI was not used to generate original data, participant quotations, or citations.

Authors' Contributions

Conceptualization: LZS, KJ
Data collection – expert walkthroughs: KS, PČ
Data collection – focus groups: KJ, AK, GG
Data collection – user walkthroughs: KJ, NK, PP, MHB
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Writing – original draft: LZS
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Conflicts of Interest

None declared.

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Abbreviations

ENT: ear-nose-throat

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