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Evacuation Problem in Mosque Buildings, The Case of Konya Hacıveyiszade Mosque

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Abstract

Evacuation of assembly buildings in emergencies such as earthquake, fire and terror is very important to prevent major casualties. To evacuate the building smoothly, it's necessary to realize the right architectural design. There are very few studies both national and international literature on evacuation of mosques in emergencies. The aim of this study is to contribute to literature by a case study on emergency evacuation of mosques. Within the scope of the study, Hacıveyiszade Mosque which is located in the city center of Konya is examined. The mosque was evaluated using a simulation study. According to the findings obtained from the simulation, the evacuation of the mosque was completed in 10 min 48s and the evacuation could not be achieved within the safe evacuation time (2.5 min) specified for this class of buildings. In this context, suggestions made to improve the evacuation performance of the Hacıveyiszade mosque.

Keywords: *Building evacuation simulation, simulation study, mosque architecture, pathfinder, assembly buildings*

Cami Yapılarında Tahliye Problemi, Konya Hacıveyiszade Cami Örneği

Öz

Toplanma amaçlı yapıların deprem, yangın, terör gibi acil durumlarda tahliye edilmesi büyük can kayıplarının önüne geçilebilmesi için çok önemlidir. Acil durumlarda yapının sorunsuz bir biçimde boşaltılabilmesi için doğru mimari tasarımı gerçekleştirmek gerekir. Camilerin acil durumlarda tahliye edilmesi üzerine ulusal ve uluslararası literatürde çok az çalışma bulunmaktadır. Bu çalışmanın amacı camilerin acil durum tahliyesi konusunda bir alan çalışması gerçekleştirerek literatüre katkıda bulunmaktır. Çalışma kapsamında Konya kent merkezinde yer alan Hacıveyiszade camisi incelenmiştir. Cami, benzetim çalışması ile değerlendirilmiştir. Simülasyondan elde edilen bulgulara göre caminin tahliyesi 10dk 48sn'de tamamlanmış ve bu sınıftaki yapılar için belirlenmiş olan güvenli tahliye süresi içinde (2.5 dk) sağlanamamıştır. Bu bağlamda Hacıveyiszade camisinin tahliye performansının iyileştirilebilmesi açısından öneriler sunulmuştur.

Anahtar Kelimeler: *Bina tahliye simülasyonu, benzetim çalışması, cami mimarisi, pathfinder, toplanma amaçlı yapılar*

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1. Introduction

Mosque buildings, which were born out of the necessity of worshiping collectively in the religion of Islam, have turned into buildings that gather more and more people in the same place because of the gathering large populations in cities. İstanbul Çamlıca Mosque, which was opened in 2019, was designed with a capacity of 63,000 people. Although this number means thousands of people being together in a closed area at the same time, it also brings some risks. It is very important to realize the architectural design that will guide a large number of people correctly in situations that require emergency evacuation of occupants such as earthquakes, fire and terror. Mosques are also buildings that emergency evacuation have great importance, as they are buildings where such large groups of people come together. For example, in an emergency such as a fire, limited number of exits and wrong architectural design may bring poisoning by causing people to stay indoors for a long time, while also leads to deaths by crowd congestion (Liu, Xu, Lu & Zhang, 2018).

There are very few studies in the literature regarding the safe evacuation of mosques. In the study of Alighadr, Fallahi, Kiyono, Rizqi & Miyajima (2011), a mosque in Tabriz was evaluated in terms of exit widths and the number of people in the mosque. Nassar & Bayyoumi (2012) evaluated the number of exits and locations in mosques through different alternatives. Another study is the research of Alighadr & Fallahi (2016) in which a mosque in Azerbaijan was evaluated. The only work on the safe evacuation of mosques in our country is Sedihemaiti's (2018) master's thesis. In this study, three traditional Sinan Mosques and Ankara Mevlana Mosque were evaluated. This research’s Ankara Mevlana Mosque part was published by Topraklı, Sedihemaiti & Ağraz (2019). It was determined that the mosque could not be evacuated within the safe evacuation period.

Due to the limitation of evacuation studies in mosques, it is very important to increase the number of studies on this subject. The purpose of this research is to make a concrete contribution to the risk assessment of today's mosque designs by obtaining numerical data on the safe evacuation of mosques through case study. Within the scope of the study, Konya Hacıveyiszade mosque, which was opened in 1994 and is one of the most widely used mosques in Konya today, was examined (Figure 1).

Figure 1. Konya Hacıveyiszade Mosque (Turkish Religious Foundation, 2017)

2. Materials and Methods

In order to evacuate occupants from the building as soon as possible, emergency exit routes of the building should be easily accessible and designed in dimensions suitable for escape. In addition, emergency exit spaces should be designed without obstacles (Sedihemaiti, 2018). In the 70's, researchers started to work on human behavior during the fire, pedestrian movement and modeling of this movement. These studies, conducted between the 70's and the 80's, are still the core of the literature on this subject. In these studies, the fluidity of the pedestrian movement was emphasized, and the pedestrian movement on the plan was considered as a fluid, and the factors such as the distance of the occupant to the exit, the movement speed of the occupant in corridors, doors and stairs were evaluated. In subsequent studies, it was seen that human beings abandoned the structure because of complex processes such as making decisions before starting a movement and heading towards exit, and the first computer-based software that enables more complex modeling has emerged. Thus, in the 90's, it has become possible to make more accurate simulation studies by reflecting human behaviors to modeling (Ronchi & Nilsson, 2016). Today, there are many softwares in which different techniques are used for emergency evacuation simulation work such as FDS + Evac, Building EXODUS, STEPS, Pathfinder, Gridflow ve Simulex.

There are certain factors that affect the evacuation time of buildings. These are occupants, architectural design and surrounding factors. The occupant is a factor that includes many variables. The emergency behavior of the occupant depends on many variables such as gender, age, anthropometric characteristics, and psychology. For this reason, emergency behaviors of different societies differ from each other. The architectural form, the correct design of horizontal and vertical circulation is among the factors that affect the evacuation period. Factors such as the correct determination of door widths, using outswing doors, ensuring fire protection of escape routes determine the evacuation period. In buildings with galleries, emergency exit stairs should be designed outside the atrium, since the spread of smoke occurs rapidly in the gallery. It is important to pay attention to this principle, since almost all mosque structures have an atrium. The third factor affecting the evacuation time is surrounding factors. These effects are factors such as breathing difficulties and vision impairment caused by smoke and toxic effects that occur during fire (Çakıcı Alp, 2011).

Considering the international safe evacuation studies for assembly buildings, it is safe to evacuate one or two-story buildings within 2.5 minutes (150 seconds) in case of emergencies (Topraklı et al., 2019). Mosque buildings are classified as assembly buildings. Konya Hacıveyiszade mosque picked as a case study and checked by the help of the simulation study that it was exceeded or not the safe evacuation time.

2.1. Hacıveyiszade Mosque

Hacıveyiszade Mosque is located at the junction of Ahmet Hilmi Nalçacı and Vatan Street, one of the busiest streets of Konya (Figure 2). It is an important part of Konya's new city center and it should be evaluated as the "Jumuah mosque" that serves to the large public buildings around it (Oral, 1993). Opened in 1996, the mosque is still used intensely today, as it is located in the city center where commercial and public buildings are located.

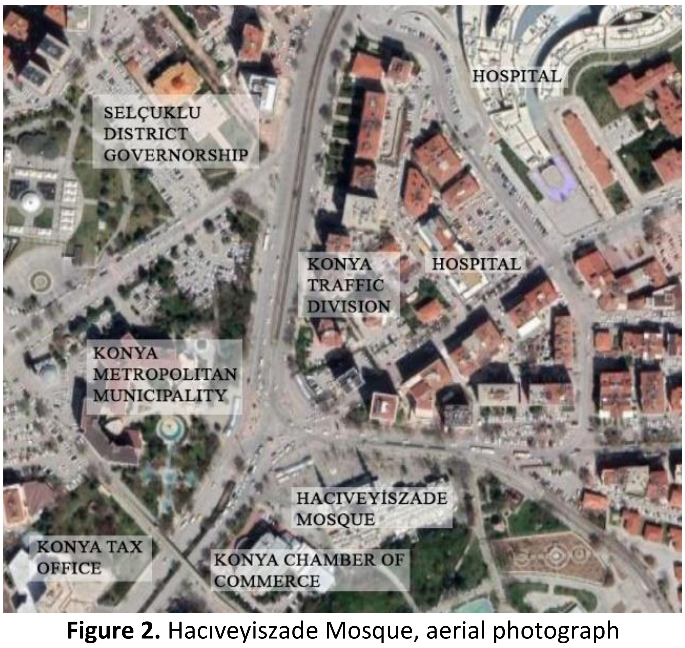

Figure 2. Hacıveyiszade Mosque, aerial photograph

The plan scheme of the mosque consists of a central domed main prayer hall and a narrow and long portico narthex located in front of the main entrance (Figure 3). The mihrab part of the qibla wall is designed to extend beyond the main form. There are three entrances on the northwest façade, one of which is the main door (Figure 4). These entrances open to a rectangular shoe rack area. Three different doors are opened to the main prayer hall. Muezzin’s and imam’s rooms are located on both sides of the shoe rack area. The women's prayer hall on the mezzanine floor is accessed through two symmetrical entrances from the northeast and southwest façades of the mosque. These entrances lead to the shoe rack area with an “L” shape stairs. It is also possible to reach the main prayer hall on the ground floor from this space. The women's prayer hall is designed in a "U" shaped form, facing the atrium (Figure 5).

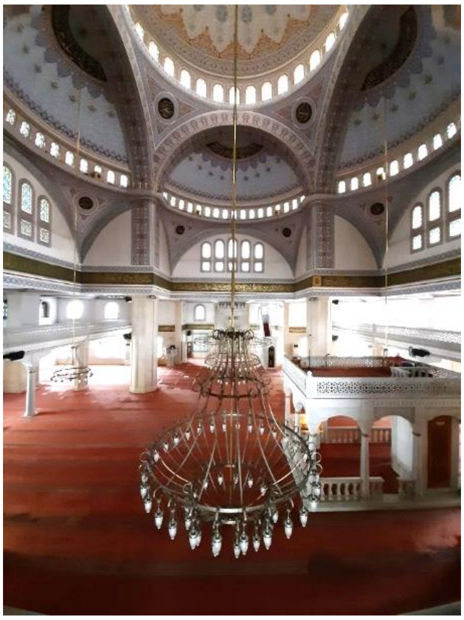

Figure 3. Hacıveyiszade Mosque, interior view (Azkur, 2020)

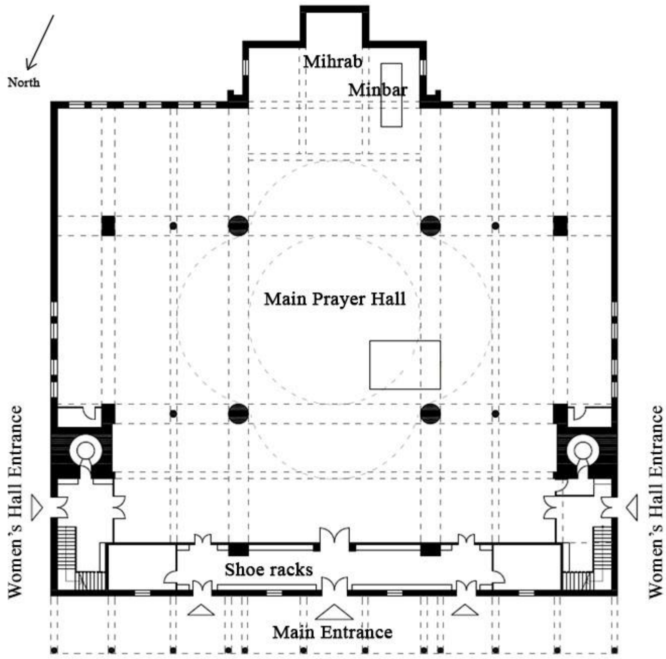

Figure 4. Hacıveyiszade Mosque, ground floor plan

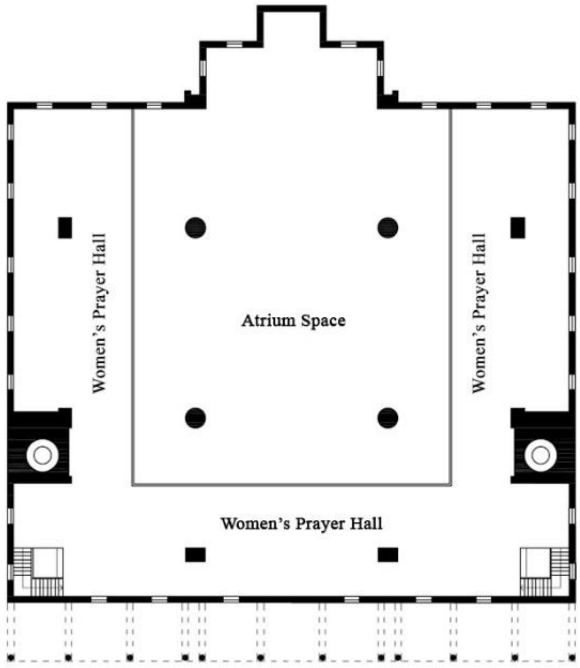

Figure 5. Hacıveyiszade Mosque, mezzanine floor plan

If the design of the mosque is summarized in the context of horizontal and vertical circulations; there are three entrances at the northwest façade and two entrances at the northeast and southwest façades. Vertical circulation consists of two stairs that reach the women's prayer hall. All the doors were used in the mosque are inswing door type.

2.2. Method of Research

Simulation study was chosen as the research method and Pathfinder software was used for the simulation. Pathfinder is an agent-based evacuation and human movement simulator. It provides graphical user interface for simulation design and implementation and two and three dimensional visualization tools for result analysis (Pathfinder User Manual, 2014). Pathfinder software preferred for the simulation since it is widely used in the literature recently.

Occupants' movement mode mainly includes Society of Fire Protection Engineers (SFPE) and Steering model in Pathfinder. The choice of evacuation route is defined that take the walking path length as the primary reference standard in SFPE mode. The occupants will pick exit according to nearby principle. In the process of simulation, it can automatically identify evacuation space density to adjust occupants speed. In this mode, the gate restricts the occupant flow; The steering system in Pathfinder moves occupants so they accomplish their current movement goal and can respond to changing environment. The evacuation strategy is formulated by combining route plan with occupant collision, and the path is determined according to the evacuation distance and the distance between occupants. In addition, gates do not restrict the occupant flow (Qin, Liu & Huang, 2020).

SFPE mode is preferred for this study. This mode implements the flow-based egress modeling techniques presented in the SFPE Handbook of Fire Protection Engineering and the SFPE Engineering Guide: Human Behavior in Fire. The SFPE calculation as described in the handbook is a flow model, where walking speeds and flow rates through doors and corridors are defined. In Pathfinder, navigation geometry can be grouped into three types of components: doors, rooms, and stairs. Rooms are open space on which occupants can walk. Stairs can be thought of as specialized rooms in which the slopes of the stairs limit the speed of the occupants. Doors are flow limiters that connect rooms and stairs. There is no specialized corridor type as in the SFPE guide. Instead, corridors are modeled as rooms with doors on either end. In this manner, corridors are handled in the same manner as rooms, with the flow being controlled by the doors (Pathfinder Technical Reference, 2014).

In SFPE Mode, the following parameters are used automatically.

Max Room Density (0.0 < Dmax, default=3.55 pers/m²): This parameter controls how many occupants will be allowed to enter a room via doors and stairways. Pathfinder uses room density to determine movement speed. If this density increases to 3.8 pers/m², the velocity equation goes to zero and movement in the room will halt1. If one or more doorways are allowing occupants to enter an area faster than they can exit, the doorway(s) will not allow occupants to enter if doing so would increase the density beyond Dmax. Using low values for Dmax (e.g., 2.8 pers/m²) results in artificially fast evacuation times.

Boundary Layer (0.0 <= BL): This value controls the effective width of every door in the simulation – including doors associated with stairs. The effective width of a door is W - 2*BL where W is the actual width of the door. The effective width of a door controls the rate at which occupants can pass through the door.

Door Flow Rates at High Density, Use a Calculated Specific Flow (on/off, default=on): This flag controls the calculation of door specific flow with respect to density. If this flag is enabled, specific flow for doors is calculated based on the occupant density in adjacent rooms. This calculation is explained in the section on movement through doors. Door Flow Rates at High Density, Always Use Max Specific Flow (on/off, default=off) – This flag controls the calculation of door specific flow with respect to density. If this flag is enabled, doors always use maximum specific flow (Pathfinder Technical Reference, 2014).

Velocity: v, at which an occupant moves depends on several factors, including the occupant's maximum velocity (v_{max}) specified in the user interface, the type of terrain being travelled on, speed modifiers and constants associated with the terrain, and occupant density in the current room.

The occupant's base speed, (v (D)), is the speed before speed modifiers and constants are applied. In a room where the density is less than 0.55 pers/m², the base speed is the following:

$$v(D) = v_{\max} * \frac{k - 0.266 * k * D}{1.19}$$

If the density (D) is 0.55 pers/m2 or higher, base velocity is determined using the following equation:

$$v(D) = v_{max} * \frac{.85 * k}{1.19}$$

Initially, to prepare the model in software the plans of the building are defined on the user interface. These plans are used in the building to define the surfaces on which people can move. Doors are defined depending on these surfaces. In addition, vertical circulation devices (stairs, ramps, etc.) are also created within the model in connection with the floors. After the building is completed with horizontal and vertical circulation areas, occupants are added to the model. The Pathfinder program simulates each occupant's evacuation by applying behavioral models that will direct occupants to the nearest exit. Special behaviors can also be defined in the software. For example, it is possible to pass only through some rooms, be directed to certain doors, or people with mobility impairments can be defined as "requires assistance for movement". Occupant speed decreases in areas where people are queuing according to algorithms defined in the software. In addition, in crowded corridors, people are directed to opposite directions, occupants are defined in a way that they prefer to walk behind faster moving individuals. The simulation is created after occupants and the building are defined as whole. The simulation continues until all occupants leave the building and calculates the duration of the evacuation. This process can also be observed in three dimensions (Figure 6).

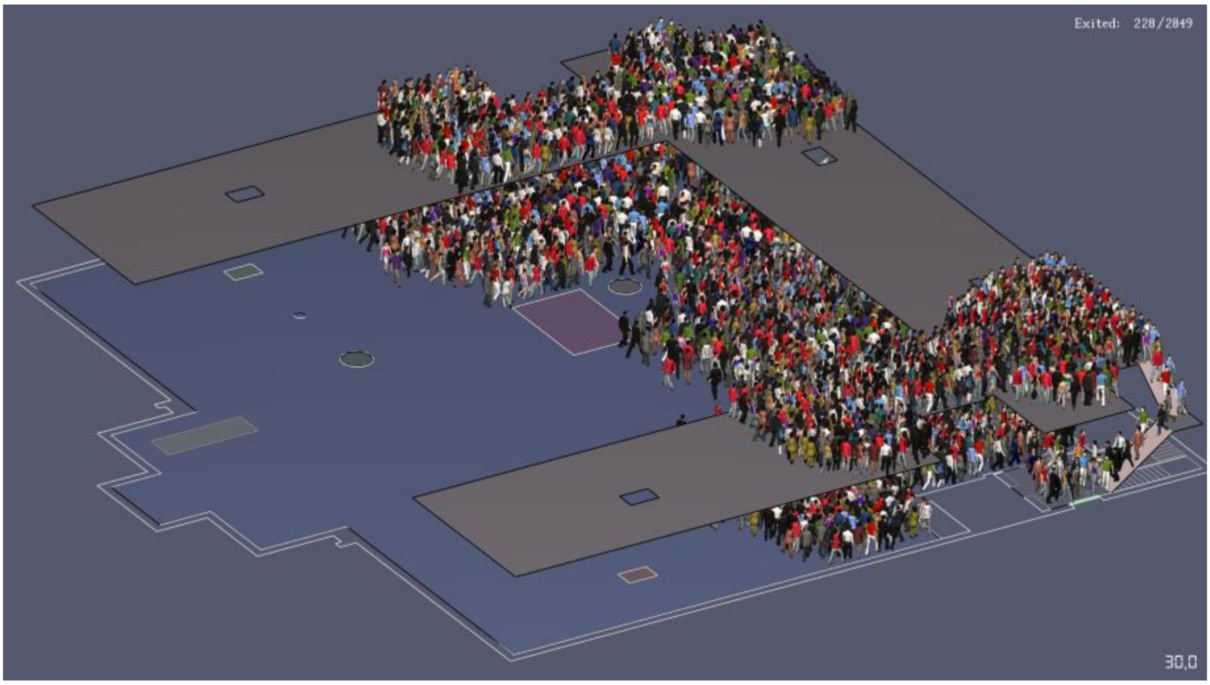

Figure 6. Occupants' movement in Hacıveyiszade Mosque during evacuation

Velocity of the occupant is characterized by the quantity and direction of the velocity vector and crucial for evacuation time. The goal of the person at the time of evacuation is to reach the nearest exit safely as a rule. Meanwhile, people may change their routes to other exit doors due to the smoke or congestion. There may also be those who direct people at the time of evacuation, and this may cause them to change their route. Occupants' walking speed in emergencies may vary from 0.80 m/sec (child), 1.10 m/sec (juvenile), 1,51 m/sec (young man), 1,45 m/sec (young woman) to 1,00 (the old) (Qin et al., 2020). In Pathfinder software the average speed is defined as 1,19 m/sec for a healthy adult. This value is also a culmination of a group of research. In this study walking speed of occupants was taken as 1.19 m/sec, which is defined as the average value in the software. All occupants were accepted to have the same characteristics for this study.

The area needed by a person of worship on the floor is 120cm x 60cm (Neufert, 2008). Hacıveyiszade mosque was studied in the context of these dimensions, and it was observed that it allowed 2849 people to pray at the same time. The building was modeled in Pathfinder software and 1781 people were placed on the ground floor and 1068 people were placed in the women's prayer hall.

3. Results and Discussion

Considering the international safe evacuation studies for assembly buildings, it is safe to evacuate one or two-story buildings within 2.5 minutes (150 seconds) in case of emergencies (Topraklı et al., 2019). The mosque was evaluated by the help of the simulation study that it was exceeded the safe evacuation time or not. Problems experienced during the evacuation were identified and solutions were offered.

According to the results obtained from the simulation, the evacuation of the building completed in 10 min. 48 sec. (648 seconds). In Figure 7, locations of the occupants are shown as colored dots that change over time.

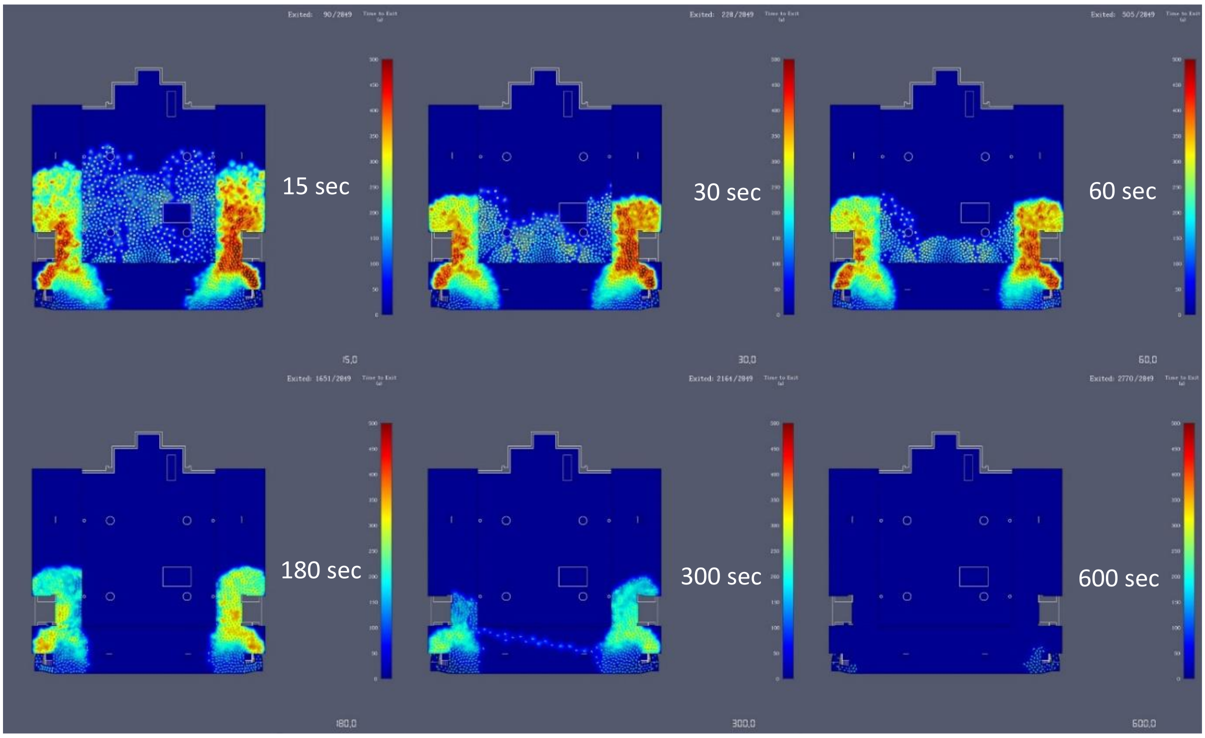

Figure 7. Location of occupants in time

According to the data obtained from the simulation, the distance traveled by users in the building to the exits was at least 4 m and at most 93.5 m. The average distance covered for 2849 people was 31.1 m. The first person leaving the building reached the open spaces in the 4th second and the last person in the 648th second. The number of people leaving the building per unit time in the first 4 minutes is higher than in the next 6 minutes (Figure 8). The change in the number of people leaving the building over time is discussed in Table 1 in detail.

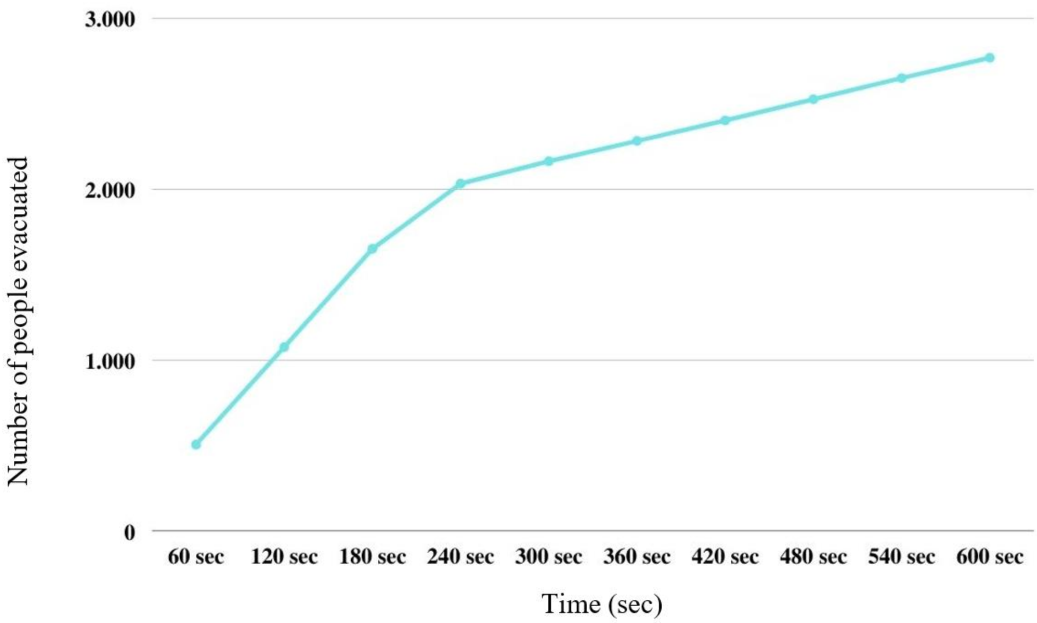

Figure 8. Number of people evacuated in time

Table 1. Number of people evacuated in time

Time (sec)	Number of people evacuated
60	505
120	1076
180	1651
240	2033
300	2164
360	2283
420	2403
480	2527
540	2651
600	2770
648	2849

Figure 9 shows the usage maps of the ground floor of the building and the mezzanine where the women's prayer hall is located. According to the findings obtained from the maps, the congestion and the crowding experienced in the women's prayer hall is considerably higher than the ground floor. Although the evacuation of the ground floor was completed in 232 seconds, it took 648 seconds for the mezzanine floor to be completely evacuated.

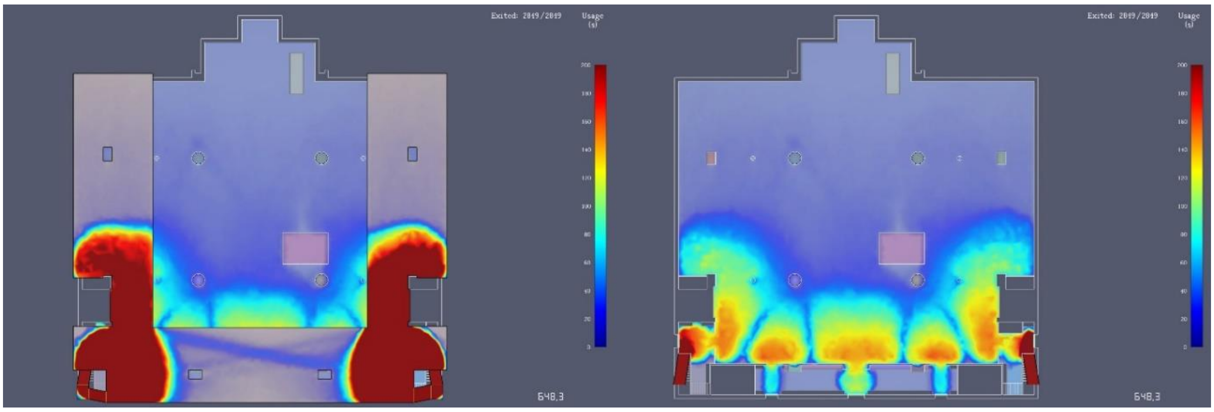

Figure 9. Ground floor (right) and mezzanine floor (left) usage maps

When the door flow rate graph, which indicates the number of occupants passing through a door per second, is examined, the door with the highest number of people exiting per unit time is the main door number 4 (Figure 10). It is seen that fewer people evacuated per unit time from doors 3 and 5, and doors number 1 and 2 play a role in the evacuation of both the ground floor and the mezzanine until the 232. second, while the flow rate during this period is 1.5 to 2.5 person / second, after which 1 to 1.5 person / sec.

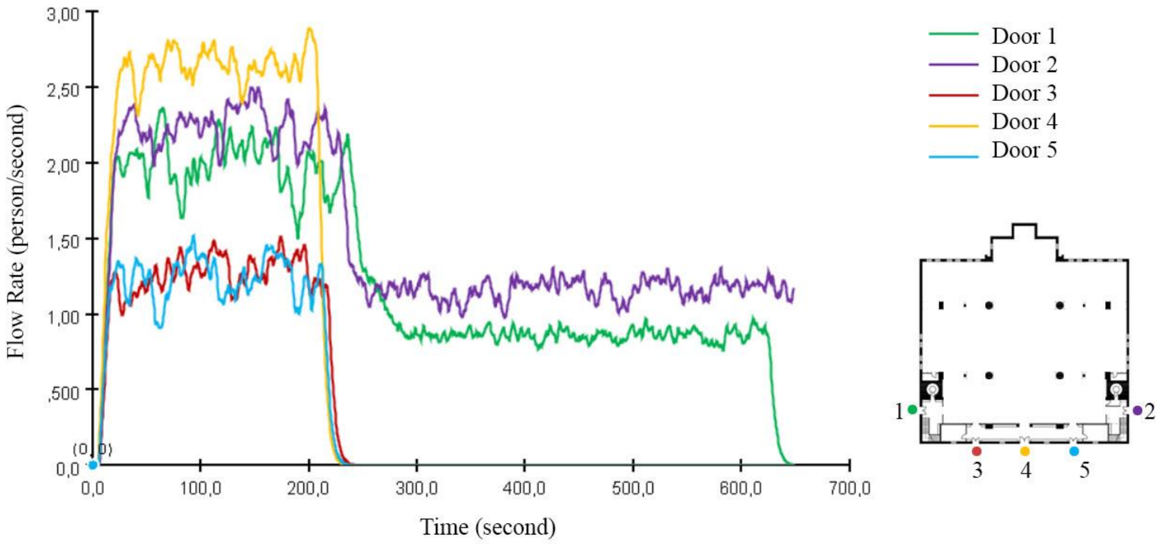

Figure 10. Door flow rates

3.1. Discussion and Suggestions

As a result of the simulation study, it was observed that the evacuation of the Hacıveyiszade mosque completed in 10 minutes 48 seconds when it was full. Results obtained from the simulation study is four times longer than the safe evacuation time and it's clear that the building will remain in an extremely dangerous situation in emergencies.

Lei & Tai (2019) investigated the efficiency of the location and number of stairs and exits during the evacuation period. According to this study, with an equivalent exit width, the evacuation efficiency of a building with two exits was higher than a building with one exit, and the time was shorter. In addition, the placement of the exits right across the stairs has been one of the factors that shortened the evacuation time. Therefore, when designing the horizontal and the vertical circulation of a building, the number and location of the exit doors should be carefully considered. Especially increasing the number of exits will prevent the formation of queues and decrease the evacuation speed of people by directing people to different directions during the evacuation.

In Hacıveyiszade Mosque all exits were arranged in the same direction and the women's prayer hall was connected to the ground floor with only two narrow stairs (Figure 11). This type of organization of the circulation increased the total time of evacuation. Even though the stairs reaching to the women's prayer hall were designed in both side façades, these exits were arranged very close to the west façade, where the main door of the mosque exists. Therefore, all the occupants were directed to the same way and unwanted queues were formed.

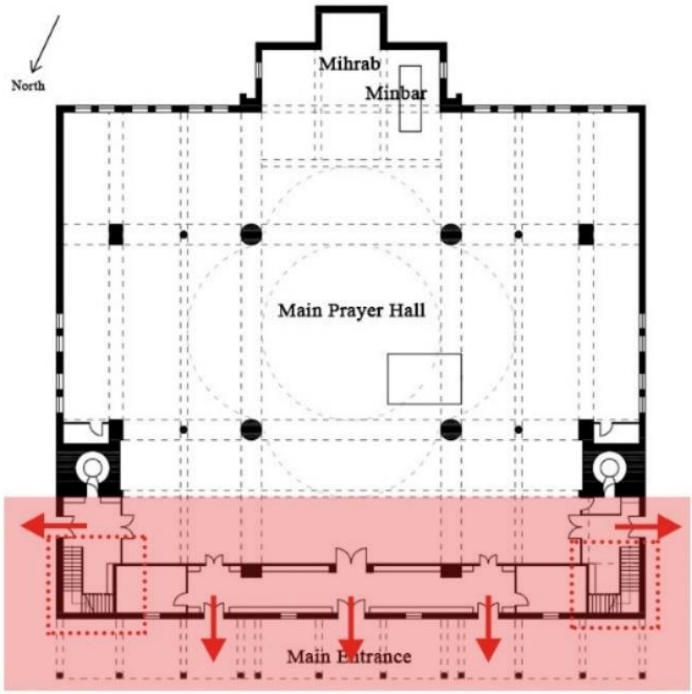

Figure 11. Emergency exits of the mosque building

One of the improvements that can be made to shorten the evacuation time is to add additional exits to the northeast and southwest façades on the ground floor (Figure 12). As, most of the occupants on the ground floor, especially in the front lines, will prefer these exits and the queuing on the entrance façade will be prevented.

In the simulation, it was observed that the occupants on the ground floor were removed from the mosque in 232 seconds. In the remaining 416 seconds, the evacuation of the women's prayer hall was completed. These data indicate that the stairs and exits used for the evacuation of the women's prayer hall are insufficient. The stairs that reach the women's hall do not allow a correct evacuation both in terms of width and the point where it is located in the plan. The width of the existing stairs, which is 134 cm, can be increased to 180 cm, and evacuation can be facilitated by enabling three people to use these stairs side by side at the same time. Positioning the exit direction of these stairs facing the side exits will also provide improvement by reducing the number of turns. In addition to the stairs existing, the evacuation time can be shortened with additional stairs positioned in the middle of the side aisles in the mezzanine plan. In Pathfinder simulation gates accepted to be open throughout the evacuation time. Yet in real life opening direction of the doors are crucial. Therefore, among all these improvements changing all the doors' opening direction will made a significant difference. Outswing type gates will facilitate the evacuation significantly as seen in Figure 12.

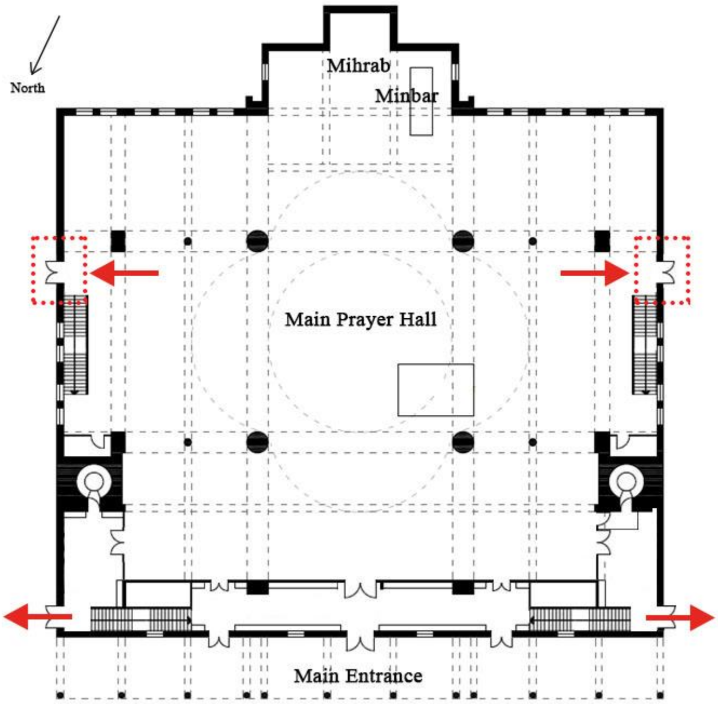

Figure 12. Design revisions to improve the evacuation performance of the mosque

4. Conclusion

A simulation study was conducted for the emergency evacuation of the Hacıveyiszade mosque, which is one of the most widely used mosques in Konya, selected within the scope of the study. The evacuation of the mosque was completed in 10 minutes 48 seconds. As this result was far above the safe evacuation time, it was observed that the emergency evacuation of the Hacıveyiszade Mosque was not safe. Especially the length of the evacuation period of the women's prayer hall is striking. Most of the mosque buildings in our country repeat similar plan schemes. Therefore, the problems detected from this case study indicates that other mosques are also at risk. For future studies, by the help of repetition of the simulation study with design changes, the efficiency of suggestions can be tested. Comparison among different mosque design schemes also can be the subject of a new study to carry out.

Acknowledgment and Information Note

The article complies with national and international research and publication ethics. Ethics committee permission was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

First author 70% contributed, second author 30% contributed. The authors declare no conflict of interest.

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