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Investigating the Impact of Staircases Rotation on the Evacuation Efficiency

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Abstract Most people use stairs during emergencies and evacuations. Therefore, this study addressed the impact of staircase rotation to minimize physical effort and evacuation time, hypothesizing that staircase rotation affects the evacuation speed and the safety of the occupants. This study consisted of two stages. In the first stage, a questionnaire was delivered to architects, with two key questions about the preferred direction in daily use and the other regarding evacuation cases. The second stage involved field experiments on two different staircases in the rotational direction, which were applied to 53 participants to measure the efficiency of the staircases in four cases (slow descent, slow ascent, fast descent and fast ascent). The counter-clockwise staircase during the field experiments showed better results and was more efficient. The heart pulse rate (pulse/min) in the clockwise case showed a clear increase compared to the counter-clockwise case by 12.89% for slow descending, 6.91% for fast descending, 21.51% for slow ascending, and 18.27% for fast ascending. Therefore, the theoretical and practical results of the study validated the hypothesis on the impact of the staircase rotation on user comfort and evacuation speed. Moreover, it was concluded that counter-clockwise staircases provided faster evacuation with less physical effort.

Keywords Architecture, Staircases, Evacuation, Staircase Rotation, High-rise Buildings, Building Codes, Schematic Design Phase, Architects

1. Introduction

1.1. Background

As a problem-solving activity, the architectural design process determines how well spatial orientation, rotation, and navigation skills of a built environment are understood. For example, staircases are critical local architectural indications that permit vertical circulation in multi-story buildings. In architecture, stairs serve as a vital circulation node, vertical connector, and means of transit between many levels. Furthermore, staircases help consolidate vertical information during movement and help users understand spatial organizations [1,2].

All architects should be familiar with the required local and international building codes; As this testimony from an architect suggests, architectural practices are impacted and formed by building regulations, codes, and standards, designed to ensure particular and predictable outcomes for all elements of architectural production, from the conceptual and schematic design phase to urban form [3,4].

Stairs are among the most significant environmental hazards. They are frequently related to falls, resulting in major injuries, concussions, and even death, which is especially concerning given the average person's time spent on stairs. Most people can cross a home staircase in 8-10s, and many are faster. This percentage doubled during the COVID-19 quarantine period when people worked from home. The stairs are likely used between 10 and 20 times a day, equivalent to five to six minutes, or approximately 0.6% of daily activity [5,6]. Therefore, the

International Building Code addresses the specifics of stairs construction, including their location, dimensions, materials, and structures [6].

1.2. Topic's Importance

Although urban areas are limited, population growth in cities continues worldwide [7,8]. Therefore, high-rise buildings have been developed to accommodate this increase [9]. According to the National Fire Protection Association and different building safety codes, buildings with 75 feet (approximately 23m) to 100 feet (approximately 30 m or 7–10 floors) are considered high-rise buildings [10]. Most high-rise buildings face similar overbuilding problems and over-habitation, leading to rapidly spreading fires that are more difficult to extinguish. Due to the high number of occupants, the successful evacuation of high-rise buildings is crucial in emergencies. During the evacuation, most people use stairs, leading to congestion [2,11]. Furthermore, older residents and slow children reduce the evacuation rate, further exacerbating congestion and slowing the evacuation process, eventually leading to stampedes [12-15].

Consequently, research on the evacuation behavior of high-rise buildings during evacuation is substantial. Therefore, the evacuation times must be investigated. The required safe exit time and the available safe exit time should be determined, considering that "required safe exit time" is always shorter than "available safe exit time." On the other hand, research should be conducted on the design of stairs and their effects on evacuation time and user behavior.

1.3. Study Questions

The study is based on a central question: What is the better rotation of stairs during evacuations? Moreover, it attempts to answer the main question: Are there differences between different staircase rotations (clockwise and counter-clockwise) that affect both time and comfort? Which rotation will provide the fastest time to escape with the least physical effort?

1.4. Study Hypotheses

This study hypothesized that the preference for counter-clockwise stair rotation might be due to generational traditions and habits. It can also be caused by the effect of the religious culture of society, especially in the Middle East, where religion plays an important role in daily life. The study tried to test these hypotheses to study their validity, which allowed us to choose the optimal solution that fits the rotation of the stairs, especially in the evacuation stairs, according to a scientific method away from the effects of inherited cultures. The study hypothesizes that occupants rush to the stairs immediately once emergencies occur, which require immediate evacuations, and assumes that the direction of rotation of the stairs can improve evacuations.

1.5. Study Problem

The greatest threat in buildings is the risk of spreading fire during the operation process, which raises several issues related to the importance of evacuation stairs (fire escape stairs) to save occupants' lives. A particularly challenging evacuation process occurs in high-rise buildings, which accommodate many occupants and have significant vertical travel distances. In an emergency, people require time to evacuate from their existing floor to a safe location [16,17].

The stairs design should consider emergencies and be prepared to receive the number of fleeing occupants. Although the importance of staircase design in this process is significant, the International Building Code neglects the impact of staircase rotations on the occupants during evacuation. In addition, architects in design schemes ignore the rotation of the staircase, despite there being a tacit agreement between them to prefer one rotation over another.

1.6. Study Objectives

This study sought to choose a better option for staircase rotation. The user's movement direction occurs during the schematic design phase. Consequently, due to the inherent stampede, danger, etc., accompanying evacuation, this study struggled to reach a decisive agreement for this rotation. The key objective is to facilitate user evacuation by minimizing physical efforts and exit time, maximizing safety.

1.7. Conceptual Framework

This study addresses the impact of rotation on users during the evacuation, in which time and comfort are significant. The applied section is made up of two parts. First, architects' questionnaires were used to determine the impact of culture and experience on design decisions. Second, an experiment with the occupants was conducted to determine the impact of the staircase rotation on them during evacuation. Finally, results, side notes, surveys, and observations are addressed in the discussion, leading to the conclusion section, where the paper summarizes the study and proposes further studies to validate the results using a larger sample size. The framework of this study is shown in Figure 1.

2. Literature Review

2.1. Topic Trends

In recent decades, new cities have begun to build more

buildings to alleviate the high demand for commercial and residential spaces [18]. Observably, notable buildings bring us countless conveniences, luxuries, and concealed risks. Once an emergency occurs (e.g., fires, chemical spills, environmental pollution, and natural disasters), evacuating all occupants safely and rapidly in buildings is a serious and central issue [19,20]. This emphasizes the importance of effective evacuation plans to minimize the number of casualties during emergencies [21]. Therefore, when designing new buildings and enforcing performance-based rules, it is crucial to understand the dynamics of human evacuation and population-based access to performance models to minimize the risk of occupants being exposed to critical conditions during a fire [22].

There are two main ways to evacuate buildings: stairs and elevators [23]. Some studies addressed people's preferences regarding evacuation by stairs or elevators. The disadvantage of evacuation elevators is that they cannot be used immediately; those evacuating must wait for the elevator to arrive. Another concern addressed in prior questionnaire surveys was the waiting time for evacuation elevators.

These studies show that people prefer not to evacuate via elevators during an emergency [24]. It is estimated that 90% - 97% of people will not wait more than 5 minutes. Common sense points out that using stairs to escape a building is the safest way. Furthermore, certain codes prohibit elevator usage during fire emergencies [23]. As a result, there was considerable interest in the impact of stairs on evacuation times. A few researchers have also studied stairs rushing to help evacuate as quickly as possible. Attention is paid to factors affecting occupant evacuation and footpath movements, such as the architectural geometry of the building, human characteristics, etc. [25,26].

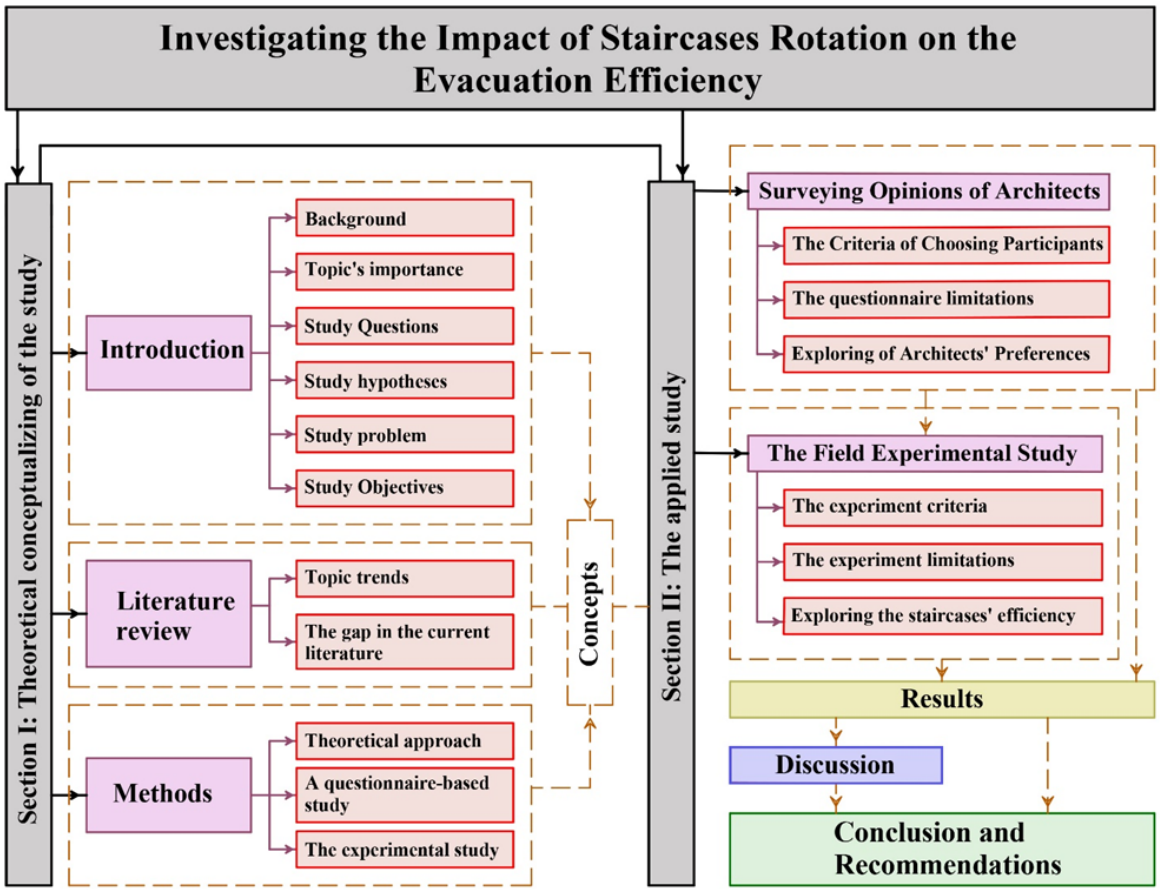

Figure 1. The conceptual framework (the paper structure) (the authors)

2.2. The Gap in the Current Literature

Stair design significantly affects evacuation procedures, which is rarely discussed in architectural literature. Unless it has been extensively covered in architectural publications, it can be harder to learn about or keep current when it has not been reported [27]. Although regulations are often based on scientific research, they have evolved slowly in certain cases. This represents deliberate attempts to balance the ideal and most common solutions [27]. The rotation of stairs can significantly affect movement efficiency and user experience. The impact can be significant if there is a clear user preference. However, the current building regulations neglect this issue [28]. There are opinions about which rotation of staircases users adopt and prefer; many reasons may explain this, for example:

- Our hearts turn slightly left. As a result, the center of gravity is on the left, and counter-clockwise rotation is preferable to alleviate the pressure on the heart. Furthermore, when the body is out of balance, it tends to fall toward the heart [29].
- The left leg is shorter for humans than the right leg due to rotation and the Northern Hemisphere. In addition, because the left leg supports the body more than the right leg, turning left is easier than turning right. [29].
- The ratio of right-handed people to left-handed people is greater than the opposite. As a result, the swing of the arms increases the movement speed, and the right hand is used more frequently. Thus, counter-clockwise rotation is the most advantageous in ascending [28].

Stairs are the most important local architectural symbols for vertical movement in multi-story buildings. In architecture, stairs are important circulation nodes and vertical interfaces that allow movement between different building levels [1]. The staircase is one of the most important aspects of good building design; moreover, architects must consider two important design parameters when designing these staircases. First, 'the construction and representation of the building should be highlighted concerning the functions of the building.' Second, the location of the stairs must be adapted to the activities of all those in the building [30]. Every occupant must have safe evacuation conditions, regardless of physical or mental characteristics [31]. However, most previous studies are related to adult evacuation behaviors, in which users are expected to be able to return to safety when they evacuate [22,32].

Scrambling up evacuation stairs can be exhausting and cause serious problems for evacuees [24]. For example, when the World Trade Center was evacuated on 11 September, several survivors reported that they had to stop and rest when they descended many floors using stairs [33]. Additionally, the interaction between evacuation and occupants is crucial in evacuations analysis. So, stair rotation is a significant factor in the efficiency and speed of evacuation. However, there are no guidelines in the International Building Code for choosing the rotation of stairs, and also, few studies have considered rotational factors and occupant preferences despite their significant importance [28].

Therefore, this study attempts to study the effect of staircase rotations (clockwise and counter-clockwise) on users, which will help scientifically prefer one direction over another. Furthermore, this study emphasizes time and comfort to speed up the evacuation process, minimizing casualties to the minimum level.

3. Methods

This study was carried out in three main phases, as shown in Figure 2. Each phase relies on a single method to achieve its detailed objectives, as follows:

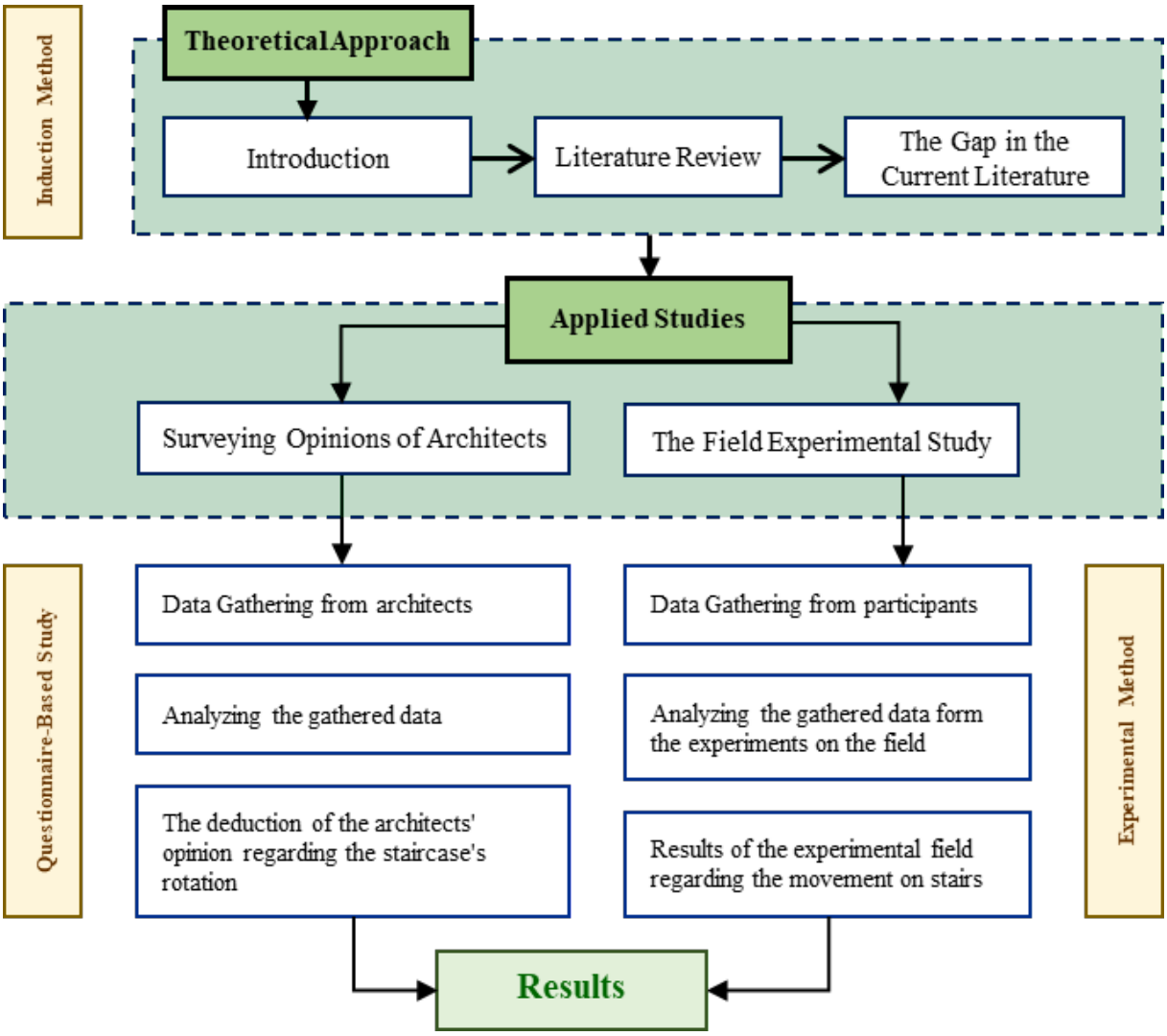

Figure 2. The scheme of the methodology of the study

3.1. Theoretical Approach

This study examined the impact of stairs' design on evacuation efficiency in the introduction and literature review, considering time and effort. Despite extensive literature reviews, there is a significant gap in the literature on this issue.

3.2. A Questionnaire-Based Study

As mentioned in the theoretical approach, staircase design plays a vital role in building design efficiency. However, it was found that professional architects neglected the impact of rotations and attributed the effect of rotations to their culture or religious reasons. This study analyzed the impact of culture, habituation, or misinformation on Middle Eastern architects.

According to professional architects, a questionnaire was designed to determine the effectiveness of staircase rotation preferences. This questionnaire-based study relied on a deductive-analytical approach, and the design of the form endeavors to minimize the study's limitations by considering individual differences.

3.3. The Experimental Study

The previous section addressed the impact of architect preferences on the design of staircases. This section uses the experimental approach to study the effect of staircase rotations on fatigue and the time it took the occupants to ascend and descend, considering evacuation. This experiment was based on measuring the heart pulse rate using a device (Beurer BM 26). It is hypothesized that the difference in the heart rate of each user would provide an overview of fatigue. This would help answer whether there are any comfortable and fast directions or its existence is just a myth. This research primarily aims to understand the most comfortable rotations of staircases to provide a fast and comfortable evacuation stair for occupants, especially in multi-story buildings.

4. Applied Studies

The applied section consists of two stages. First, a survey was conducted to review the opinions and expectations of professional Middle Eastern architects to study the validity of the proposed hypotheses. The second stage was a practical experiment with stairs users in the case of normal use and evacuation.

4.1. Surveying Opinions of Architects

It should be noted that the survey was conducted on a group of 113 professional Middle Eastern architects using the illustrated questionnaire in (Appendix 1), as follows:

4.1.1. Criteria of Choosing Participants

Criteria were developed to reduce the variables to the minimum required to achieve a reasonable amount of data to form the results, as follows:

- The architects are Middle Eastern with field experience and are familiar with the study context with more than two years of experience.
- There were no aspects of the questionnaires that were difficult to understand.
- Furthermore, all participants demonstrated a clear understanding of the questionnaires.

4.1.2. The questionnaire limitations

A spatial limitation affects the proposed survey, as the 113 architects were from the Middle East. Consequently, the answers given were limited by the effects of Middle Eastern and Islamic cultures.

4.1.3. Exploring Architects' Preferences

A survey was conducted based on two specific questions in serious situations, as shown in Figure 3. The first question was, "What is the best path from point A to B?" This question examines professional architects' preferences for staircase rotation. Therefore, their answers reflected the effect of experience on their design decisions. Furthermore, the study collected the reasons for their responses.

The second question concerns a serious situation: What if a fire at point B calls for immediate evacuation? What is your fastest path to reach point A safely?" This question examined professional preferences in emergencies and evacuations. Then, by comparing their responses to the two questions, the study could check whether there was a conflict in design decisions about preferences.

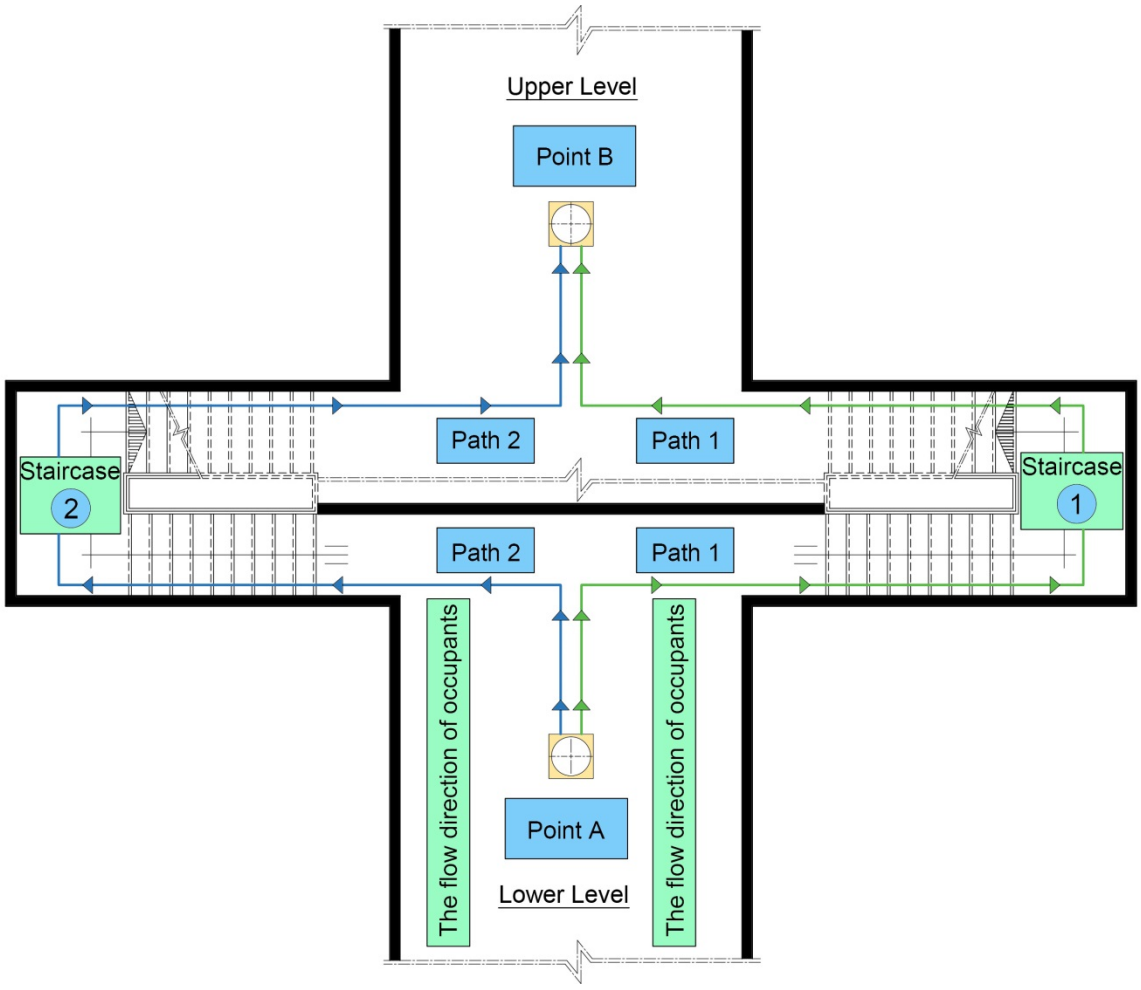

Figure 3. The plan of the staircases survey. Staircase 1: anti-clockwise Staircase 2: clockwise

4.2. The Field Experimental Study

A practical experiment was conducted on many participants (53 participants) to measure the efficiency of stairs rotation and its impact on user comfort during evacuation in four cases (slow descent, slow ascent, rapid descent, and rapid ascent). The experimental results were obtained by monitoring the difference in heartbeats as an indicator of the effort spent. The heart pulse rate is considered the measurement unit of the experiment, as the difference between the pulse rates reflects the effort exerted while using the stairs [34]. Furthermore, the time required to reach the end of the stairs in both rotations was measured.

4.2.1. The Field Experimental Study Criteria

The criteria were developed for participants who volunteered to reduce the variables to the minimum to achieve acceptable results and evaluate the results objectively.

- The participants' ages ranged from 23 to 30 years. The experiment was based on the effect of stairs on young people.
- Participants did not have genetic diseases or diseases that negatively affected their performance during the experiment, such as heart disease or high blood pressure.
- The observance of symmetry and conformity should be perfect in terms of heights and dimensions and good lighting and ventilation between the two types of staircases (counter-clockwise and clockwise).
- The same method was used for each participant to measure the heart pulse rate and the same device monitor (Beurer BM 26), as shown in Figure 4.

Figure 4. "Beurer BM 26" device, the tool used to measure heart pulse rate

- In addition, the calculation of the time taken to ascend and descend stairs was standardized.
- Calculate each case of stairs, whether ascending or descending (fast and slow), on separate days so that the effort expended on the results does not affect the rest.

4.2.2. The Field Experimental Study Limitations

These criteria directly benefited the results of the experiment but put the results under a set of limitations as follows:

- The experiment was conducted on 16 January 2022, at noon.
- This study analyzes the performance of stairs from an architectural perspective to understand all aspects of the architectural design of stairs concerning evacuation status.
- Another limitation of the study is the volunteers, as it focused on analyzing the youth but did not study the performance of stairs for the elderly or young.
- The stairs were "Dog-Leg stairs," with three flights and 19 steps (seven for the first flight, five for the second, and seven for the last flight). The width of the stairs was 110 cm, the depth of the treads was 28 cm, and the height of the riser was 15 cm. The landing was performed after seven steps, and the landing width was 110 cm and 250 cm in length, as shown in Figure 5.
- Perhaps the temperature of different seasons affected the performance of the volunteers.
- The experiment was carried out on one available staircase (Dog-Leg stairs with three flights), and the study did not test any other types of stairs. Furthermore, the study excluded the (straight flight stairs) type.

4.2.3. Exploring the Efficacy of Staircases in the Field

Each staircase was individually studied in a multi-story residential building. The study started by measuring the heart pulse rate before using the staircase and setting a stopwatch. After that, tell the volunteer that there is an emergency and that you must descend the stairs at a slow speed and calculate the time it takes you to reach the ground floor when you descend or the fourth floor when you ascend. Participants were instructed not to use stair handrails while ascending or descending.

On arrival, the heart pulse rate was measured again to observe the effect of stairs. The experiment was repeated the next day, but in the new case, he ascended at the same speed as he used the previous day. Participants were instructed not to use stair handrails while ascending or descending. The width, treads were 28 cm, and risers were 110, 28, and 15 cm, respectively. The stairs were "Dog-Leg stairs" with three flights with 19 steps (seven for the first flight, five for the second, and seven for the last flight). The landing was 110 cm wide and 250 cm long.

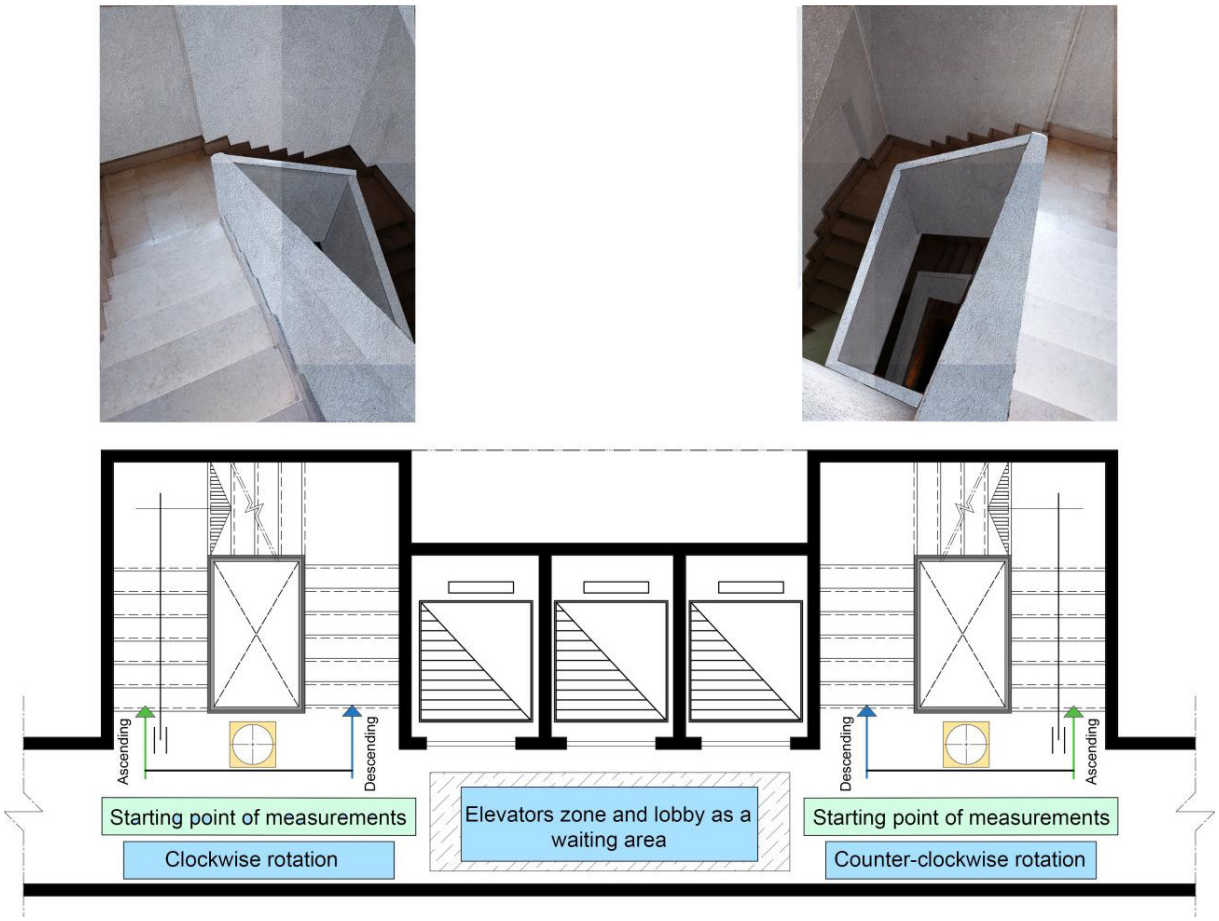

Figure 5. The experimental staircases, two mirrored staircases in a residential tower with a width of 110 cm, the treads were 28 cm, and the risers were 15 cm. The stairs were "Dog-Leg stairs," with 3 flights with 19 steps (7 for the first flight, 5 for the second)

The same experiment was repeated in the following days; however, this time, the participant descended and ascended quickly as the emergency was at its most serious. The same experiment was repeated on both stairs and with all participants. Collect data consisting of heartbeats before and after using the stairs and calculate the time to use them. Participants responded to a survey about how they felt when using stairs. Symptoms or complaints experienced during the experience were also compiled.

By calculating the averages for all participants, the results reflected the average efficiency of the stairs at the time of use during the evacuation, allowing the study to determine which was the most appropriate for the evacuation.

5. Results

5.1. Results of Opinions of Architects (Questionnaire)

According to professional architects, the survey's main purpose was to observe the rotation preferences of stairs. The participants were 53.8% female and 46.2% male, Figure 6. Based on the survey results, the study observed in the first question that 91.3% chose path 1, and 5.4% of the participants chose path 2. Although the International Building Code (IBC) did not specify a preferred rotation of staircases, only 3.3% chose that path 1 and Path 2 were the same despite their awareness of IBC, Figure 7.

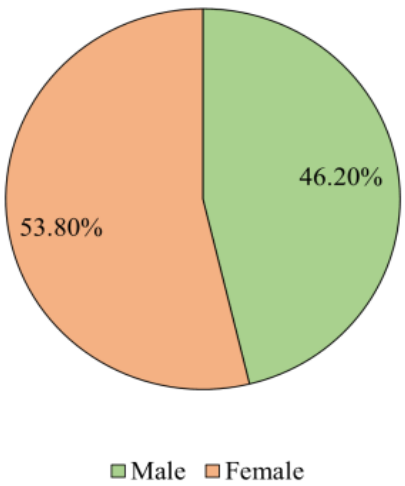

Figure 6. Participant's Gender

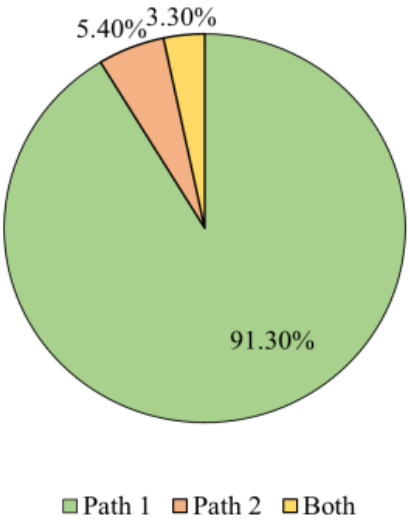

Figure 7. Question 1 results

The survey checked the reason for each choice and concluded that 34.62% referred to reasons for religious reference. Furthermore, 47.26% referred to the reasons for medical preferences and traditional habits, and 18.12% referred to design purposes and occupant behavior. They thought the right was the easiest direction for the occupants, and they thought most would find and expect it easily if the staircase was located on their right-hand side, Table 1.

Table 1. Reference of the choices for Question 1

Religion	Medical and Habits	Occupants' Behavior
47.26%	34.62%	18.12%

The second question in the survey was intriguing as it showed extreme disagreement and conflict of opinion despite the consensus in answering the first question of most participants. Although Path 2 was still ascending clockwise, 41.15% of participants decided it was the best escape, as it was only in the right direction. 55.63% of the participants preferred Path 1, as it was their first choice. Only 5.22% thought there was no difference between using Path 1 and Path 2, as shown in Figure 8.

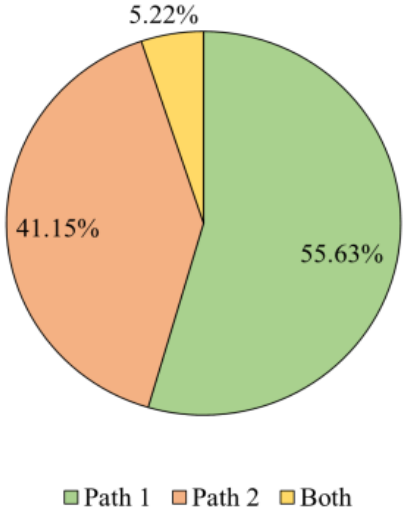

Figure 8. Question 2 results

5.2. Results of the Field Experimental Study

The results are summarized in Table 2, which lists the average rates. The experiment results showed differences between the efficiencies of the two stairs, as follows:

Table 2. Results of the average heart pulse rate and time for clockwise and counter-clockwise staircases regarding the movement on stairs

Cases of movement (speed)	The average heart pulse rate before using stairs (Pulse/min)	The average heart pulse rate after using stairs (Pulse/min)	The difference between before and after using stairs (Pulse/min)	Percentage (%) between before and after using stairs	The average time (second)/ Participant
For clockwise staircase					
Slow descending	89.15	105.40	16.25	18.23%	**48.33** sec.
Fast descending	88.17	107.27	19.10	21.66%	**32.06** sec.
Slow ascending	88.33	127.31	38.98	44.13%	**50.18** sec.
Fast ascending	88.65	137.41	48.76	55%	**28.86** sec.
For counter-clockwise staircase					
Slow descending	89.75	94.72	4.79	5.34%	**46.26** sec.
Fast descending	88.80	101.90	13.10	14.75%	**29.63** sec.
Slow ascending	88.86	108.96	20.1	22.62%	**47.36** sec.
Fast ascending	88.62	121.17	32.55	36.73%	**29.30** sec.

The difference in the increased heart pulse rate (Pulse/min) (clockwise staircase)		**Difference in time (second)/ participant (clockwise staircase)**	
Slow descending	12.89%	**Slow descending**	2.07
Fast descending	6.91%	**Fast descending**	2.43
Slow ascending	21.51%	**Slow ascending**	2.82
Fast ascending	18.27%	**Fast ascending**	-0.44

In the slow movement, the counter-clockwise is faster than the clockwise case on average by 2.07 sec. in descending and 2.82 sec. in ascending. The slow descent efficiencies for the clockwise cases were 83.13%, and the counter-clockwise cases were 94.19%. The counter-clockwise case was better in slow descending by 11.06%. The efficiency of slow ascending for the clockwise case was 43.96%, and the counter-clockwise case was 50.96%. The counter-clockwise case was better in slow ascending by 7.00%.

In the fast movement, the counter-clockwise movement is faster than the clockwise movement by an average of 2.43 sec. in descending order. However, the clockwise direction was unexpectedly faster by 0.44 sec. in ascending. The efficiencies of fast descent for the clockwise cases were 65.26% and for the counter-clockwise case was 83.90%. The counter-clockwise case was better for fast descent by 18.64%. The efficiency of fast ascending for the clockwise case was 29.24%, and for the counter-clockwise case was 42.51%. The counter-clockwise case was better in fast ascending by 13.27%, as shown in Figure 9. Additionally, Figure 10 shows the average time in seconds for each participant to finish ascending or descending stairs regarding the inputs of the experiment.

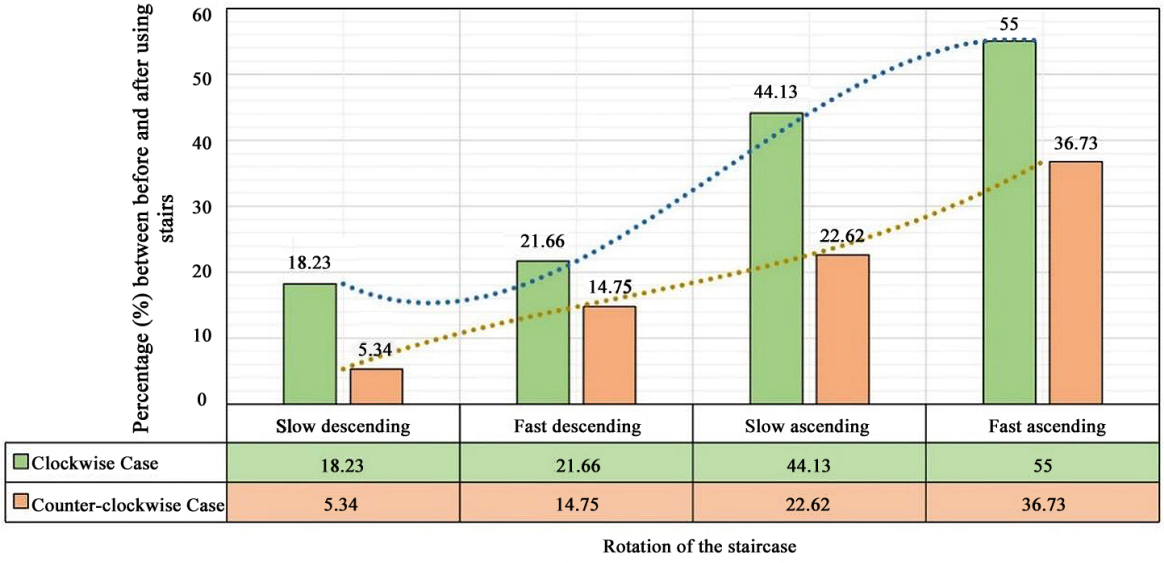

Figure 9. Percentage (%) between before and after using stairs

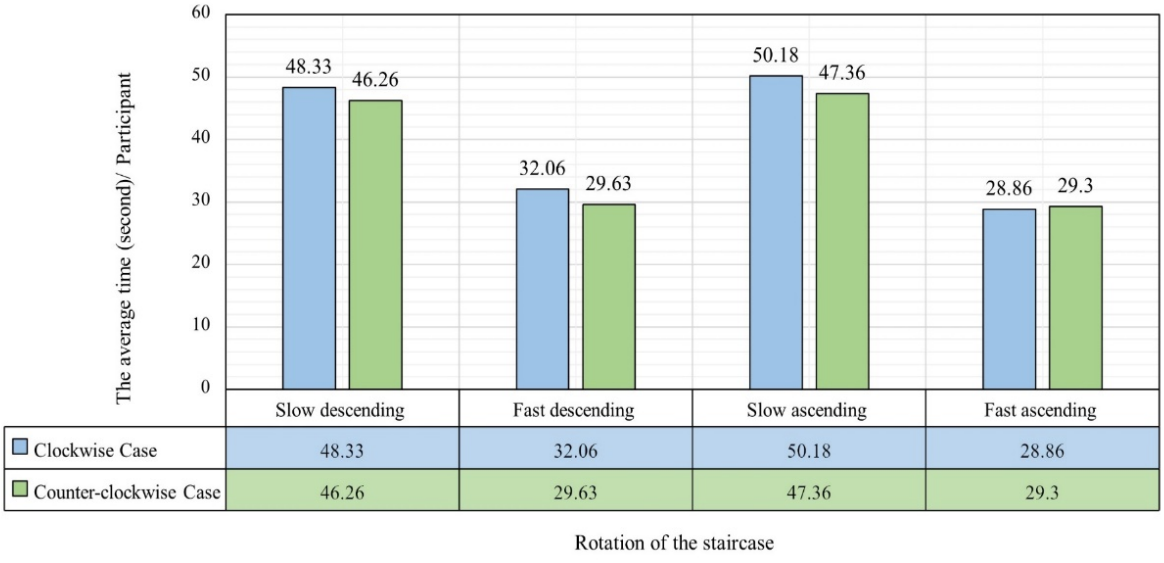

Figure 10. The average time (second)/ Participant

6. Discussion

6.1. Highlighting the Results

Although the IBC did not specify any preferences for staircase rotations, the study's survey found that 91.30% of professional architects fully believe that a counter-clockwise staircase is more comfortable and faster than a clockwise one ascending. They do not know exactly why they choose the counter-clockwise direction. However, the surveys found that 34.62% of the participants referred to religious reasons in the right direction, and the choices had an expressive and influential value in many decisions in Middle Eastern society. 47.26% of the participants thought that counter-clockwise was better for medical reasons. They had never experienced it before, so the study referred to their reasons for inherited habits and experiences without knowing the real reason.

Although there is almost a complete agreement on the counter-clockwise preference in the ascending condition, the study observed a significant difference in descending conditions. The ratio was reduced to approximately 55.63%, and 41.15% chose the right direction; however, this was a clockwise rotation. There were no significant differences in the reasons for the two situations, allowing the study to observe the effect of stair rotations on evacuations.

The experiment was based on a study of the impact of stair rotation on users. Each participant ascended and descended stairs slowly and quickly on different days. By calculating the time taken to complete the staircase and the difference in heartbeat rate as a criterion for the effort expended, this study can determine the efficiency of the staircase. The experiment was based on a test of four floors in a multi-story building. The evacuation was considered a case study of the experiment.

At a slow descending speed and before using stairs, the average heart pulse rate was 89.15 pulse/min for the clockwise case and 89.75 pulse/min for the counter-clockwise case. After completing the stairs, the heart pulse rate was measured as an expression of the exerted effort and calculated each participant's ending time. The heart pulse rate was increased on average to 105.40 pulse/min for the clockwise case, and the end time was 48.33 sec. Moreover, it increased to 94.72 pulse/min for the counter-clockwise case, and the ending time was 46.26 sec. The difference between the two averages indicated an increased effort for each participant.

Consequently, the effort exerted for the clockwise case was 16.25 pulse/min, representing 18.23% ((105.40-89.15)/89.15×100). Furthermore, the effort exerted for the counter-clockwise case was only 4.79 pulse/min, representing 5.34% ((94.72-89.75)/89.75×100). Therefore, the increased heart pulse rate difference showed that participants made 12.89% more effort in the clockwise case than counter-clockwise. Moreover, they were late by 2.07 sec. / participant on average. As a result, the counter-clockwise case was the best option for descent slow-speed usage.

At a fast-descending speed and before using the stairs, the average heart pulse rate was 88.17 pulse/min for the clockwise case and 88.80 pulse/min for the counter-clockwise case. After completing the stairs, the heart pulse rate was measured as an expression of the exerted effort and calculated each participant's ending time. The heart pulse rate was raised on average to 107.27 pulse/min for the clockwise case, and the ending time was 32.06 sec. Moreover, it increased to 101.90 pulse/min for the counter-clockwise case, and the ending time was 29.63 sec. The difference between the two averages indicated an increased effort for each participant.

Consequently, the effort exerted for the clockwise case was 19.10 pulse/min, representing 21.66% ((107.27-88.17)/88.17×100). Furthermore, the effort exerted for the counter-clockwise case was only 13.10 pulse/min, representing 14.75% ((101.90-88.80)/88.80×100). Therefore, the increased heart pulse rate difference showed that participants made 6.91% more effort in the clockwise case than counter-clockwise. Moreover, they were late by 2.43 sec. /participant on average. As a result, the counter-clockwise case is the best option for descent fast-speed usage.

At a slow ascending speed and before using stairs, the average heart pulse rate was 88.33 pulse/min for the clockwise case and 88.86 pulse/min for the counter-clockwise case. After completing the stairs, the heart pulse rate was measured as an expression of the exerted effort, in addition to calculating the ending time for each participant. The heart pulse rate was increased on average to 127.31 pulse/min for the clockwise case, and the ending time was 50.18 sec. Moreover, it increased to 108.96 pulse/min for the counter-clockwise case, and the ending time was 47.36 sec. The difference between the two averages indicated an increased effort of each participant.

Consequently, the effort exerted for the clockwise case was 38.98 pulse/min, representing 44.13% ((127.31-88.33)/88.33×100). Furthermore, the effort exerted for the counter-clockwise case was only 20.10 pulse/min, representing 22.62% ((108.96-88.86)/88.86×100). Therefore, the increased heart pulse rate difference showed that participants made 21.51% more effort in the clockwise case than counter-clockwise. Moreover, they were late by 2.82 sec. / participant on average. As a result, the counter-clockwise case was the best option for ascending slow-speed usage.

At a fast ascending speed and before using the stairs, the average heart pulse rate was 88.65 pulse/min for the clockwise case and 88.62 pulse/min for the counter-clockwise case. After completing the stairs, the heart pulse rate was measured as an expression of the exerted effort, in addition to calculating the ending time for each participant. The heart pulse rate increased on average to 137.41 pulse/min for the clockwise case, and

the end time was 28.86 sec. Moreover, it increased to 121.17 pulse/min for the counter-clockwise case, and the ending time was 29.30 sec. The difference between the two averages indicated an increased effort of each participant.

Consequently, the effort exerted for the clockwise case was 48.76 pulse/min, representing 55.00% ((137.41-88.65)/88.65×100). Furthermore, the effort exerted for the counter-clockwise case was only 32.55 pulse/min, representing 36.73% ((121.17-88.62)/88.62×100). Therefore, the increased heart pulse rate difference showed that participants made 18.27 more effort in the clockwise case than in the counter-clockwise case. However, they reach early by 0.44 sec. / participant on average. As a result, the counter-clockwise case was the best option for ascending fast speed usage of exerted effort, but the clockwise case was better for reaching early.

According to the results of the field experiments, the counter-clockwise staircase is a better option for evacuation in both cases (descending and ascending). It is the most efficient of the two rotational cases because it provides a fast way to reach safety with minimal effort. Although these results are based on a field experiment conducted on only four floors in a multi-story residential building, the study assumes that the efficiency of the counter-clockwise staircase will be improved more than that of the clockwise case as the number of floors increases.

6.2. Observations and Recorded Side Notes

During the study, three side notes were recorded, which are compatible with other researchers regarding the behavior of users on the stairs during the evacuation, as follows:

- It is an interesting observation regarding the behavior of user movements during evacuation. It was found that the first (2-3 treads) and last two before (landing) are used for pacing the movement. In addition, users jump above the middle treads at high speeds on the stairs. The movement behavior is shown in Figure 11.

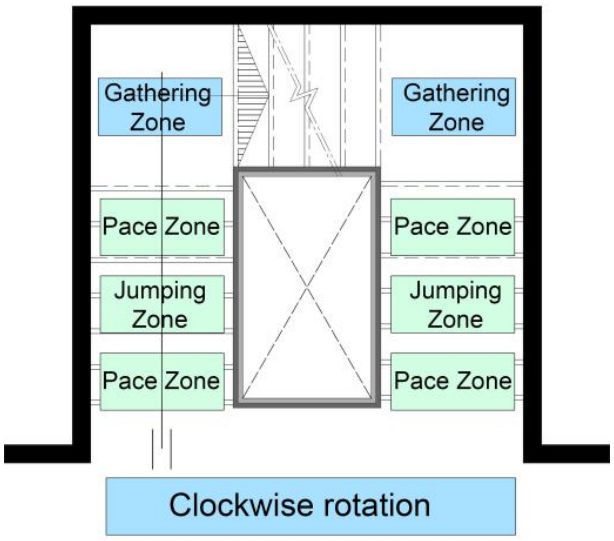

Figure 11. Movement behavior of users on staircases during the evacuation

- A high percentage of participants, approximately 70%, was observed to move in the "inside" direction, as shown in Figure 12, rather than outside the stairs. This observation is generally agreed upon, as outlined in previous studies [23,35,36].

Figure 12. the stairs inside and outside directions

- These observations are particularly relevant for two reasons: pedestrians tend to use shorter paths to evacuate (they are always in the inside direction). Moreover, compared to walls, handrails are easier to hold, which improves balance during movement. Furthermore, moving inside during evacuation beside handrails, especially the right-handed strategy in descending, as appears in the counter-clockwise staircase, helps prevent pedestrian collisions with firefighters, who find their way (outside) empty.
- Previous studies [1,37-40] have mentioned that females tend to refer to landmarks more frequently than males to find their way, especially in new environments. On the contrary, men use both geometric and landmark information. When the distance and the landmarks are equal, there is no difference between the gender preferences. However, the study found that the females were more oriented toward the right path than the males. During the experiment, the women scored well when choosing the right staircase as the most comfortable, and their choices varied depending on the direction of ascent or descent. However, this difference was not evident among professional architects during the survey.

7. Conclusions

Building evacuation behavior requires extensive research since most people take the stairs during the evacuation, causing congestion and stampedes. The International Building Code provides guidelines on where, how, and what stairs should look like, and the rotating stairs during an evacuation are not considered. Despite disregarding building codes, most professional architects and architectural study materials assert that the counter-clockwise case is more efficient than the clockwise case. The design of stairs should minimize the safe exit time relative to the available exit time with the least effort. Thus, this study struggled to reach a consensus on the effect of staircase rotation on user safety by minimizing physical effort and evacuation time.

The applied section comprises two stages. The first was a questionnaire of 113 professional Middle Eastern architects. It was conducted based on two specific questions to identify the preferences for staircase rotation according to professional architects and to reflect on the impact of experience on their design decisions and its effect on evacuation.

The second stage of the study involved 53 participants in a field experiment to measure staircase rotation efficiency and impact on user comfort during an evacuation under four conditions (slow descent, slow ascend, fast descent, and fast ascend). The efficiency of the staircase rotation is determined by measuring the difference between the heart pulse rate before and after using the staircase and the time it takes to end the stairs.

At the slow movement speed, the counter-clockwise case was faster than clockwise on average by 2.07 seconds in descending and 2.82 seconds in ascending order for each participant. Moreover, results show that the clockwise case's effort was 12.89% in descending and 21.51% in ascending, more than the counter-clockwise case. Furthermore, at the fast movement speed, the counter-clockwise case was faster than clockwise on average by 2.43 seconds in descending. However, the clockwise case appeared to be faster by 0.44 sec. in ascending order compared to the counter-clockwise case. In addition, results show that the clockwise case's effort was 6.91% in descending and 18.27% in ascending, more than the counter-clockwise case. Consequently, the counter-clockwise staircase during the field experiment showed better results and was more efficient than the clockwise case, making it more suitable for evacuating occupants in a faster time with the least effort, proving the validity of the research hypothesis.

This study revealed the impact of staircases' rotation and user behavior during the evacuation, and it aimed to prove its findings with practical measurements in a field experiment. This highlights the importance of constructing a stair consistent with users' behaviors and their vital effectiveness in evacuation. This study addressed the neglect of staircase rotations in international building codes.

For future studies, this topic should be validated with larger sample size, focusing on:

- The sample size should be increased to include larger age groups to study the effect of the rotation of stairs on different age groups and then compare the research results and increase their precision.
- Testing both staircase rotation cases during one evacuation.
- Doing more practical experiments at higher buildings to overcome the study's limitations and increase the accuracy of the results.
- Studying the effect of thermal factors on volunteers.
- Studying the effects of different stair shapes (i.e., L-shaped, spiral staircases, etc.).

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Data Availability Statement

The data files collected can be obtained from the second author on request.

Conflicts of Interest

The authors declare that they have no conflict of interest.

Appendix 1

I invite you to voluntarily answer the questions embedded in the questionnaire as an expert. My research on the impact of staircase rotation partially depended on the data gathered. This questionnaire has five multiple-choice questions and three open-ended questions. Approximately 10 min were required to be completed.

Your help is greatly appreciated.

Additionally, if possible, I would appreciate it if you shared this survey with architecture and urbanism expert groups.

Firstly, the multiple-choice questions

Q1: What is your gender?

A. Male ☐

B. Female ☐

Q2: How many years of experience do you have in architectural design?

A. 2-5 years ☐

B. 5-10 years ☐

C. 10-15 years ☐

D. Over 15 Years ☐

Q3: where are your projects located?

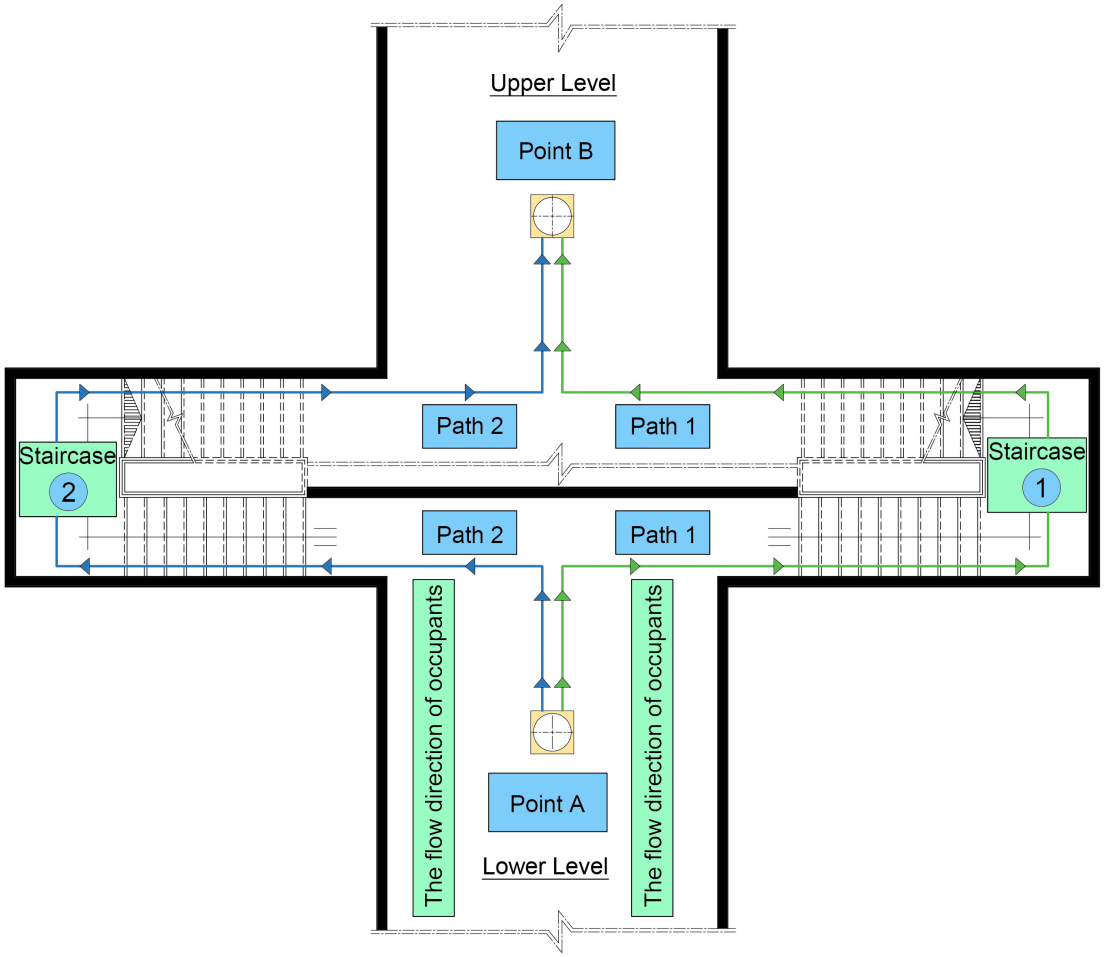
A. Middle-East ☐

B. Globally ☐

Q4: What is the most comfortable path to ascend from Point A (lower level) to Point B (upper level) in the following figure?

A. Path 1 ☐

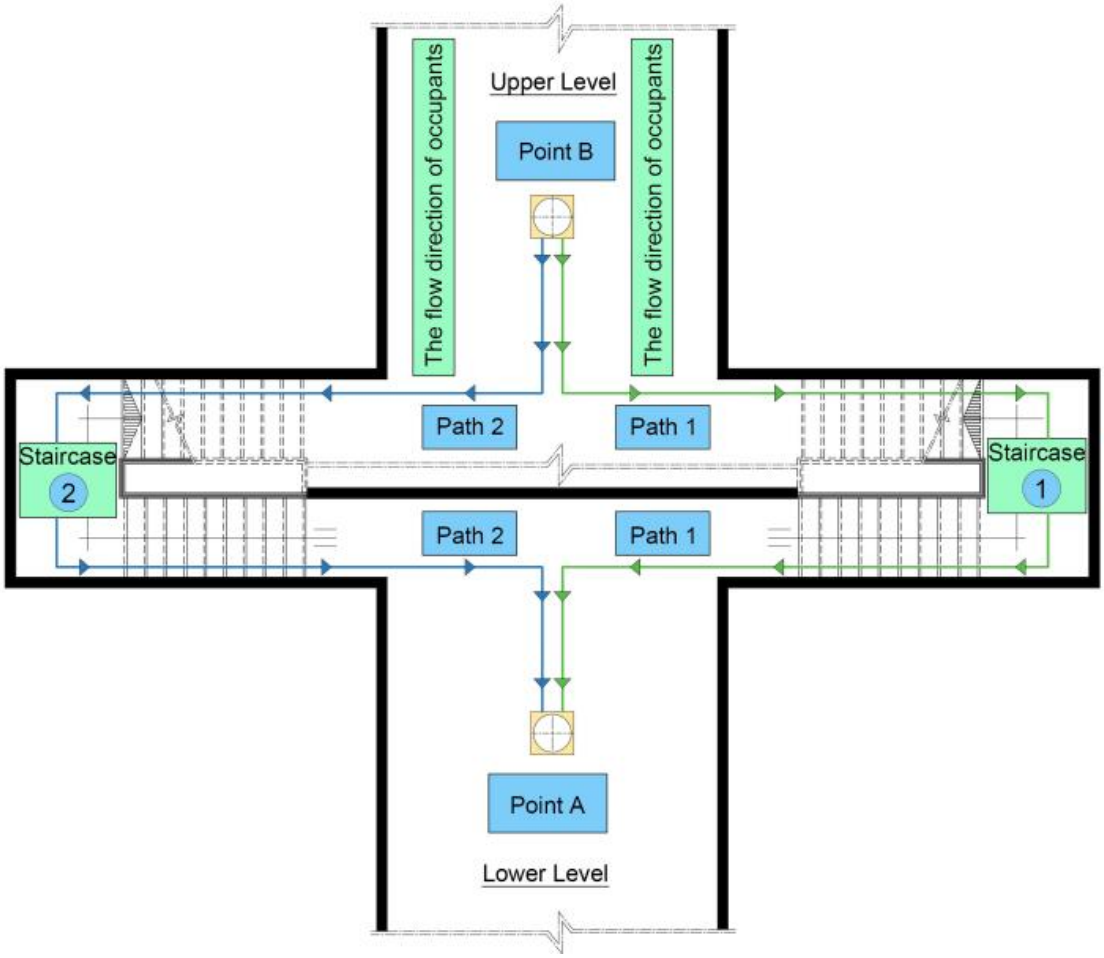
B. Path 2 ☐



Q5: What if a fire at Point B (upper level) calls for immediate evacuation? What is the fastest path for you to reach point A (lower level)?

A. Path 1 ☐

B. Path 2 ☐



Secondly, the open-ended questions

Q6: Why do you think this path is the best?

Q7: Please, illustrate your preference.

Q8: Is there anything else you'd like to add?

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