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# Architectural features and indoor evacuation wayfinding: The starting point matters

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ABSTRACT

Effective indoor wayfinding in the event of an emergency is key to guaranteeing safe and timely evacuation. However, despite the increasing number of evacuation studies, only a limited number focus on the influence of architectural elements. Through a virtual reality experiment, we create a link between human factors in indoor emergency wayfinding and architectural design by exploring interior wall transparency, evacuation starting points, and architectural landmarks. Our findings show that wall transparency only impacts wayfinding when combined with visibility at route starting points, and that staircases and ramps are the most significant architectural landmarks in emergency wayfinding. These differ from previous studies that primarily emphasize overall visibility in a building. Additionally, in cases of more complex evacuation scenarios with low visibility conditions, wayfinding necessitates a greater number of architectural features. These findings enhance the understanding of architectural designs as complex, multi-leveled systems with numerous distinct features that evoke a set of structural relationships in emergency situations.

## 1. Introduction

### *1.1. Indoor wayfinding and emergency evacuation*

Wayfinding within a building during emergency situations is essential for guaranteeing safe and swift evacuation. The current study focuses on a commercial building, frequented by the public, where straightforward and direct evacuation is crucial. Wayfinding performance, navigation, and evacuation behavior within such complex venues are largely influenced by the legibility of the building's architecture (Kaplan & Kaplan, 1982; Weisman 1981), features, design, and layout (Natapov et al., 2020; Nilufar and Choiti, 2019; Liao et al., 2014; Kobes et al., 2010).

Navigation is influenced by landmarks, i.e., significant elements that are clearly visualized within the structured environment. In their study of the relationship between spatial cognition and navigation, Parush and Berman (2004) found indoor navigating with landmarks to be more efficient than without. Sharma et al. (2017) found neural correlations (using electroencephalogram and EEG analyses) that indicate the integration of sensory cues and memory requirements for encoding contextual information of landmarks.

### *1.2. Route choice in real and virtual environments*

Prior knowledge of the surroundings and external aids, such as signage, were found to have a positive influence on the efficiency of evacuation (Kobes et al., 2010; Wiener et al., 2009; Hund and Minarik, 2006). Wiener et al. (2009) presented an extended taxonomy of wayfinding that distinguishes tasks according to the external constraints and levels of spatial knowledge that are available to the navigator. As such, understanding navigators' route choice during wayfinding is vital for ensuring the most efficient evacuation from a building (Shi et al., 2021; Hochmair et al., 2008). Wagoum et al. (2012) presented an event-centered wayfinding algorithm that proposes a strategy within a grid-based structure for identifying the shortest and fastest paths. Moreover, a route-choice algorithm for pedestrian evacuation was developed by Guo et al. (2013), reproducing more route choice models in a given scenario and allowing for more realistic behavior.

Due to difficulties in collecting behavioral data from naturally occurring evacuation settings, many studies employ laboratory-based virtual evacuation experiments (Schrom-Feiertag et al., 2017; Haghani et al., 2016; Li et al., 2019; Portman et al., 2015). However, this class of experiments raises questions regarding contextual bias and

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generalizability, i.e., How valid are human behaviors and decisions in virtual reality (VR) settings? Coutrot et al. (2019) found a significant correlation between virtual and real-world wayfinding performance. Kuliga et al. (2015) examined the extent to which user cognition, user behavior, and user experiences are analogous in real and virtual environments. Using a multi-method approach within a real conference center, a highly-detailed virtual model, and virtually implemented systematic redesigns, they showed that VR is a valuable and valid research tool for studies relating to the human–environment interaction.

### 1.3. Indoor visibility in wayfinding

Positive wayfinding performance is dependent on the degree of complexity and legibility of built environments, with visual access being a critical factor (Peponis et al., 1990). Visibility, visual access, and overall visuospatial characteristics play a central role in navigation performance (Emo, 2018; Wang et al., 2014). Along this line, Lam et al. (2003) suggested a quantitative measure – a so-called visibility index – for evaluating large-scale public buildings according to their ease of orientation.

Wayfinding in an unfamiliar environment is primarily performed based on people's sense of sight, which shapes their spatial memory and behavior (Fisher-Gewirtzman, 2018; Fisher-Gewirtzman, 2019; Natapov & Fisher-Gewirtzman, 2016; Wiener et al., 2009). Hölscher and Brösamle (2007) found that individuals with less accurate knowledge of the setting tend to rely more on locally visible information, i.e., the extent of the observable world at a local point in space, when employing their route choice strategy.

Jeon et al. (2011) studied evacuation activities in visually constrained conditions, such as diminishing visibility, and found that significant changes in people's travel distance and movement speed were associated with the gradation of the changing visibility caused by smoke. Moreover, visibility varies between indoor and outdoor environments (Vanclooster et al., 2016), whereby indoor environments provide less visibility and more broken lines of sight compared to outdoor environments that provide a wider view (Hölscher et al., 2006; Richter et al., 2011).

Visibility can also facilitate predictions of task difficulty regarding origin–destination pairs, with visually integrated spaces, i.e., spaces that have highly connected structure of rooms and circulation areas, tending to act as a wayfinding anchor as they offer a greater number of possibilities. For example, people are more likely to pass through integrated locations (Haq & Zimring, 2003; Hölscher et al., 2012; Peponis et al., 1990). Several evacuation studies examined the location of the final destination and exit in terms of overall visual accessibility and found that its degree of accessibility had an immense impact on ensuring safe and effective escape (Feng et al., 2021; Nilufar and Choiti, 2019; Tianfu et al., 2017; Heliövaara et al., 2012). In addition, overall visibility properties of the building layout seem to be positively related to the distance traveled – namely, people walk the longest unnecessary distances in layouts with the lowest visibility, regardless of their degree of familiarity with the environment (Li & Klippel, 2010). Visual access can be improved by wall transparency of the building. Increased transparency of the architectural design is associated with the rise of modern architecture that firstly appear in in the 1910s and 1920s (Whiteley, 2003). Transparency is highly relevant to the retail building typology. As this typology has changed with the development of consumer capitalism in the 1950s and '60s and underwent further transformations of meaning and associations in the 1990s, sometimes within architecture and sometimes from wider social developments. In this study we focused on the influence of transparency in modern architecture on evacuation, studying how an approach initially associated with technological advances, honesty and truth, evokes safety, security and legibility issues.

### 1.4. Objectives

Review of the existing literature shows that previous studies have not examined the evacuation process with respect to the visibility of the starting point, transparency or opacity of the building's walls, and specific architectural elements inside the building (such as staircases and ramps) – factors that may have a significant impact on how evacuees choose their initial route and evacuation strategy. There is a consensus among wayfinding researchers that fully understanding evacuees' perceptions of their physical surroundings and decision-making processes are of the utmost importance (Kobes et al., 2010).

Research also shows that notable landmarks and the visual accessibility of physical surroundings influence people's ability to evacuate the building. However, despite the increasing number of studies examining wayfinding and evacuation systems, few have focused on the influence of architectural and spatial elements on wayfinding capabilities. This is the first study that directly examined the interaction between three architectural features of an evacuation setting: local landmarks, global landmarks, and indoor visibility and starting point. *Local landmarks* include architectural elements such as staircases, ramps, doors, windows, and atriums; *global landmarks* refer to external buildings in the proximity or sight of the evacuation; and finally, *indoor visibility* refers to the overall indoor visibility (i.e., wall opacity and transparency) and to the encapsulated, two-dimensional visibility at the starting point of the evacuation task. At this juncture, a multi-level examination of the influence of visibility was introduced.

In order to explore the impact of these factors on the participant's ability and manner of evacuating a building, an experiment was conducted in a controlled VR setting to address three research questions:

(1) Among the local and global landmarks, which are the most influential in an evacuation setting?
(2) How is wayfinding performance – as reflected through evacuation duration, distance traveled, and route complexity – affected by the opacity and transparency of the interior walls?
(3) How is the visual accessibility of the starting point, within the building layout, related to wayfinding performance?

Based on previous research, the assumption was that both visual accessibility of the starting point within the building layout, and wall visibility will play a role in the participant's ability to evacuate. We hypothesized that in the case of a starting point with poor visibility and opaque walls, the evacuation process will be longer than in the case of a starting point with good visibility and wall transparency. We also anticipated the receipt of an assessment regarding the relative weight of each influencing factor and understanding their interplay.

## 2. Methodology

### 2.1. Participants

The study included 30 participants, unfamiliar with the building: 19 females and 11 males. The majority of the participants were in their twenties and all were undergraduate Architecture students, ranging from their first to their fifth and final year of their studies. The participants had prior experience navigating in VR settings. A post hoc computation of achieved power resulted in a value of 0.88, suggesting that the sample size was sufficient. Participants' sample was fairly representative across three aspects that had to be balanced during the study - different levels of expertise with architectural settings, familiarity with VR navigational devices and gender diversity. The study was approved by the Technion IIT Ethics Research Committee. All participants volunteered to participate, and an informed consent was obtained from each participant and the data were analyzed anonymously. Each participant contributed up to thirty minutes of their time.

### 2.2. Case study

The virtual case-study model in this research was based on an existing small-scale commercial center located in an urban environment. The building has three levels: an upper level (+1), street level (0), and a basement (−1) – all of which have an open-space concept. The modeled structure has multiple entrances (and exits), with many route options on each floor. "Shops" are defined as individual multi-level volumes spanning from the basement to the upper level. The center of the building opens up to an atrium that is comprised of a pedestrian ramp and several staircases that connect all levels. In our virtual model, the commercial center was represented in white, while the surrounding structures were represented in light beige, thereby creating a visual distinction between them. Fig. 1 presents an external view of the commercial center in its urban environment. The model building was presented to the participants with both transparent interior walls (model A) and with opaque interior walls (model B), as seen in Fig. 2.

### 2.3. Experiment design

To address the research questions, a two-by-two, within-participant experimental design was employed. The first variable was a manipulation of the building's transparency, whereby in one condition, the commercial center was modeled as only having transparent walls, and in the second, as only having opaque walls. The rationale of this manipulation was to examine the influence of the overall visibility in a building on evacuation wayfinding. The second variable was a manipulation of the visibility from the evacuation starting point, whereby in one condition, the starting point had high visibility, while in the second condition, the starting point had poor visibility. The underlying logic behind variable is to identify a key, characteristic locations of the layout. These locations will gain maximum or minimum of movement on the aggregated level. When applied to the three different levels of the building, the design resulted in 12 within-participant experimental conditions, as seen in Table 1.

In order to define "high visibility" and "low visibility" starting points for emergency evacuation, we analyzed the visibility of the floor layouts of the opaque building model. To do so, Visibility Graph Analysis (VGA) based on Space Syntax theory (Turner and Penn, 1999; Turner et al., 2001) was conducted using Depthmap software. The opaque building model was used for this analysis even though transparent and opaque walls differ in some characteristics (e.g., transparent walls enable more views than opaque ones), yet both buildings provide the same degree of accessibility (i.e., amount of space a person can reach), and as such, the opaque model is representative of both models from this aspect. Based on this analysis, six possible starting points were defined in each building (12 in total).

Fig. 3 (a) shows the VGA of the hallway space on the three floors in the opaque model. The most visible areas with the highest direct visual connections are shown in red, while the lowest visibility areas and connections are shown in blue. Fig. 3 (b) shows the starting points in both the opaque and transparent buildings and Table 1 presents an evaluation of these starting points on each floor for both building versions.

The starting points were manually determined so as to preserve the architectural logic of the building. They were set outside the shops, with a minimum distance from the exits, facing hallways, and matching overall open space configuration. Following the 'high' visibility areas, the starting points are presumed to be optimal for wayfinding and are located in the most visible places on the floor (marked in grey). The 'low' visibility starting points are located in visually segregated places (marked in red).

The most efficient escape routes from each starting point (1–6) were determined as a benchmark measure of participants' routes in VR. These routes represent the ideal in terms of time and traveled distance. The routes were defined by principal investigators (PI) who were familiar with the buildings and simulated possible escape routes of visitors in this shopping mall. Fig. 4 shows the routes from each starting point overlaid on the floor plans of the opaque building. The time it took the PIs to evacuate and the distance they traveled are presented in Table 2.

It can be seen above that route duration and distance were less for high visibility starting points as compared to low visibility starting points.

### 2.4. Apparatus

The experiment was conducted in the Faculty of Architecture and Town Planning, Technion IIT Visualization Laboratory. The laboratory setting included a darkroom equipped with a three-dimensional (3D) immersive theater consisting of a 2.4 M × 7.0 M screen with a 75° field of view and three high-definition (HD) projection design projectors.[1] The experiment apparatus consisted of a joystick movement controller and 3D glasses that the participants wore over their eyes, equipped with sensors with tracking cameras that follow the participants' "moves" within the virtual model. For all participants, the system was initially set at the same exact speed of movement, simulating the average human walking speed (approximately 4 km per hour.) Fig. 5 shows a demonstration of the experiment.

### 2.5. Measures

The following five measures were examined and analyzed in this study: wayfinding performance, route traveled, route drawings, post-scenario difficulty rating, and post-experiment questionnaires.

Wayfinding performance. Four metrics were extracted from the video recordings of all evacuation scenarios:

- Duration – Length of time, measured in seconds, from the participant's commencement of travel within the building until evacuation of the building.
- Distance traveled – Distance, measured in meters, from the commencement of travel within the building until the participant evacuated the building.
- Unnecessary turns – Number of superfluous turns made by participants relative to the number of turns made by the PIs in the optimal escape routes.
- Unnecessary level changes – Number of superfluous level (floor) changes made by participants relative to the number of level changes made by the PIs in the optimal escape routes.

**Route traveled.** The actual route traveled by the participant extracted from the video recording and drawn on the building plan. This metric was used to analyze the most frequented routes used.

**Route drawings.** After each evacuation scenario, participants were asked to sketch – in freehand and from memory – a map of one of the routes they took ("To the best of your memory, please sketch one of the floorplans and the most memorable evacuation route.") These sketches were used to analyze the most notable indoor landmarks imprinted in their spatial memory.

Post-scenario difficulty rating. After each evacuation scenario, participants were asked to rate the extent of evacuation difficulty on a scale of 1 (very difficult) to 7 (very easy.)

**Post-experiment questionnaire.** At the end of the experiment, participants were asked to answer the following four open-ended questions and volunteer additional comments:

[1] Designed by Antycip Simulation, the laboratory's 3D capacities are created by VizTech XL software, which produces 3D images from a wide range of software, including the SketchUp used in the experiment.

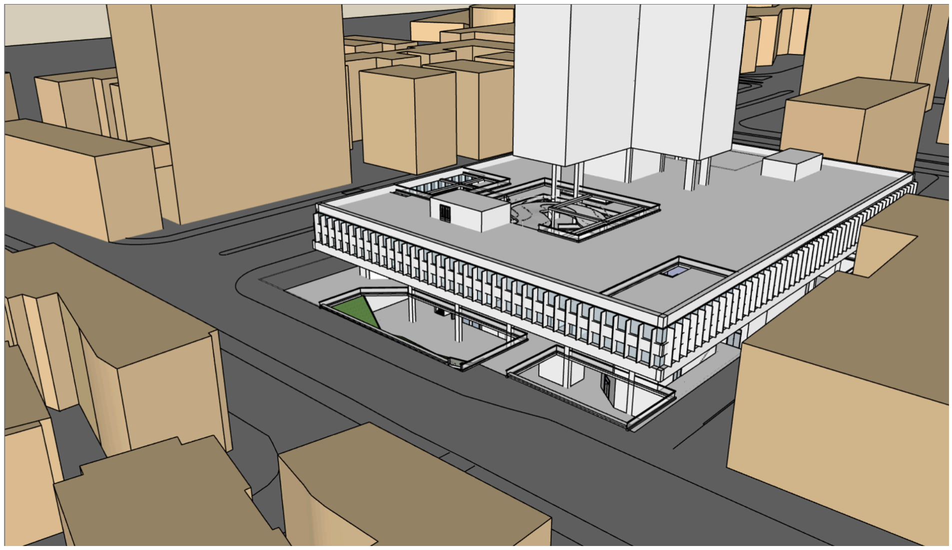

**Fig. 1.** The Commercial Center within its surrounding Urban Environment.

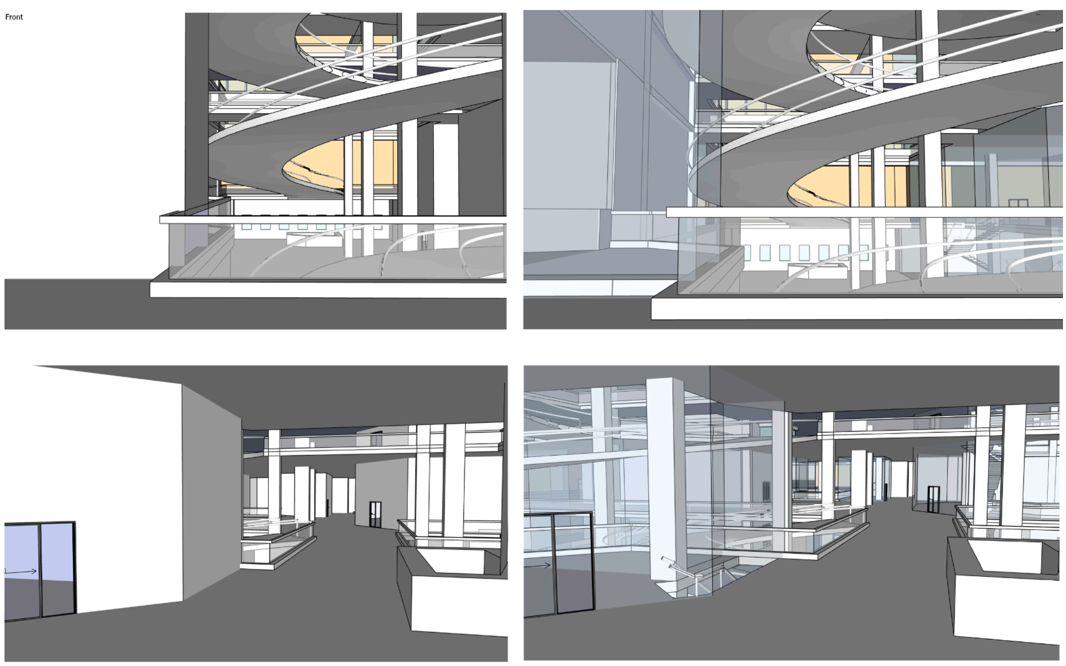


**Fig. 2.** Interior Space of the Building Models: Opaque Walls (Left); Transparent Walls (Right).

**Table 1**
Experimental design.

| Floor | Transparent walls - A | | Opaque walls - B | |
|---|---|---|---|---|
| | good | bad | good | bad |
| +1 | A1 | A4 | B1 | B4 |
| 0 | A2 | A5 | B2 | B5 |
| −1 | A3 | A6 | B3 | B6 |

(1) When you began the evacuation, what influenced your decision as to where to turn?
(2) What influenced your decision as to where to turn at various intersections along your evacuation route?
(3) What helped you evacuate yourself from the building?
(4) Did the transparent or opaque walls influence the evacuation process?

Questions 1–3 relate to landmarks while question 4 refers to the walls of the structure.

### 2.6. Procedure

Each participant was individually invited to the Visualization Laboratory at a certain time and day that was convenient for them. After being informed of the study protocol, they were asked to sign a written consent form agreeing to participate in the experiment. The first stage entailed the participants becoming acquainted with operating the system. To do so, they were given a few minutes to gain control of the VR environment – practicing on a different virtual model than the one used for the study. Next, participants were shown the study's built-up VR environment, were positioned inside the shopping mall, and instructed to picture themselves suddenly having to evacuate the building as quickly as possible because of an earthquake. Each participant was


**Fig. 3.** (a) Visibility Graph Analysis; (b) Floorplans with Starting Points in Both Buildings.

asked to do so four times (We choose 4 runs instead of six available to shorten the experiment time). The order of the starting viewpoints was counterbalanced and randomized, whereby each participant was given four different starting point: two with high visibility and two with low visibility (the participants were not informed of the difference between these points). Third, at the end of the four evacuation sessions, the participants were asked to draw a sketch of the path they remember the best, while noting elements that they recall along the route. They were also asked to rate the evacuation difficulty on a scale of 1–7. Finally, they were also asked to complete a questionnaire. All of this data was later analyzed and compared by the researchers, to achieve maximum information about the chosen routes.

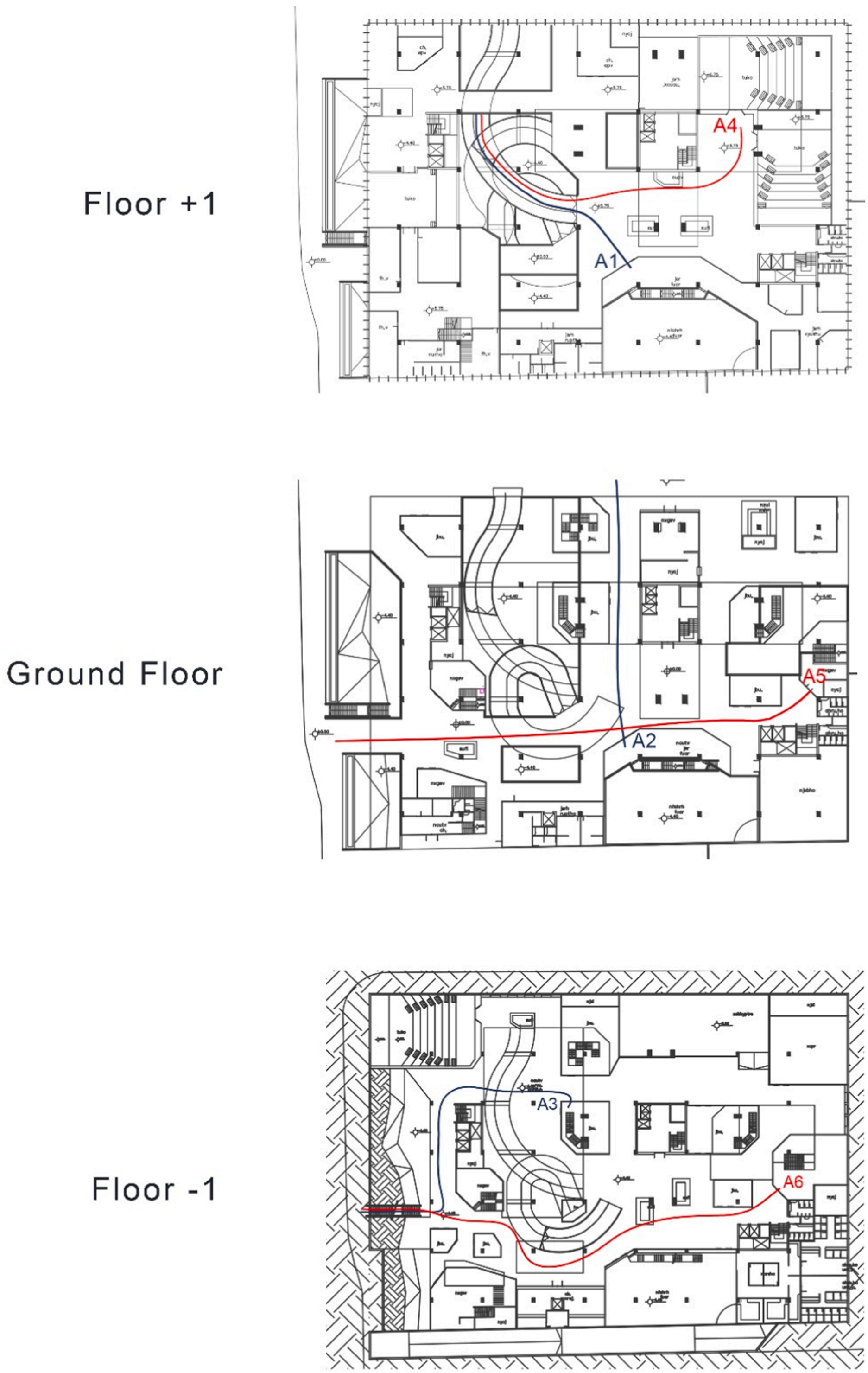


**Fig. 4.** Most Efficient Escape Routes from all Starting Points for all Three Floors (high in grey, low in red).

## 3. Results

### 3.1. Wayfinding performance

#### 3.1.1. Duration

Table 3 presents the means and standard errors of the duration of the evacuation scenario as a function of the structures (wall opacity or transparency) and starting points (high or low visibility) comparing to the most efficient escape routes.

A two-way ANOVA did not yield any significant differences. However, it should be noted that the interaction between the influence of the structure and the starting points was $p = .06$, suggesting that the longest evacuation route chosen was with the low visibility starting point in the opaque model.

#### 3.1.2. Distance

Table 4 presents the means and standard errors of the distance traveled during the evacuation scenario as a function of the structures and starting points. The findings show that distances traveled from low visibility starting points were significantly longer than those traveled

**Table 2**
Duration and distance for six optimal evacuation routes in the opaque walls structure (defined by PI).

| | Starting points | | | | | |
|---|---|---|---|---|---|---|
| | High visibility | | | Low visibility | | |
| Floor | Start point | Time | Distance | Start point | Time | Distance |
| +1 | A1(B1) | 32.02 sec | 61.06 m | A4(B4) | 1.03 sec | 81.75 m |
| 0 | A2(B2) | 27.67 sec | 46.52 m | A5(B5) | 49.17 sec | 89.16 m |
| −1 | A3(B3) | 49.12 sec | 62.80 m | A6(B6) | 57.16 sec | 93.27 m |

from high visibility starting points – in both the opaque and transparent building models [F (1,27) = 15.6, $p < .01$, $\eta_p^2 = 0.36$]. No significant interaction was found between visibility of starting points and building model.

### 3.1.3. Unnecessary turns

Table 5 presents the means and standard errors of the number of unnecessary turns during the evacuation scenario as a function of the structures and starting points. While a two-way ANOVA did not yield any significant differences in unnecessary turns between wall transparency and starting point visibility. However, as the interaction between the influence of the structure and the starting points was $p = .06$, it seems that more unnecessary turns were taken with poor visibility starting points in the opaque building model.

### 3.1.4. Unnecessary level changes

Table 6 presents the means and standard errors of the number of unnecessary changes between the three levels during the evacuation scenario as a function of the two variables: the building models and the starting points are presented in Table 6. There was a significant interaction between the two variables (F (1,29) = 5.58, $p < .05$, $\eta_p^2 = 0.16$) suggesting that there were more unnecessary level changes when participants started from the low visibility starting points in the opaque structure compared to the high visibility starting points in both structures.

## 3.2. Landmarks and routes analysis

### 3.2.1. Landmark identification

The influence of various indoor landmarks was analyzed based on the participants' sketches and questionnaires. The frequency of six key landmarks that appeared in participants' sketches, drawn from memory, is presented in Table 7. These landmarks include staircases, ramps, the outside, doors, open spaces, and windows. The findings show that movement elements (staircases and ramps) were the most frequently depicted landmark in the participants' sketches, for both the transparent and opaque building models. No distinction was found between the two models with regards to the frequency of the various depicted landmarks.

The frequency of key landmarks that appeared in the participants' answers to the relevant questions (1–3) in the post-experiment questionnaire is presented in Table 8. Again, staircases and ramps were found to be the most frequently mentioned landmark that influenced wayfinding and evacuation decisions.

### 3.2.2. Analysis of routes and associated indoor landmarks

Analysis of the video recordings and post-experiment route drawings was aimed at identifying the following the most frequent routes chosen by the participants and the indoor landmarks that were associated with those routes.

The analysis was conducted in a number of stages:

**Table 3**
Duration of Evacuations as a Function of Structure and Starting Point Visibility.

| Structure | Transparent | | Opaque | |
|---|---|---|---|---|
| Starting point visibility | High | Low | High | Low |
| M (SD) | 107.5 (18.9) | 106.2 (7.13) | 84.5 (11.35) | 134.6 (16.33) |

Mean times (and standard errors) are presented in seconds

**Table 4**
Distance travelled during evacuations as a function of structure and starting point visibility.

| Structure | Transparent | | Opaque | |
|---|---|---|---|---|
| Starting point visibility | High | Low | High | Low |
| M (SD) | 82 (9) | 129.4 (8.3) | 101.9 (12.8) | 142.8 (13) |

Mean distances (and standard errors) are presented in meters.

**Table 5**
Unnecessary turns during evacuations as a function of structure and starting point visibility.

| Structure | Transparent | | Opaque | |
|---|---|---|---|---|
| Starting point visibility | High | Low | High | Low |
| M (SD) | 0.8 (0.25) | 0.7 (0.16) | 0.57 (0.19) | 1.27 (0.25) |

Mean number of turns (and standard errors) are presented in numbers.

**Table 6**
Unnecessary level changes during evacuations as a function of structure and starting point visibility.

| Structure | Transparent | | Opaque | |
|---|---|---|---|---|
| Starting point visibility | High | Low | High | Low |
| M (SD) | 0.3 (0.085) | 0.43 (0.09) | 0.17 (0.07) | 0.67 (0.13) |

Mean number of unnecessary level changes (and standard errors) are presented in numbers.

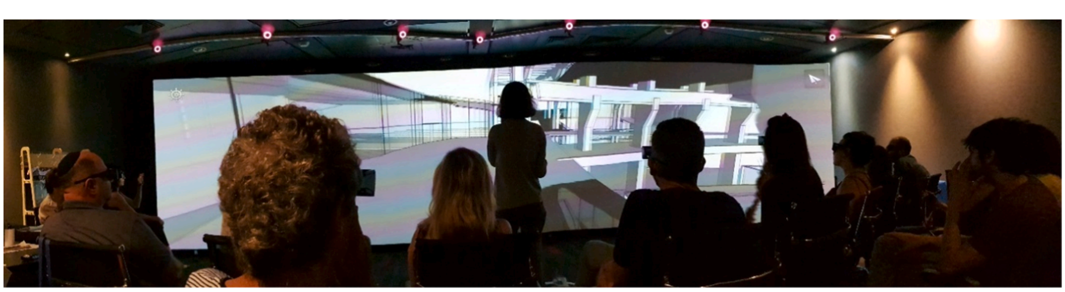

**Fig. 5.** Demonstration of Navigating through the Virtual Model at the Visualization Laboratory.

**Table 7**
Frequencies of Key Indoor Landmarks in Participants' Sketches from Memory.

| | Transparent | Opaque | Total |
|---|---|---|---|
| Stairs | 18 | 23 | 41 |
| Ramps | 19 | 17 | 36 |
| The outside | 15 | 13 | 28 |
| Doors | 10 | 11 | 21 |
| Open space | 9 | 7 | 16 |
| Windows | 3 | 0 | 3 |

**Table 8**
Frequencies of Key Indoor Landmarks According to Participants' Post-Experiment Answers.

| | Q1 | Q2 | Q3 | Total |
|---|---|---|---|---|
| Stairs | 34 | 30 | 16 | 80 |
| Ramps | 14 | 14 | 12 | 40 |
| The outside | 14 | 18 | 36 | 68 |
| Doors | 16 | 8 | 2 | 26 |
| Open space | 18 | 16 | 6 | 40 |
| Windows | 4 | 2 | 10 | 16 |

Participants were presented with the following three open-ended questions after the experiment:

1. What influenced your decision regarding where to turn when you began your evacuation?
2. What influenced your decision regarding where to turn at the various intersections throughout your evacuation route?
3. What helped you evacuate the building?

(1) For each of the 12 possible starting points (A1-A6 in the transparent building, and B1–B6 in the opaque building), mapping was conducted for all chosen routes, using participants' trajectories overlaid on the architectural plans – resulting in *spaghetti diagrams*. Fig. 6 (a) presents an example of this mapping for starting point A1.
(2) Generalizing the most frequently chosen route in each scenario, as shown in Fig. 6 (b).
(3) Identifying the indoor landmarks associated with each generalized route. This analysis was guided by the findings of the landmark identification analysis described above.

To further evaluate the routes, we generated an abstract visualization of these routes, similar to the popular visualization style of underground train maps (termed here as a *metro diagram*). Such visualization detaches the route from its geographical anchors, placing the emphasis on the origin, waypoints, and destination, and on the lines that connects all these points (see Fig. 7 for an example). Using the metro diagram, each entire route was segmented into legs. A leg was defined from the presence of one influential landmark up to where another influential landmark presented itself. Each leg has three attributes: length, color, and direction. The length proportionally represents the distance and time of the given leg; the color represents the influential landmark at the beginning of a given leg. A dotted leg represents the lack of a clear influential landmark; finally, the direction represents a change in the direction of the route.

Fig. 8 presents all metro diagrams for the high visibility starting points, while Fig. 9 presents them for the poor visibility starting points.

These diagrams facilitated a qualitative analysis of the most frequent routes and associated landmarks as a function of the building models and the starting points.

Based on these visualizations, a number of observations can be made. First, the most frequent routes and associated landmarks are similar for all high visibility starting points and in both buildings, as seen in Fig. 8 which presents six diagrams with high visibility starting points. In all these scenarios, regardless of the building, participants went through the nearest door and then either up the ramp and then outside, or directly outside whenever possible. It should also be emphasized that those most frequent routes are similar to the optimal evacuation routes presented in Fig. 3. It is worth noting, however, that in two scenarios with poor visibility starting points in the transparent building there was an unnecessary floor change, in contrast to only one scenario with an unnecessary floor change from a high visibility starting point in the transparent building.

Furthermore, greater variability can be observed in the most frequent routes and associated landmarks for all low visibility starting points, as seen in Fig. 9, which presents scenarios A4, A5, A6 in the transparent building, and B4, B5, and B6 in the opaque building. It should be observed that the routes taken and the associated landmarks differ between the two building models. In addition, the routes taken are not the same as the optimal routes (defined by the PI) from those starting points (as shown in Fig. 3). Moreover, in one route with a poor visibility starting point in the transparent building, and in two out of the three poor visibility starting points in the opaque building (B5 and B6), two primary routes taken were identified. Notably, the most frequent routes with all three poor visibility starting points involved a floor change compared to a floor change in only one scenario with a high visibility starting point (B1).

### 3.2.3. Post-scenario difficulty rating

Table 9 presents the means and standard errors of the difficulty of the evacuation scenario as rated by the participants, as a function of the structures and starting points. While the two-way ANOVA did not yield any significant differences, however, it should be noted that the

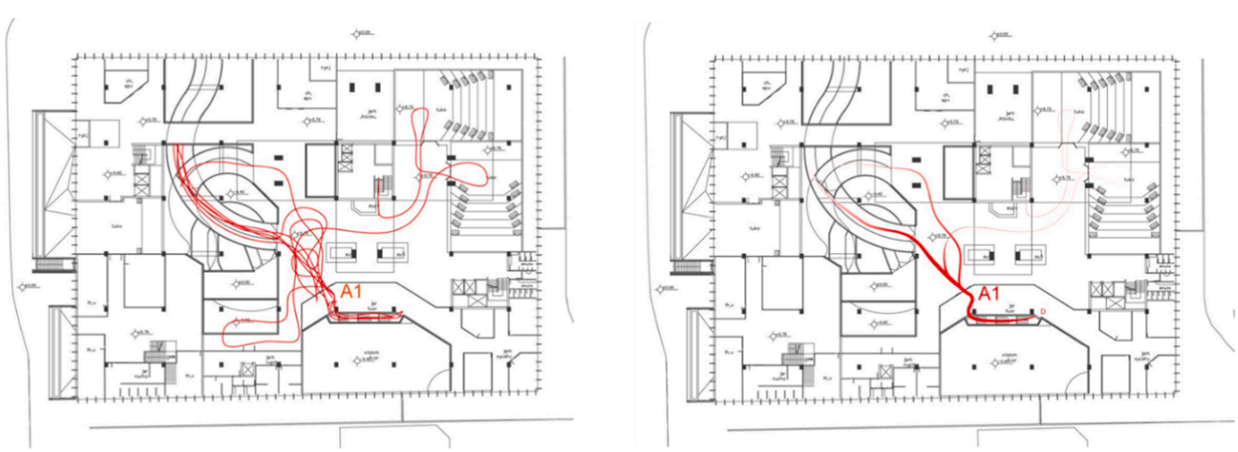


**Fig. 6.** Example of Most Frequently Taken Routes: Left = S paghetti Diagram, Right = Generalized. This example demonstrates the high visibility starting point A1 in the transparent building model.

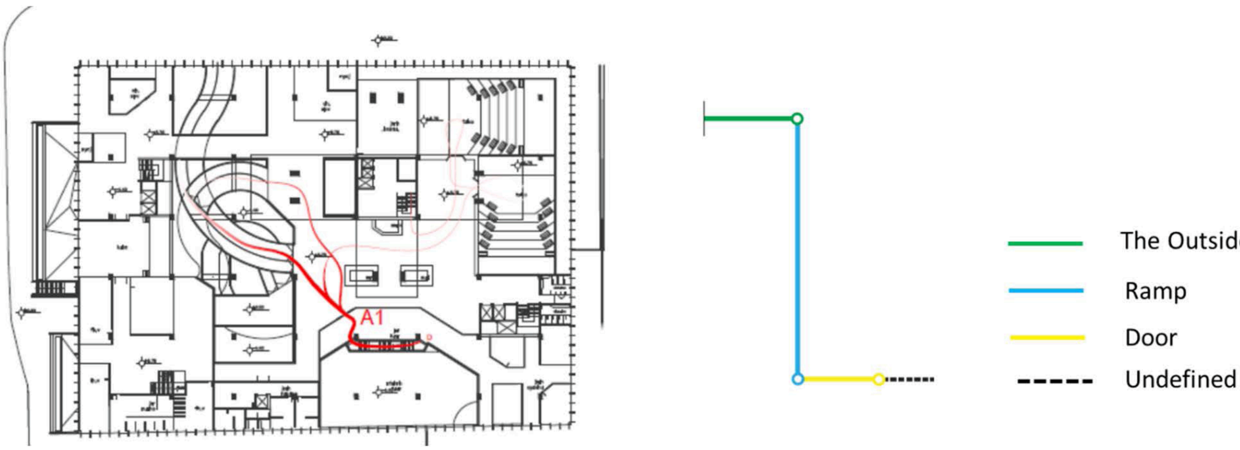


**Fig. 7.** Most Frequent Route and Influential Landmarks for Scenario A1(Scenario A1 has a high visibility starting point in the transparent building). Left: Spaghetti diagram; Right: Metro diagram.

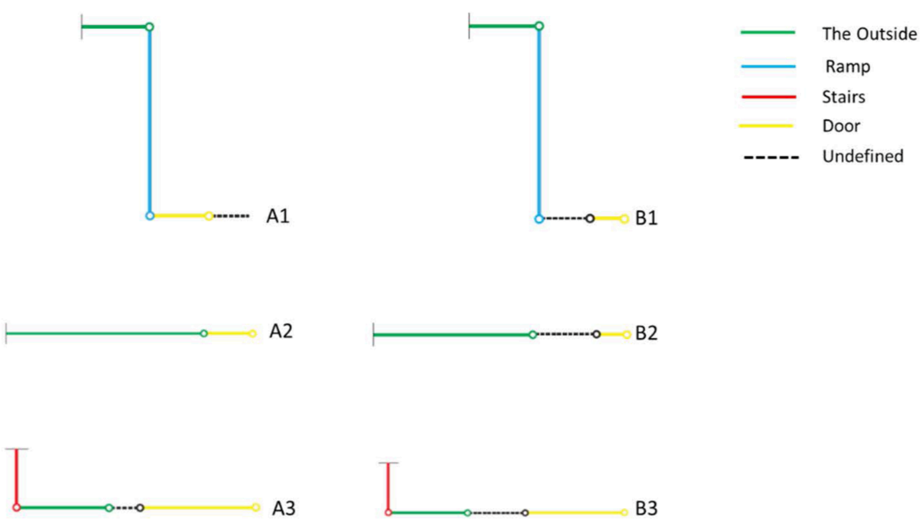


**Fig. 8.** Most Frequent Routes and Influential Landmarks for Scenarios with High Visibility Starting Points. Left: Transparent building; Right: Opaque building.

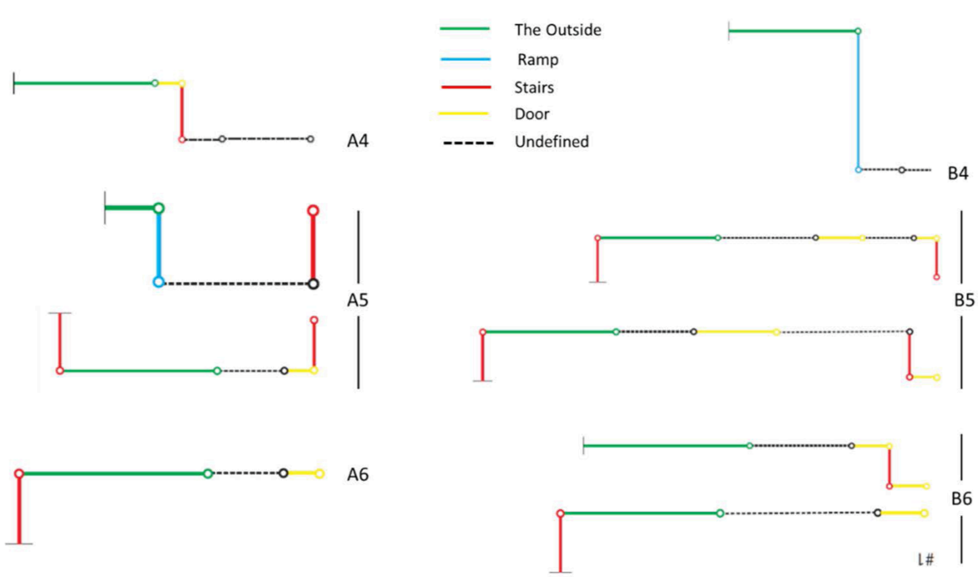


**Fig. 9.** Most Frequent Routes and Influential Landmarks for Scenarios with Low Visibility Starting Points. Left: Transparent building; Right: Opaque building.

**Table 9**
Difficulty of the evacuation scenario rated by participants.

| Structure | Transparent | | Opaque | |
|---|---|---|---|---|
| Starting point visibility | High | Low | High | Low |
| M (SD) | 5.3 (0.37) | 5.2 (0.26) | 5.6 (0.32) | 4.5 (0.33) |

Mean number of unnecessary level changes (and standard errors) are presented in numbers.
Participants were asked to rate each evacuation scenario after the experiment.

interaction between the impact of the high visibility and low visibility starting points was $p = .08$, suggesting that scenarios with poor visibility starting points in the structure with the opaque walls were rated as more difficult.

## 4. Discussion

In this study, we examined architectural features that influence indoor wayfinding during emergency evacuation situations and the manner in which this process unfolds. We developed two highly accurate virtual reality building models in order to examine the influence of wall transparency within a commercial center located in an urban environment. The first model was built mostly of transparent interior walls, while the second was comprised of opaque walls. We then used the two-way ANOVA statistical analysis to compare participants' performance in the VR setting and the predefined optimal escape routes according to the visibility of the starting point: one studied condition was a high visibility starting point, while the other was a poor visibility starting point.

The participants' chosen escape routes in the VR setting were analyzed with respect to the following performance measures: route duration, distance traveled, number of unnecessary turns, and number of unnecessary floor changes. In addition to examining the chosen routes, we also analyzed the participants' post-experiment input via a questionnaire, rating of route difficulty, and route sketching from memory. In doing so, we identified local and global architectural features (or landmarks) that influenced their spatial memory, choices and stated difficulty rating. Finally, we developed a method for illustrating the most frequently chosen routes and exploring the impact of the identified landmarks on these routes.

While wall transparency contributes to the improved visibility of a building, our results revealed that as an isolated architectural feature, wall transparency has no significant influence on emergency wayfinding – as the overall performance in the transparent building model did not yield significant differences in comparison to performance in the opaque building. This finding differs from previous research that indicates that visibility and visual access are important determinants of architectural vitality, spatial memory, and wayfinding behavior (Fisher-Gewirtzman, 2018; Fisher-Gewirtzman, 2019; Natapov & Fisher-Gewirtzman, 2016; Wang et al., 2014; Wiener et al., 2009). This difference may be the result of the type of visual properties studied as well as how they are quantified and measured. Previous research employs two techniques – Isovist, an area of the floor plan that is visible from a given point in the space (Davis & Benedikt,1979) and VGA, a method for computing the visibility of the floor plan grid points (Hölscher et al., 2006; Hölscher & Brösamle, 2007; Nilufar and Choiti, 2019; Tianfu et al., 2017; Zhu et al., 2020). Both techniques only take into account the floor plan configuration. In this study, however, we break the concept of architectural visibility into two components: the degree of visibility in relation to both the route starting point and wall transparency. Modifying wall transparency, as innovatively applied here, reproduces 3D visibility, which reflects a more accurate and reliable architectural experience.

Our results show that when combined, the starting point visibility and the wall transparency impact wayfinding behavior in relation to the escape duration, number of unnecessary turns, and number of unnecessary floor changes. For example, evacuation from a building with opaque walls combined with starting from a low visibility location was generally found to be more complex and more confusing and take longer. Moreover, the participants' subjective rating of route difficulty showed scenarios with poor visibility starting points and opaque walls to be the most difficult scenario for wayfinding. Therefore, overall visibility in the building only facilitates a more optimal evacuation route choice when the starting point offers good visibility.

We also demonstrated that the length of the chosen route when starting from the low visibility location was significantly longer in both transparent and opaque buildings. When disregarding the visibility of the walls, our study indicates that starting points have the greatest impact on the distance traveled. This finding is in line with studies that have addressed architectural layout in connection to wayfinding and evacuation and found that the visibility of particular locations has a vast impact on ensuring a safe and effective route (Haq & Zimring, 2003; Holscher et al., 2012; Nilufar and Choiti, 2019; Tianfu et al., 2017). However, these studies focused on final exits or corridor intersections (i.e., location anchors within the floor plan) and did not examine the starting point of the route – the place where the cognitive processes that underlie wayfinding actually unfolds when the initial spatial decision is first made. Here, for the first time, we demonstrated the importance of initial starting points for achieving successful wayfinding. These locations strongly influence the distance traveled by evacuees, which is critical in many cases of emergency situations. As such, our findings suggest that the chosen evacuation route is influenced by the visibility at the point where evacuation begins, regardless of the overall visibility in the entire building.

Our subsequent findings identified landmarks as playing an important role in wayfinding in emergency situations. While research on landmarks is not new, the problem of selecting and depicting relevant landmarks for each scenario remains unsolved (Binski et al., 2019; Krukar et al., 2017). In recent decades, particularly as landmarks have begun to appear in commonly accessible navigation systems, the need for formalizing landmarks that are pertinent for emergency evacuation and ways in which to communicate them has become readily apparent. Moreover, the term 'landmark' is often used as a categorical label for a range of concepts that are not always specified adequately (Montello, 2017). In this study, however, we were specifically interested in architectural features that play a role in emergency wayfinding and that can be classified as landmarks. Thus, when analyzing participants' questionnaires and sketched spatial memories, we found that global landmarks such as external buildings did not appear to impact the wayfinding process. Neither did local landmarks such as doors, windows and atriums. Only moving elements, staircases and ramps, were mentioned by the majority of participants and as such could perhaps be considered an important landmark in emergency wayfinding. This conclusion is in line with Memikoğlu and Demirkan (2020) and Hölscher et al. (2006), who found that staircases were recognized as important local architectural cues influencing spatial cognition. As such, this study demonstrates the human tendency to automatically seek and follow architectural elements that provide visual access and a way out – such as staircases – regardless of the overall visibility in the building. Therefore, the unsuitable location of staircases could be recognized as a major wayfinding obstacle and should be recognized when designing buildings and addressing emergency wayfinding.

By innovatively implementing two qualitative graphical techniques, *spaghetti diagram* and *metro diagram*, we post-processed frequently chosen routes and generated new ones that represent the most commonly chosen route segments. Analyzing these new aggregated routes enabled us to examine how they relate to the visibility of the starting points and landmarks previously identified. Surprisingly, no differences related to opacity and transparency of walls were found in the routes produced by the spaghetti diagrams, which appear identical in both the transparent and opaque building models. In line with our quantitative findings, our qualitative findings indicate that aggregated routes involved more unnecessary floor changes and turns in the case of low visibility. Moreover, in the case of high visibility starting points, new routes were exceedingly similar to the optimal evacuation routes, while the opposite was found with regards to poor visibility starting points. When analyzing landmarks presented along these routes, we found that in cases of high visibility, staircases and ramps were recurrent elements. Contrary to our supposition, greater variability of landmarks was found for low visibility starting points in both building models. In these scenarios, we saw the mention of more doors, stairs, ramps, and external buildings. This finding suggests that in more complex scenarios with low visibility, wayfinding requires additional assistance by way of architectural landmarks.

## 5. Conclusion

The intention of this study was to create a link between emergency wayfinding and architectural design. We pioneered the investigation of starting points and wall transparency, conducted a thorough examination of the influence of architectural elements that function as landmarks in emergency wayfinding. Overall, our results indicate that evacuation processes in conditions of poor visibility at the starting point combined with opaque walls are more difficult than evacuation processes with better visibility and transparent walls. While claiming that visibility and transparency prevent wayfinding errors (such as unnecessary turns or floor changes) may sound insignificant or trivial, this conclusion in fact diverges from previous research that primarily emphasizes overall visibility in a building. Moreover, it provides important insight into understanding architectural design as a complex multi-leveled system in which different architectural features form a set of structural relationships. When considered individually, no one factor – visual access, location, landmarks, or transparency – may guarantee unencumbered evacuation. Therefore, architectural design should be seen as a system of ‘organized and designed complexity’ in which a number of features interact simultaneously and are interrelated within an organic whole.

Finally, this study examined how particular architectural structures and features function as landmarks during evacuation. In the majority of existing studies in the field of spatial cognition, landmarks are treated as ‘atypical’ objects, not as a part of the overall typical design. Here, however, we open up a whole new discussion on how taxonomy of the architectural landmarks can be created, starting with staircases – as they were found to be the most prevailing feature. Understanding the conjunction of human behavior and architectural design in emergency evacuation is a significant concern for architects, researchers, educators, post-occupancy evaluators, and building managers. Improving wayfinding accessibility and creating building designs that are more user-friendly could greatly contribute to safety in public gatherings and spaces.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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