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ANALYSIS OF EVACUATION EFFECTIVENESS IN SPORTS FACILITIES

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ETHICAL STATEMENT

I hereby declare that in this thesis study I prepared in accordance with thesis writing rules of Gazi University Graduate School of Natural and Applied Sciences;

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SPOR YAPILARINDA TAHLİYE ETKİNLİĞİNİN ANALİZİ
(Yüksek Lisans Tezi)

Hatice TORAMANLI

GAZİ ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
Mayıs 2022

ÖZET

Spor yapılarının sayısı dünyada ve ülkemizde giderek artmaktadır. İleri teknoloji yapım teknikleri, karmaşık strüktürleri ve yüksek insan kapasiteleri ile dikkat çekici olan bu yapıların emniyet tehdidi gibi bir sorunu vardır. Bu karmaşık yapılarda, tarih boyunca, çökme, yangın, patlama veya terör saldırıları görülmüştür. En önemlisi ise barındırdıkları büyük nüfus yoğunluklarıyla, yaralanma veya ölüm ile sonuçlanan izdihamlara neden olabilirler. Bu noktada, bu yapılarda kullanıcı yürüme hızı tahliye etkinliğinde önem kazanmaktadır. Bu çalışmada kapalı spor salonlarının tahliye süreleri üzerinde çalışılmıştır. Spor salonlarının tahliyesinde, kullanıcı yürüme hızlarının tahliye sürelerine etkileri araştırılmıştır. Literatürdeki kullanıcı yürüme hızları üzerinden, spor yapıları için optimum yürüme hızları hesaplanmış ve bu hızların tahliye süreleri ölçülmüştür. Bu çalışma için danışmanın yönlendirmesiyle İstanbul Esenler Kapalı Spor Salonu projesi seçilmiş ve tahliye analizi için Pathfinder programında simülasyon yapılmıştır. Pathfinder, kolaylıkla ulaşılabilen ve tahliye analizi için akademik çalışmayı destekleyen bir programdır. Projedeki sabit koltuk sayısı dikkate alınarak, modele 8828 kullanıcı tanımlanmıştır. Kapalı spor salonunun tahliye sürelerini ölçmek için, programın varsayılan kullanıcı yürüme hızı (1,19 m/s), spor yapılarının kadın-erkek kullanım oranlarına göre literatürden elde edilen yürüme hızı (1,384 m/s) ve gerçek olaylar ve tatbikatlardan elde edilen yürüme hızı (2,5 m/s) olmak üzere üç farklı kullanıcı yürüme hızı belirlenmiştir. Analizler sonucunda en uzun tahliye süresi 10,74 dk. (senaryo1-1,19 m/s yürüme hızı) en kısa tahliye süresi ise 7,14 dk. (senaryo 3-2,5 m/s yürüme hızı) olarak ölçülmüştür. 1,384 m/s yürüme hızına sahip 2. senaryonun tahliye süresi ise 9,14 dk. olarak ölçülmüştür. Ayrıca, 2. Senaryoda, kapalı spor salonunun alt çanak ve üst çanak tahliye süreleri ölçülmüş ve alt çanak tahliye süresinin 2,98 dk., üst çanak tahliye süresinin ise 9,01 dk. olduğu gözlenmiştir. Tezin sonucunda, kapalı spor salonlarında kullanıcı yürüme hızının artmasının tahliye süresini kısalttığı ve tatbikatlarda ve gerçek olaylarda ortaya çıkan tahliye sürelerinin simülasyon sonuçlarından daha kısa olduğu gözlenmiştir. Ayrıca, alt çanak ve üst çanak tahliye sürelerinin aynı olmadığı, üst çanak tahliye süresinin toplam tahliye süresine çok yakın olduğu gözlenmiştir. Son olarak, daha fazla seyirci kapasitesine sahip üst çanakta, merdiven-koridor birleşimlerinin, kuyruk yoğunluklarının ve sıkışmaların, alt çanaktan daha fazla olduğu gözlenmiştir.

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ANALYSIS OF EVACUATION EFFECTIVENESS IN SPORTS FACILITIES

(M. Sc. Thesis)

Hatice TORAMANLI

GAZİ UNIVERSITY

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ABSTRACT

The number of sports venues in the world and in our country is growing. These buildings, which are striking with their advanced technology construction techniques, complex structures, and high human capacities, face a safety threat. In these complex structures, collapse, fire, explosion or terrorist attacks have been seen throughout history. Most importantly, their high population densities can cause stampedes, which can result in injuries or death. At this point, the building user's walking speed becomes important in evacuation efficiency. The evacuation times of indoor sports halls have been researched in this study. The effects of user walking speed on indoor sports hall evacuation times have been investigated. The optimum walking speeds for sports venues were calculated based on user walking speeds in the literature, and the evacuation times of these speeds were measured. İstanbul Esenler Sports Arena was chosen with the guidance of the supervisor for the study and examined by simulation in the Pathfinder Software for evacuation analysis. Pathfinder is an easily accessible program that allows for academic research on evacuation analysis. 8828 occupants are defined in the model based on the fixed number of seats. Three different user walking speeds (the program's default user walking speed – 1.19 m/s, the walking speed obtained from the literature according to the male-female usage ratios of the sports venues – 1.384 m/s, and the walking speed obtained from real events and drills – 2.5 m/s) were determined to measure the evacuation times of the indoor sports hall. According to the results, the longest evacuation time is 10.74 min. (scenario 1-1.19 m/s), the shortest evacuation time is 7.14 min. (scenario 3-2.5 m/s). The evacuation time of scenario 2 with a walking speed of 1.384 m/s, is 9.14 min. In addition, the lower and upper bowl evacuation times of the indoor sports hall were measured in scenario2, and it was observed that the lower bowl evacuation time is 2.98 min. and the upper bowl evacuation time is 9.01 min. As a conclusion of the thesis, it was determined that increasing user walking speed in indoor sports halls decreases the evacuation time, and the evacuation times in drills and real events are much shorter than in simulation results. Furthermore, it was observed that the evacuation times of the lower and the upper bowls are not the same, and the evacuation time of the upper bowl is very close to the total evacuation time. Finally, it was observed that the stair-corridor mergings, queuing densities, and accumulation are higher in the upper bowl which has more spectator capacity than in the lower bowl.

Science Code	: 80117
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LIST OF SYMBOLS AND ABBREVIATIONS

The symbols and abbreviations used in this study are presented below with their explanations.

Symbols	Explanations
cm	Centimeter
m	Meter
m/min	Meter/Minute
m/s	Meter/Second
m^2	Square meters
min	Minute
s	Second

Abbreviations	Explanations
ASET	Available Safe Egress Time
BSI	British Standards Institution
FIFA	Fédération Internationale de Football Association
IBC	International Building Code
NFPA	National Fire Protection Association
RSET	Required Safe Egress Time
TET	Total Evacuation Time
TRFP	Turkey’s Regulation on Fire Protection
UK	United Kingdom

1. INTRODUCTION

Thesis topic

Sports venues can hold a huge number of individuals because of their function. They change every week, with different occupancies and uses. Effective evacuation performance in sports facilities is difficult due to a large number of spectators at sporting or public events under normal evacuation conditions. Crowding can easily lead to congestions and stampedes as the population grows. These stampedes can cause serious injuries and even death. The walking speed of users is one of the key reasons of congestion. It is critical to evacuate the occupants from the building as quickly as possible with optimum user walking speed. This depends on accurately determining the sports facility's user walking speed.

Focus and scope

The effect of user walking speed on evacuation of indoor sports halls is the main focus of this thesis. In this context, an analysis of the İstanbul Esenler Sports Arena has been made with the courtesy of AYT PROJE Design Team. The factors of users and buildings on the evacuation, evacuation time calculation methods, and studies on evacuation of sports facilities have been researched.

Research question

During the design of sports venues with large populations, architectural codes and regulations are consulted. When calculating the evacuation time using regulations, very optimistic results that do not reflect the reality are obtained. These results differ in simulations, drills, and real-life scenarios. Because there is a key factor as the user walking speed which changes due to age, gender, health status or personality of the user. In this context, the study started with the following research question.

- RQ: How effective is the user walking speed in evacuating sports venues?

Objectives

The goal of this thesis is to determine how walking speeds obtained from the literature affect the evacuation of sports facilities. The research method is to use Pathfinder Simulation Software, which is an easily accessible program that allows for academic research on evacuation analysis. The usage of stair exits and exit gates, the lower and upper bowl evacuation timings and the differences in real-life scenarios and drills have been investigated.

Anticipated outcomes

Within the scope of the thesis, a model of an indoor sports hall with 8828 spectators was created using the Pathfinder Simulation Software. Three different occupant walking speeds obtained from the literature were defined to the model and simulations were generated. The evacuation time with the highest walking speed of three scenarios is assumed to be the shortest of all. The aim of this thesis is to find the effects of user walking speeds on the evacuation of indoor sports facilities.

Conflict of Interest

İstanbul Esenler Sports Arena was designed by the supervisor and is adviced for the author to inspect within the scope of the thesis. It is confirmed that beyond this point there is no conflict of interest is existing.

2. LITERATURE REVIEW

The literature of the thesis is given in the following six subsections. Building evacuation in section 2.1, egress components in section 2.2, methods to calculate the building evacuation times in section 2.3, development of sports facilities in section 2.4, the importance of evacuation in sports facilities in section 2.5 and studies on evacuation efficiency in section 2.6 are given.

2.1. Building Evacuation

Today, crowds of people congregate in small spaces and buildings are growing in size and complexity. There is a very large population of people during organizations in sports venues, entertainment, cultural and health facilities. In this case, high-security measures are required for the participants in case of any emergency. In these cases, participants must be taken from the hazardous area as soon as possible.

Evacuation is the escape of pedestrians from a dangerous area, building, or potential-real danger via a safety zone. Emergency evacuation is required in case of emergencies like fire, natural disasters (earthquake), terrorist attacks, structural collapse, etc.

People may be hurt or killed by fire, terrorist attack, or toxic gas if the crowd is unable to escape from the building in time due to a failure to avoid obstructions or a poor choice of exit. Also, the behavior of the crowd (e.g. running to the exits at the same time, pushing, suppressing, and treading) itself may lead to injury and death (Zheng, Zhong, & Liu, 2009).

Evacuation is a complex process that involves many disciplines. It has physical, psychological, and social sides.

Mainly requirements for an evacuation can be counted as below (Wu, 2013) ;

- Timely: the individuals must be evacuated to the safety area before the danger occurs.
- Security: the individuals must be evacuated through safe positions without no harm.
- Convenient: the evacuation design must match with individuals’ psychological situations.
- Benefits: the evacuation design must be practical and economic.

Figure 2.1. The evacuation of a stadium (independent, 2015)

There are 4 types of evacuation (Klüpfel, Schreckenberg, & Meyer-König, 2005):

1. Emergency Evacuation: It is a rapid evacuation from a near (unavoidable) hazardous situation.
2. Controlled Evacuation: It is an evacuation that is not directly life-threatening.
3. Partial Evacuation: In this case, only people in the hazardous area are evacuated.
4. Internal Displacement: If exit paths are closed, the individuals in the hazardous areas are evacuated through less hazardous areas.

The 4th type is identified as ‘’horizontal discharge area’’ in Turkey’s Regulation on Fire Protection.In addition to all these classifications, Müller (1998) also includes another concept within the evacuation, which is:

5. Stay Put: Make individuals stay in the area if it is safer than others and bring this area to safer conditions.

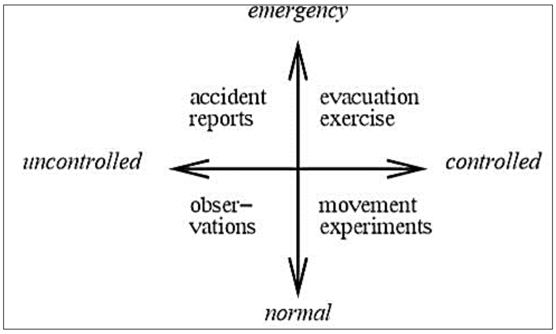


Figure 2.2. Data in evacuation process (Klüpfel et al., 2005)

The evacuation process depends on the characteristics of the places where that process occurs and qualifications of the users who act in those places.

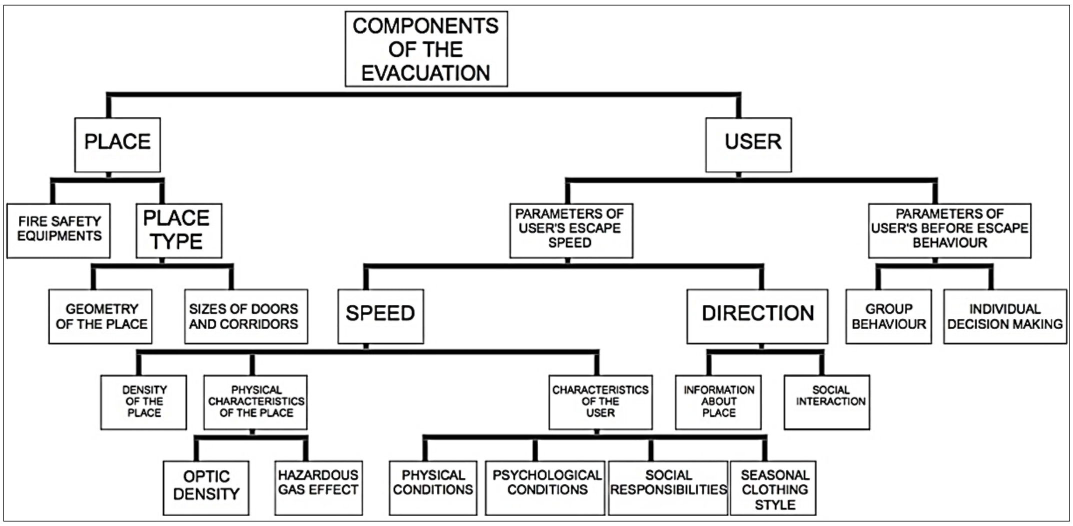


Figure 2.3. The components of evacuation (Cakici Alp, 2011)

The main factors that affect the evacuation and evacuation timing are user factors, building factors, and physical conditions of the environment.

2.1.1. User factors

The behavior, psychological status, physical qualifications, and movement characteristics of the participants in the building directly affect the evacuation (Hofinger, Zinke, & Künzer, 2014).

General human qualifications:

- Stress factor
- Emotion factor

Individual qualifications:

- Physical state (size, age)
- Mental state (happy, tired, drunk)
- Knowledge of emergencies
- Personality (anxiety, cowardice)
- Motivation (control, curiosity)

Anthropometry

Anthropometry is formed from the combination of the words "Anthropos (human) and metering (measure)" in the ancient Greek language. Anthropometry is the measurement of the human individual (wikipedia, 2019). It works with ergonomy of the furniture, moving and still structures. The factors that affect the dimensions of the human body are age, gender, job, cultural structure, the climate he/she lives in, his/her diet type, and his/her health conditions.

The anthropometric dimensions of the human body are used in every step of the architectural design. Therefore, the buildings are formed due to the human's and society's anthropometric qualifications. The evacuation is related directly to the physical qualifications of the human and the dimensions of the building.

Movement

The earliest thought on human action under panic suggests that users lost their humanity under panic and act with animal instincts. In 1957, Quarantelli stated that people do not act with animal instincts under panic, but they do not care about the life safety of other users while acting under their own needs (Santos & Aguirre, 2004). According to Johnson and Feinberg (1997) man is a social being, even when they are in dangerous situations, so they care about other people's life safety and they never act with animal instincts. The users of the building change their directions and move faster to rescue their friends and resist danger.

In real life, building evacuation is a complex process where people with different characteristics and different environmental factors come together. The evacuation process is guided by the various physical and psychological characteristics of these different people, as well as their interactions with the environment. As the user and the environment change, the evacuation timing changes in different ways. As a result, for a realistic evacuation modeling, it is required to investigate the movement characteristics of the various users mentioned above and to determine their distribution in the community.

User movement is formed with user walking speed and user walking direction choice.

<u>User walking speed</u>

Each individual in a building has a walking speed. This is the speed at which the individual walks upon open-floor space when there is no one except him/herself. An individual's walking speed depends on age, gender, and environmental conditions.

Figure 2.4. Pedestrian walking (openfit, 2010)

Walking speeds vary greatly due to land usages such in residential, shopping, and business areas. Pedestrians walk faster in commercial areas than in recreational areas. Conditions such as facility type and environmental factors impact walking speed. Pedestrians in major cities walk at a faster velocity than those in smaller cities. Walking speed and city size has a relationship (Rastogi, Thaniarasu, & Chandra, 2011).

Table 2.1. Average walking speeds in different countries (Rastogi et al., 2011) adopted by the author

Author	Year	Country	Average Speed	Adopted by Author
			m/min	m/s
Fruin	1971	United States	81	1.35
Bornstein and Bornstein	1976	France	90	1.50
Bornstein	1979	Republic of Ireland	76	1.26
Polus et al.	1983	Israel	79	1.31
Tanaboriboon et al.	1986	Singapore	74	1.23
Koushki	1988	Saudi Arabia	65	1.08
Morrall et al.	1991	Sri Lanka	75	1.25
Morrall et al.	1991	Canada	84	1.40
Knoblach et al.	1996	United States	86	1.43
Lam and Cheung	2000	China	74	1.23
Tarawneh	2001	Jordan	80	1.33
Finnis and Walton	2008	New Zealand	88	1.46
Kotkar et al.	2010	India	72	1.20
			Average	1.31

User walking direction

Proulx and Reid (2006) conducted a survey, after the fire in the 39-floor Chicago Cook Country Administration building in 2003, which resulted in the death of 6 people. It is stated that the users who evacuated the building without being affected by the fire are the people who have been working in the building for a long time and the people who participated in the evacuation drills. In the study, it is also emphasized that the duration of the user's residence in the building is one of the most important aspects impacting the user's direction data.

In addition, the authors state that the floor where the user is, is also affected by the evacuation attempt. For example; the user who lives on the upper floor of the building is less inclined to leave the building.

User behavior

Understanding human behavior is of great importance for realistic evacuation analysis. An individual's action or response is the outcome of a decision-making procedure. People pass a process of specific stages, including hearing, understanding, believing, and individualizing the warning, in which they think of aspects of their reaction before doing an act (Kuligowski, 2008).

There are cue-related factors and occupant-related factors that influence the evacuation process. Occupant-related factors are described above (e.g., gender, age). Cue-related factors are the behavioral process that depends on decisions based on external and internal cues during an emergency situation (Kuligowski, 2008).

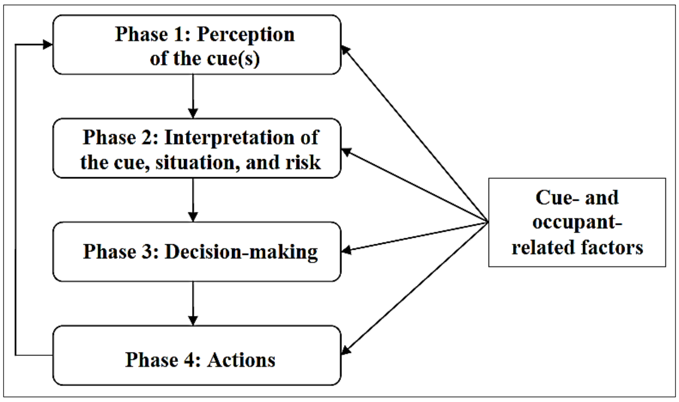


Figure 2.5. A conceptual model of behavioral process for emergency situations (Kuligowski, 2008)

Panic behavior

People do not panic in an emergency and do not stampede and crush each other, contrary to the popular notions (Proulx, 2001). Panic is not the same as human conduct in an emergency, which presupposes illogical behavior for a scenario. People make sensible decisions when they comprehend the circumstances during an emergency. Even in the absence of panic, emergency circumstances are characterized by the occupants' failure to react and ignore the problem, even when they hear the alarm or notice the signs of a dangerous scenario. Taking action and evacuation time are delayed as a result of such avoidance (Proulx, 2001).

Decision-making under stress

Decision-making in stressful situations varies from decision-making in normal situations. Because the risk is too high and time is limited. To these differences, a third was added by Proulx (2001), the information required to make a decision is exceptional and cannot be fully obtained.

Ozel (2001), stated that especially in fire situations, the limited time is very effective on stress, because the environment may not be observed completely. Therefore, for example, some exit doors may not be visible. In addition, stress was considered necessary in some cases, as it leads to action during danger.

Stress leads to some information not being used in the evacuation process. For example, in fires, people may not notice the optimal exit or exit signs. This will increase the probability of people using the exits they know (Ozel, 2001).

Crowd behavior

Crowds are huge groups that occupy on one location and share a mutual interest (Klüpfel et al., 2005).

People’s personalities and decision-making styles may differ in crowds from when they are alone. For example, a person can copy the reactions of others or act as a leader of the crowd (Proulx, 2001).

The same reaction cannot be expected from the crowd in a stadium, a cinema, or a theatre, during an emergency situation. Even the place, where the crowd is during the emergency situation, has an effect on the reactions. For example, in a hotel, the users who are in their rooms, at the swimming pool, or the restaurant, will not act in the same way (Proulx, 2001).

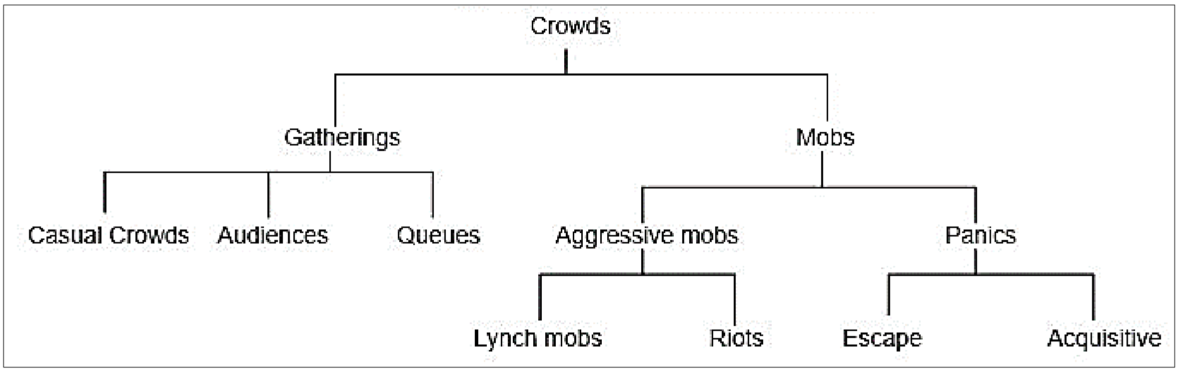


Figure 2.6. Classification of crowds (Klüpfel et al., 2005)

Wayfinding

Wayfinding is how people find their way around a building (Raubal & Egenhofer, 1998). The studies show that architectonical constructions may be confusing for a user. People want to have the abilities to be successful in wayfinding. According to Raubal and Egenhofer (1998) wayfinding is connected to the layout of the building or area and is not connected to escape route signs. The individuals in the building generally evacuate with the routes they know and these are mostly the main exits which are the entrances of the building (Kobes et al., 2010). For the healthy wayfinding, the user of the building shall be familiar with the venue and the exits must be accessible for every occupant in the building.

2.1.2. Building factors

The design of a building's exit system is critical to ensuring that everyone can evacuate safely during an emergency situation. To specify how many exits are necessary, which width they should have, and the estimated number of people that are present in the building, some issues should be determined. Below are these issues which should be considered during the design stage.

Occupant load

The total number of people who can inhabit a building or a portion of a building at any given moment (National Fire Protection Association [NFPA], 2018). The occupant load is the individuals number for whom the exits of the building are designed (International Building Code (IBC), 2018).

The occupant load factor changes in different uses of buildings. This factor is provided in NFPA (2018) in Table 7.3.1.2, IBC (2018) in Table 1004.5, and Turkey's Regulation on Fire Protection [TRFP], 2012 in Appendix 5/A.

Exit capacity

The exit capacity is the total number of people who can cross a certain entrance in 1 minute. It must be suitable for the building occupant load. It is determined by the usable width of egress components (doors, stairs, corridors, etc.).

For the width of exit capacity; stairs, doors, corridors, and the other exit accesses are calculated as 50 cm. width units in TRFP (2012) and as 55 cm. width units in NFPA (2018).

The capacity factors are provided in NFPA (2018) (Table 7.3.3.1), IBC (2018) (Section 1005) and TRFP (2012) (Appendix 5/B).

A building's occupant load may surpass what it was built for and the evacuation process can result in queuing, bottle-necking, or slow egress. Therefore; Egress Capacity ≥ Occupant Load.

Stair use and merging effect

Today, stairs represent the main exit component for many buildings. The usage of stairs for vertical evacuation is common in all types of buildings except for a few such as healthcare and detention.

The assumptions considered while depicting the movement of pedestrians are used to calculate the evacuation times on stairs. This includes, for example, the connection between walking speeds, densities, and flows in addition a variety of other behavioral parameters (e.g. motivation, fatigue, etc) (Sano, Ronchi, Minegishi, & Nilsson, 2017).

The merging effect on stairs refers to the meeting of a stairwell's flow of people with the flow of individuals from each floor of a multi-story structure (Sano et al., 2017). Merging flows on fire safety influence the sequence in which separate floors are evacuated. In actuality, multi-story buildings are evacuated from top to bottom floor due to the merging ratio (i.e. the proportion of individuals arriving at the landing from the floor divided by the proportion arriving from the stairs) (Sano, Ronchi, Minegishi, & Nilsson, 2018). This has the potential to have a significant impact on a building's safety conditions in the event of an emergency situation, given that the cause of the emergency might be on any floor of a multi-story structure and might affect occupants on different floors to varying degrees.

Merging flows include complicated interactions among pedestrians, decreasing the evacuation process' efficiency. Researchers discovered that the merging ratio affects on flow rates and stair evacuation times during stair evacuation (Zheng, Tian, Zhang, Hu, & Tong, 2019). The merging ratio was determined to be around 50:50 in a recent study. The merging ratio, on the other hand, is proportional to the pedestrian density (Zheng et al., 2019)

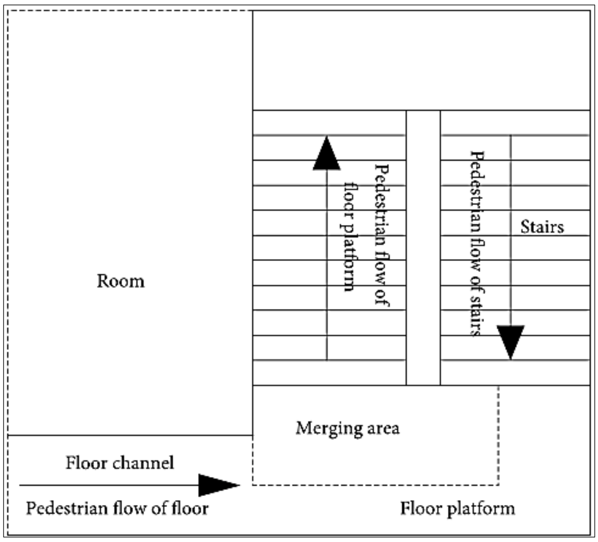


Figure 2.7. Structure of the stairs (Zheng et al., 2019)

<u>Concourse areas</u>

Concourse areas that surround the seating bowl in a sports venue are critical areas for crowd evacuation. Not only do they function as a circulation zone between the seating bowl and the stadium exit routes, but they also hold the majority of the stadium's services, such as restrooms and concession stands (Culley & Pascoe, 2015).

Concourse areas are used when spectators choose to leave the sitting area, enjoy the resources at the sports venue, and then return to their seats after the game's half-time break. Therefore, they should be sufficient in terms of pedestrian densities.

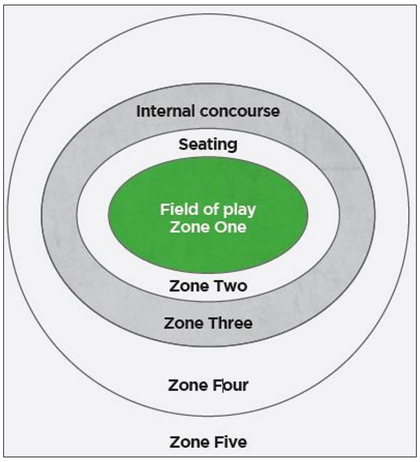


Figure 2.8. A safe stadium zoning diagram (John, Sheard, & Vickery, 2013)

- Zone one: The field of play (pitch)
- Zone two: Areas for sitting and standing for spectators
- Zone three: Internal concourses, restaurants, bars, and other public gathering places
- Zone four: The region for circulation between the stadium building and the outer barrier.
- Zone five: The space outside the perimeter barrier

Concourses are commonly necessary to handle long lines that form at the top of exit stairs or gates after an event or during an evacuation. It is crucial to establish the size of these queues since they must fit securely inside the available area.

The primary parameters of the concourse areas are (John et al., 2013):

1. The pattern must be smooth so that people do not get lost.
2. The venue must be evacuated quickly and safely in an emergency.
3. Toilets and catering facilities must be easily accessible.

External concourses are as important as internal concourses. After passing the building line, occupants will proceed to the external concourse. This wide outside area is crucial for moving a substantial section of the stadium's population, either inside or outside of the building line (Culley & Pascoe, 2015).

2.1.3. Evacuation timing: movement of people

When evacuation studies in the literature are examined, it is seen that the most emphasized performance factor is the evacuation period. In the studies of determining the evacuation timing, the observations and experiences have been used until now.

The following are the five stages of evacuation time:

1. T_d (Detection time): The time taken by users to detect the emergency situation. The alarm devices and alarm signal detection time are included.
2. T_a (Alarm time): The start time of the alarm system is detector movement and is defined as the alarm start time.
3. T_{pre} (Pre-evacuation time): Starting from the pre-departure time for evacuation until the start of the evacuation. Includes realization and reaction time.
4. T_{rec} (Realization time): The time from the first detection of the user to the perception of the user.
5. T_{res} (Reaction time): The time after the decision to escape and movement to exit starts.

$T_{RSET} = T_{START} + T_{ACTION}$

$T_{START} = T_d + T_a + T_{pre}$

T_{ACTION} (Movement time): The time that the evacuation process is done.

Total evacuation time (TET) is the time interval from the start of an alarm until the last evacuee reaches safety (British Standards Institution [BSI], 2019).

Pre-evacuation time is the interval between the first alert and the initial movement of evacuees to leave the building (Lovreglio, Kuligowski, Gwynne, & Boyce, 2019). The Pre-evacuation time occurs during identification time and reaction time. Recognition time is being warned by a sign that there is an emergency situation. Response time is knowing there is an emergency to start to escape (Ng & Chow, 2006). It is hard to predict pre-evacuation time because of its relation to human behavior (Lovreglio et al., 2019).

The time gap between the initial evacuation movement and the final evacuee reaching the exit is referred to as movement time (Proulx, 1995). The movement phase can be affected by the factors such as bottlenecks, intersections, physical characteristics of evacuees, counterflow, and congestion (Ng & Chow, 2006).

Movement time and pre-evacuation time form the total evacuation time (TET). To determine the safe evacuation for buildings, RSET (required safe egress time) and ASET (available safe egress time) terms are used (Ng & Chow, 2006).

ASET (available safe egress time): The time when safe conditions are guaranteed.

RSET (required safe egress time): The time required for all evacuees to reach the safe area. It consists of detection, notification, reaction, and movement (evacuation) phases.

The basic condition to guarantee the evacuation of users is given by the following equation: RSET < ASET

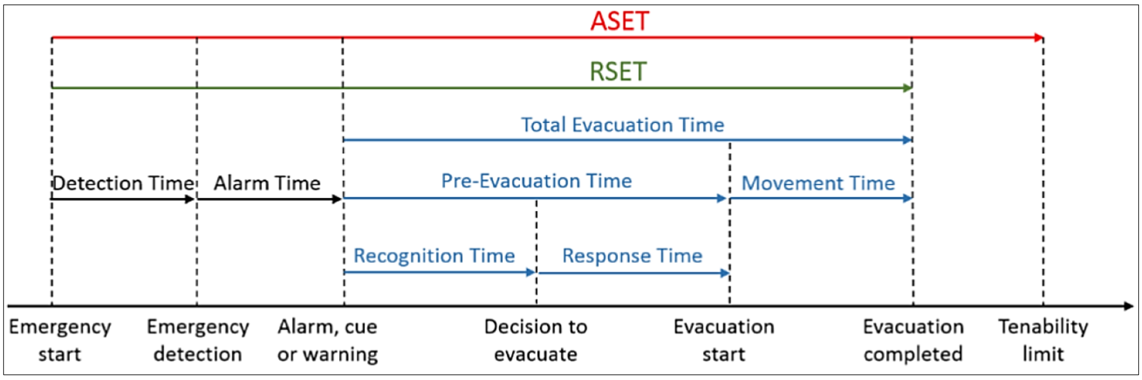


Figure 2.9. Evacuation process of users in case of emergency (Proulx, 2002)

2.1.4. Pedestrian movement

Pedestrians could be individual but they may form structures at larger scales. Pedestrian flow shall be described with speed and density (Khisty, 1985):

$q = k\,v$ flow = density × speed

The definitions are given below (Gupta & Pundir, 2015):

- Flow is the pedestrian number who cross through a point in a defined time.
- Density is the pedestrian number in a defined length of a walkway per unit of area.
- Speed is the distance pedestrian travels in one unit of time.

The behavior of a pedestrian flow over an area under various situations is described by flow characteristics. The parameters of flow can be explained by speed, flow, and density concepts. Below are diagrams of pedestrian flow in normal and panic conditions:

Lane formation

Lane formation can be understood as pedestrians tending to walk on the side with heavy vehicle traffic (Helbing, Farkas, Molnar, & Vicsek, 2002).

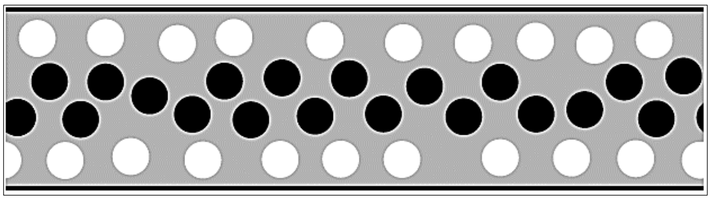


Figure 2.10. Formation of lanes with opposite walking directions (Helbing et al., 2002)

Oscillations at bottlenecks

If people don’t panic they can go straight through the bottlenecks. If a pedestrian can pass a narrow bottleneck, other pedestrians can easily follow (Helbing et al., 2002).

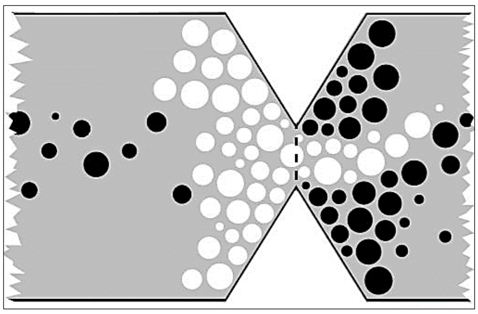


Figure 2.11. Passing direction oscillations at a bottleneck (Helbing et al., 2002)

Dynamics at intersections

Inconsistent and short movements can be seen at various alternatives at intersections. Vertical and horizontal directional movements can cross and turn into temporary roundabout traffic (Helbing et al., 2002).

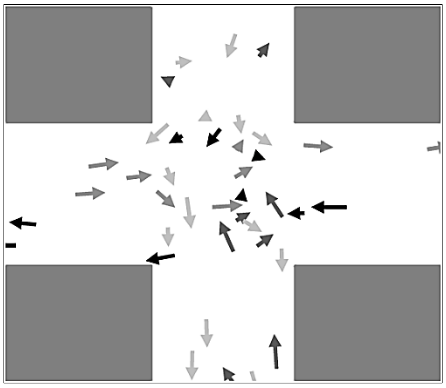


Figure 2.12. Short intersecting pedestrian streams with a roundabout (Helbing et al., 2002)

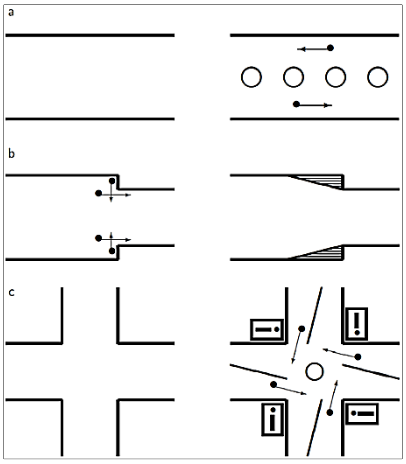


Figure 2.13. Conventional and improved elements of pedestrians movements (Helbing et al., 2002)

2.2. Egress Components

Egress is a continuous vertical or horizontal way with no obstruction which starts from any part of the building and ends with a public way outside of the building (IBC, 2018) The buildings must be designed with enough exits in case of emergency situations. Escape routes are arranged in the exact number and position of capacity appropriate to the usage type, occupancy load, structure, and height of the building, to provide escape opportunities for all users in each building.

Every exit must be seen clearly and the route of the exit must be accessible for every user of the building. The components of means of egress must be far away from all obstructions as they will be used in emergency situations (NFPA, 2018). The means of egress must not be divided into individual rooms or other spaces by barriers, railings , or gates (NFPA, 2018).

The path of egress must travel along and should not be interrupted by a building part. The minimum width and required capacity cannot be changed with something else (IBC, 2018). Continuity is very significant for the sizing of means of egress components. The minimum width should not change from component to the exit (IBC, 2018).

A means of egress is made up of three main parts: the exit access, the exit, and the exit discharge.

2.2.1. Exit access

The part of a building or structure that connects any occupied portion to an exit (IBC, 2018). Exit access is a continuous and unhindered road from a random point in the building to a ground-level street or road (Turkey’s Regulation On Fire Protection, 2012).

- Exits from rooms and other independent spaces,
- Corridors and similar passages on each floor,
- Floor exits,
- Stairs reaching to the ground floor,
- Routes leading to the last exit of the building on the same floor can be counted as exit accesses. Elevators are not exit accesses.

2.2.2. Exit

The exit is the part between the exit access and the public way (Turkey’s Regulation On Fire Protection, 2012).

- Exterior exit doors at the exit discharge level,

- Interior exit stairs and ramps,
- Exterior exit stairs and ramps,
- Exit aisles,
- Horizontal exits can be counted as exits.

2.2.3. Exit discharge

The distance between the end of an exit and a public way (IBC, 2018). The exit discharge shall be arranged in such a way that the direction of aisles from the exit to the building's exterior is clear. Ramps, stairs, doors, corridors, exit passageways, escalators are the components of exit discharge (NFPA, 2018).

<u>Stairways</u>

The common staircase of the buildings, which can be used in case of emergency, is considered an escape stair. They cannot be designed apart from the other parts of the exit ways. There must not be any flammable materials on the surfaces of the escape stairways. Walls must be stable minimum of 120 minutes and doors minimum of 90 minutes on fire resistance (Turkey’s Regulation On Fire Protection, 2012).

Stairways are designed for the individulas evacuation in a safe way. There are normal stairs and escape stairs for evacuation in the buildings. They must not be built side to side and the transition to escape stairs should not be done from normal stairs. At least half of the escape stairs in terms of capacity and number should be opened directly to the exterior of the building (Turkey’s Regulation On Fire Protection, 2012).

According to IBC (2018) the measurement of stairs shall be as written below:

- The minimum width should be minimum of 111.8 cm. If the stair has an occupant load less than 50, it should have a width minimum of 91.4 cm.
- Occupant load * 7.6 mm (for per occupant)
- Stair riser heights should be 17.8 cm. maximum and 10.2 cm. minimum.
- Tread depths should be 27.9 cm. minimum.
- Landings should not be narrower than the width of the stairs.

- A flight of stairs should not have a height of more than 365.8 cm between floor levels or landings.

According to TRFP (2012), the measurement of stairs shall be as written below:

- Stair riser heights should not be more than 17.5 cm; step width should not be less than 25 cm.
- Doors opening to the exit ladder shelf can never be positioned to narrow more than 1/3 of the escape route.
- If an escape stair ends on a hall, foyer, hallway, or lobby and the exit can be seen from the endpoint of the stair, then the distance between the endpoint of the escape stair and the exterior of the building should not be more than 10 meters.
- If the building has a sprinkler system, this distance can be maximum of 15 meters.

<u>Doors</u>

A door must be side-hinged if it is an escape door (NFPA, 2018). The exit passageways doors must stand against heat and smoke for a minimum of 90 minutes.

According to IBC (2018) the measurement of doors shall be as written below:

- The minimum clear opening width is 81.3 cm.
- Doorways with swinging doors (with the door open 90 degrees) are 81.3 cm.

Below is the table which consists of egress components' measurements and occupant load calculations in IBC, NFPA and TRFP.

Table 2.2. Egress components in codes compiled by the author

	IBC	NFPA	Turkey's Regulation
Stairways			
Minimum Width	111.8 cm.	111.8 cm.	100 cm. (Residences) 125 cm. (Other Structures)
Minimum Width (Occupant Load Of Less Than 50)	91.4 cm.	91.5 cm.	80 cm.
Risers	Min. 10.2 cm Max. 17.8 cm.	Max. 19.81 cm.	Max. 17.5 cm.
Tread Depth	Min. 27.9 cm.	Min. 27.9 cm.	Min. 25 cm.
Occupant Load	51 cm. For Per Occupant	55 cm. For Per Occupant	50 cm. For Per Occupant

Table 2.2. (continued) Egress components in codes compiled by the author

	IBC	NFPA	Turkey's Regulation
Doors			
Fire Resistance	90 minutes	90 Minutes	90 minutes
Clear Opening Width	81.3 cm.	81.3 cm.	Min. 80 cm. Max. 120 cm.
Ramps			
Slopes	%8	%8	Max. %10
Clear Width	91.4 cm.	111.76 cm.	100 cm.
Corridors			
Heights	228.6 cm.		210 cm.
Width (Occupant Load 100 And More)	182.8 cm.	91.44 cm.	110 cm.
Exit Passageways			
Heights	228.6 cm.		210 cm.
Width	111.8 cm.	111.2 cm.	110 cm.
Minimum Width (Occupant Load Of Less Than 50)	91.4 cm.	91.5 cm.	100 cm.
Exit Access			
Serving	6 people	6 People	
Length from The Most Remote Point	15 mt.	15 mt.	10 mt.
Width	45.5 cm.	45.5 cm.	80 cm.
Height	96.5 cm.	96.5 cm.	

2.3. Methods for Calculating Building Evacuation Times

The evacuation timing performance of a building has been calculated with two different methods before the usage of mathematical models (Gwynne, Galea, Owen, Lawrence, & Filippidis, 1999). These are evacuation demonstrations and safety standards set by codes and regulations.

The evacuation demonstrations do not include the human psychology and human behavior factor. They have the risk of injury for occupants, as well as the absence of realism because participants do not experience the trauma or panic of a true emergency situation (Gwynne et al., 1999).

The codes and regulations interfere with the plan of the building, number and width of exit doors, escape distance, stairs, corridor widths, and even railing heights however there is no scientific evidence as to whether these defined rules are sufficient or how their interaction with other measures and conditions can produce results. They do not take into account the impact of smoke density, toxic gases, or travel speeds of the occupants (Gwynne et al., 1999).

The research on the evacuation time calculations are evaluated in 3 categories:

1. Analytical Methods (Empirical formulas)
2. Flow or Hydraulic Models (Mathematical formulas)
3. Computer-Based Evacuation Models (Simulation models)

2.3.1. Analytical methods

Analytical methods do not address emergencies but are defined as standard human movement velocities and spatial dimensions. Architectural element size limitations seen in the safety codes and regulations are connected to these formulas (Olsson & Regan, 2001).

The rules and principles that are mostly known about building safety and that have lost their validity today, are based on this first step of the studies (Olsson & Regan, 2001).

BSI (2019), makes admissions based on experiences to figure out how long it takes to evacuate. According to these admissions, the pedestrian flow through a unit width per minute is 40 people and a floor evacuation time is 2 and a half minutes. The stairs hall must be designed according to the admissions of, 1 person fits into 1 meter in a stair step and 0.3 m^2 space in landings, to achieve the recommended flow rate.

The equation below gives the human capacity that the building can carry (P):

$$P = p\ n + (t_e - t_s)\ r\ w$$

- P: the stair capacity
- n: the number of upper floors
- t_e: the recommended evacuation time of one floor (2.5 minutes)
- t_s: the time one person uses to go 3-meter floor height with stairs (0.4 minutes)
- r: the number of people passing a unit width per minute (40 people /minute)
- w: stairway width

The other equations (admitted the evacuation time of a floor is 2.5 minutes) that guess the evacuation time are (Zicherman, 1992):

$$T_e = 200\ b + (18\ b + 14\ b^2)\ (n - 1)$$

$$\mathrm{Te} = \frac{\sum_{i=k}^{n} Q_i}{N' \ b_{k1}} + k\, t_s \quad (2.1)$$

- b: Stairway width
- n: total floors number
- Q: people’s numbers on each floor
- N: Flow speed
- k: total floors number

2.3.2. Flow or hydraulic models

Hughes (2002), defines the models in which large crowds are defined in unified, nonlinear, and partial differential equations. These equations come from a synthesis of the pedestrian movements and flow works of Predtetschenski and Milinskii (1971).

S = k – akD

- S: Speed
- D: Density
- a: 0,286 for k_1 and 0,266 for k_2

k: fixed value for every building part classified as k_1 and k_2 (NFPA, 2018)

The flow has a distinctive characteristic during evacuation. When the warning comes, the flow starts. It reaches its top density and falls again after a while. The people flow seems like a stick.

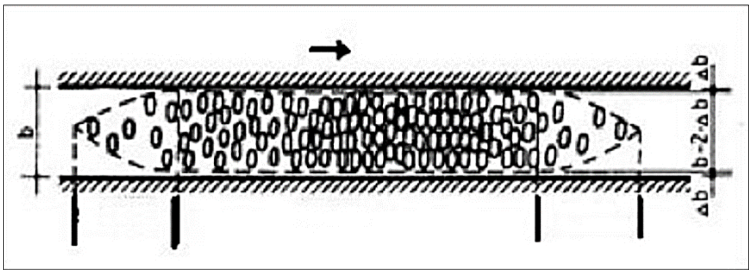


Figure 2.14. The flow of people (Hughes, 2002)

2.3.3. Computer-based evacuation models

In case of any danger, the models that provide the crowd to perform the evacuation as soon as possible, are called emergency evacuation models. There are 3 approaches used by computational models to analyze evacuation. These are (Gwynne et al., 1999):

1. Optimization
2. Simulation
3. Risk Assessment

- Optimization models treat the individuals as a homogenous community and do not recognize the individual's behavior (Gwynne et al., 1999).
- Simulation models evaluate the behavior and movement of the individual to get acceptable results (Gwynne et al., 1999). They are the methods to see the results of scenarios that are not accessible owing to limits imposed by observations and experimentations (Klüpfel et al., 2005).
- Risk Assessment models identify hazards due to emergency situations and quantify risks (Gwynne et al., 1999).

Evacuation simulation models are separated into 3 categories according to the modeling methods (Kuligowski, Peacock, & Hoskins, 2005):

1. Behavioral models, includes occupants performing actions and their decision-making.
2. Movement models, transporting passengers from one area to another (generally to an exit).
3. Partial behavioral models, incorporates occupant movement and occupant behaviors.

Evacuation simulation models are divided into 3 categories according to the strategies used for occupant movement throughout the building (Kuligowski et al., 2005):

1. Fine Network Models (F)

This model divides the floor plan into grid cells. The dimensions and form of the cells differ from model to model. If a large geometry is used in the model, many compartments may exit with many nodes. In this type, the right geometry of the space can be modeled and each individual can be located at any time during evacuation (Gwynne et al., 1999).

2. Coarse Network Model (C)

This model divides the floor plan into corridors, rooms, and stairs which are represented by nodes. These are connected by arcs. The occupants move on the segments and their positions are not defined as well as in the fine network models. If there are obstacles in the modeling space, this model presents difficulties. Because the location of the occupant is not represented, the interaction between them can not work (Gwynne et al., 1999).

3. Continuous Network Models (Co)

This model makes a 2D model of the floor plan of the space. The building occupant walks from one point to another (Kuligowski, 2005).

Evacuation simulation models are divided into 2 categories according to pedestrian perception (Pelechano & Malkawi, 2008):

- Macroscopic models
- Microscopic models

<u>Macroscopic models</u>

Macroscopic models study the pedestrian flow as a whole. The movements and behaviors of individuals within the flow of people are not taken into consideration (Kormanová, 2013). These models ignore individual behavior for evacuations and it accepts the discharge movement as a homogeneous flow (Naser & Kamrani, 2012).

The advantages of the macroscopic models are their mathematical structures and usage of few parameters. But accepting the pedestrian as an unthinking element can cause disadvantages for the model because a pedestrian’s behavior can change the crowd’s behavior in panic situations (Shiwakoti & Nakatsuji, 2005).

Microscopic models

Microscopic models study the individuals with details, distinguish individuals and their responses such as personal reaction times or exit preferences (Kormanová, 2013). The evacuees are thought as individuals who have parameters such as age, gender, and body size. These models allow a more pragmatic operation of pedestrian movements (Shiwakoti & Nakatsuji, 2005). However, they prohibit using analytical models. Therefore, optimal solutions are not generally available in these models (Naser & Kamrani, 2012). Instead, a simulation-based approach may be used to assess actual or future efficiency. This is why microscopic models are called computer-aided simulation models.

2.4. Development of Sports Facilities

The development of technology and production methods has caused more budgets to be allocated to sports venues, as sports are great investment, promotion, advertising, and propaganda tools. Environmental awareness, sustainability, the universal design which have become widespread in the world due to their scale, importance, impact, and problems, issues, and trends have shown their impact in sports venues and many applications have been made on their behalf.

The sports venues can be listed among the places as below;

Table 2.3. The types of sports venues (Selo & Erdonmez, 2018)

Name / Type of Sports Venue	Example
Open Spaces	Everywhere
Common Spaces	City Squares
Specialized Venues for Those Engaged in Sports (Athletes / Coaches Etc.)	Palaistra, Gymnasion, Thermal Structures
Specialized Venues for Sports Persons and Spectators	Stadium, Amphitheater, Ballcourt, Hippodrome
Technological Structures	Stadiums, Sports Halls

Sports structures are one of the most important building types in history. They represent the first examples of architecture with Ancient Greek Stadia and the most beautiful examples with the Colosseum in Ancient Rome and Olympic Park in Munich.

2.4.1. Greek stadia

The Greek Stadia which was used as foot racecourses had a U-shape scheme with a straight end. They were built on a hillside so that spectators could have good sightlines or on flat ground. Stadia built on the flat ground were found in Ephesus, Athens, and Delphi. The Athens stadium was built in 331 BC, rebuilt in 160 BC, and again in 1896. The 1st modern Olympic Games were held in Athens, Greece, in 1896. In its current form, it can accommodate up to 50 000 people in 46 rows (John et al., 2013).

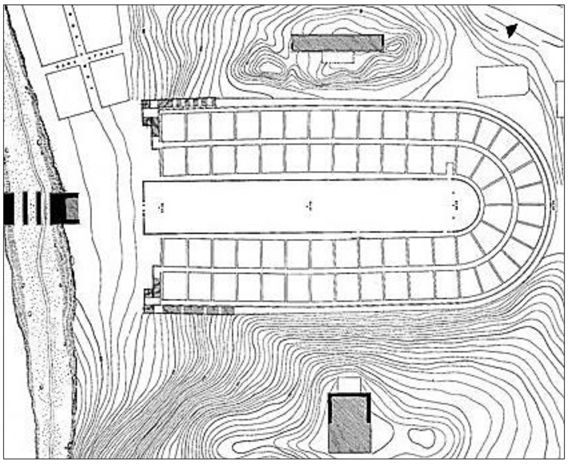


Figure 2.15. The u-shaped stadium in Athens (Architectural Review, 2021)

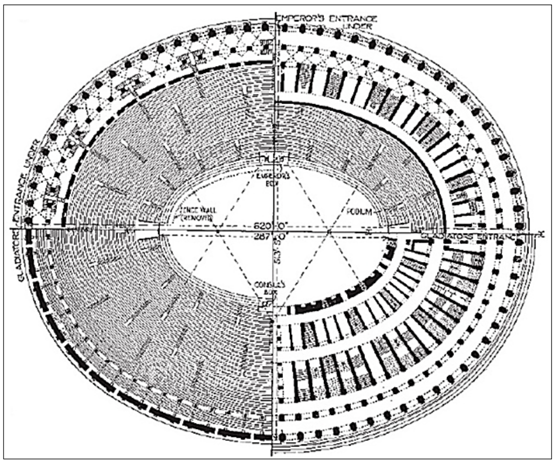
Stadia built on a hillside were found in Olympia, Thebes, and Epidauros. They are similar to Ancient Greek theatres. They are essentially elongated theaters where spectacular physical feats are performed (Selo & Erdonmez, 2018). In Olympia, there was a sports field with a training gymnasium and a colonnade with stone steps for spectators. Later on, two -facing each other- stands were built that accommodated up to 45 000 spectators. The basic shapes of Ancient Greece can now be found in modern and large-capacity stadiums.

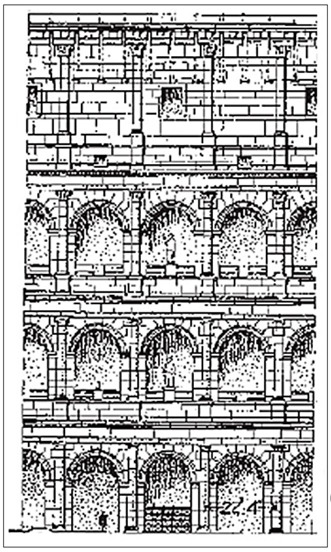
2.4.2. Roman amphitheatres

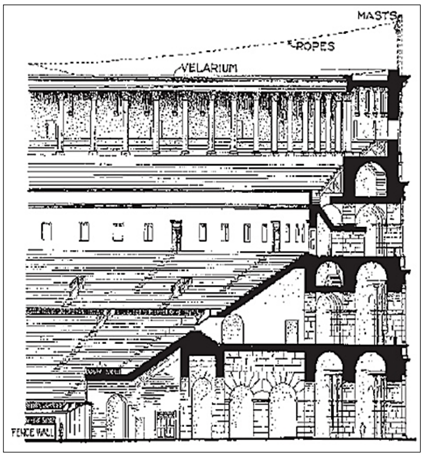
The Romans were interested in public mortal fighting more than athletic competitions. They developed an elliptical and amphitheatrical form of high-rising seats. These seats allowed spectators to have a clear view. The word 'arena' derives from the Latin language, which means sandy soil and refers to the sand that is laid among the playfield to soak the blood that had spilled (John et al., 2013).

The elliptical form derives from the joining of two Ancient Greek theatres. The Romans constructed artificial slopes around the central stage with timber, stone as in Arles, and Nimes, and concrete as in Rome, Pula, and Verona (Selo & Erdonmez, 2018).

Colosseum, built-in AD 82, is the best example of this building type and is a fusion of engineering and art. It is an ellipse of 189 m by 155 m and has 48 000 spectator seats (Fletcher & Cruickshank, 1996). Today, it still inspires designers. The London Olympic Stadium has footprints of this ancient building.


(a)


(b)



(c)

Figure 2.16. The plan (a), the elevation (b), the section of the Colosseum of Rome (c) (Fletcher & Cruickshank, 1996)

In the medieval and after; recreation, entertainment, and sports facilities left their place for religious activities. No new sports stadia or amphitheaters were built in this age.

By the 19th century, with the use of steel in 1850, the stadium structure witnessed a renaissance following the industrial revolution. The public was showing an increasing interest in large-scale spectator events and there were new structural technologies that made it easier to build stadia or enclosed halls (Selo & Erdonmez, 2018).

A congress convened in 1894 at the request of Baron Pierre de Coubertin. The first modern Olympic Games were staged in Athens in 1896, as a result of this. Therefore, the ancient stadium in Athens was redesigned by the architect Ernst Ziller with a Greek elongated U-pattern. The Olympic Games were then held every four years (Wimmer, Humann, & Martovitskaya, 2016).

The development and standardization of stadium playgrounds took some time, especially in Olympic stadiums, and it began in the middle of the twentieth century, evolving into shapes that can be called interesting by today's standards.

The stadium audience area has continued to develop until today. The tendency to host and receive the most audience, which is still valid today, has prevailed in the first period. The comfort and safety conditions remained in the background, and as many spectators as possible were taken to the stadium.

2.4.3. 20th-century olympic stadia

The White City Stadium, London (1908), designed by James Fulton with a steel frame and 80 000 spectator capacity was built for the 1908 Modern Olympic Games. It was demolished in the 1980s (Wimmer et al., 2016).

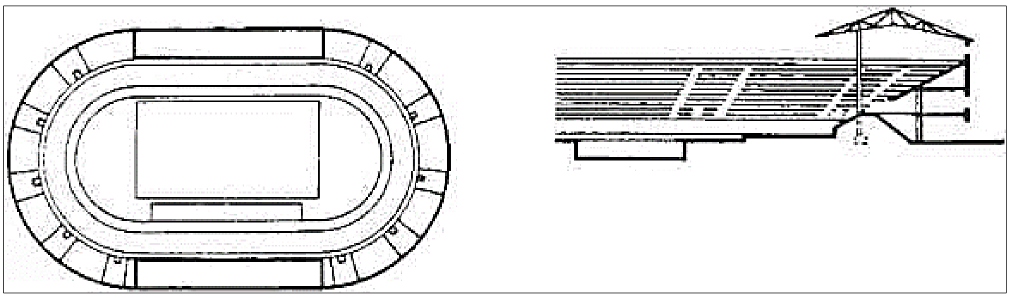
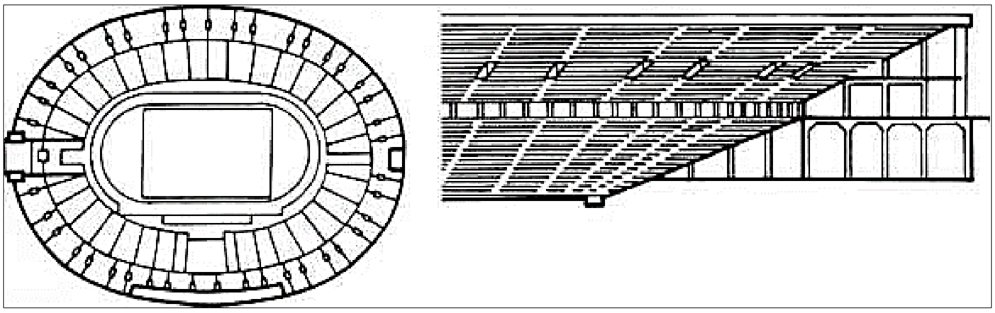


Figure 2.17. The White City Stadium (John et al., 2013)

Even though the games were canceled due to World War I, the Berlin Stadium, designed by Otto March, was built in 1913 with a capacity of 60 000 spectators (Wimmer et al., 2016).


(a)


(b)


(c)

Figure 2.18. The Berlin Stadium (1913) (a), the plan and section (b), The Berlin Stadium (1936) (c) (John et al., 2013)

Werner March renovated it for the first time in 1936 to seat 110 000 spectators, and again in 2006 for the FIFA World Cup.

The 1948 Olympics were held in London, when Sir Owen Williams, the stadium's original designer, restored the 24-year-old Wembley Stadium (Wimmer et al., 2016).

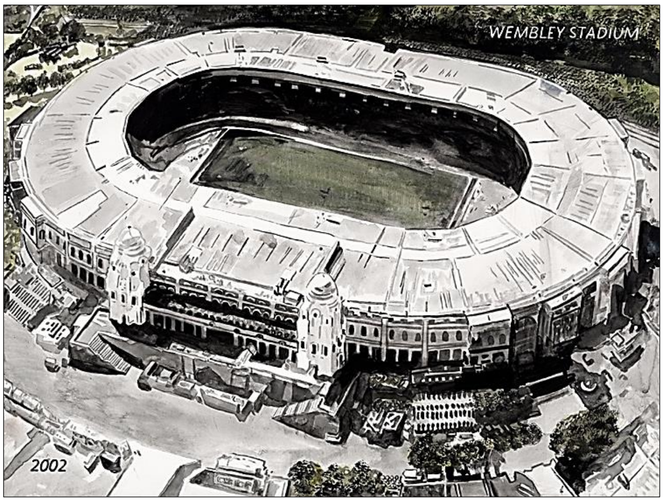


Figure 2.19. The Wembley Stadium (John et al., 2013)

Annibale Vitellozzi designed the Rome Olympiad in 1960. For the FIFA World Cup in 1990, a roof was built. It was planned with an athletics stadium in one section and other facilities in the city's urban areas (Wimmer et al., 2016).

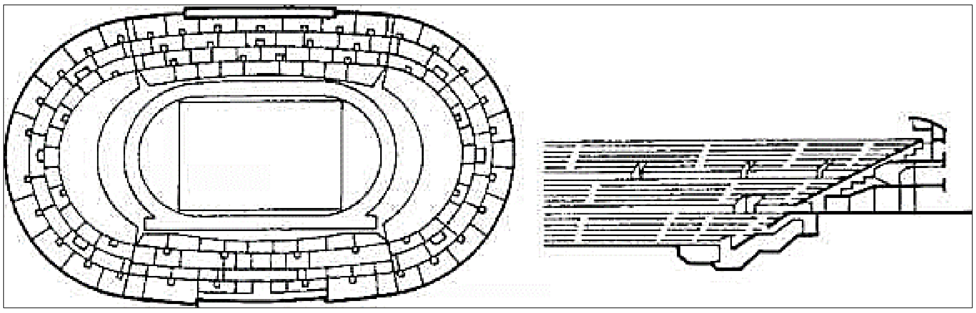


Figure 2.20. The Rome Olympic Stadium (1960) (John et al., 2013)

Kenzo Tange designed the Jingu National Stadium in Tokyo in 1964. Sports and a swimming arena with capacities of 4 000 and 15 000 spectators, were constructed with the stadium (Wimmer et al., 2016).

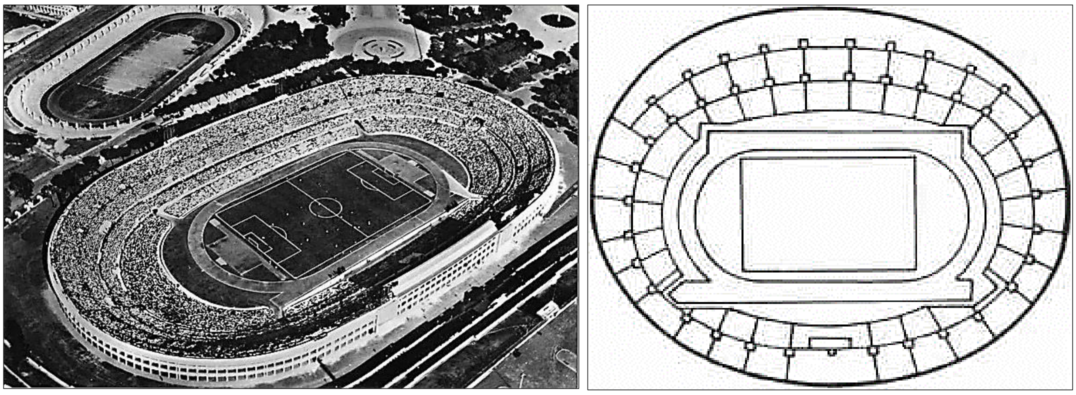


Figure 2.21. The Jingu National Stadium (1964) (John et al., 2013)

The University Stadium in Mexico was built in 1953 with a 70 000 spectators’ capacity and was later expanded to 87 000 spectators to host the Olympic Games in 1968. It makes little use of reinforced concrete and blends in seamlessly with its surroundings (John et al., 2013).

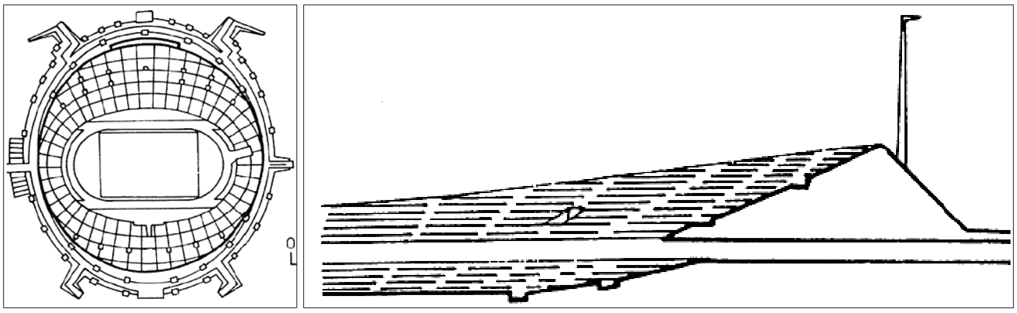
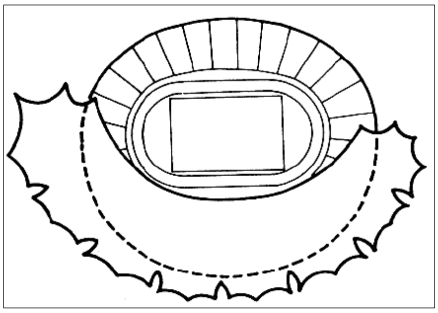


Figure 2.22. The University Stadium, Mexico City (1968) (John et al., 2013)

The Munich Olympic Stadium was built in 1972 to host the Olympic Games. It was thrown a very pricey yet pleasantly lightweight roof over one side of the stadium. The stadium was designed by architects Günter Behnisch and Partners (John et al., 2013).

(a)

Figure 2.23. The Munich Olympic Stadium (a), the plan and section (b) (sportycious, 2021)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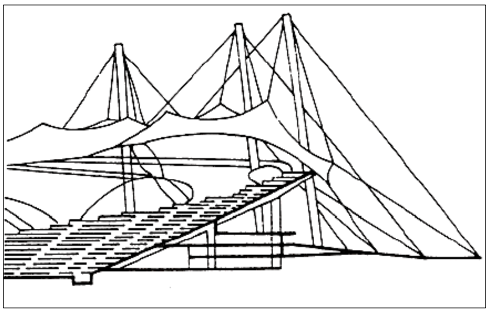

(c)

Figure 2.23. (continued) The Munich Olympic Stadium (a), the plan and section (b) (sportycious, 2021)

Vittorio Gregotti renovated the Montjuic Stadium which was built in 1929 for the Barcelona International Exposition to host the Olympic Games in 1992 in Barcelona. Only the Romanesque façades were kept to accommodate the bulk of track, field, and pitch sports. Everything within the stadium's outer walls was taken down (wikipedia, 2020).

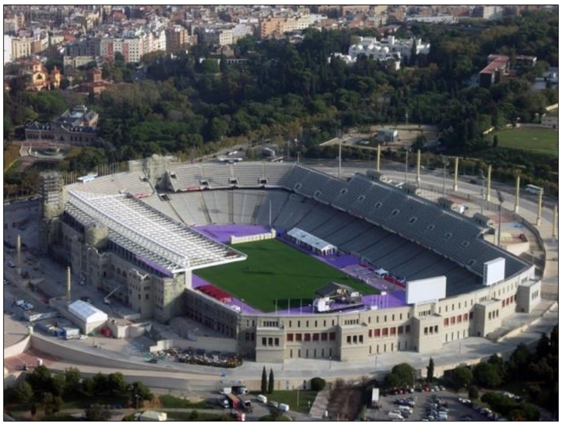


Figure 2.24. The Montjuic Stadium, Barcelona (flickr, 2007)

Centennial Olympic Stadium was the unique stadium for the Summer Olympics of 1996 and Paralympics in Atlanta, the United States, seating 85 000 people. The stadium's construction started in 1993, and it was ready for the opening ceremony in July 1996 (wikipedia, 2021).

Figure 2.25. The Centennial Olympic Stadium, Atlanta (wikipedia, 2021)

Stadium Australia is a multi-purpose stadium which is located in Sydney's Olympic Park. The stadium, known as Olympic Stadium in Australia, was completed in March 1999 in time to host the Summer Olympics in 2000 (wikipedia, 2020).

Figure 2.26. The Olympic Stadium, Sydney (wikipedia, 2020)

The Beijing National Stadium was completed in March 2008, and it served as the venue for the 2008 Summer Olympics in Beijing. It is called Bird's Nest because of its structure. As a result of a competition attended by world-renowned architects, the Swiss firm Herzog & de Meuron Architekten undertook to realize the design. The building which was founded in 2003 and completed in 5 years, can host 91 000 people (wikipedia).

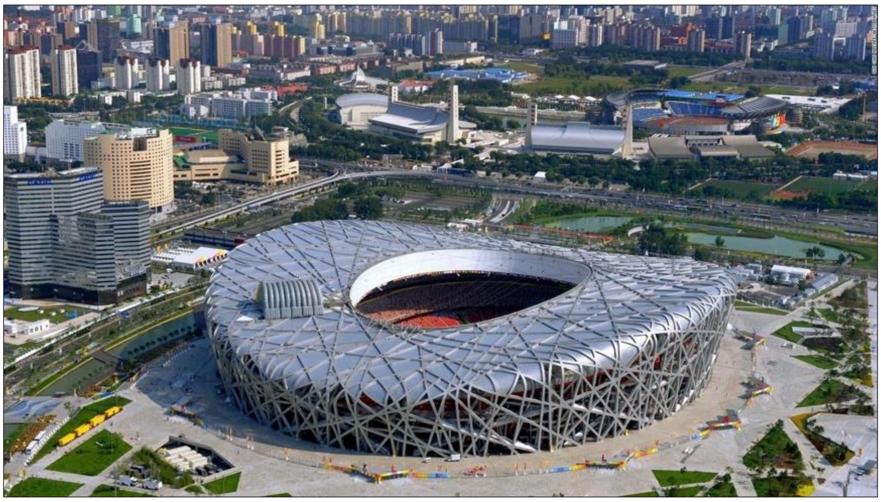


Figure 2.27. The Beijing Olympics, Beijing (wikipedia, 2008)

The London Olympic Stadium was built for the 2012 Summer Olympics and Paralympic Summer Games in London. The stadium's construction was completed on March 29, 2011. The torch for the 2012 Summer Olympics was lit in this stadium. It is a design by sports architects Populous and structural engineers Buro Happold (wikipedia, 2016).

Figure 2.28. London Olympics Stadium (wikipedia, 2016)

As previously said, Olympic stadiums are being built, as were increasingly ambitious facilities for specialized sports such as soccer, rugby, American football, baseball, tennis, and cricket. Soccer is by far the most popular of these. With a regular ground capacity of 103 000 people, the Maracana Municipal Stadium in Rio de Janeiro, Brazil, is the largest in the world. The stadiums built for the FIFA World Cups in Italy in 1990 and Korea and Japan in 2002 established extremely high design requirements (John et al., 2013).

Sports venues in Turkey

The number of sporting structures in Turkey has increased in recent years. Many indoor sports venues have been created in Turkey either by the private sector or by government effort. The number of sporting facilities in Turkey is estimated to be 3 174. There are around 1 652 stadiums and football pitches for the government and 2 515 sports venues for the private sector (gsb.gov.tr, 2019).

Figure 2.29. Some examples of stadiums from Turkey compiled by the author

2.5. The Importance of Evacuation in Sports Facilities

The number of stadiums and sporting venues is steadily increasing around the world. They are utilized for large-scale cultural and entertainment events in addition to sporting events. As a result, stadiums have become one of the most popular gathering spots for a huge number of people in everyday life. They are known for their majestic constructions, intricate structures, and extensive equipment. Behind these qualities, however, there is a big issue: security threats. These complex structures can be easily collapsed, a little sloppy management can result in a fire or an explosion, they can become targets of terrorist attacks, and the most important of all; having a large population of density, can easily lead to crowds, which can result in stampedes. These stampedes can result in injuries and deaths.

Sports venues' stampedes are rare in number but their impact on the death occurs in large numbers. They are generally the results of the egress and evacuation problems (Hoskin, 2004). Stadium disasters occurred in the last century are shown in the table below.

Table 2.4. Stadium disasters in the last century (Hoskin, 2004) updated by the author

Year	Location	ountry	Incident	Contributing Factors	njuries	eaths
1902	Ibrox	UK	Structural Failure		517	6
1946	Bolton	UK	Structural Failure	Stampede	500	3
1964	Maryland	USA	Crushed, lacerated children	Escalator gate closed, human error	60	
1964	Lima	Peru	Stampede-Crushing	Riot following referee decision	500	18
1967	Kayseri	Turkey	Stampede	Fighting weapons and resulting riot	600	0
1968	Buenos Aires	Argentina	Stampede-Crushing	Hooliganism, fire	200+	4
1971	Salvador	Brazil	Stampede	Fighting led to flight	1500	
1971	Ibrox	UK	Structural Failure-Crushing	Crowd behavior egress reverse flow	140	6
1974	Cairo	Egypt	Stampede-Trampling	Riot following referee decision	27	9
1979		Nigeria	Stampede-Trampling	Lighting failure led to flight		4
1981	Athens	Greece	Stampede-Trampling	Locked gate, no front to back communication	38	4
1981	Hillsborough	UK	Crushing	Crowd surge		
1982	Moscow	USSR	Crushing	Reverse flow in egress	250	1
1982	Cali	Columbia	Stampede-Trampling	Intoxicated patrons inciting flighr	100+	4
1985	Bradford	UK	Fire	Rubbish ignites poor housekeeping	30	6
1985	Mexico City	Mexico	Crushing	No front to back communication at locked gates	437	0
1985	Heysel	Brussels	Structural Failure-Crushing	Crowd behaviour	700	9
1988	Kathmandu	Nepal	Stampede-Crushing	Hail storm led to flight, locked exits	400+	3
1989	Hillsborough	UK	Crushing	Inappropriate police behaviour	1900	6
1991	Orkney	South Africa	Crushing	Fighting led to flight against fences		0
1992	Bastia	Corsica	Structural Failure	Temporary stands collapse	50	0
1992	Rio de Janeiro	Brazil	Structural Failure-Crushing	Crowd behaviour	180	0
1996	Guatemala City	Guatemala	Stampede	Individuals falling down	undreds	83
2000	Harare	South Africa	Stampede-Crushing	Inappropriate police behaviour	00	12
2000	Sao Januario	Brazil	Stampede-Crushing	Fighting and oversold event	undreds	
2000	Monrovia	Liberia	Stampede	Crowd behaviour	undreds	3
2000	Harare	Zimbabwe	Stampede	Crowd behavior egress reverse flow		13
2001	Ellis Park	South Africa	Crushing	Crowd behaviour and oversold event	77	47
2001	Accra	Ghana	Stampede-Crushing	Inappropriate police behaviour	20	126
2001	Akashi	Japan	Crushing	Insufficient egress due to poor organisation		10
2012	Port Said	Egypt	Stampede-Crushing	Riot following match defeat		73

The Monrovia, Harare, Ellis Park and Port Said stampedes have been added to the list by the author (cbsnews.com, 2012).

2.5.1. Evacuation parameters for sports facilities

Flow rates

Effective evacuation performance is a challenge in sports facilities because of the large number of spectators at sporting and public events. The most important way to ensure crowd safety is the design of the circulation system. The majority of stadium evacuation planning revolves around determining the entire width of exits. They must be linked to the recommended flow rates in building codes as well as the evacuation time minimum criteria (John et al., 2013).

The capacity of the stairs and level surfaces is also a significant metric for assessing the efficiency of stadium evacuation. The flow rate is the people's number per second per meter wideness.

The flow rate values observed in the literature for stadiums are shown in table 2.5.

Table 2.5. Flow rate values in stadiums (Graat, Midden, & Bockholts, 1999)

Authors	Stairs	Levels	Subject
Predtechenski (1969)	0.66	0.80	Stadia Max Flow Rate
Poyner Et Al. (1972)		1.42	Soccer Stadium
Neufert (1980)	1.25		Olympic Stadium Amsterdam
Taylor Report (1990)		1.67	Video Footage Of Gate C From Hillsborough Disaster
Templer (1992)	1.03	1.26- 1.42	Commuters +Stadium (Fruin 1970)
Green Guide (2008)	1.21	1.82	Unknown (For Purpose Of Calculation Only)
Gwynne (2009)		0.77	Observed Specific Flow Rate-Width
		0.92	Rate-Eff. Width From The Arena Exits

Crowd characteristics

Crowd behavior in sports venues can vary greatly because of the various types of events that are held. The likelihood of harmful behavior in a stadium or entertainment audience is substantially higher than in other crowd demographics (Berlonghi, 1995).

In terms of typology, stadium crowds for sporting events may be classed as follows:

- Attending the events as the major goal,
- The time duration is moderate,
- Start and end times that are certain,
- Seating assignments tailored to the individual,
- Conflict and interaction potentialities are at an all-time high,
- Singles, couples, and groups of friends or work associates are among the members,
- Luggage that is careless.

The following describes the demographics of stadium crowds (Berlonghi, 1995):

- Young/ Old,
- People that are crippled, unwell, or injured,
- Accident or attack victims,
- Persons who have gone missing,
- Drunks,
- Neutrals and partisans.

Unlike most other moving crowds, an egressing stadium crowd is unique. After the events, the majority of the crowd tries to depart as soon as possible. Behavioral factors have been found to have a substantial impact on such disparities (Hoskin, 2004):

- The absence of a visual stimulation,
- A lack of options,
- One’s identity acceptance as a member of a group.

Environmental elements such as egress routes, as well as human factors, influence crowd movement. According to studies, long egress and waiting time, increases tension, turning the egress population into an escape population with a tendency for violence.

2.5.2. Stadium evacuation in codes, standards and regulations

In 2000, NFPA 101A established an international standard for evacuation facilities, and each government is in charge of ensuring that evacuation facilities and infrastructure are standardized.

The most important factor to evaluate the effective stadium evacuation is the evacuation time in terms of minutes. In each building code, there is a sample for designers to compute the overall width of the exits during the first design phase.

8 minutes is an international rule for large stadiums. However, the specific rules for the amount of time allowed vary by country and region. The Green Guide in UK recommends the escape time from any seat must not be more than 8 minutes (Green Guide, 2008). Unfortunately, no mention is made of where the escapee should be after 8 minutes. In Italy, all spectators must discharge their seats in 5 minutes and the entire building in the next 5 minutes (John et al., 2013). FIFA suggests all spectators must enter an exit system in 8 minutes maximum (FIFA, 2008). In China, a large stadium needs 6-8 minutes for a safety evacuation (Code of China, 2003).

Table 2.6. Stadium evacuation times in international codes compiled by the author

International	8 Minutes
UK	No More Than 8 Minutes
Italy	5 Minutes for The Seats + 5 Minutes for The Building
FIFA	Maximum 8 Minutes
China	6-8 Minutes
Turkey	Currently abolished *3 Minutes in Masonry Structures (in a Unite Width 50 Cm.)
	*2 Minutes in Wooden Structures (in a Unite Width 50 Cm.)

*not valid since 2002 in Turkey's Regulation on Fire Protection.

2.6. Studies on Evacuation Efficiency

2.6.1. Studies on evacuation models and methodological approaches

- Friedman (1992), identified 62 computer programs and 12 sub-models which have been used in the fire engineering profession, in categories that are zone models for compartment fires (31 models), field models for compartment fires (10 models), submodels for fire survival (12 models), submodels for building evacuation (4 models), submodels for operating thermal detectors (5 models) and fire-sprinkler interaction models (3 models).

Zone models for compartment fires (ARGOS, ASET, ASET-B, BRI-2, CCF, VENTS, CFAST, CFIRE-X, CiFi, COMPBBRN-III, COMPF2, DACFIR-3, DSLAYV, FAST, FIRAC, FIRIN, FIRST, FISBA, FPETOOL, HarvardMarkVI, Hazard I, HEMFAST, IMFE, MAGIC, NRCC1, NRCC2, OSU, POGAR, R-VENT, SFIRE-4, WPI-2, ZMFE)

Field models for compartment fires (BF3D, FISCO-3L, FLOW3D, JASMINE, KAMELEON E-3D, KAMELEON II, KOBRAA-3D, PHOENICS, RMFIRE, UNDSAFE)

Submodels for fire survival (CIRCON, COFIL, COMPSL, INSTAI, INSTCO, NAT, RCCON, RECTST, SQCON, TASEF, TCSLBM, WSHAPS)

Submodels for building evacuation (EESCAPE, EVACNET+, EVACS, EXITT, EXIT89, HAZARD I)

The author identified the uncertainties in the fire models as:

- CO^2 spread because of incomplete combustion,
- Drift rate into the smoke
- The mix of cold and hot air
- Heat loss because of the distance from the fire
- Demolition of the windows
- Movement of the smoke in different geometries
- Smoke through the ventilation systems
- Possibility of fire products on people

- Possibility of fuel-rich fire when products meet with fresh air

The author thinks fire models can be validated only by realistic fire tests. If a fire model can be worked with the help of several tests with the right conditions but a minimum gap occurs, the confidence of the model becomes risky.

- Gwynne et al. (1999), classified 22 egress models according to 3 different approaches which are optimization, simulation, and risk assessment. Due to these approaches the classifying of egress models is below:

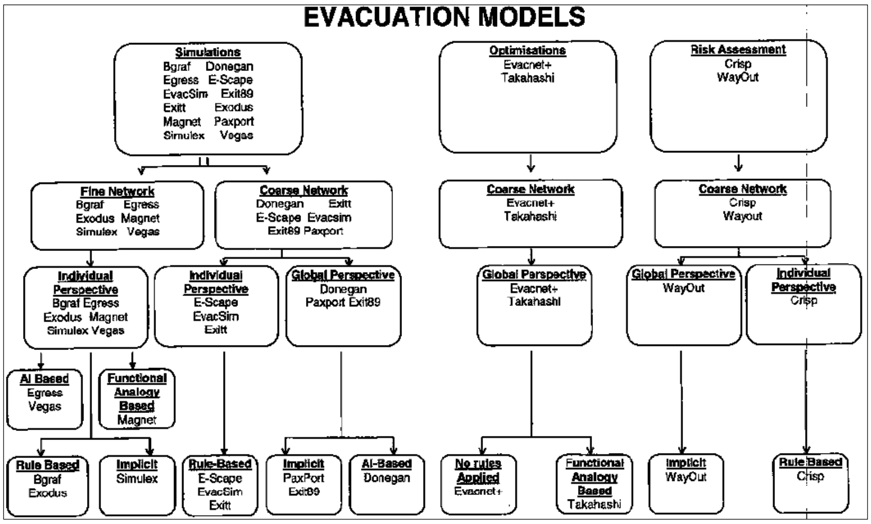


Figure 2.30. Evacuation models (Gwynne et al., 1999)

The authors made some classifications when evaluating 22 evacuation models. They are:

- Enclosure representations of the models
- Fine network approach
- Coarse network approach
- Population perspectives
- Individual perspective
- Global perspective
- Behavioral perspective
- No behavioral rules system
- Functional analogy behavior system
- Implicit behavior system

- Rule-based behavioral system
- Artificial intelligence-based behavioral system

According to the author, the 3 main approaches to design of an enclosure for evacuation are configuration, behavior, and environment. The attempts in the simulation can be categorized into two which are considering human movement and considering human movement with behavior. The first category is called the 'ball-bearing' model which treats the individuals as unthinking objects and which does external simulation. Individuals are treated as active agents in the second category model, including behaviors such as exit choices and personal reaction times.

At the end of the study, the authors put the parameters that evacuation performance depends on:

1. Physical situation of the space (size, shape, number of exits)
2. Function of the space (prison, hospital, theatre)
3. Nature of the people using the space (age, gender, familiarity with the space)
4. Nature of the environment of the space (time of the day, season, smoke, toxic gases)

- Olenick and Carpenter (2003), updated Friedman (1992)'s work. 168 computer modeling programs from worldwide are identified and categorized. Some information such as availability, price, contact information, etc. are included. A survey of fire models is made with the information mentioned below.
- Model name
- Description
- Organizations
- References
- Availability
- Hardware
- Language

The survey created a mechanism to update the database periodically. According to the authors; the identifications of the models are:

1. Zone Models, divide the space into compartments like a single room or multi rooms.
2. Field Models, divide the compartments into too many numbers of volumes.
3. Detector Response Models, forecast the time it takes for a device, such as a sprinkler or a thermal detector, to respond.

Model	Country	Identifying Reference	Description
Allsafe	NORWAY	[101]	Egress model including human factors
ASERI	GERMANY	[102]	Movement of people in complex geometries, including behavioral response to smoke and fire spread
buildingEXODUS	UK	[6]	Evacuation model that includes interactions for thousands of people in large geometries
EESCAPE	AUSTRALIA	[103]	Evacuation of multistory buildings via staircases
EGRESS	UK	[104]	Cellular automata evacuation of multiple people through complex geometries. Includes visualization
EgressPro	AUSTRALIA	[122]	Egress program that includes coping times and sprinkler-detector activations
ELVAC	US	[105]	Egress program for use of elevators for evacuation
EVACNET 4	US	[106]	Determines optimal building evacuation plan
EVACS	JAPAN	[107]	Evacuation model for determining optimal design
EXIT89	US	[108]	Evacuation from a high-rise building
EXITT	US	[5]	Node and arc type egress model with people behavior included
PATHFINDER	US	[129]	Egress model
SEVE-P	FRANCE	[109]	Egress model with graphical output that includes obstructions
Simulex	UK	[110]	Coordinate-based egress model which models evacuation in multistory buildings
STEPS	UK	[130]	Egress model
WAYOUT	AUSTRALIA	[111]	Egress part of the FireWind suite of programs

Figure 2.31. Identified egress models from the survey (Olenick & Carpenter, 2003)

- Kuligowski (2005) , categorized 28 egress models according to the capabilities listed below:

1. Object
2. Accessibility to the general public
3. Movement, partial-behavioral, and behavior modeling methods
4. Model's structure
5. The model's point of view and the occupants' point of view
6. Occupant behavior
7. Occupant movement
8. Data from fires
9. Results
10. CAD drawings usage
11. Abilities for visualization

12. Confirmation research
13. Unique characteristics
14. Restrictions

The classification of these egress models based on modeling methods is made in the study. These are movement models, partial behavioral models, and behavioral models:

1. Movement models:

FPETool, EVACNET4, Takahashi's Fluid Model, PathFinder, TIMTEX, WAYOUT, Magnetic Model, EESCAPE, EgressPro, ENTROPY Model, and STEPs

2. Partial Behavioral models:

PEDROUTE/PAXPORT, EXIT89, Simulex, GridFlow, and ALLSAFE

3. Behavioral models:

CRISP, ASERI, BFIRES-2, buildingEXODUS, EGRESS, EXITT, VEgAS, E-SCAPE, BGRAF, EvacSim, Legion, and Myriad

The data about reviewed egress models are presented in the table below:

Model	Available to public	Modeling Method	Purpose	Gird/ Structure	Perspective of M/O	Behavior	Movement	Fire data	CAD	Visual	Valid
EVACNET4	Y	M-O	1	C	G	N	UC	N	N	N	FD
WAYOUT	Y	M	5	C	G	N	D	N	N	2-D	FD
STEPS[c]	Y	B	1	F	I	C, P	P, E	Y1,2	Y	2,3-D	C,FD,PE
PEDROUTE	Y	PB	3	C	G	I	D	N	Y	2,3-D	N
Simulex[b]	Y	PB	1	Co.	I	I	ID	N	Y	2-D	FD,PE, 3P
GridFlow	Y	PB	1	Co.	I	I	D	N	Y	2,3-D	FD, PE
FDS+Evac[c]	Y	PB	1	Co.	I	I, C, P	ID	Y3	N/Y	2,3-D	FD,PE,OM
Pathfinder 2009[c]	Y	PB	1	Co.	I/G	I	D,ID	N	Y	2,3-D	C,FD,PE,OM
SimWalk[c]	Y	PB	1,3	Co.	I	C, P	P	N	Y	2,3-D	FD,PE,3P
PEDFLOW[c]	Y	B	1	Co.	I	C, P	ID	Y2	Y	2,3-D	PE
PedGo[c]	Y,N1	PB/B	1	F	I/I,G	I/C, P	P,E (CA), C	Y2	Y	2,3-D	FD,PE,OM,3P
ASERI[c]	Y	B-RA	1	Co.	I	C, P	ID	Y1,2	Y	2,3-D	FD, PE
BldEXO[b]	Y	B	1	F	I	C, P	P, E	Y1,2	Y	2,3-D	FD,PE,OM,3P
Legion[c]	Y,N1	B	1	Co.	I	AI, P	ID, C	Y1	Y	2,3-D	C,FD,PE,3P
SpaceSensor[c]	Y	B	3	Co.	I	C, P	C, Ac_K	N	Y	2,3-D	FD,OM
EPT[c]	Y,N1	B	1	F	I	AI	UC,C	Y2	Y	2,3-D	FD
Myriad II[c]	Y, N1	B	1	C, F, Co.	I	AI	D, UC, IP, Ac_K	Y1	Y	2,3-D	PE, 3P
MassMotion[c]	Y, N1	B	1	Co.	I/I,G	AI,P	C	N	Y	2,3-D	C,FD,PE,OM
PathFinder	N1	M	1	F	I/G	N	D	N	Y	2-D	N
ALLSAFE	N1	PB	5	C	G	I	Un_F	Y1,2	N	2-D	OM
CRISP	N1	B-RA	1	F	I	C, P	E,D	Y3	Y	2,3-D	FD
EGRESS 2002	N1	B	1	F	I	C, P	P,D (CA)	Y2	N	2-D	FD
SGEM[c]	N1	PB	1	Co.	I	I	D	N	Y	2-D	FD,OM
EXIT89[c]	N2	PB	1	C	I	I/C, P	D	Y1	N	N	FD,3P
MASSEgress[b]	N2	B	1	Co.	I	C, AI	C	N	Y	2,3-D	PE,OM
EvacuatioNZ[c]	N2	B	1	C	I/I,G	I, C, P	D, UC	Y2	Y	2-D	FD, PE,OM

Figure 2.32. Reviewed egress models (Kuligowski, 2005)

The study provides users the data to select the best egress model for the building interested because each model is unique and has advantages and disadvantages.

- Santos and Aguirre (2004), a thorough examination of selected simulation models according to the descriptions of the characteristics opposite to empirical tests used in Kuligowski (2005)'s survey. They described the simulation methods as;

1. Flow-based modeling (EVACNET4, LOS),
2. Cellular automata modeling (EGRESS, Pathfinder, TIMTEX),
3. Agent-based modeling (SIMULEX, EXIT89, grid flow),
4. Models that incorporate sociological factors (EXODUS, ASERI, CRISP3, BFIRES) on computer models.

The absence of the social sciences approaches which can improve the simulation models is evaluated in the article. With these approaches, authors claim that engineers, computer scientists, and fire scientists could render more realistic models.

According to the study, the evacuation behavior has 3 analytical dimensions:

1. The evacuation's physical location (the environment and hazard)
2. The current management of the emplacement (procedures and rules)
3. The social and organizational features who participate in the evacuation

The three phases of simulation modeling are mentioned in the article which is flow, individual, and group. Nowadays, simulation modeling is beginning to incorporate socio-psychological and social phenomena.

The authors suggest governments sponsor a uniform simulation program that could combine the validation of the simulation models each with its advantages and disadvantages.

- Zheng et al. (2009), determined the 7 methodological routes for crowd evacuation which are cellular automata models, lattice gas models, social force models, fluid-dynamic models, agent-based models, game-theoretic models, and approaches based on experiments with animals. The benefits and drawbacks of the paths were discovered.

The conclusions are:

1. A combination of various approaches must be used for evacuation simulation

2. A wide range of psychological and physiological features of pedestrians must be included in the simulation models
3. The models that have been added to include some human features such as kin behavior or panic behavior are closer to real evacuations.

The features that authors describe the evacuation models are:

Items of features	Descriptions
Approaches	Seven modeling approaches are applied to study crowd evacuation separately and in combination. They are approaches based on *cellular automata (CA), lattice gas (LG), social force (SF), fluid dynamics (FD), agent-based (AB), game theory* and *experiments with animals*.
Individuals/groups	In some models (approaches), pedestrians are ideally considered as *homogeneous* individuals. However, in others, pedestrians are looked on as *heterogeneous* individuals (groups) by the difference of characteristics (e.g., gender, age, psychology).
Scale	In some models (approaches), where collective phenomena emerge from the complex interactions between many individuals (self-organizing effects), pedestrian dynamics is modeled on a *microscopic* scale. In others, when a crowd of pedestrians is considered as a whole, pedestrian dynamics is modeled on a *macroscopic* scale.
Space and time (SAT)	Some modeling approaches are *discrete* in space and time; the others are *continuous*.
Situations	Crowd movement is described in *normal* and *emergency* situations.
Typical phenomena	Different behaviors can be reproduced in the pedestrian flow simulations.

Figure 2.33. The features of the evacuation models (Zheng et al., 2009)

Table 2.7. Studies on evacuation crowd models - methodological approaches compiled by the author

Authors	Number of Models/		Type of Models	Methods	Gaps in the Literature
Friedman (1992)	62	3	Fire/ Smoke/ Egress	Information Supplied by The Modelers	Uncertainities Correlated Burning Rates - Calculations of Radiative Flux
Gwynne Et Al. (1999)	22	3	Egress	Survey	No Model to Date Thoroughly Explores All the Behavioral Dimensions of Evacuation That Have Been Established
Olenick And Carpenter (2003)	168	6	Fire/ Smoke/ Egress	Survey	Lack of Information About Models for Construction Quality including Fire Output on İnternet
Kuligowski (2005)	28	3	Egress	Information Based on Literature	Lack of Updates as New Models Start to Be Used and The Old Ones Retire
Santos And Aguirre (2004)	17	4	Egress	Information Based on Published Descriptions	Lack of Research and Theory to Base the Models on Rational Assumptions About Social Conduct in Crisis Situations
Zheng Et Al. (2009)		7	Egress	Information Based on Literature	Incorporating the Psychological and Physiological Factors into the Evacuation Models to Reach Realistic Results

2.6.2. Studies on building evacuation using pathfinder software

- Bao (2011), took a five-star hotel with an area of 91 511 m^2 and a height of 22.6 m as the case study. The hotel has a banquet hall with an area of 1 600 m^2 on the second basement level. The hall has a refuge walkway on the west side and an exterior yard on the east side. The only safe area according to the code of China, is this refuge way with 85 m length and 4 m width.

The acceptances for fire simulation (Fire Dynamics Simulator) are:

- At 2 m height, the smoke temperature should not be more than 60 ^{0}C and visibility should not be less than 10 m.
- The fire growth coefficient is α＝0.04689 kW/S2
- When the automated sprinkler system is successful, the maximum heat release rate is 2.5 MW; when the automatic sprinkler system is inefficient, the maximum heat release rate is 8 MW.

The two fire scenarios are shown below:

Fire scenario	Fire growth coefficient（kW/s^2）	Smoke exhaust system	Automatic Sprinkler system	Maximum heat release rate（MW）
1	0.04689	Useless	Effective	2.5
2	0.04689	Useless	Useless	8

Figure 2.34. Fire scenarios (Bao, 2011)

According to the acceptances listed above, the time of simulation in Fire Dynamics Simulator ends in the 1 600s. in both scenarios. But the visibility in the hall is lower in the second scenario in which the automatic sprinkler system is ineffective.

The acceptances for occupant evacuation (PathFinder) are:

- Talarm is 60s,
- Tresp is 120s,
- Tstart is 180s,

- The evacuation move time has a safety factor of 1.5 times.
- The walking speed is 1 m/s.
- The upstairs speed is 0.6 m/s.

The comparison of the two scenarios' results are:

Fire scenario	Evacuation area	Evacuation direction	T_{RSET}(/s)	T_{ASET}(/s)	Safety (yes/no)
1	Banquet hall	To refuge walkway	359	465	Yes
	Banquet hall	To antechamber	320	465	Yes
	Antechamber	To exterior yard	335	724	Yes
2	Banquet hall	To refuge walkway	359	356	No
	Banquet hall	To antechamber	320	356	Yes
	Antechamber	To exterior yard	335	609	Yes

Figure 2.35. Fire scenarios' results (Bao, 2011)

The conclusions made by the author at the end of the study are:

- The area of the banquet hall (1 600 m^2) is not feasible for the smoke prevention zonings. The hall must be divided into zonings.
- The exterior yard should be used effectively during staff evacuation.
- Wang, Chen, Yan, Yuan, and Liang (2014), studied Wanling International Exchange Center located in Guangzhou which has 49 floors (B1-5 shopping center floors,6-39 office floors, 40-49 hotel floors). The building has an area of 230 000 square meters. The 10th, 22nd, and 34th floors are refuge floors.

The authors set a fire scene according to these parameters: The fire's heat release rate is 1.5 MW, and the time of rise is 160 s. The computation time is 600s, and the device locations are P1: (8.5m, 8.0m, 2.0m); P2: (9.5m, 9.0m, 2.0m); P3: (9.5m, 9.0m, 2.0m); P4: (9.5m, 9.0m, 2.0m); P5: (9.5m, 9.0m, 2.0m); P6: (9.5m, 9.0m, 2.0m); P7: (21.0m, 27.5m, 2.0m). In the simulation of fire situations, when the timer reaches 240 seconds, the smoke has made its way down the corridor. When the time is up to 180 seconds, the corridor temperature is 70 degrees Celsius, and visibility is less than 10 meters.

The simulation results show that before the 40s, people were told to go towards the exit, staircases started congestion after 50s, and fluctuations for a cycle in 50s. About 100 seconds of stairs, all congestion. People will not walk away from the exit without a cause at first, by passing obstacles or shortening the waiting time, people will move to large spaces in the intermediate process. 963s is the total time to end the evacuation. The evacuation efficiency is at its best in the last 300s.

The conclusions of the study are as follows:

- In the beginning stage, due to the planning of the path and the guidance mechanism, the evacuation is slow. However, as time passes, congestion decreases and evacuation speed improves, and evacuation efficiency increases.
- In the high-rise buildings, the elevator might be included in the evacuation plan because the people can not be evacuated to safe areas with staircases.
- Benbu, Kefan, and Yu (2017) studied a college library in Wuhan which has five floors each 6 meters in height, as the case. The library has a 4 700 m^2 total area and can hold more than 5 000 students. The building has 11 exits, especially on the 1^{st} and 2^{nd} floors. The exits on the 1^{st} floor are in different directions but the exits on the 2^{nd} floor are in the south and north directions. The library has 6 stairs. Two of them are in the center and 4 of them are located in each corner of the building. The study admits students' numbers on each floor as 1 640 (1), 1 334 (2), 1 199 (3), 950 (4), 843 (5), and in total 5 966.

The authors used Pathfinder simulation software to build the full-size model of the library. Then five scenarios were built to evaluate the evacuation scenes:

- Scenario 1: Both doors and stairs are open, with either exit allowing all pedestrians to evacuate.
- Scenario 2: All stairwells are accessible, and only exits W1-1 and S2-1 can be evacuated by pedestrians.
- Scenario 3: Exit W1-1, S2-1 is accessible, individual doors and stairs are locked, and the pedestrian flow is divided between the north and south.
- Scenario 4: All stairwells are accessible, exit N2-1, 2^{nd} floor S2-1 is open,
- Scenario 5: All stairs are available, there are open exits W1-1 and S2-1, and there are well-trained evacuation guidance personnel.

According to the scenarios, the results in the Pathfinder simulation program are:

- Scenario 1: The evacuation time is 538.5s in total. At the exits on the 1st floor, there is an arching anomaly when the simulation started at around 15s. The doors are jammed by a huge number of pedestrians because the exits on the 1st floor are small and the distribution of rooms is complex.
- Scenario 2: Owing to the small number of opening exits, the maximum evacuation period is 1.208s. Exit S2-1 ended its evacuation mission at 844s, whereas exit W1-1 continued to the finish.
- Scenario 3: The total evacuation time is 941.5s. and the traffic flow hedging has been eliminated. It can offset the use of staircases by observing the scene from the whole, through the decentralization of the crowd on the 1st floor, but it is not obvious on other floors.
- Scenario 4: The total evacuation time is 819.5s. which reduces the evacuation time by %30.
- Scenario 5: The total evacuation time is 547.3s. which is equal to scene 1. Scene 5 thus effectively alleviates the congestion of staircases relative to other scenes, making the use of stairs appear average and decreasing the time of evacuation.

The suggestions authors made after the scenarios studied above are:

- The exits' location has important role in evacuation efficiency. For example, 2nd floor opening exits will decrease evacuation time by 35%.
- The imbalance of staircase use is the primary factor that limits the time of evacuation. If the pedestrians jam in the staircases, a big stampede risk occurs. When all staircases can be used during the evacuation, 22% of evacuation time can be saved.
- Decentralization of the crowd and well-trained staff potentially cut the time it takes to evacuate by more than half.
- Long, Zhang, and Lou (2017)**,** studied an old dormitory of a university that was built in 1933. The dormitory has 55 m in length and 20 m in width. It has no sprinkler or alarm system against fire disasters. It has 25 rooms on four floors with four students located in each.

The authors set a fire scenario as all the wall surfaces are made of 0.013 m thick gypsum, the surfaces of the desk, cabinet, and bedboard which are made of yellow pine with a 0.013 m thickness while the floor is built of 0.013 m thick tiles. The 3D model was created in

Pyrosim software model and the end time of the simulation was set to 600s. Then, the Pyrosim model was imported to Pathfinder simulation software. The dormitory's entire capacity was set at 400 students. Each student was modeled as individual not in groups. Their speed was set to 1.19 m/s as in the default value. They chose the shortest path to exit.

The results at the end of the simulation are as below:

- When all the doors and windows are open, the temperature of the corridor is lower near the ends. There is no effect on personal escape at the entrance of the stairs because the temperature is not high thereThe temperature can be divided into 3:in the first 30s time, between 30s-100s time, the balancing time.
- Within the first 100 seconds, the ceiling temperature of the fire origin region reaches its maximum.
- When it comes to visibility, the nearer the origin of the flames, the lower the visibility is. The visibility in front of the room where the fire originated reduced to 2.5 meters in 20 seconds.
- Workers' escape will be significantly restricted if the smoke layer is less than 2.5 meters high, and no escape will be possible if the smoke layer is less than 1.5 meters high, according to the BSI (2019).
- There were 400 students in the dormitory, and the best escape time was 164.8 seconds.

In the first 30 seconds, the evacuees' speed is faster than the rest of the time.

The conclusions of the study are as follows:

- The patterns of temperature variations in the building are the same with all windows open. The temperature remains the same for the first second. In a short time, it grows to the top and slowly stabilizes. The hottest temperature location is the fire's origin room, which is roughly 50 ° C hotter than other areas.
- The shorter the time it takes for the drop to occur, the closer the fire origin room window is opened to the fire source.
- With the window open for the first 20 seconds, the height of the smoke layer remains unaltered. It rapidly drops from 20 to 40 s to the lowest height and then stabilizes at 1.4 m.

- With all windows open, the smoke has a greater impact on rooms above the fire's source. The smoke is more strongly affected by the horizontal corridors and stairs when the window is closed.
- 164.8 s. is the safest time to escape. The evacuation speed is quicker for the first 30 seconds and thereafter slows.
- The exit door should be at least 3 meters wide, and the stairwell should be at least 1.75 meters wide so as not to jeopardize the safe evacuation of personnel.
- Hadi Sutrisno and Amiruddin (2018) studied an 8-story building with 35 people using Pathfinder simulation software. The simulation-derived evacuation time is compared to the actual evacuation time. The simulation and actual evacuation used the same parameters to get the results that are nearest to reality.

The parameters accepted in the simulation were:

- Height: This parameter specifies the cylinder height for collisions between occupants. The information is used to restrict collisions that can occur when a simulation is carried out on the floor between occupants on different floors.
- Reduction factor: In a small hallway, this parameter determines whether one occupant can pass another occupant. The individual must be able to pass through the aperture up to half his or her shoulder width.
- Comfort Distance: This setting specifies the most comfortable spacing between two persons in a row.
- Persist Time: This feature specifies the most amount of time that can be spent on a task when the occupant attempts to settle the conflict of motion.
- Collision Response Time: This parameter takes control of the distance where the occupants start recording confrontations with other individuals.
- Slow Factor: This option specifies a small portion of the occupants' speed that they see as slow.

In real evacuation:

- The evacuation of the building was done 3 times.

- The building’s occupants were informed about the number of exits, the equipment entering and exiting the premises, assembly point locations, and the proper evacuation process.
- The information was taken from the time when 35 occupants reached the assembly point from the top floor.

In simulation software, the evacuation time from the top floor to the assembly was 3 minutes and 36 seconds. The real evacuation time; first evacuation:3 minutes 48 seconds, second evacuation: 3 minutes 31 seconds, and third evacuation:3 minutes 18 seconds.

The results show that; the time spent in the first evacuation exceeded the time spent in the simulation. However, the time spent in the second and third evacuations was less than in the first. This suggests that the more evacuation exercises that are held, the more familiar the occupants get with the evacuation process and the faster they can depart. As they go out of the building to the assembly point, the occupants will be less fearful. If they are familiar with the circumstances during the fire and a bottleneck or a high number of occupants would be less likely to congregate at one point on one of the evacuation routes if the occupants are less panicked.

- Qin, Liu, and Huang (2020) took Shanghai Disneyland station which is 5.7 m in height and 150 m in width, as the research object of the study. Evacuees are divided into seven categories as child, adolescent, young man, young woman, middle-aged man, middle-aged woman, and elderly person. The station chosen for the study has ten doors and 120 lines to queue up. The number of passengers on the train is accepted as 1 542, 1 224, and 906. The radiation density of the fire scenario is accepted as 2.5kW / m^2. at which the human limit is longer than 300s.

When two trains arrive at the same time at the station, with 120 passengers on the platform and 960 passengers in the hall (a total of 1080 people), the evacuation time is 667.5 seconds

which is more than 328 seconds. Because of that, two trains should not arrive at the same time.In the second pedestrian scenario, the evacuation time is 329 seconds when one train arrives at the station with 120 passengers on the platform and 180 passengers in the hall (a total of 300 people).

With these two scenarios, it is seen that the evacuation time is determined by the number of passengers on the platform, not the overall number of passengers at the station.

The results of the study are as follows:

- If a fire breaks out on the platform, it will take users longer to escape than it will take pedestrians to escape the fire's source.
- In the scenarios used in the simulation, there was no bottleneck in the hall. But there was a high possibility of clustering on the stairs.

Table 2.8. Studies on evacuation using pathfinder simulation software compiled by the author

Authors	Case Buildings	Software Programs	Number of Evacuees	Goals
Bao (2011)	A Five-Star Hotel Banquet Hall	Fire Dynamics Simulator + Pathfinder	1 600 m^2	The Hall Must Be Divided into Zonings
Wang et al. (2014)	Wanling International Exchange Center	Pathfinder	4 600 m^2	The Elevator Can Be Added to Evacuation Design in the High-Rise Buildings
Benbu et al. (2017)	A College Library in Wuhan	Pathfinder	5 966 people	Decentralization of the Crowd and Staff Can Cut the Escape Time by More Than Half
Long et al. (2017)	Old Dormitory of AUniversity	Pyrosim+Pathfinder	400 people	The Exit Door Should Be at Least 3 m. Wide, the Width of the Stairway Should Not Be Less Than 1.75 m.
Sutrisno & Amiruddin (2018)	An 8-Story Building	Pathfinder+real evacuation	35 people	The More Evacuation Exercises Are Carried Out, The More Occupants Become Used to The Evacuation Process
Qin et al. (2020)	Shanghai Disneyland Station	Pathfinder	1 080 people	The Time It Takes for Building Users to Evacuate is Longer Than the Time it Takes for Pedestrians to Escape the Fire's Source

2.6.3. Studies on evacuation of sports facilities

- Klüpfel (2007), studied the World Youth Day 2005 (WYD) in Cologne and Westfalenstadion in Dortmund as the case buildings.

The 2005 World Youth Day was hosted in Cologne, Germany in August of that year. The liturgy with Pope Benedict XVI was the concluding event. It was held on a big (about 92 hectares) piece of land with a stage in the center. A total of 800 000 pilgrims were hosted during the event. Various simulations were created to assess the functioning of the roadways in the event of an emergency evacuation. A fire near the central stage was simulated and the majority of the audience evacuated the arena in 30 minutes but it took another hour and a half to get the entire audience out of the arena.

For the second case study, the video was shot at a Dortmund international match between Germany and Scotland in Westfalenstadion in Dortmund to compare the reliability of simulation results. The first six minutes of video footage are matched to the first three minutes of the simulation. The varied time intervals are due to the fact that real occupants move more slowly. The scenarios in both simulation and reality are pretty similar after 13 minutes. After less than 15 minutes, the real evacuation is completed.

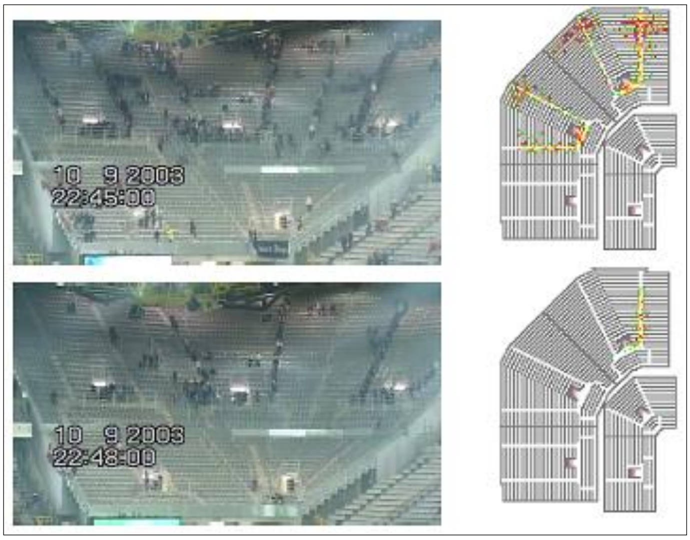


Figure 2.36. Comparison of the results of video footage and simulation (Klüpfel, 2007) videoshots are at t=10 and t=13 minutes

INDIVIDUALS	PATIENCE	SPEED 1	SPEED 2	BODY SIZE
Male	0.6	1.3	1.0	0.5×0.3×1.7
Female	0.6	1.1	0.7	0.4×0.3×1.6
Senior	0.4	0.8	0.6	0.4×0.2×1.6
Teenager	0.4	0.9	0.6	0.3×0.2×1.3

CROWD/TYPE	INDIVIDUAL PERCENTAGE			
	MALE %	FEMALE %	SENIOR%	TEENAGER%
Sports crowds	60.7	13.4	6.7	19.2
Cultural crowds	30.2	32.8	23	14

Figure 2.37. Spectator types-related parameters and crowd demography of the study (Liu, Liu, Badler, & Malkawi, 2011)

The capacity of seating is 2 800 spectators. The total widths of exits are 6.6 m. There are 40 rows of 0.8m in width of each. Twelve different types of gangways and vomitories that have been constructed. The design variations of terraced stands in planes are shown in Figure 2.38. below.

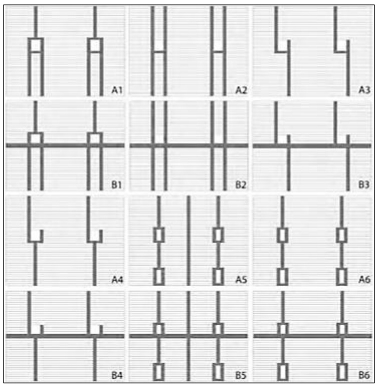


Figure 2.38. Gangway and vomitory layouts of the study (Liu et al., 2011)

The author did simulations with the software STEPS for three merging points on sixty scenarios:

- Scenario 1-24: with twelve alternative gangways and vomitory configurations
- Scenario 25-48: there are twelve distinct vomitory access possibilities, each with its outflow – inflow stream.
- Scenario 49-60: on the terraced stands, there are six vertical circulation measures with varying walking orientations.

At the end of the simulations, with a 1.6 m clear width lateral gangway:

1. Six models, on average, improved the overall egress time to 327s from 310s, which is 5.5 percent quicker than the base case;
2. The model raised the average waiting time from 3 320s to 3 834s, a 15.5 percent increase over the base case.

The author's conclusions at the end of the study are as follows:

- The simulation findings show that, for a given overall width of system exits, evacuation performance changed significantly between models with different egress route designs.
- Evacuation time increases along with the gangway increases.

- It is necessary to develop comprehensive safety assessment guidelines that contain more quantitative evaluation values in performance-based rules.
- Long periods of waiting during the evacuation process in huge crowds, such as stadiums with a huge number of spectators and intricate circulation networks, can cause anxiety and agitation in the crowds, resulting in non-adaptive behavior.
- Zarket, Aldana, Fox, Diehl, and Dimitoglou (2014), took the Ladd Peebles Stadium in Mobile, Alabama as the case building. They did not use an evacuation simulation but rather created a platform with the help of 'Unity,' a multi-platform video game development engine. The traffic flow was first tested using three scenarios in the study.

The following parameters were established for the study:

1. The average person's breadth and depth were estimated to be 51.50 cm and 29.00 cm, respectively.
2. With exits 1.5 m wide, the maximum speed of each person passing through was estimated to be 2 725 people per second.
3. Two sections with a total capacity of 2 391 people were taken to the simulation.

The evacuation simulation results were obtained from 1 000 agent runs on a 1.0 timescale. Each of the three scenarios received ten runs. There are three scenarios: one exit is blocked and the other is normal size, two exits are open, and one exit is larger in size. As a result of the simulation, it is clear that, because people can sit in random seats in a stadium, the amount of time each evacuation scenario will take will vary depending on their distance from the exits at the start of the evacuation. The outcomes of the 2 391 people evacuated are shown below;

Number of Exits	Two	One	One (double width)
Mean	401.7	465.9	330.4
Median	405.5	470.0	331
Range	77	79	57
Standard Deviation	21.936	24.369	17.413

Figure 2.39. The outcomes of agents (Zarket et al., 2014)

The authors' conclusions at the end of the study are as follows:

- The single larger exit has a higher flow rate and, in some cases, allows for evacuation in as little as 101 seconds while maintaining a flow rate more than double that of the two exit configurations.
- A decrease in the level of service maintained by individuals in larger exits as a result of the increased number of people attempting to use it
- Even when the number of exits was cut in half, the models showed that wider exits resulted in much faster evacuations, even when spectator safety was the only requirement.
- Including psychological and behavioral features would significantly improve the model's fidelity.
- Lin, Wu, and Hsueh (2015) took the Taipei Arena as the case building. The study aims to look at the feasibility of utilizing Pathfinder to simulate crowd evacuation at a large-scale venue. The movements of the crowds inside the large-scale venue vary dramatically from those in the surrounding structures. Seats are typically installed on terraces to produce the proper slope for spectators to view the activity. These seating areas are linked to the plane level via longitudinal stair-like walkways, which are subsequently linked to the passage areas and exits. Thus, in large-scale venues, crowd movements can be separated into four stages:

1. Choosing an exit,
2. From the seating area to the stair-style longitudinal walkway along with the seats (L shaped evacuation characteristics),
3. Transferring from the longitudinal walkway to the passage area (L shaped evacuation characteristics),
4. Along the passageway, making way to the exit.

The authors compared the simulation results to real evacuation data from previous studies to confirm the logic of the walking speed settings. They discovered that the first parameter setting was very close to the physical experiment result. Therefore, they accepted the walking speed as 0.65 m/s.

The authors built an occupant-movement model that includes the main entrance and mid-point exits and created six sub-models for various seating areas. Four scenarios were implemented at Taipei Arena. The simulation results are shown below:

Evacuation Strategy	*Evacuation Time*	*Marginal Effect*
Close emergency exits/staircases	24'06''	-
Open emergency exits/staircases	22'41''	Decrease 1'21''
Close emergency exits/staircases & install a new stair passage	19'11''	Decrease 4'55''
Open emergency exits/staircases & install a new stair passage	18'26''	Decrease 5'40''

Figure 2.40. Simulation results (Lin et al., 2015)

Pathfinder with both microscopic and macroscopic (mesoscopic) perspectives, according to the authors, is more conservative than other simulation software for large-scale indoor venues. Because models with macroscopic perspectives do not account for real people's interactions with one another.

The authors' conclusions at the end of the study are as follows:

- People in different seating areas must use different evacuation paths to reduce occupant movement conflict.
- People walk at different speeds due to differences in gender and age, so this study simulated heterogeneous crowd evacuation.
- Installing a new stairwell would be more beneficial than opening all existing emergency exits/stairwells.
- Crowds have a significant impact on a large-scale venue.
- Peterson and Jonsson (2018), selected three venues Manchester Arena, Troy Hobart Arena, and Talking Stick Resort Arena as the case buildings. These structures are designed to seem like concert arenas, which are one of the different sorts of sports facilities.

The strategy they used for the study is called ‘uniform spawn’. It spawns a certain number of people in random locations within a defined perimeter. In order to best match the locations of the potential crowd, they have defined this limit differently in each stadium.

To simulate, they determined three strategies of the simulation. Closest exit (CE), main exit (ME), designated exit (DE):

- CE: The exit that is closest to the spawn place of the agents is chosen. When determining this distance, physical barriers such as walls are ignored.
- ME: The main entrance is designated as the aim for all agents.
- DE: A variety of uniform spawners, each with a different exit as a goal
- Only seat-less part of the layouts (the space in front of the stage) was modeled.

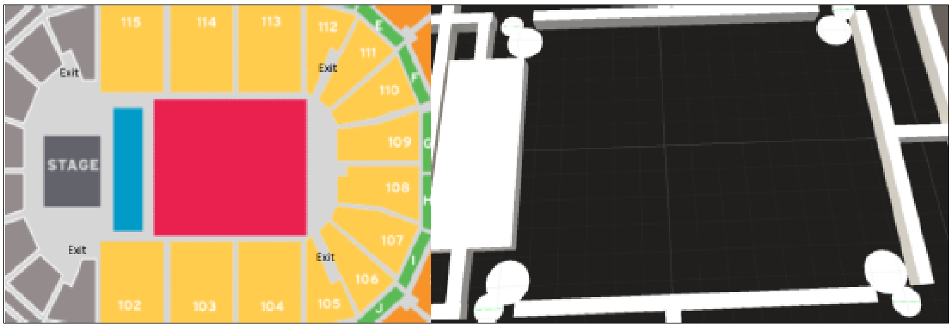


Figure 2.41. Manchester Arena (layout and model)(red+blue=standing part)(the main exit is in the bottom right corner) (Peterson & Jonsson, 2018)

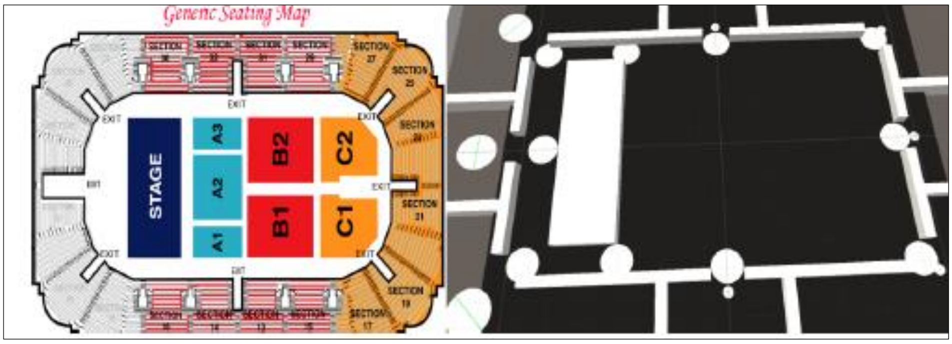


Figure 2.42. Troy Hobart Arena (layout and model)(red+blue=standing part)(The main exit is the middle exit to the left of the stage, and it is the widest exit on the seating arrangement) (Peterson & Jonsson, 2018)

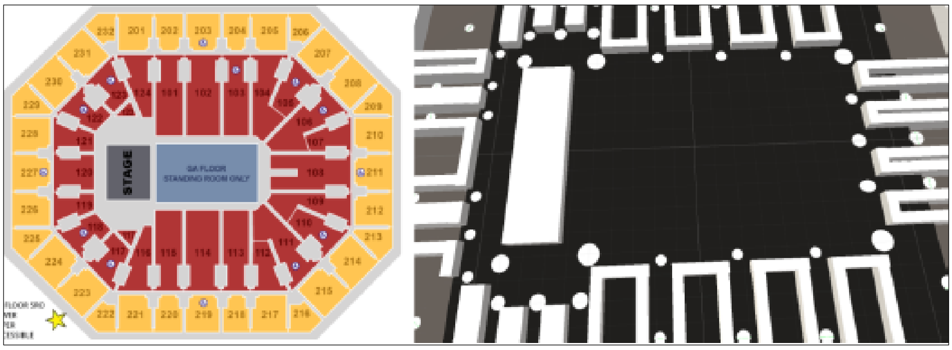


Figure 2.43. Talking Stick Resort Arena (layout and model)(The main exit is identified by a star) (Peterson & Jonsson, 2018)

They settled 2 000 occupants in each of the arenas. They wanted to test three distinct percentages of population size, namely: When the venue is 75 percent full, when it is half-full, and when it is completely packed.

In the simulation, the avoidance radius maintains a specified distance between each agent. As a result, the authors set it to 0 to prevent stampedes. The walking speed of the users is ranged from 6 m/s to speed up the simulation. As a result, people frequently become stuck along walls.

Strategy	50% filled	75% filled	100% filled
Closest exit	46,33	43,22	45,33
Main exit	59,77	74,44	89,89
Designated exit	49,44	57,22	55,78

Figure 2.44. Average evacuation times of 3 arenas (Peterson & Jonsson, 2018)

The authors' conclusions at the end of the study are as follows:

- Based on the findings of the experiments, the CE strategy seems to be the best option for evacuating a venue.
- In an emergency, heading towards the nearest exit is beneficial, but it isn't always the greatest option, such as when there are free exits in the back of a half-full venue.
- Zong, Wang, Du, and Jiang (2019), selected the Wuhan Sports Center Stadium as the case model. The stadium, hosting 60 000 people, is one of China's largest gyms. The stadium is 296 meters long and 38.27 meters high. It is 263 meters long and 54.68 meters high, with two-story stands running east-west. The stadium's stands, stairs, tunnels, and

exits are abstracted into 157 nodes in this study. Each node has a capacity that represents the number of users it can accommodate. Two nodes that may be reached from each other build an edge, which depicts a stadium corridor.

Microsoft Visual Studio 2008 was utilized as the experimental platform for developing the model and implementing the algorithm. The evacuation environment is designed as a network of dot-line structures. To alleviate the evacuation problem, HDAFSA is offered. Every evacuee is referred to as a fish. Artificial fish swarms are employed to replicate evacuee movements by hunting, crowding, following, and waiting.

The spectators are placed at random across the stadium’s 42 stands at the start of the simulation, and the pedestrian speed is set to 2 m/s.

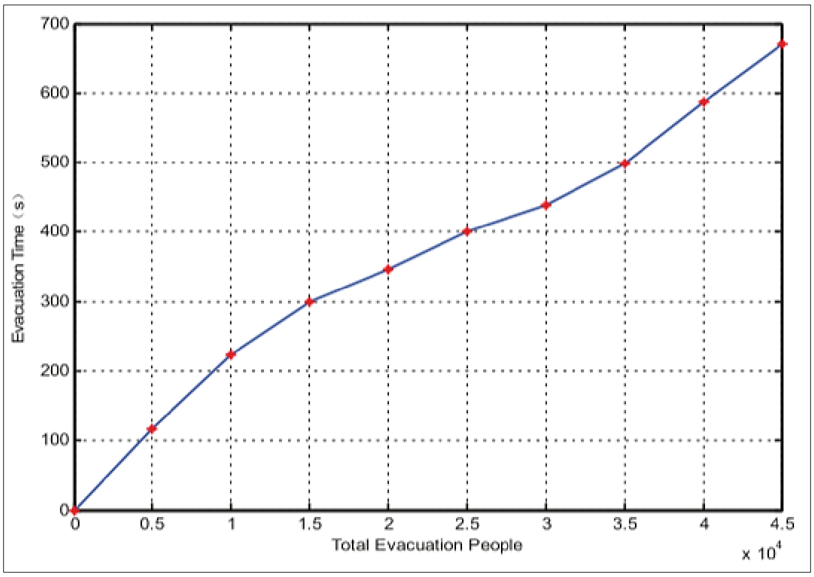


Figure 2.45. Evacuation time varies depending on the amount of evacuees (Zong et al., 2019)

The number of evacuees was increased from 5 000 to 45 000 to measure the performance of the AFSA algorithm, and it was discovered that as the number of people rises, so does the time require for evacuation.

The authors simulated three scenarios with different behaviors in the AFSA algorithm.

- Preying behavior (the evacuation time is short; evacuation path is long)
- Following behavior (the evacuation duration is long, but the evacuation route is short)

▪ AFSA’s four behaviors (the evacuation time and the evacuation path are the shortest)

Algorithms or Behavior	Total time (s)	Total length	Program execution time (s)
AFSA	348.83	1275639.10	19.05
Preying behavior	357.39	1806019.11	11.45
Following behavior	389.12	1282737.82	6.03

Figure 2.46. Evacuation results of single AFSA behavior (Zong et al., 2019)

The authors concluded that it is more effective than single-behavior evacuation in terms of avoiding congestion and reaching a level between speedy evacuation and a short evacuation path after the simulations.

The authors' conclusions at the end of the study are as follows:

▪ Improving the effectiveness of emergency evacuation and providing scientific evacuation procedures in public spaces is a pressing topic.
▪ Other strategies, such as the suggested model and algorithm in this work, can result in reduced evacuation time, shorter evacuation pathways, and less congestion.
▪ The hierarchical path selection technique makes evacuation planning more efficient.
▪ Gravit, Kirik, Savchenko, Vitova, and Shabunina (2022), took the Roman Colosseum in İtaly and Gazprom Arena in St. Petersburg as the case buildings. The study's goal is to recreate two entertainment buildings while analyzing the stair's geometric qualities and carrying capacity. A flow model was created using the simulation software Sigma FS to achieve this goal.

The study's parameters were determined as follows:

1. The walking speed of the occupants was arranged to be 1.66 m/s.
2. Occupant load was accepted as 0.1 m^2 /1 person
3. Gender, age, and health status inequalities were overlooked.

The building's emergency exits for the lower bowl audience are mostly on the 3rd floor in the Gazprom Arena (Only the eastern-sector audience has direct access to the third-level exterior stylobate from the second floor). The third-floor level is also where the egress from the upper bowl is on. Stairs can be reached from the 5th and 6th floors for this purpose. The spectators take the stairwell outdoors to the 3rd floor exterior stylobate. Along the stadium's perimeter, there are 12 similar access steps.

There are 80 arches that form 80 amphitheater entryways around the circumference in Colosseum. The entrances and exits are on the ground floor. As a result, only top-down evacuation is possible. The line-of-sight downstairs in the Colosseum is on both sides of every exit to the lower gallery.

A quarter of the Colosseum and the Gazprom Arena is used to check the two arenas. Because the upper bowl of both structures is symmetrical. Furthermore, the capacity of the Colosseum stairs is equivalent to that of the Gazprom Arena stairs. According to simulation results, the evacuation for the thought part of the Gazprom Arena varies between 520 and 2080 seconds, depending on the load on the stairs, and can be controlled by human flow organization. The total evacuation time of the Colosseum is 14.5 minutes, which includes the longest time to evacuate the sector's stairs (840 seconds) as well as the plus time to exit the building (30 s).

The authors' conclusions at the end of the study are as follows:

- There is a requirement to optimize evacuation (help in loading stairs)
- The Colosseum design appears to be superior to the Gazprom Arena.
- The main problem is to ensure that vertical communication channels are distributed uniformly throughout the arena's perimeter, as well as the escape route capacity and flow intensity.
- The geometric elements of the escape pathways also contribute to the flow's intensity.
- The Colosseum's stair solution is the most efficient technique to achieve the quickest feasible evacuation time.
- The Colosseum satisfies contemporary evacuation criteria and may be repurposed as a modern sport and entertainment facility.

Table 2.9. Studies on evacuation of sports facilities compiled by the author

Authors	Case Buildings	Software	Number of Evacuees	Evacuation Times	Walking Speeds
Klüpfel (2007)	World Youth Day	PedGo	36.000 Persons	120 min.	
	Westfalenstadion	PedGo	36.000 Persons	15 min.	
Liu et al. (2011)	A Piece of a Typical Stadium	STEPS	2.800 Persons	5.45 min.	1.72 m/s
Zarket et al. (2014)	Ladd Peebles Stadium	Unity	2.391 Persons	7.76 min.	
Lin et al. (2015)	Taipei Arena	Pathfinder 2011	14.960 Persons	22.41 min.	0.65 m/s
Peterson and Jonsson (2018)	Manchester Arena		2.000 Persons	1.62 min.	6 m/s
	Troy Hobart Arena		2.000 Persons	1.73 min.	6 m/s
	Talking Stick Resort Arena		500 Persons	1.13 min.	6 m/s
Zong et al. (2019)	Wuhan Sports Center Stadium	AFSA algorithm	45.000 Persons	11.25 min.	2 m/s
Gravit et al. (2022)	Roman Colosseum	Sigma FS	48.000 Persons	14.5 min.	1.66 m/s
	Gazprom Arena		68.000 Persons	34.6 min.	1.66 m/s

When researching studies on the evacuation of sports facilities, it is seen that there are 3 types of methods to determine evacuation times. These are;

- Simulations
- Drills
- Real situations

However, it is clear from the literature that sports facility evacuation drills are not widely practiced. Below are some samples of the capacity and evacuation speed of some Spanish stadiums based on drills:

Table 2.10. Spanish stadiums capacity and evacuation speed drills (hsdl.org, 2010)

	Capacity	Evacuation Speed
El Campo Nou (Barcelona)	98 000	15 min.
La Romareda (Saragoza)	34 000	10 min.
El Jose Zorilla (Valladolid)	33 000	4 min.
Santiago Bernabeu (Madrid)	80 000	15 min.

As can be seen from the table above, Santiago Bernabeu Stadium in Madrid with a capacity of 80 000 spectators, is evacuated in 15 minutes during drills. However, a description of how the evacuation speed changes in a real situation (bomb threat) is described below.

The Santiago Bernabeu stadium in Madrid was evacuated on December 12, 2004, due to a bomb threat. The stadium's emergency mass evacuation plan was used for the first time by police and stadium security personnel. In less than 8 minutes, more than 70 000 individuals exited the premises without incident (hsdl.org,2010).

The Basque newspaper "Gara" received an anonymous phone call at 7:55 p.m. saying that the terrorist group Euzkadi ta Askatasuna (ETA) had hidden a bomb at the Santiago Bernabeu, which was set to detonate at 9:00 p.m. At 8:15 p.m., police officers called Victor Garcia Hidalgo, the stadium's security head and General Director of the Spanish Police, who was watching the game at the stadium. Garcia Hidalgo organized an emergency crisis committee on the site and met with the Minister of the Interior, as well as police and security personnel. Garcia Hidalgo ordered the general evacuation at 8:45 p.m., barely fifteen minutes before the projected detonation time. They coordinated and monitored the flow of evacuees using the stadium's sound system and megaphones, as well as the 315 security video cameras. Before and during the evacuation, 32 security personnel monitored the escape routes, clearing obstructions. They used the 51 external exits and 27 anti-panic doors to send people across the soccer field. The evacuation was completed without incident at 8:53 p.m (hsdl.org, 2010).

According to drills, it was expected that a total evacuation would take 15 minutes. However, in just 8 minutes, almost 70 000 people had evacuated the building without incident.

Figure 2.47. Santiago Bernabeu stadium before the terrorist alarm and during evacuation (elmundo.es, 2004)

As can be seen from a real-life scenario, the evacuation time and, as a result, the occupant walking speed changes. During real-life evacuations, evacuation times are seen to be shorter than during drills.

The Spartan Stadium in Michigan, US was evacuated on August 14, 2015, due to the largest emergency evacuation drill in Spartan Stadium history. Inside Michigan State's football stadium, almost 15 000 Arrowmen assembled (Scouting Magazine, 2015).

(a)

(b)

(c)

Figure 2.48. Spartan Stadium drill before evacuation (a), evacuation start (b), during evacuation (c) (Scouting Magazine, 2015)

According to the drill, a crowd of 15 000 people was able to safely exit the building in 15 minutes.

As can be seen from the examples of literature above, the drills have no specific evacuation time standards as they depend on the land, the time, the number of people, and the human behavior. The drills' time is likewise affected by the occupants' walking speed. As the event at the Santiago Bernabeu stadium showed, real-life evacuation times are shorter than drill times. People can make sensible decisions when they comprehend the circumstances during an emergency. Even when there is no panic, emergency situations are defined by the occupants' failure to react and disregard the problem, even though they hear the alarm or see symptoms of a dangerous situation. As a result of this avoidance, action and evacuation times are delayed.

3. RESEARCH METHOD & MATERIAL

A newly designed sports arena with 8 828 seat capacity was chosen for the case and it was modeled within a 6-month trial version of Pathfinder 2021 simulation software. In this section; an introduction of the case building that was chosen for the study, the data needed to build the model, the techniques for acquiring it, and the models that have been built will be discussed.

3.1. İstanbul Esenler Sports Arena

Table 3.1. and the figures from 3.1. to 3.10. give a general summary of the arena. It is a basketball arena for national and international matches with 8 828 seats. They are all covered by the roof. The main concourse is on Ground Floor (+0.00). It has lower level seats on 1st and 2nd Basement Floors (-3.60 and -7.20), upper seats on 1st Floor (+4.50), spectator circulation on 2nd Floor (+11.70) and balcony seats on 3rd Floor (+15.30) and service places on 4th Floor (+18.90).

Table 3.1. İstanbul Esenler Sports Arena overview

Name	İstanbul Esenler Sports Arena
Design Team	AYT PROJE Design Team (Architect A. Yagmur Toprakli)
Client	Republic of Turkey Ministry of Youth and Sports
Base Area	10 145.64 m^2
Total Floor Area	79 408.62 m^2
Total Capacity	8 828 seats
Floor Number	2 underground floors, 4 ground floors
Height	25.30 m.
Main Structure	Partly steel-Partly reinforced concrete

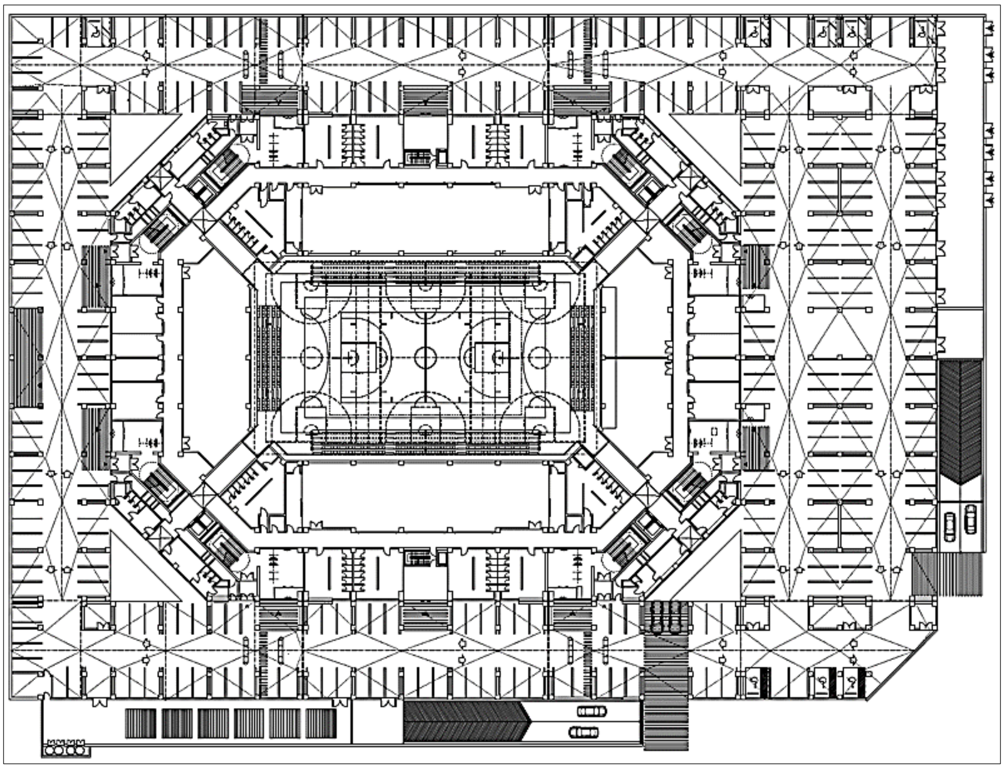


Figure 3.1. Second basement (-7.20 m) floor plan of İstanbul Esenler Sports Arena

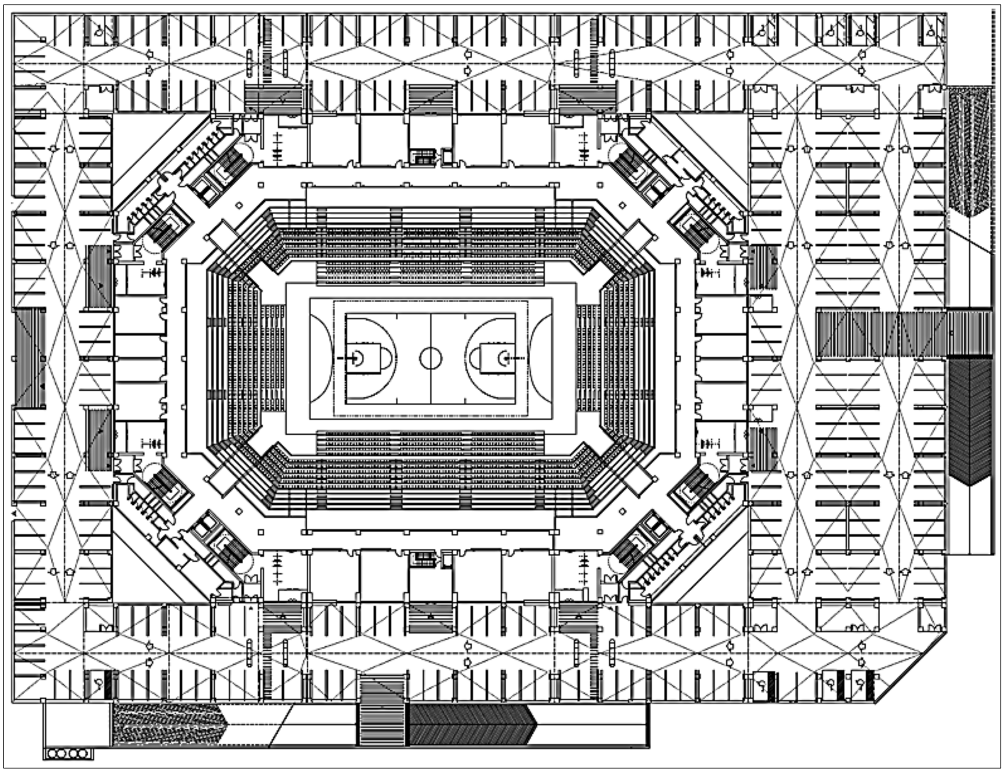


Figure 3.2. First basement (-3.60 m) floor plan of İstanbul Esenler Sports Arena

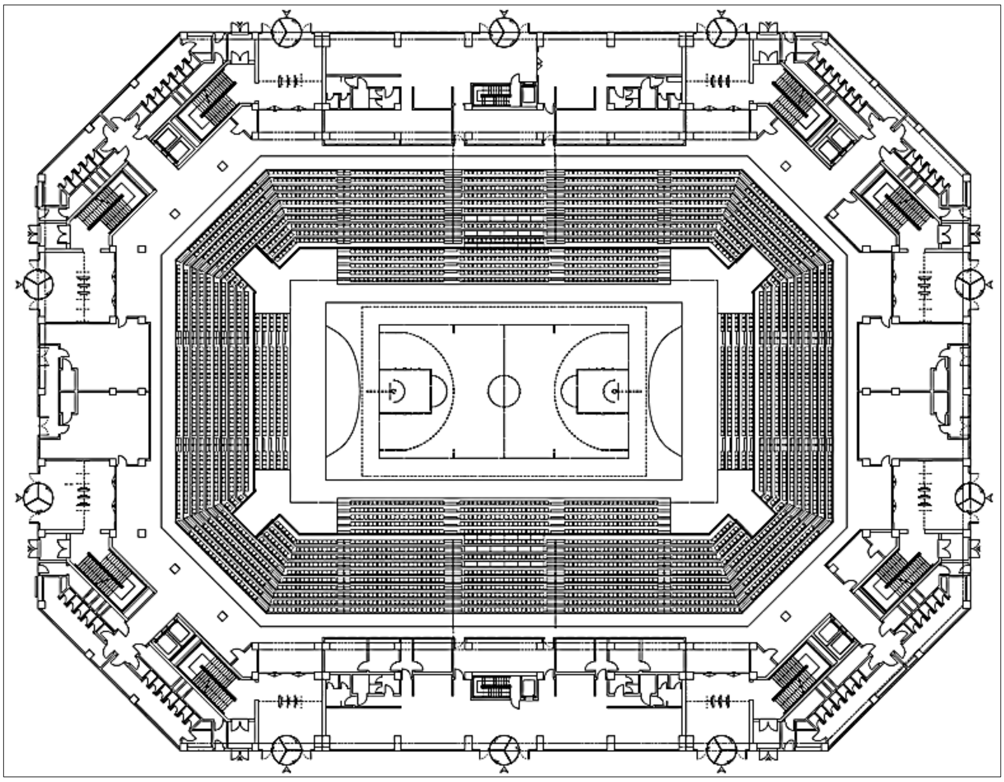


Figure 3.3. Ground floor (+0.00 m) plan of İstanbul Esenler Sports Arena

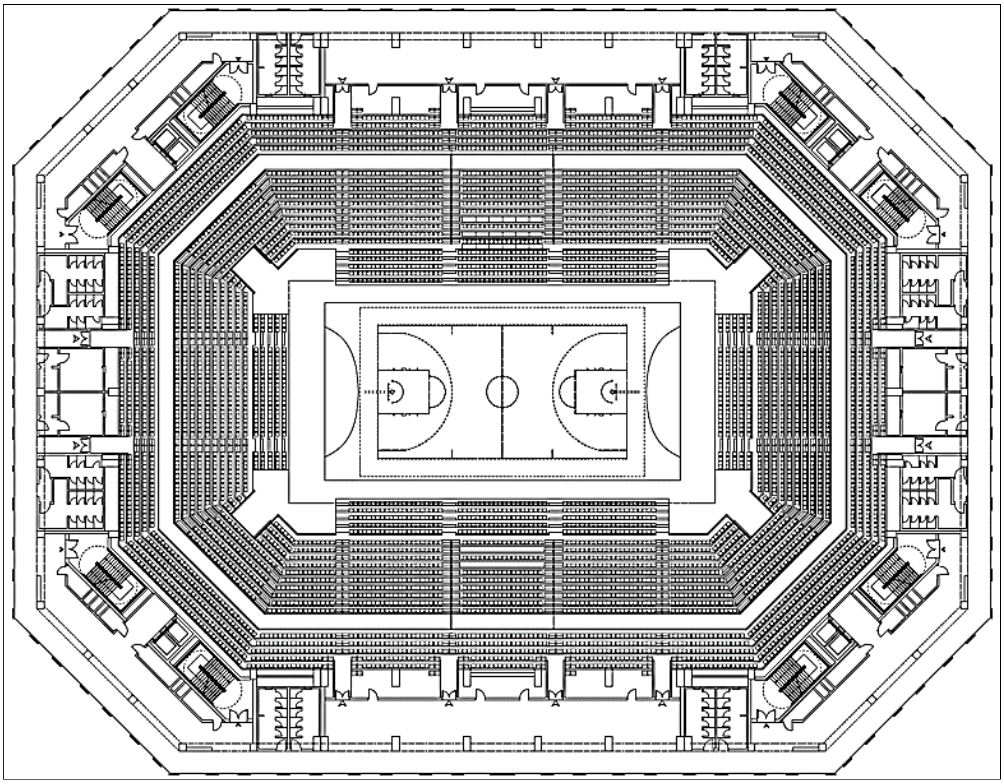


Figure 3.4. First floor (+4.50 m) plan of İstanbul Esenler Sports Arena

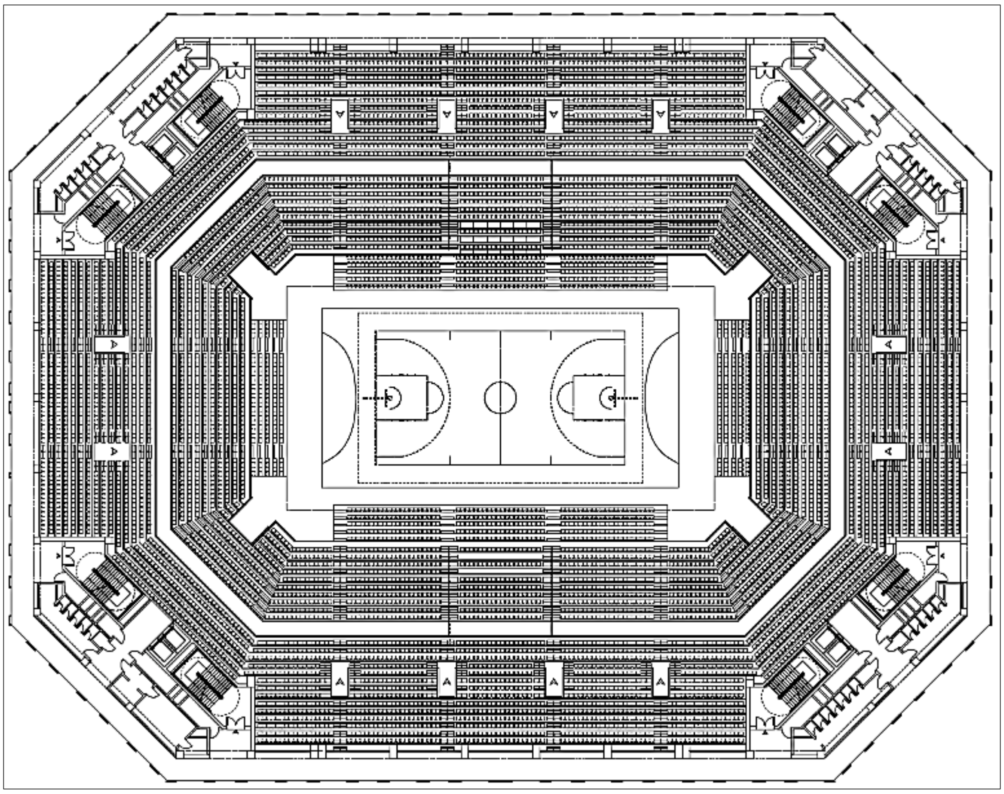


Figure 3.5. Second floor (+11.70 m) plan of İstanbul Esenler Sports Arena

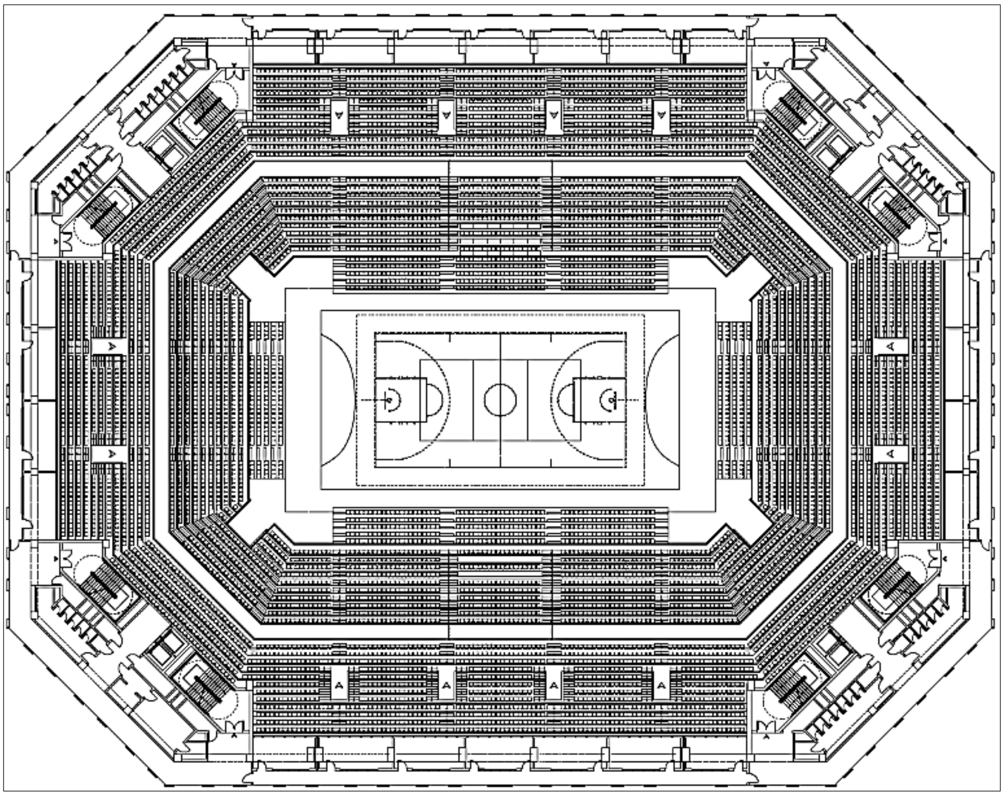


Figure 3.6. Third floor (+15.30 m) plan of İstanbul Esenler Sports Arena

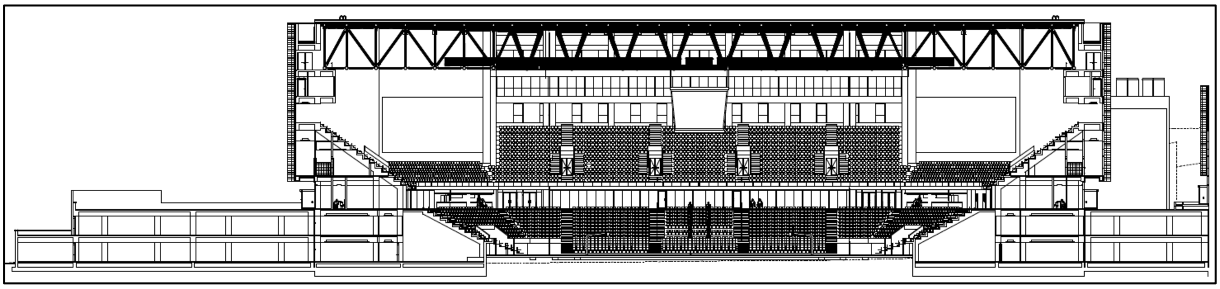


Figure 3.7. Section AA of İstanbul Esenler Sports Arena

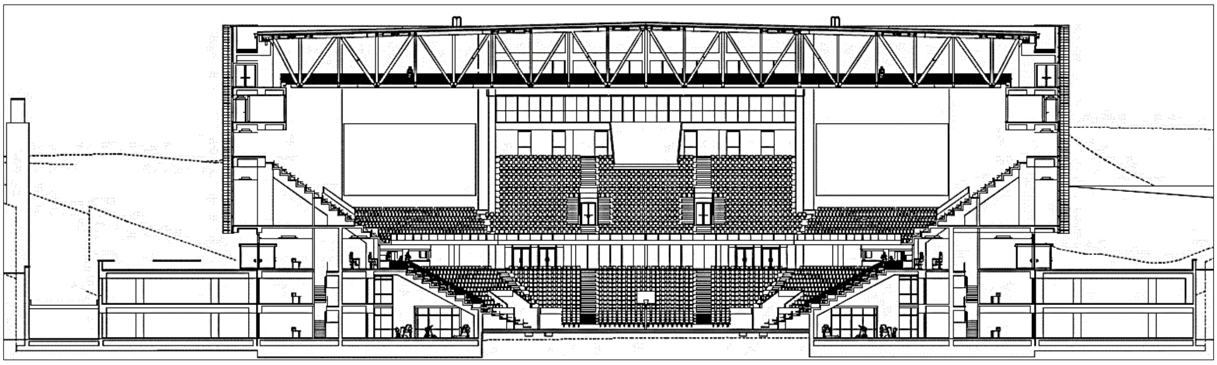


Figure 3.8. Section BB of İstanbul Esenler Sports Arena

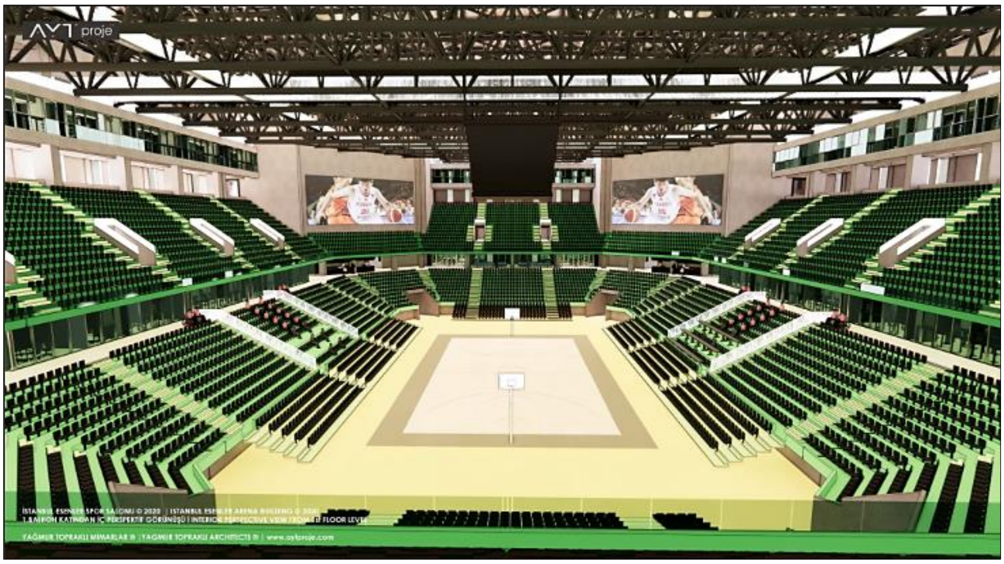


Figure 3.9. 3D Interior image of İstanbul Esenler Sports Arena

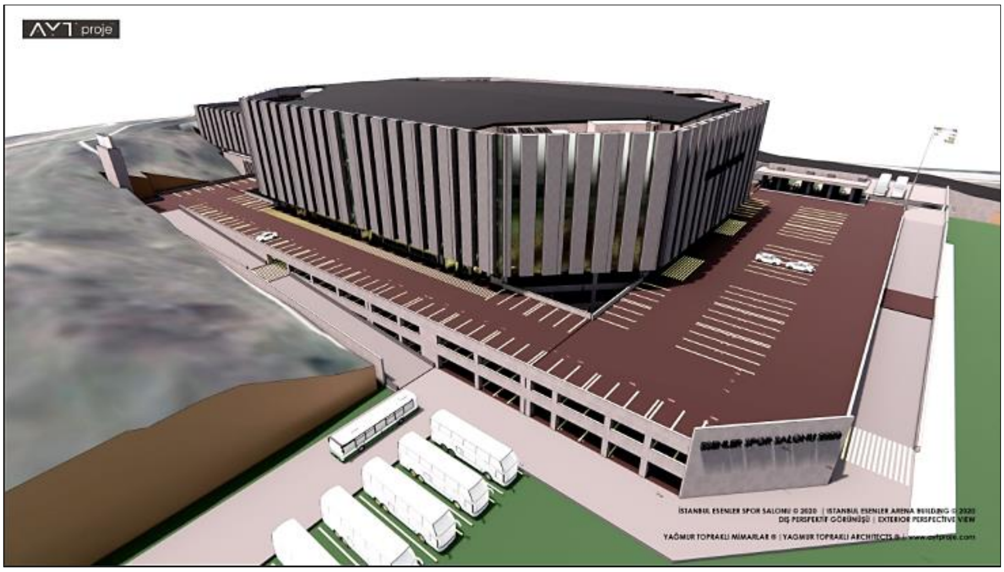


Figure 3.10. 3D exterior image of İstanbul Esenler Sports Arena

3.1.1. Building parameters of İstanbul Esenler Sports Arena

İstanbul Esenler Sports Arena is designed by AYT Design Team (Architect A. Yagmur Toprakli) and will be built in Esenler / İstanbul in 2023. The building has an individual training hall connected to the west façade on the second basement, first basement, and ground floor. But this part of the building was left out of the study. Above the ground floor, there are 4 floors. There are also 2 basement floors under the ground floor. The basement floors are parking garages with 295 cars capacity on each. Basement floors were also left out of the study.

The building was modeled with Ground Floor (+0.00), 1st Floor (+4.50), 2nd Floor (+11.70), and 3rd Floor (+15.30). The 4th Floor (+18.90) and the roof were not included in the model.

The main exits of the building have 18 doors in total.2 doors for spectators and 1 door for the press at the north entrance, 2 doors for spectators at the east entrance, 2 doors for spectators and 1 door for VIP at the south entrance, and 2 doors for spectators at the west entrance on the ground floor. 8 doors are stairway exits to outside of the building which are located at the 4 corners on the ground floor.

The figures below show the entrances and exits on each floor:

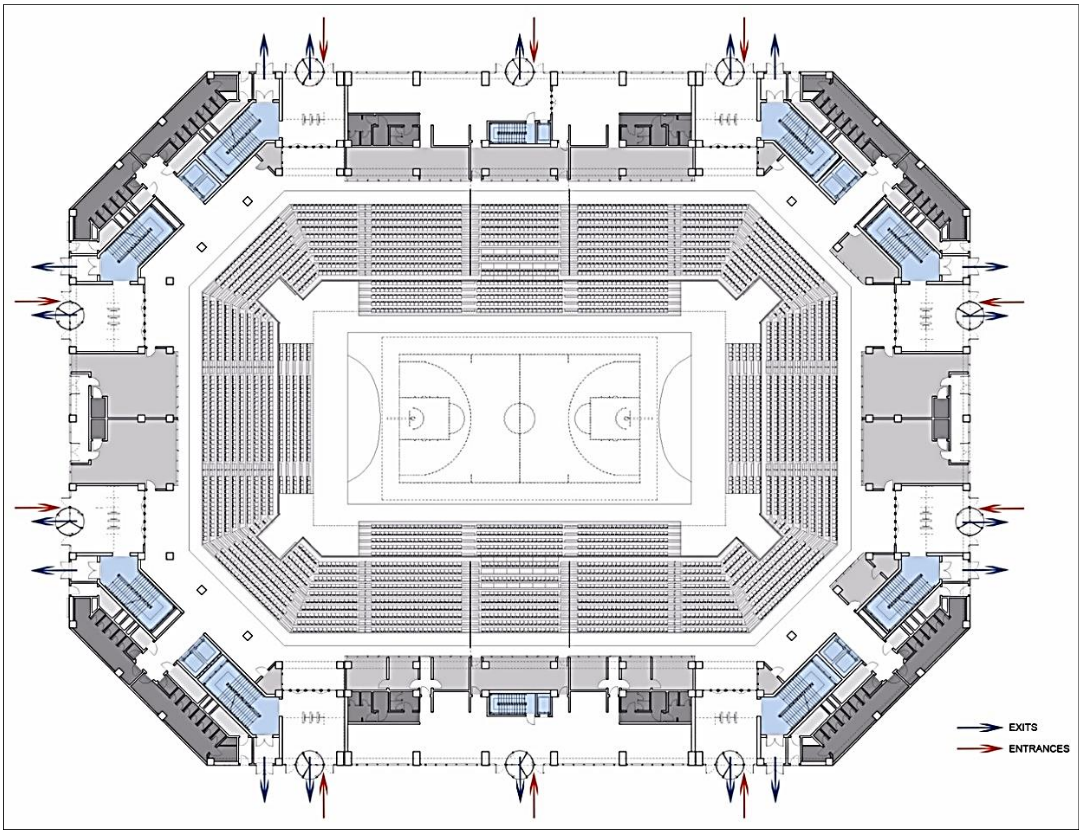


Figure 3.11. The entrances and exits on ground floor (+0.00 m)

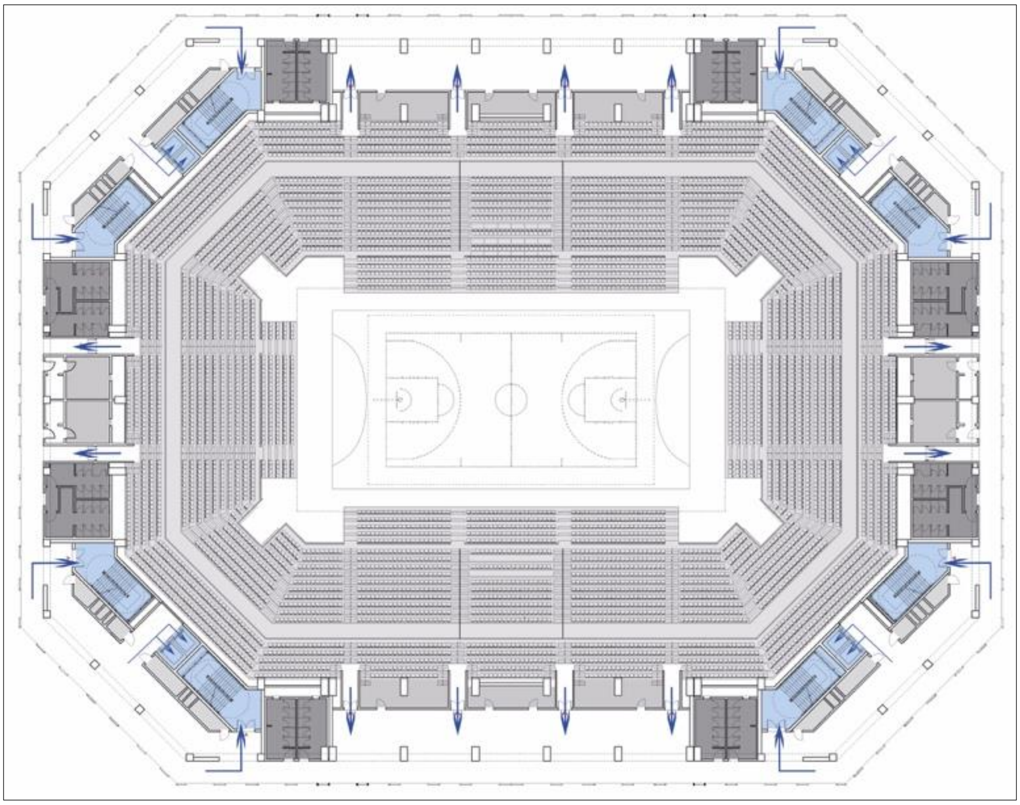


Figure 3.12. The exits on 1st Floor (+4.50 m)

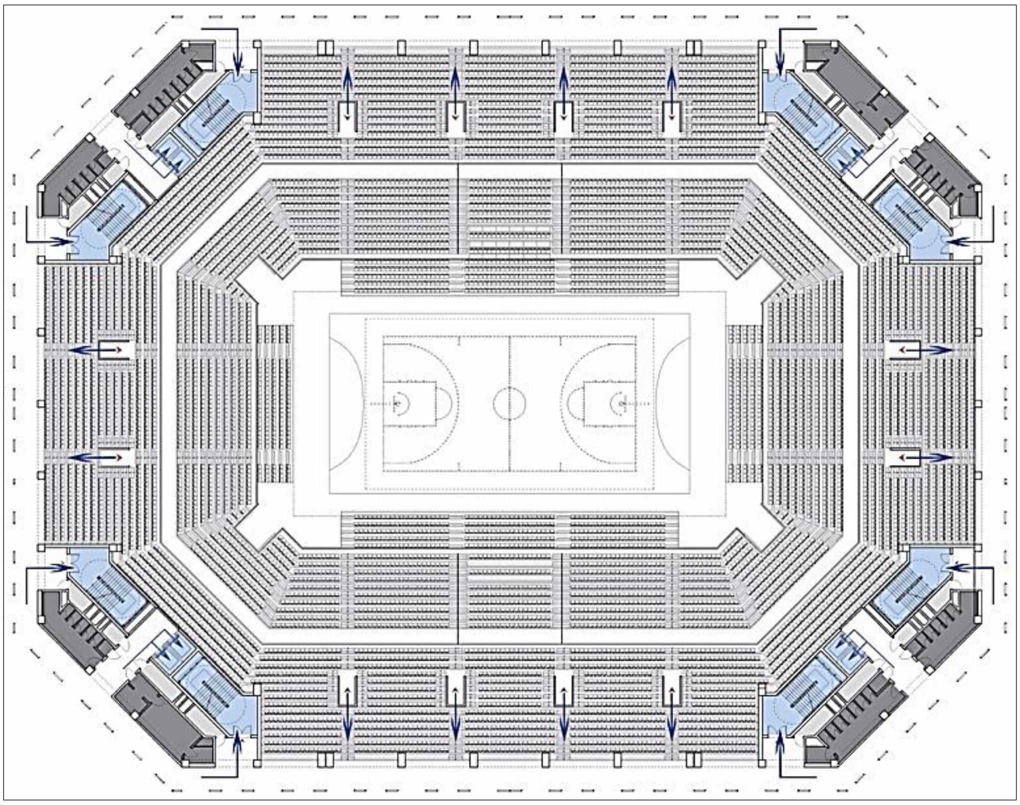


Figure 3.13. The exits on 2nd Floor (+11.70 m)

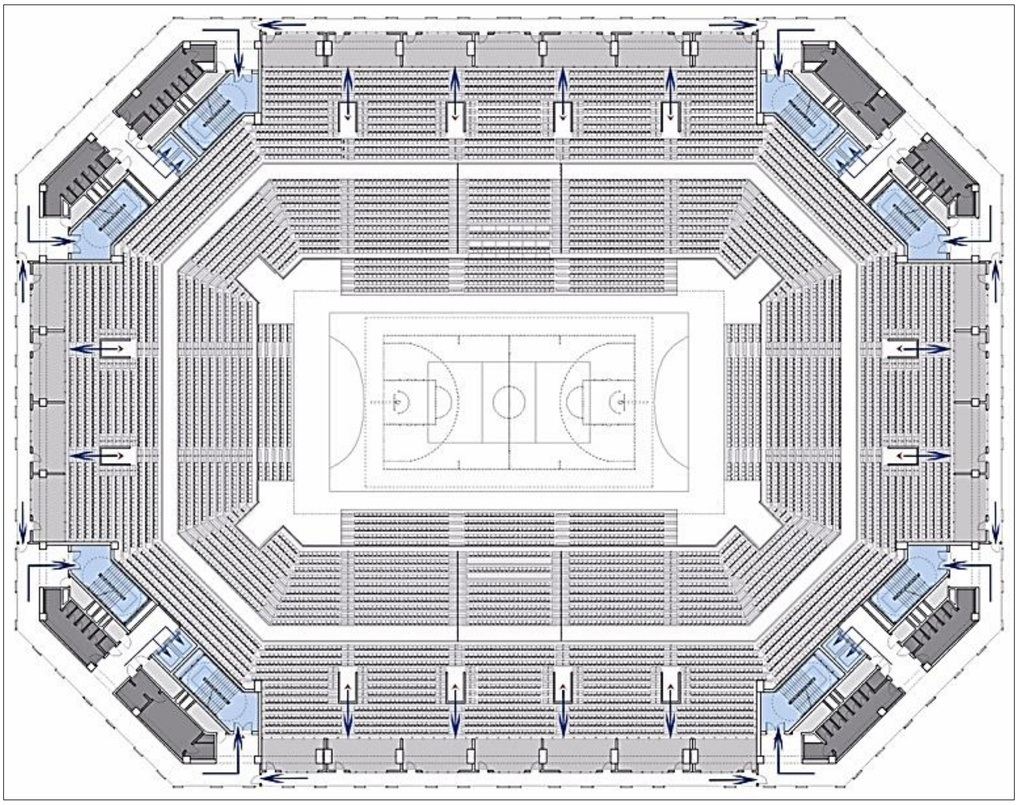


Figure 3.14. The exits on 3rd floor (+15.30 m)

3.1.2. Stairwell parameters of İstanbul Esenler Sports Arena

There are 8 stairs in the building which are located at each corner of the building. The floor height (4.5 m.) is divided into 30 steps from ground to 1st floor, 7.2 m. is divided into 48 steps from 1st to 2nd floor, and 3.6 m. is divided into 24 steps from 2nd to 3rd floor. The riser height is 15 cm, and the tread length is 30 cm. The stair width is 205 cm. The doors of the stairs have a 200 cm. clear opening width. They are 90 degrees swinging doors. The entrance hall of the stairs has 325 cm. width and 430 cm. length.

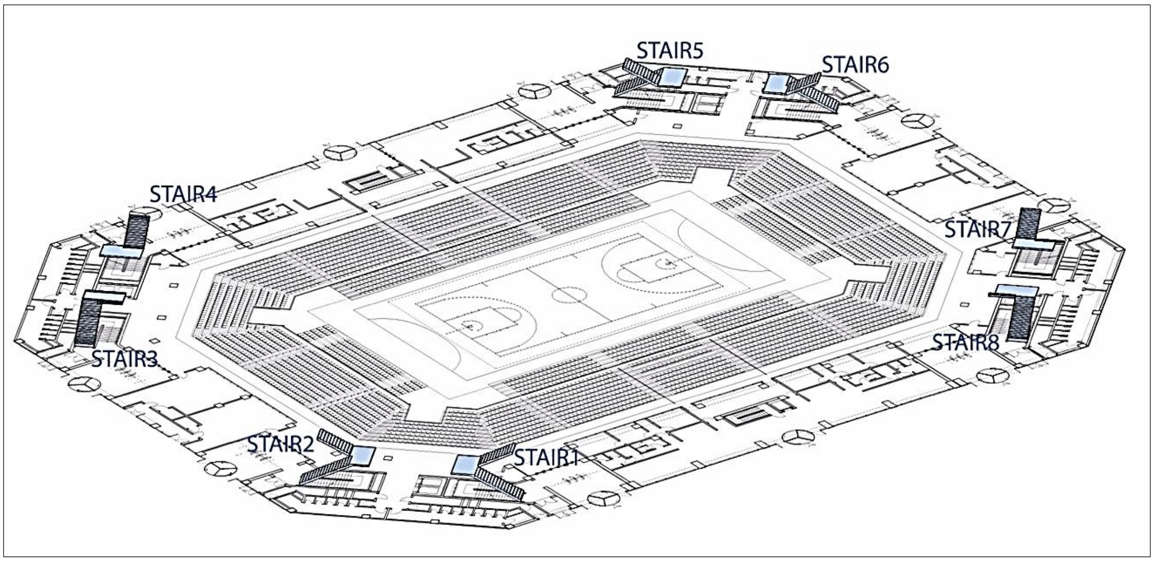


Figure 3.15. Stairwell layout of İstanbul Esenler Sports Arena

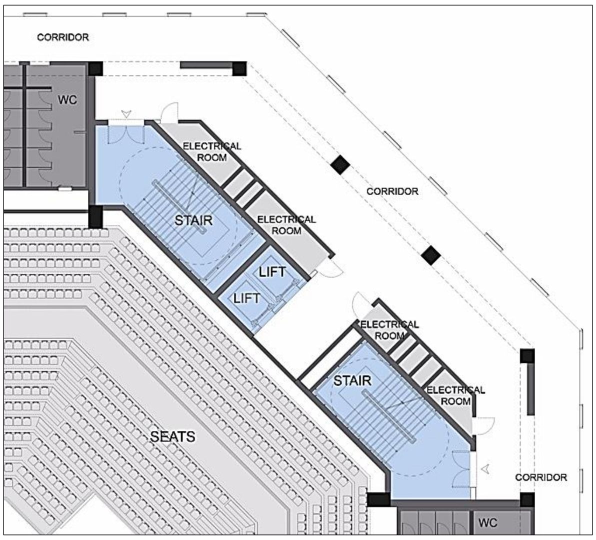


Figure 3.16. An example of the core

Each staircase was named separately in the model. The riser heights and treads were modeled according to the original plans. The step width was determined as 205 cm. (clean width).

Figure 3.17. Stair properties of İstanbul Esenler Sports Arena

3.2. Modeling Procedures

3.2.1. Occupant load calculation of the case study

When the occupant load is calculated according to Turkey’s Regulation on Fire Protection, NFPA, and IBC, the table below is obtained.

Table 3.2. Occupant load of İstanbul Esenler Sports Arena calculated by the author

Floors	Gross Area (m^2)	TRFP	NFPA	IBC
Ground Floor				
Gross Area	7 955			
Fıeld+Spectators	3 455			
Excludıng Fıeld	4 500	450		
1st Floor				
Gross Area	8 810			
Fıeld+Spectators	4 935			
Excludıng Fıeld	3 875	388		
2nd Floor				
Gross Area	8 810			
Fıeld+Spectators	6 429	6 429		
Excludıng Fıeld	2 381	238		
3rd Floor				
Gross Area	8 810			
Fıeld+Spectators	6 082			
Excludıng Fıeld	2 728	273		
Number of Fıxed Seats			8 828	8 828
Total Occupant Load		7 778	8 828	8 828

According to NFPA and IBC; for areas having fixed seats and aisles,the occupant load shall be determined by the number of fixed seats installed therein (NFPA, 2018) (12.1.7.2). Therefore, the number of fixed seats is the occupant load in NFPA and IBC. 8 828 occupants are defined to the model, which is the number of fixed spectator seats in İstanbul Esenler Sports Arena.

The calculations for the case building on occupant load, exit width - number and the evacuation time according to Turkey's Regulation On Fire Protection are described below;

3.2.2. Occupant load - exit width calculation

The width of exit capacity for stairs, doors, corridors, and the other exit accesses are calculated as 50 cm. width units.

Unless otherwise stated, the evacuation time through a unite width (50 cm.) is 3 minutes in masonry buildings and 2 minutes in wooden buildings.

40 occupants can pass in 1 minute through a unite width (50 cm.).

The occupant load of İstanbul Esenler Sports Arena is;

The area of spectators and field is 6 429 m^2 therefore the occupant load is 6 429 occupants.

The area of excluding field on the ground floor is 4 500 m^2 therefore the occupant load is

4 500 / 10 m^2 = 450 occupants.

The area of excluding field on the 1st floor is 3 875 m^2 therefore the occupant load is 3 875 / 10 m^2 = 388 occupants.

The area of excluding field on the 2nd floor is 2 381 m^2 therefore the occupant load is 2 381 / 10 m^2 = 238 occupants.

The area of excluding field on the 3rd floor is 2 728 m^2 therefore the occupant load is 2 728 / 10 m^2 = 273 occupants.

<u>The occupant load of the building is </u>6 429 + 450 + 388 + 238 + 273 = <u>7 778 spectators</u>

The exit width of the building must be 7 778 / (3*40) *50 cm. = 3 240 cm= 32.4 m.

The exit width of the building is (575 cm * 10) + (200 cm * 8) = 7 350 cm= 73.5 m.

73.5 m.> 32.4 m.

The number of the exits must be (32.4 / 2) + 1 = 17

The number of the exits of the building is 10 exit doors+8 stairway exit doors =

18> 17

3.2.3. Evacuation time calculation (including all exit doors)

The evacuation time through a unite width (50 cm.) is 3 minutes in masonry buildings and 2 minutes in wooden buildings.

40 occupants can pass in 1 minute through a unite width (50 cm.).

The exit width of the building is 73.5 m.

The occupant load of the building is 7 778 spectators

The unit width is 50 cm.

The number of occupants who can pass through 1 meter in 1 minute is 80.

73.5 m. * 80 occupants = 5 880 occupants in 1 minute

5 880 * 3 =17 640 occupants in 3 minutes

In this case; 7 778 occupants can evacuate the building in 1.32 minutes = <u>79.2 seconds</u>

<u>8 828 occupants can evacuate the building in 1.50 minutes = 90 seconds</u>

3.2.4. Evacuation time calculation (excluding stairway exit doors)

The exit width of the building (excluding stairway exit doors) is 73,5 m. – 16 m. = 57.5 m.

The occupant load of the building is 7 778 spectators

The unit width is 50 cm.

The number of occupants who can pass through 1 meter in 1 minute is 80.

57.5 m. * 80 occupants = 4 600 occupants in 1 minute

4 600 * 3 =13 800 occupants in 3 minutes

In this case; 7 778 occupants can evacuate the building in 1.69 minutes = 101.4 seconds

8 828 occupants can evacuate the building in 1.91 minutes = 114.6 seconds

3.2.5. Pathfinder simulation software

PATHFINDER is an agent-based evacuation simulation that was improved by Thunderhead Engineering Company. Pathfinder allows analysis for stadiums, skyscrapers hospitals, aircraft, and other buildings. It supports the Autodesk formats DXF and DWG, BIM format IFC and FBX, DAE, and OBJ formats.

Pathfinder has a floor extraction tool that allows you to rapidly design the occupant walking space for the evacuation model using imported geometry. Import type parameters enable correct object types to be applied automatically during model development.

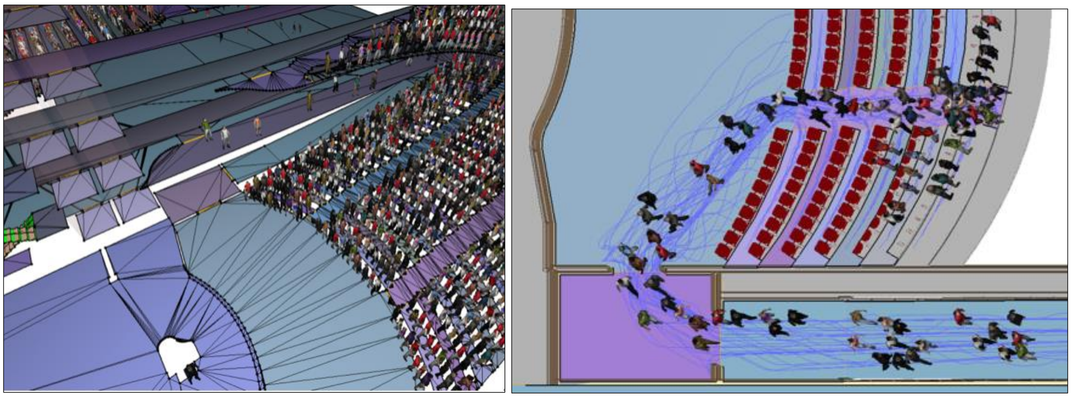


Figure 3.18. 3D results view of Pathfinder (thunderheadeng, 2019)

The simulation software uses a 3D triangulated mesh to describe the geometry of the model. The use of triangulation allows occupants to move freely within the model when it is compared to other simulators.

İstanbul Esenler Sports Arena was modeled in Pathfinder 2021, with basic spatial blocks including floors, rooms, doors, exits, and stairs.

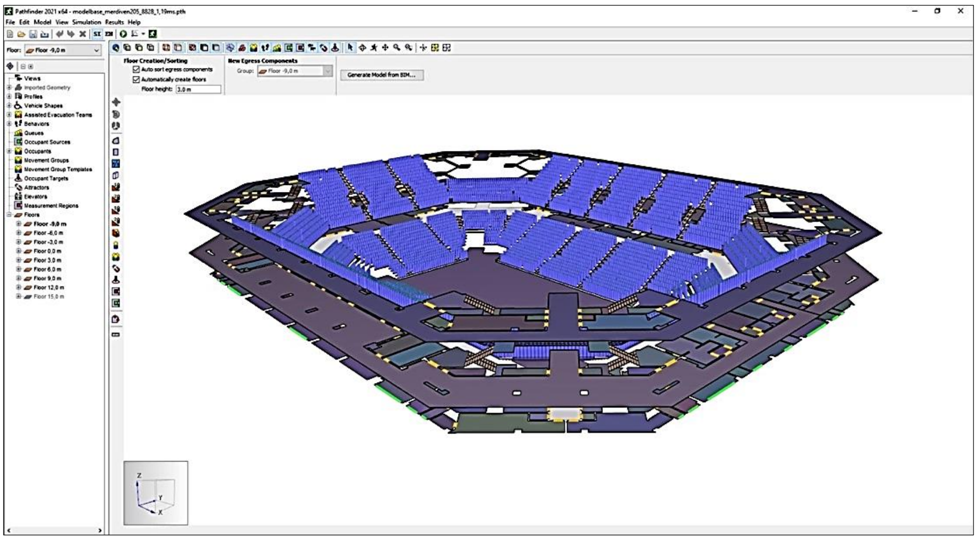


Figure 3.19. User interface of Pathfinder software

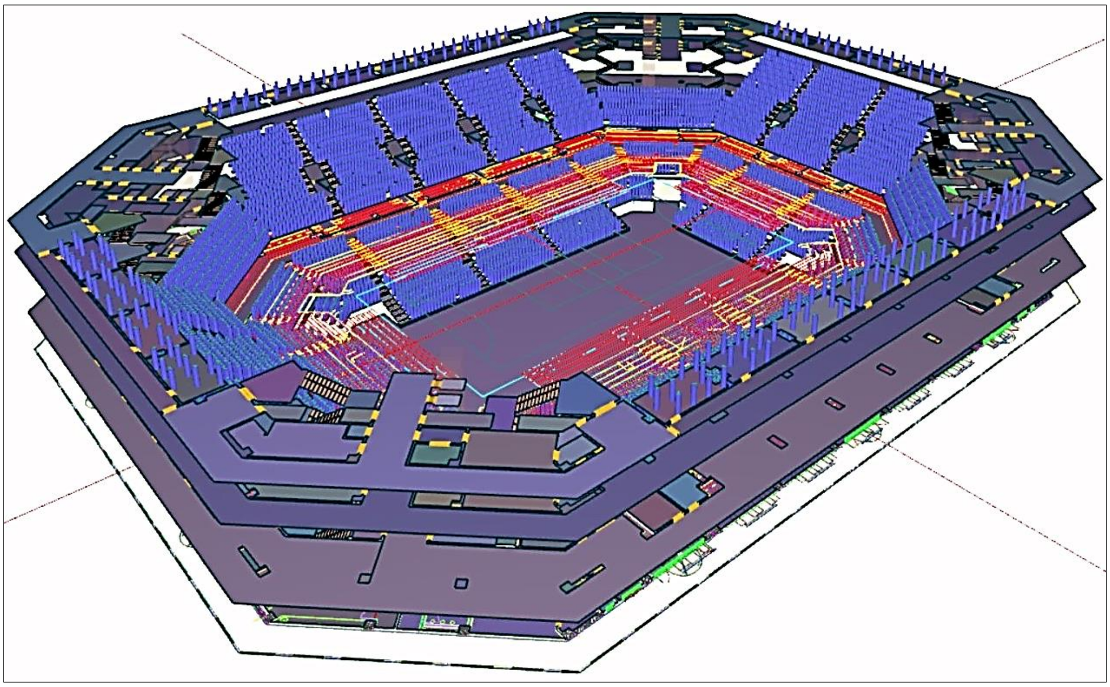


Figure 3.20. Numerical spatial model of İstanbul Esenler Sports Arena

Floor plans were received from the authors of the building in CAD format. Every floor and exit of the building were modeled numerically according to the original plans.

Pathfinder is a microscopic simulation model that can model occupants in 3D with different parameters such as behavior, walking speed and different diameters or heights. Because individual behavior was not included in the study, each occupant was treated the same.

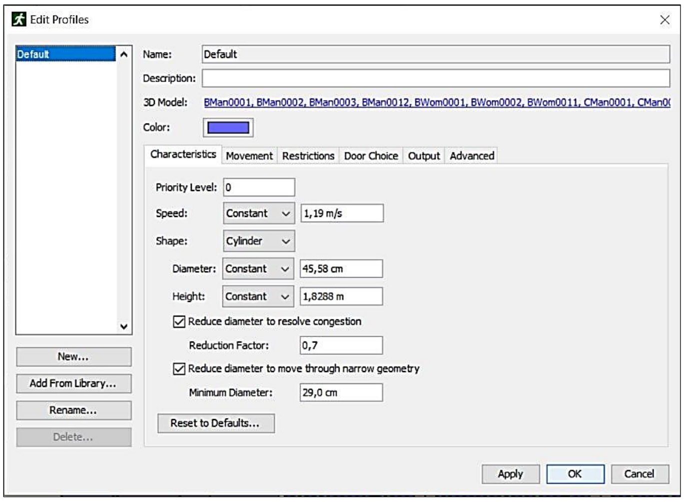


Figure 3.21. Occupant profile of İstanbul Esenler Sports Arena

When the simulation begins, the software directs each occupant to the exits by taking the shortest and most direct route. It is possible to program occupants to use or avoid evacuation components such as stairs, elevators, escalators, and ramps.

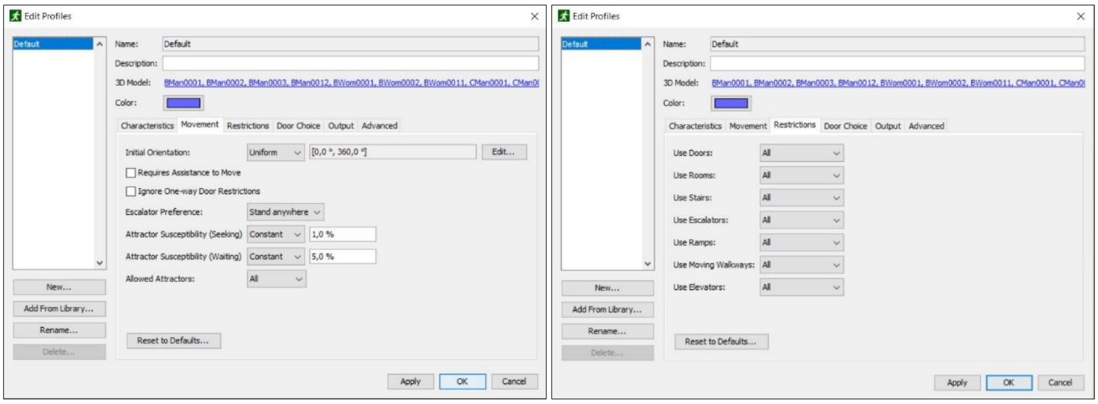


Figure 3.22. Occupant movement properties of İstanbul Esenler Sports Arena

Each occupant can be modeled with various profiles or behavior in the pathfinder simulation program. In scenarios with different walking speed values, the behavior is set to the software default profile ‘go to any exit’.

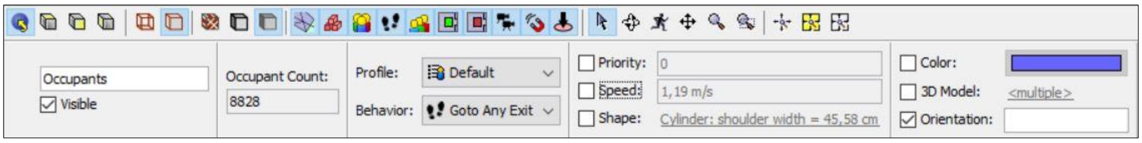


Figure 3.23. Occupant properties in the ribbon menu

After all of the building and occupant parameters have been defined to the software, the occupants were assigned to floors and distribution was created.

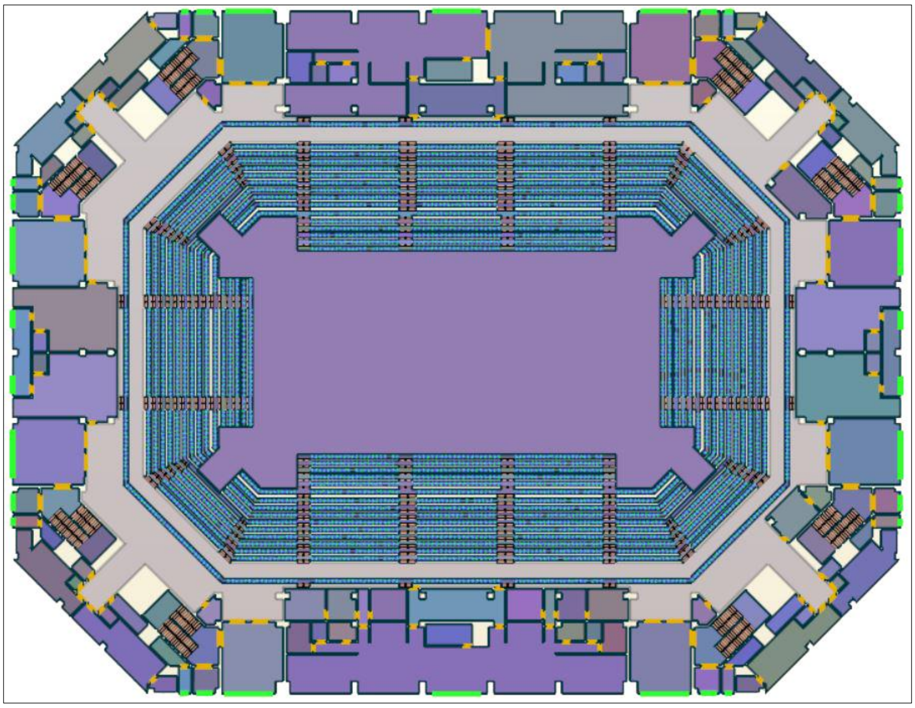


Figure 3.24. Distribution of occupants on ground floor at the initial stage of modeling

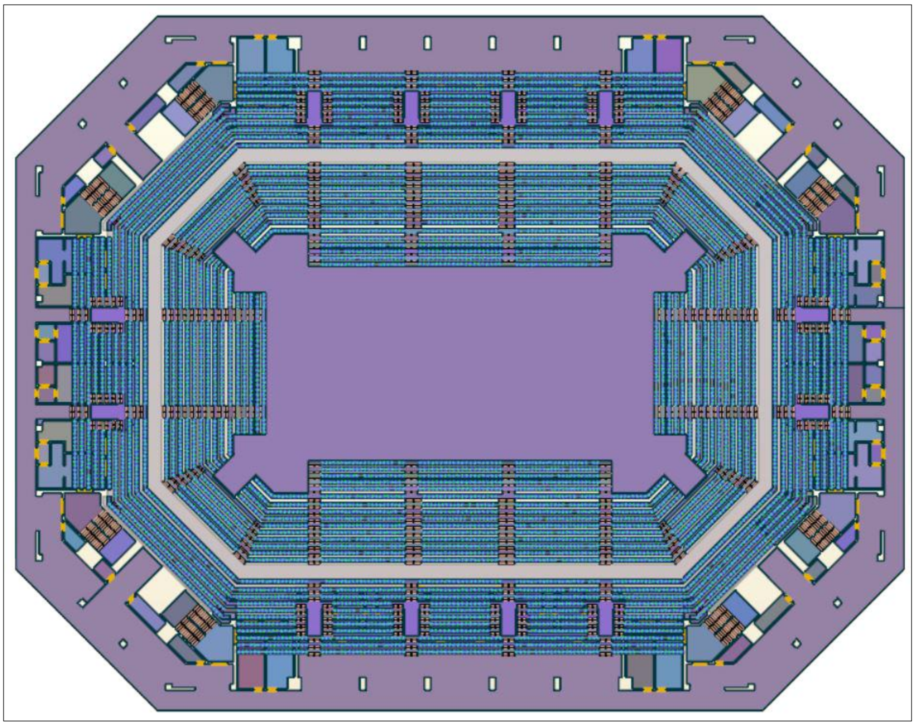


Figure 3.25. Distribution of occupants on 1st floor at the initial stage of modeling

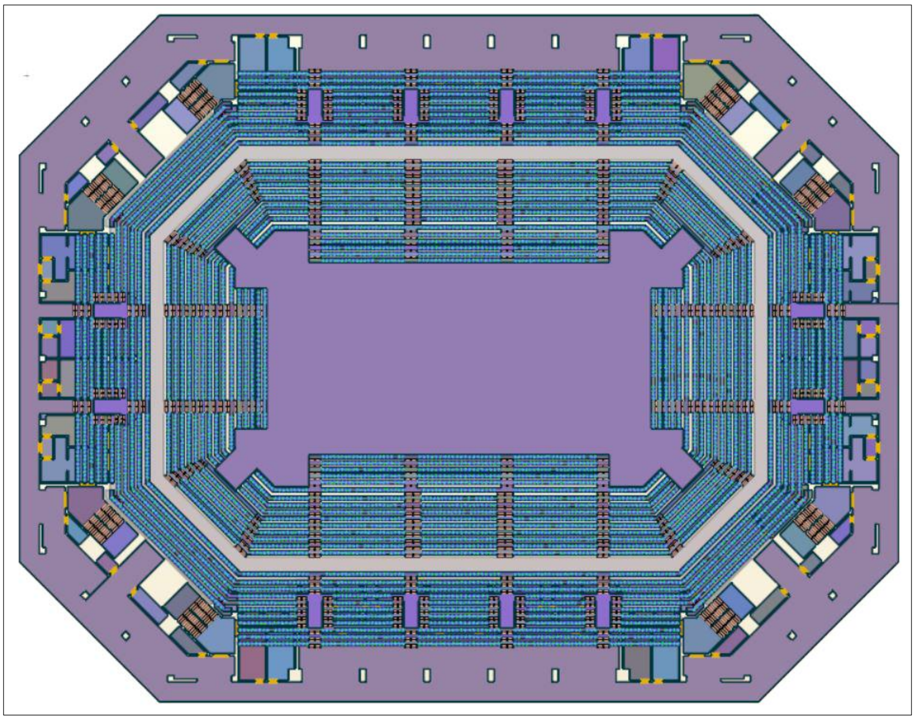


Figure 3.26. Distribution of occupants on 2nd floor at the initial stage of modeling

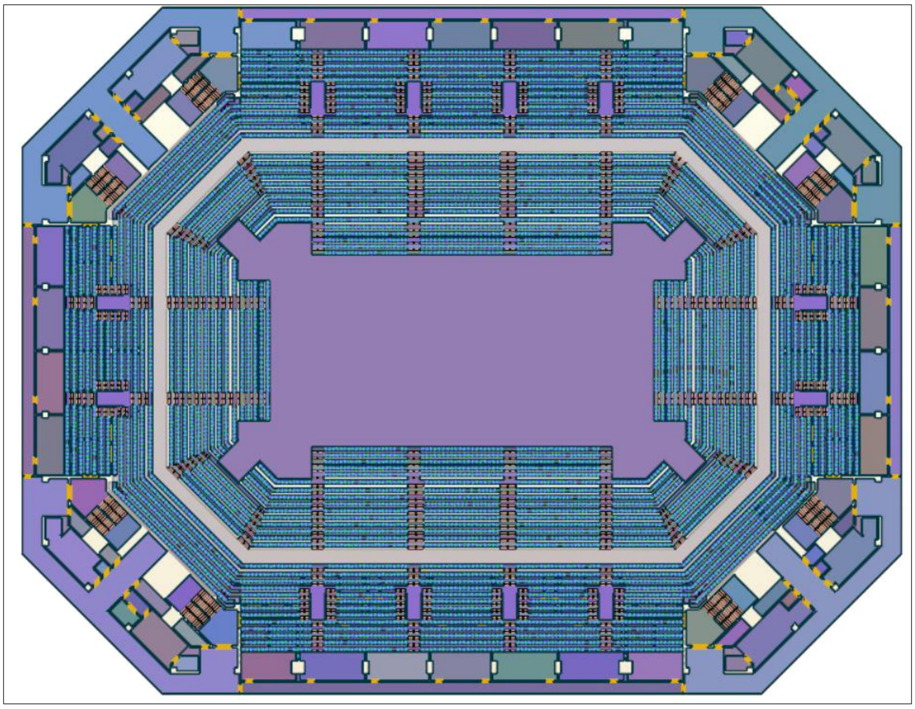


Figure 3.27. Distribution of occupants on 3rd floor at the initial stage of modeling

3.3. Simulation Methods

Within the scope of the thesis, three alternative scenarios were modeled. The occupant walking speeds according to the default value of the software, age and gender averages and values obtained from the drill literature were all assessed.

Table 3.3. Modeled scenarios of the thesis

	Scenario 1	Scenario 2	Scenario 3
Walking Speed of Occupants	1.19 m/s	1.384 m/s	2.5 m/s

In three scenarios: all entrance/exit doors within the scope of the case building were defined as “exits”. Access to these exits consists of egress route components, floor exits, stairs, and elevators. According to the project, the total exits number is 18 and the total width of the exit is 7 350 cm.

Building and stairwell parameters of three scenarios are;

- The walking speed of the occupants was set to the values of 1.19 m/s, 1.384 m/s, and 2.5 m/s as three different values.
- 8 828 occupants were loaded into the building. This is the fixed seats number of the case building.
- The occupants in concourse areas without fixed seats, such as waiting rooms, lodges, toilets, or corridors were excluded from the simulation.
- 18 exit doors (8 of them are stairs exit doors) on the ground floor were defined as unobstructed open exits, to the software.
- 8 stairs of the building which are located at corners were defined in the software.
- The stair width was set to 205 cm.
- The stair riser height was set to 15 cm.
- The tread length was set to 30 cm.
- The doors of the stairs have a 200 cm. clear opening width.
- The entrance hall of the stairs has 325 cm. width and 430 cm. length.
- The elevators of the building were not included in the simulation.

The occupant walking speeds of three scenarios are as follows:

3.3.1. Scenario1: 1.19 m/s user walking speed

Below is the explanation of the default walking value (1.19 m/s) of the Pathfinder:

Fruin (1987), divides the population into six age and gender groups, however, for all of them, he simply produces a single normal distribution of walking speeds. In Pathfinder, this is achieved by using the same normal distribution for all six population groups and an aggregate profile named "Average All". The built-in SFPE-based speed-density relation is used for all profiles in this collection. The original data was reported as an absolute measurement of walking speed across several people, rather than a number that could be normalized to a given speed (1.2 m/s) (thunderheadeng, 2021).

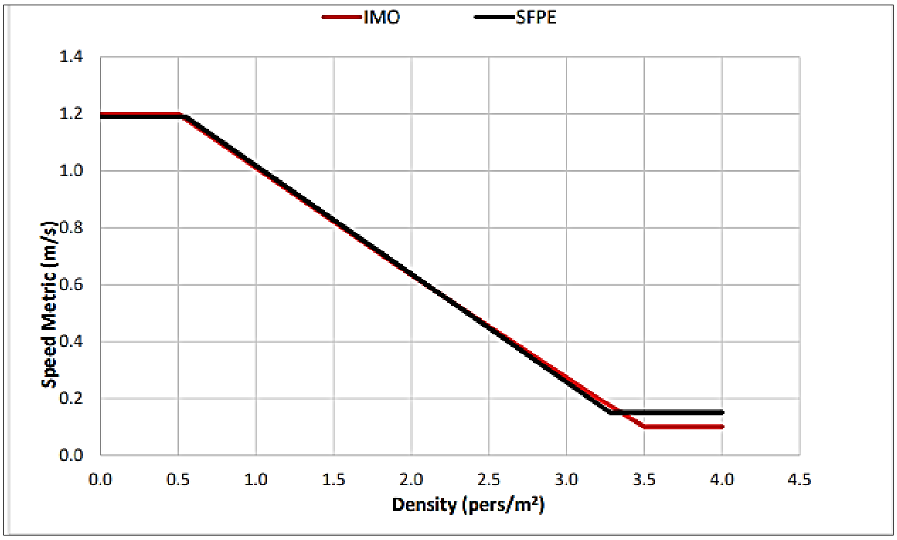


Figure 3.28. Walking speed graph as a function of density (thunderheadeng, 2021)

3.3.2. Scenario2: 1.384 m/s user walking speed

In some countries, men are more likely than women to participate in sporting activities. The gender rate of attendance at women's sporting events may differ in different nations because 'sport' is a stage for the display of masculinity. The table below shows the percentage of women who attend sporting events in European countries. The table assesses the relationship between these rates and gender equality and this seems to be very related to the human development index.

Table 3.4. The average rate of women's sports event attendance in different countries (Lagaert & Roose, 2016) updated by the author

Country	Sample	GEI	HDI	Sport event attendance rate: TOTALa	Sport event attendance rate: WOMENb
Austria (AT)	864	50.5	0.851	0.546	0.378
Belgium (BE)	867	55.6	0.865	0.406	0.306
Bulgaria (BG)	798	42.3	0.749	0.188	0.088
Cyprus (CY)	423	38.5	0.828	0.239	0.103
Czech Republic (CZ)	911	40.3	0,845	0.44	0.301
Denmark (DK)	843	71.1	0.891	0.464	0.404
Estonia (EE)	842	45.3	0.821	0.29	0.241
Finland (FI)	869	70	0.869	0.419	0.313
France (FR)	856	52.5	0.867	0.314	0.235
Germany (DE)	1335	49.7	0.887	0.396	0.290
Greece (GR)	884	38.2	0.853	0.223	0.130
Hungary (HU)	869	37.2	0.805	0.307	0.194
Ireland (IE)	749	50.8	0.89	0.61	0.489
Italy (IT)	840	34.6	0.858	0.368	0.276
Latvia (LV)	795	44	0.786	0.372	0.311
Lithuania (LT)	817	43.6	0.806	0.186	0.127
Luxembourg (LU)	420	53.7	0.876	0.39	0.317
Malta (MT)	412	43.4	0.801	0.296	0.205
Poland (PL)	805	42.7	0.803	0.231	0.138
Portugal (PT)	778	37.4	0.79	0.298	0.176
Romania (RO)	806	36	0.75	0.262	0.168
Slovakia (SK)	919	41.5	0.803	0.55	0.420
Slovenia (SI)	808	52.7	0.855	0.373	0.279
Spain (ES)	850	48.7	0.844	0.291	0.200
Sweden (SE)	884	72.8	0.887	0.535	0.441
The Netherlands (NL)	859	63.6	0.888	0.445	0.407
United Kingdom (GB)	1094	62	0.888	0.353	0.261
				Average	0.267= %26.7

a: The proportion of all respondents in the country sample who have attended a sporting event.
b: The Proportion of all female respondents in the country sample who have attended a sporting event.
GEI: Gender Equality Index; HDI: Human Development Index.

According to these data, the rate of women's attendance is %26.7 and the rate of men's attendance is %73.3. When these ratios are multiplied by the average walking speed of men and women shown in the table below, the average walking speed for an indoor sports hall is obtained.

Table 3.5. Average walking speeds of occupants (Rahouti et al., 2021) updated by the author

		Walking Speed Range (m/s)
Occupants' Characteristics	Male	1.51
		1.41
		1.41
		1.30
	Average of Male	1.41
	Female	1.41
		1.35
		1.28
		1.24
	Average of Female	1.32
	Young	1.46
		1.36
	Average of Young	1.41
	Average of Male Dominant	1.384*
	Average of Tree (Equal Use)	1.379**

* (1.41*0.733) + (1.32*0.267) =1.384 m/s by data (average of male dominant)
** (1.41/3) + (1.32/3) + (1.41/3) = 1.379 m/s (average of three = female+male+young)

According to the calculations above, the walking speed of the second scenario was defined as 1.384 m/s.

3.3.3. Scenario3: 2.5 m/s user walking speed

The 2.5 m/s walking speed value is based on literature research:

Xie et al. (2018), evaluated the individual and small group evacuation performance in normal and visually impaired conditions. 75 people took part in the evacuation exercise, which took place in a 5-story office building. Occupants start the evacuation from the 4th floor to the 1st floor using two stairs. Occupants in group one was ordered to leave as individuals, while those in group two were advised to evacuate in small groups. They took part in four scenarios with varying visibility conditions. The horizontal speed, descending speed on stairs and overall speed of occupants are measured. Horizontal speed refers to the rate of movement down a flat surface, such as a building corridor. On the stairwell, movement speed is defined as descending speed and overall speed refers to the average speed over the course of the evacuation.

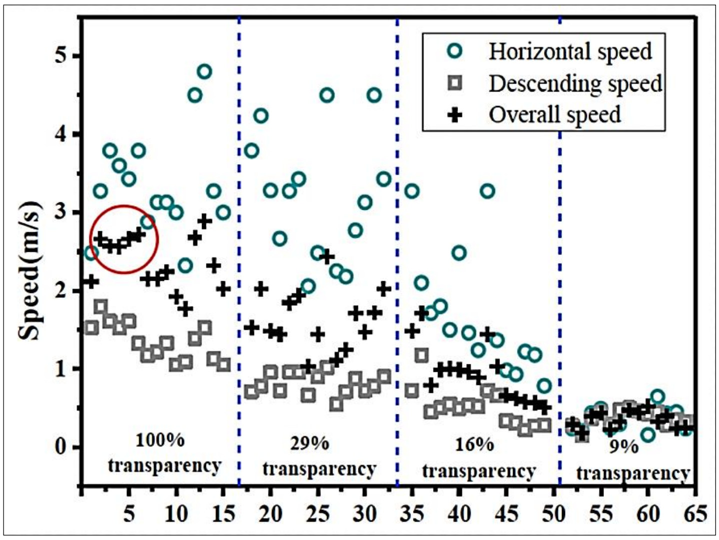


Figure 3.29. Individuals' movement speeds under various conditions (Xie et al., 2018)

The overall speed measurements are considered for the thesis study. The individual overall speed is calculated as 2.5 m/s and the small groups’ overall speed is calculated as 1.91 m/s in %100 transparency visibility conditions.

Klüpfel (2007), showed The World Youth Day 2005 (WYD) in Cologne and the non-emergency exit from a football stadium which are two instances of pedestrian flow simulation and analysis in action. To simulate the egress behavior, the author defines some values. The general population used in the two scenarios uses these standards based on the literature research.

Parameter	Minimum	Maximum	Mean	Std. Dev.	Unit
Free Walking Speed	2	5	3	1	m/s
Dawdling Probability	0	0.3	0.15	0.05	-
Reaction Time	0	10	5	2	s

Figure 3.30. Parameters of the standard population (Klüpfel, 2007)

The standard free walking speed is 2 m/s at the minimum rate and 5 m/s at the maximum rate. The average of the two values is 3.5 m/s and with a standard deviation of 1 m/s, therefore it can be defined as 2.5 m/s.

4. RESULTS

This section examines the simulation results, achieved after modeling and simulating İstanbul Esenler Sports Arena on the Pathfinder 2021 Simulation Software using the parameters listed in subsection 3.1 and matching the scenarios below.

Table 4.1. Evacuation Time Calculations of İstanbul Esenler Sports Arena

	Content	Variables	Evacuation in Seconds	Evacuation in Minutes
Scenario 1	Walking Speeds	1.19 m/s	644.5 s	10.74 min.
Scenario 2	Walking Speeds	1.384 m/s	548.5 s	9.14 min.
Scenario 3	Walking Speeds	2.5 m/s	428.8 s	7.14 min.

Table 4.1 gives the simulation results of the İstanbul Esenler Sports Arena. The evacuation time is in three different intervals, the shortest is 7.14 minutes, and the longest is 10.74 minutes. The change rate of evacuation time is of %33.51.

As can be seen in Table 4.1. the shortest evacuation time of all three scenarios is the one with the walking speed of 2.5 m/s which was obtained from the drills' literature. The longest evacuation time of all is the one with the walking speed of 1.19 m/s which was the default value of the Pathfinder Simulation Software.

The data obtained from simulations of three modeled scenarios, as well as the explanations for these results, are detailed in the subsections that follow.

4.1. Comparison of Scenarios

In the 1st scenario with the 1.19 m/s walking speed, the total evacuation time is 10.74 minutes. Below are the diagrams of 10 s, 60 s, 90s, 150 s, 300 s, and 600 s time intervals of the evacuation process.

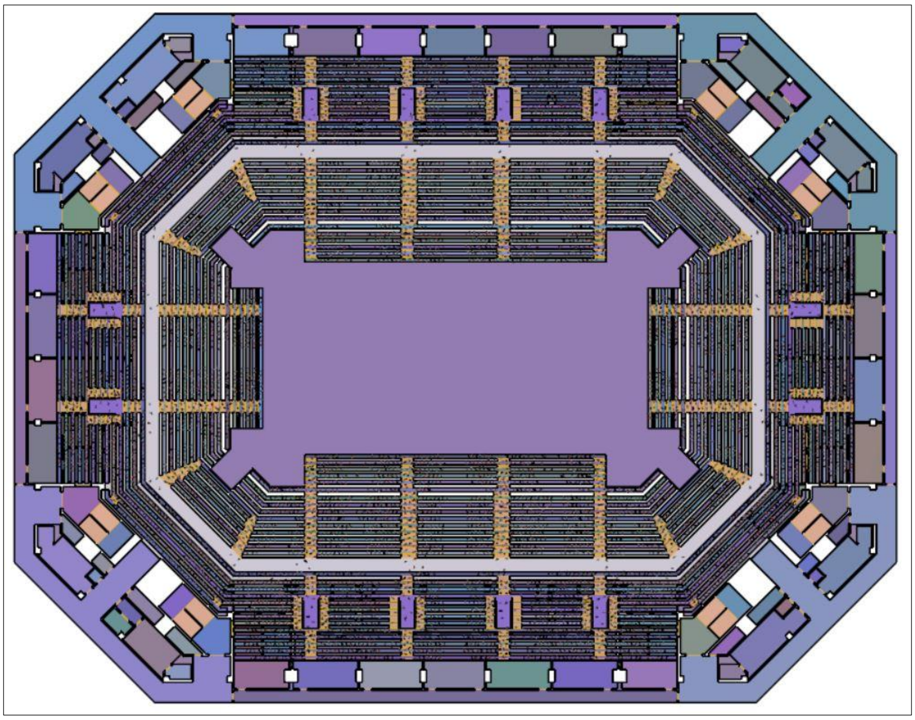


Figure 4.1. (1st scenario) 0 evacuated / 8 828 remaining occupants (10th second of evacuation)

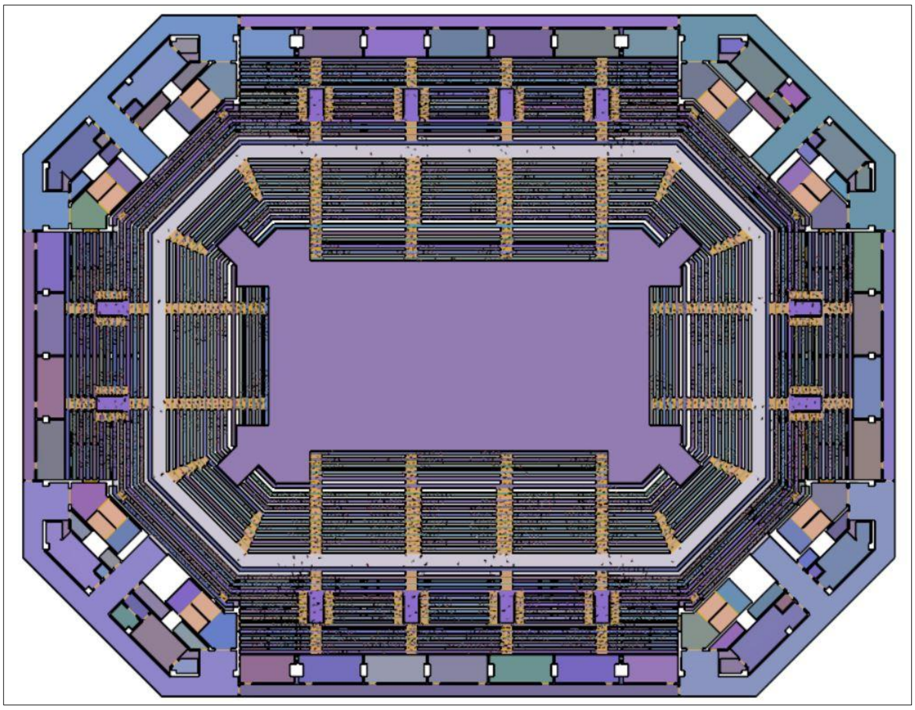


Figure 4.2. (1st scenario) 1 173 evacuated / 7 655 remaining occupants (60th second of evacuation)

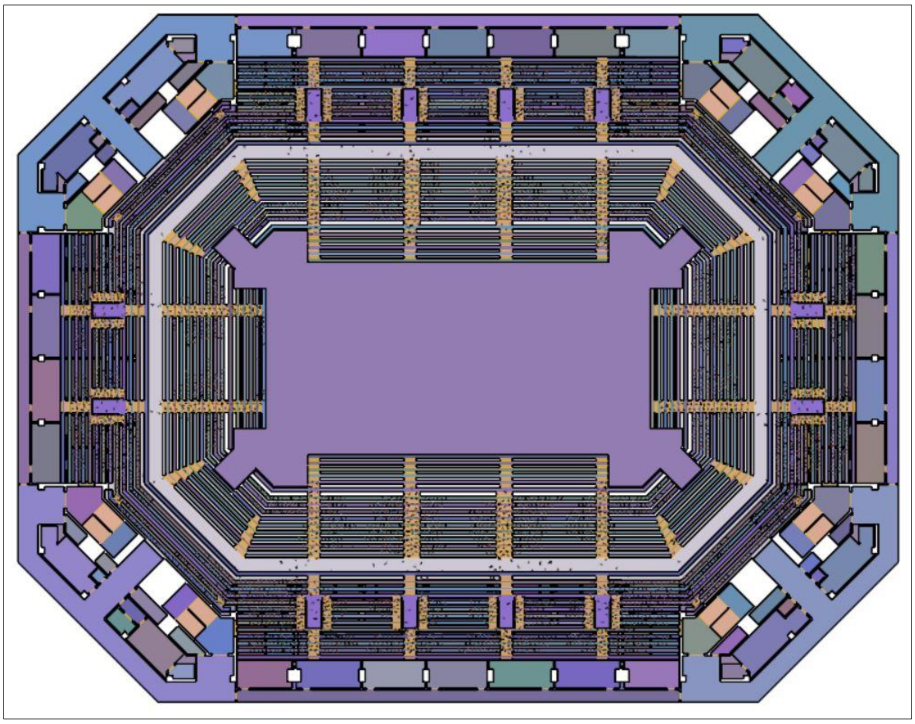


Figure 4.3. (1st scenario) 2 246 evacuated / 6 582 remaining occupants (90th second of evacuation)

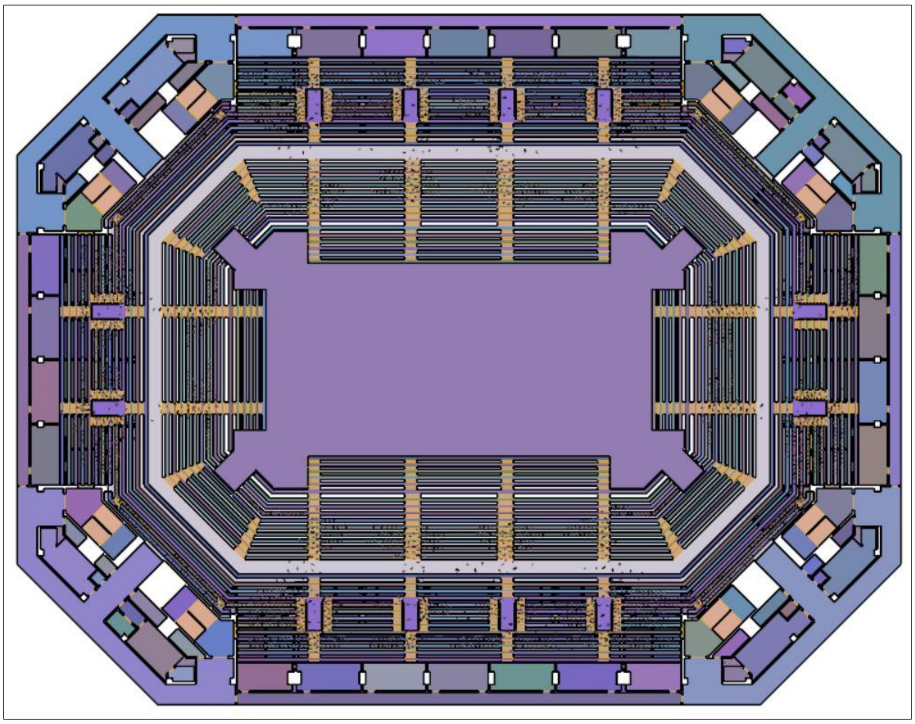


Figure 4.4. (1st scenario) 4 194 evacuated / 4 634 remaining occupants (150th second of evacuation)

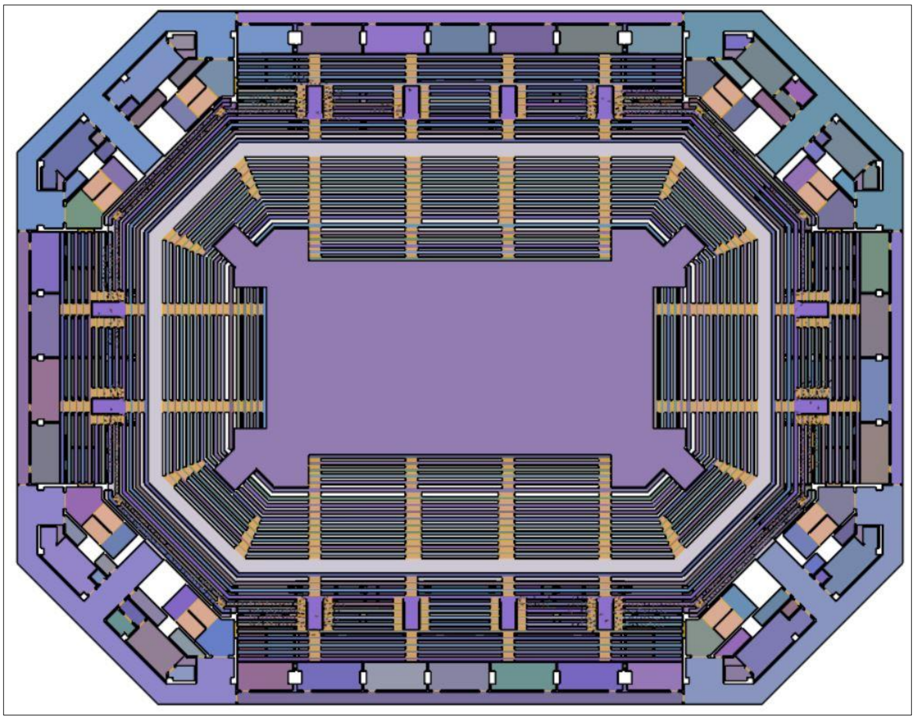


Figure 4.5. (1st scenario) 7 319 evacuated / 1 509 remaining occupants (300th second of evacuation)

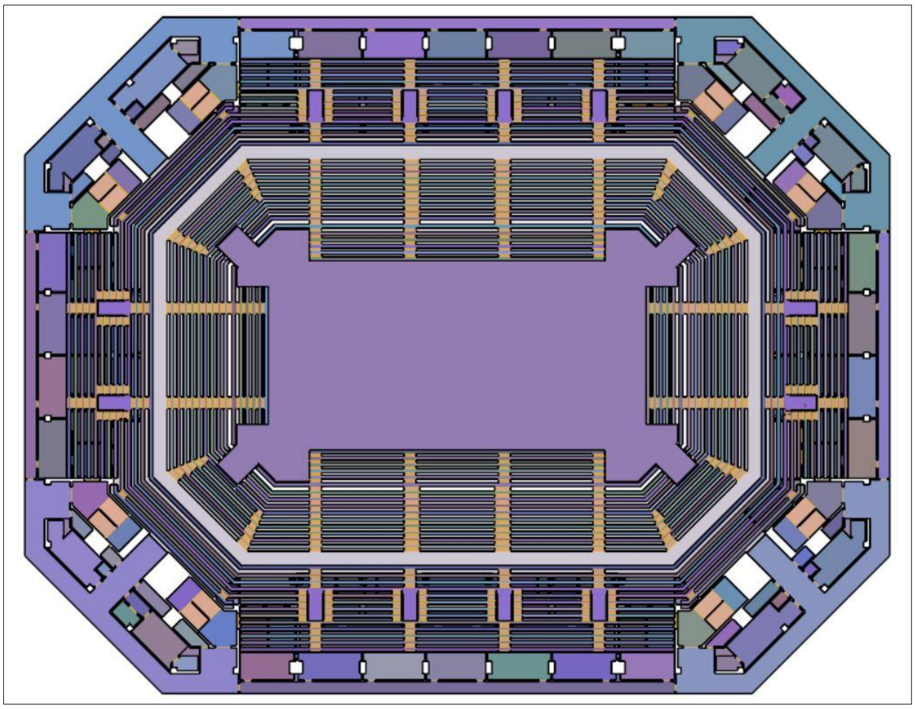


Figure 4.6. (1st scenario) 8 781 evacuated / 47 remaining occupants (600th second of evacuation)

At the end of 644.5 s = 10.74 m., 8 828 occupants evacuated the building.

In the 2nd scenario with the 1.384 m/s walking speed, the total evacuation time is 9.14 minutes. Below are the diagrams of 10 s, 60 s, 90s, 150 s, and 300s time intervals of the evacuation process.

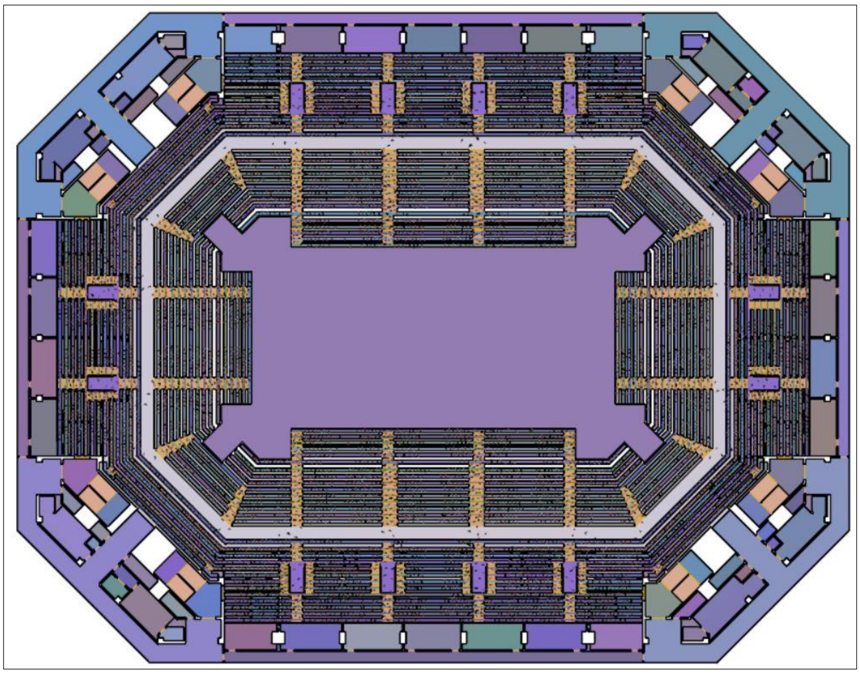


Figure 4.7. (2nd scenario) 0 evacuated / 8 828 remaining occupants (10th second of evacuation)

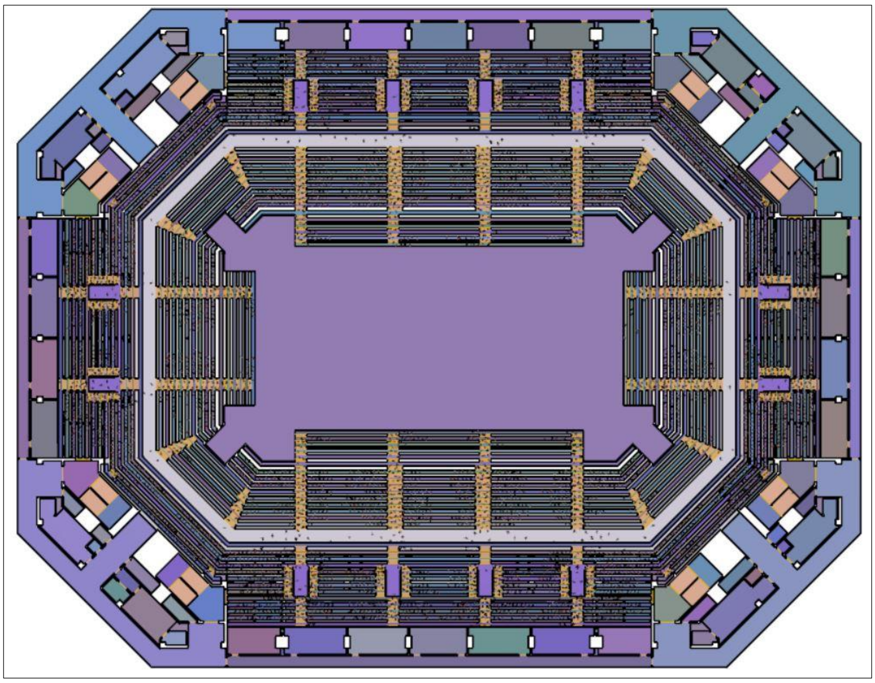


Figure 4.8. (2nd scenario) 1 469 evacuated / 7 359 remaining occupants (60th second of evacuation)

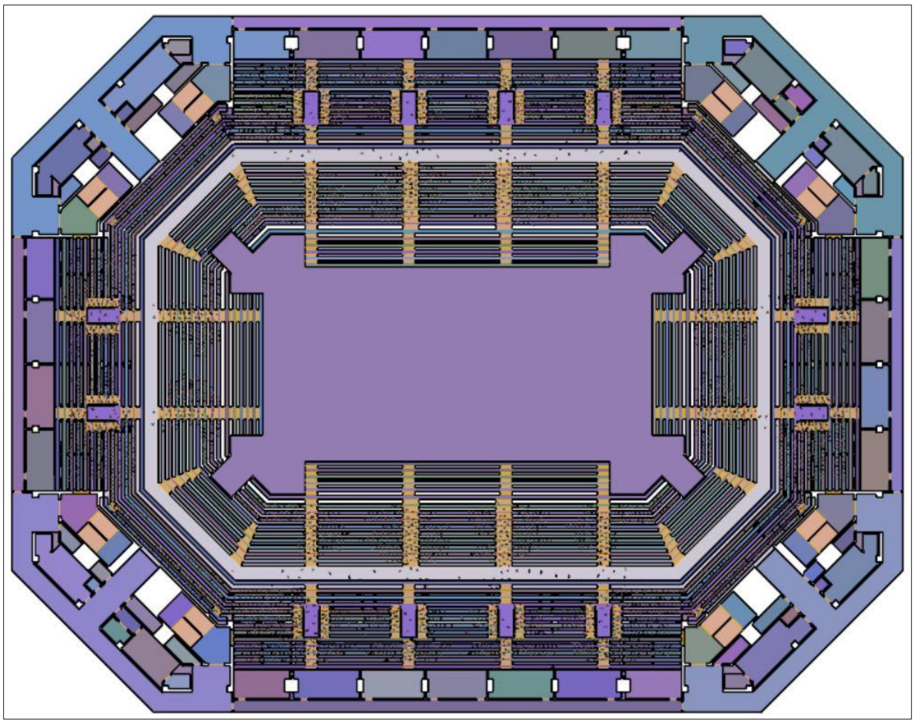


Figure 4.9. (2nd scenario) 2 732 evacuated / 6 096 remaining occupants (90th second of evacuation)

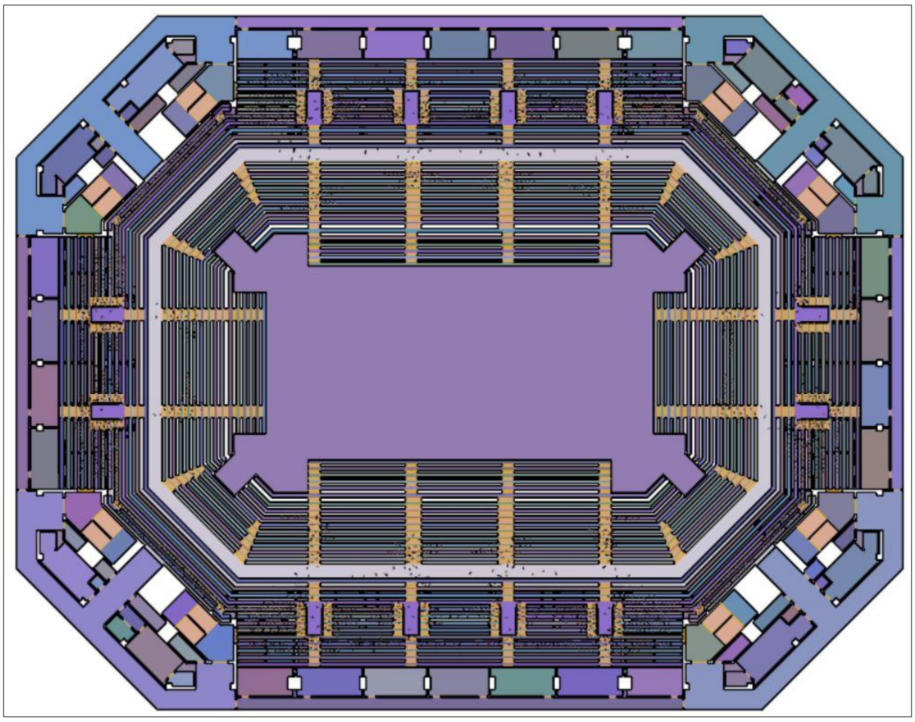


Figure 4.10. (2nd scenario) 4890 evacuated / 3 938 remaining occupants (150th second of evacuation)

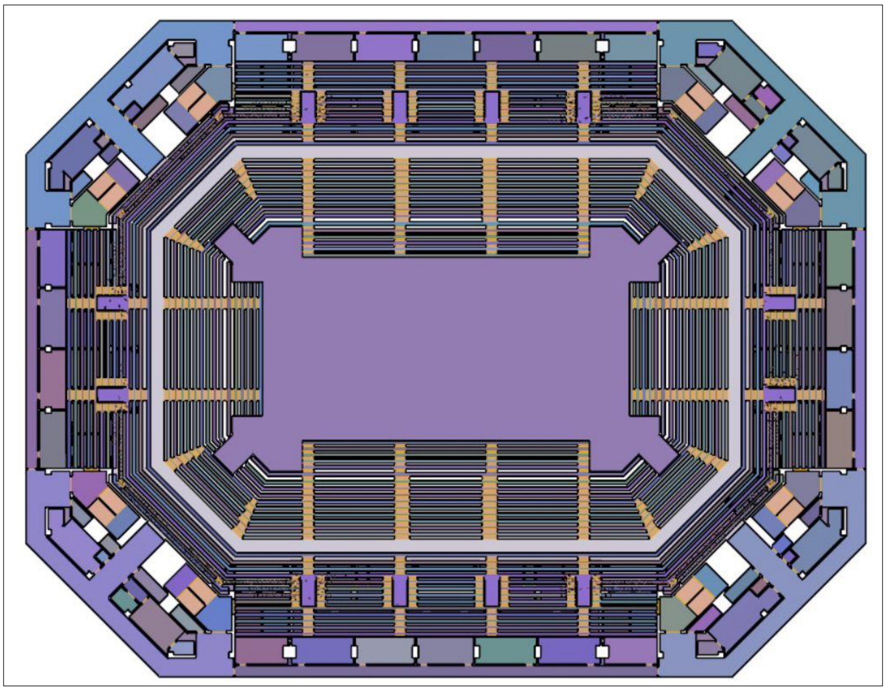


Figure 4.11. (2^{nd} scenario) 7 767 evacuated / 1 061 remaining occupants (300^{th} second of evacuation)

As can be seen from the figures above, on 300^{th} s, 7 767 occupants are evacuated, 1 061 occupants have remained.

At the end of 548.5 s = 9.14 m., 8 828 occupants evacuated the building.

In the 3^{rd} scenario with the 2.5 m/s walking speed, the total evacuation time is 7.14 minutes. Below are the diagrams of 10 s, 60 s, 90s, 150 s, and 300 s time intervals of the evacuation process.

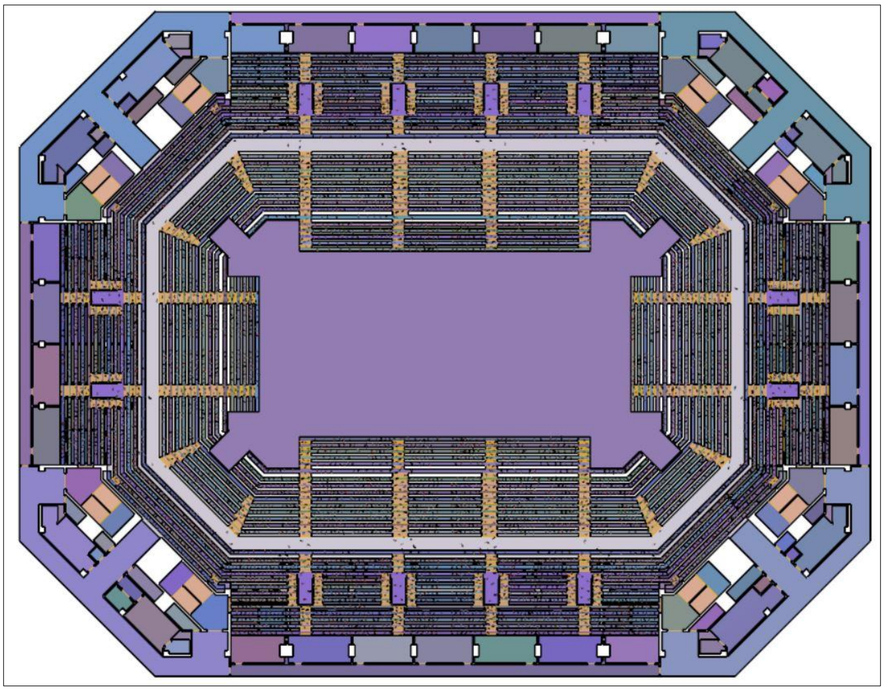


Figure 4.12. (3rd scenario) 67 evacuated / 8 761 remaining occupants (10th second of evacuation)

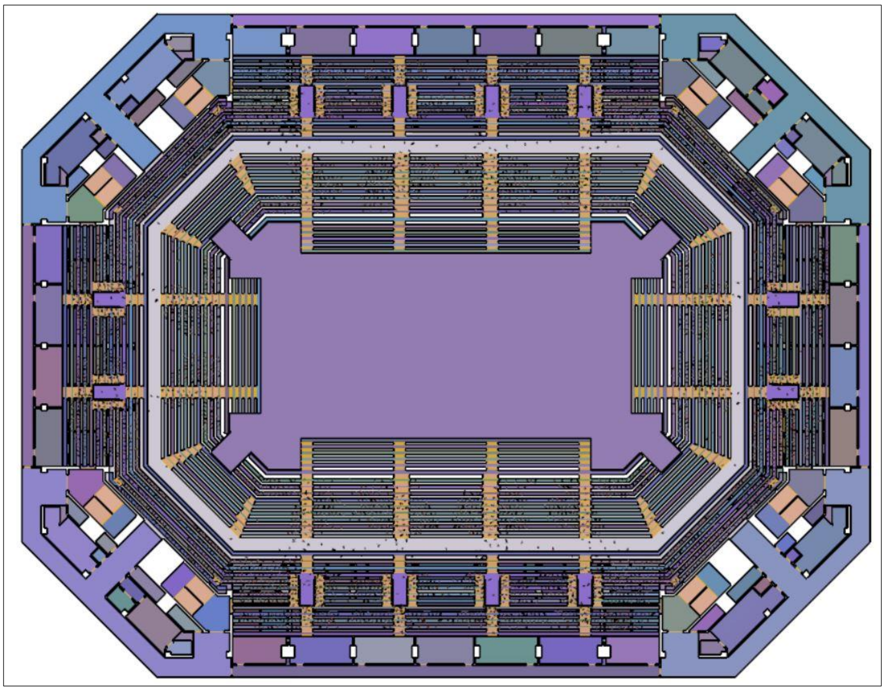


Figure 4.13. (3rd scenario) 2 887 evacuated / 5 941 remaining occupants (60th second of evacuation)

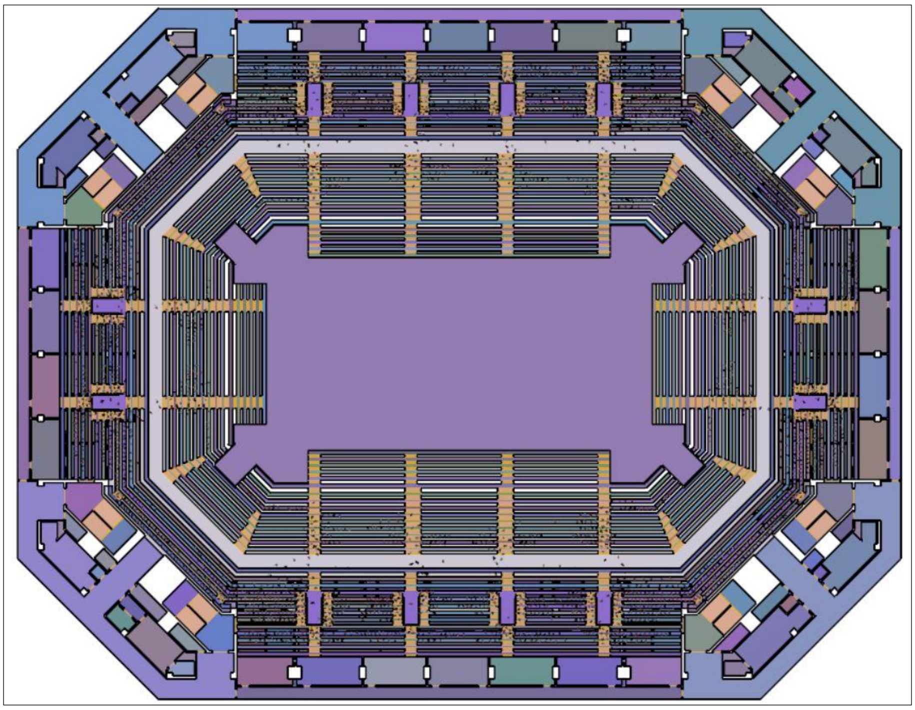


Figure 4.14. (3rd scenario) 4 667 evacuated / 4 161 remaining occupants (90th second of evacuation)

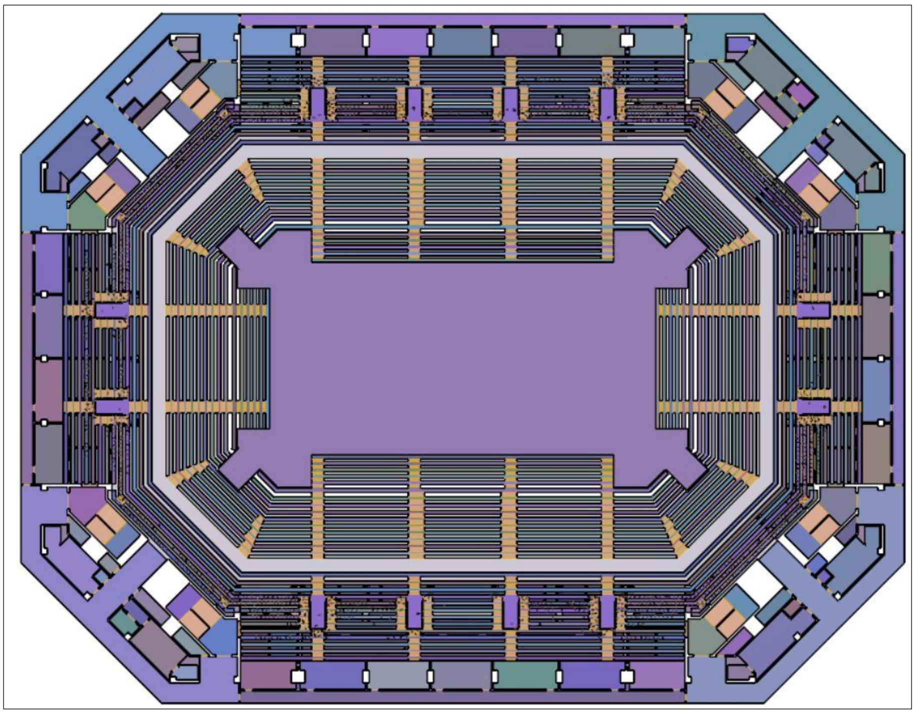


Figure 4.15. (3rd scenario) 6 954 evacuated / 1 874 remaining occupants (150th second of evacuation)

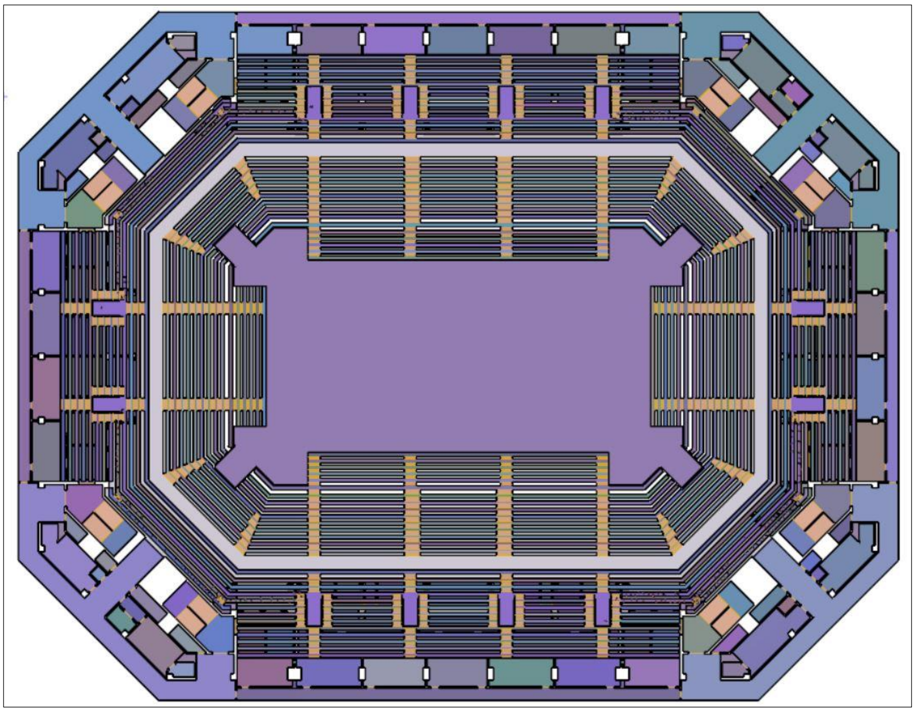


Figure 4.16. (3rd scenario) 8 488 evacuated / 340 remaining occupants (300th second of evacuation)

As can be seen from the figures above, on 300th s, 8 488 occupants are evacuated, and 340 occupants have remained.

At the end of 428.8 s = 7.14 m., 8 828 occupants evacuated the building.

Table 4.2. The number of evacuated occupants at intervals in three scenarios

		10 s	60 s	90 s	150 s	300 s	600 s	Time (s)	Time (min)
Scenario1	1.19 m/s	0	1 173	2 246	4 194	7 319	8 781	644.5 s	10.74 min
Scenario2	1.384 m/s	0	1 469	2 732	4 890	7 767	_	548.5 s	9.14 min
Scenario3	2.5 m/s	67	2 887	4 667	6 954	8 488	_	428.8 s	7.14 min

As can be seen from the table, in the first 10 seconds no occupants are evacuated from the building in scenario1 with a walking speed of 1.19 m/s and in scenario2 with a walking speed of 1.384 m/s. These 10th second-time intervals are the first elbow points in both scenarios. The evacuation begins between the 14th and the 16th seconds in the 1st and 2nd scenarios.

There are remaining occupants (8 828 - 8 781 = 47) at 600th seconds of evacuation in the 1st scenario. Because the total evacuation time of the scenario1 is 644.5 s = 10.74 min. The remaining time of the total evacuation process is 44.5 s.

There are no remaining occupants at 600th seconds of evacuation in the 2nd and 3rd scenarios. Because the total evacuation time of the scenario2 is 548.5 s = 9.14 min. and scenario3 is 428.8 s = 7.14 min. In both of these scenarios, the overall evacuation process has been completed in the 600th second.

The number of evacuees at the intervals gradually increases from the 1st to the 3rd scenario. In the first scenario with 1.19 m/s walking speed and in the 2nd scenario with 1.384 m/s walking speed, the values are close to each other. The increase rate between the number of evacuees of 1st and 2nd scenarios is calculated as %25.2 at 60s, %21.6 at 90s, %16.50 at 150s, and %6.12 at 300s. The most effective change is in the first 60th second of the evacuation process. This rate decreases as the number of remaining users decrease as time progresses.

The change rate of evacuation time is of %33.51 between the shortest (7.14 min) and the longest (10.74 min). This also supports the change rates between the first scenario with 1.19 m/s walking speed and the 3rd scenario with 2.5 m/s walking speed. The increase rate between the number of evacuees of 1st and 3rd scenarios is calculated as %146.12 at 60s, %107.79 at 90s, %65.8 at 150s, and %15.9 at 300s. These rates between 1st and 3rd scenarios are higher than between 1st and 2nd scenarios. The number of evacuees changes fast as walking speeds increase. The most effective change is in the first 60th second of the evacuation process. This rate decreases as the number of remaining users decrease as time progresses.

In figures 4.17. and 4.18., purple lines show the paths that occupants take during the evacuation. Two stairs in each corner of the building serve as both normal and emergency stairs. The stairs are accessible via two corridors of the same width that run in opposite directions. The corridor’s width is 250 cm.

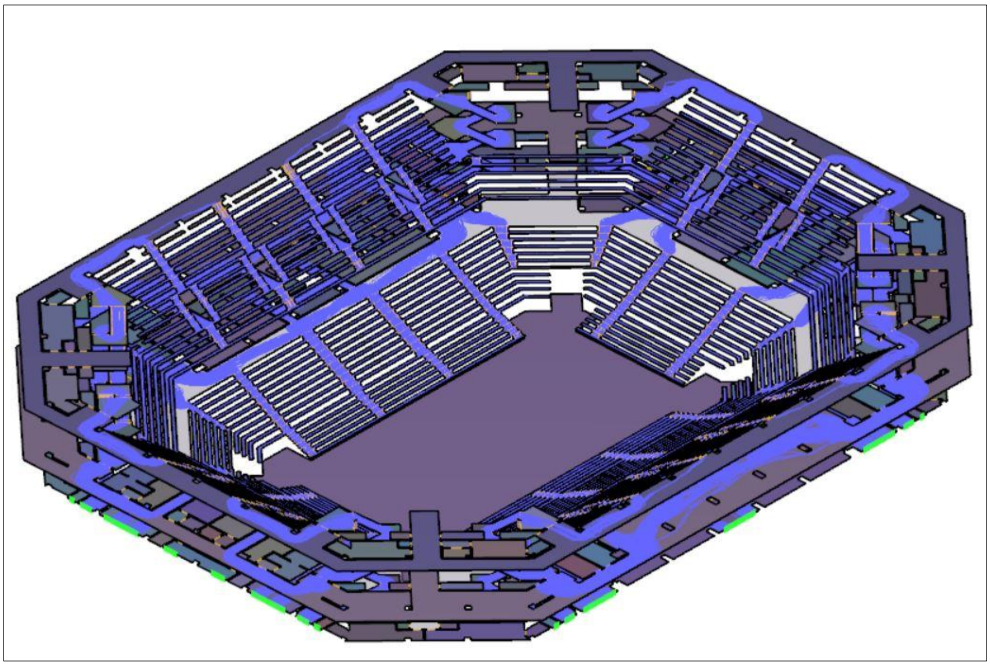


Figure 4.17. Occupant paths in 3 scenarios

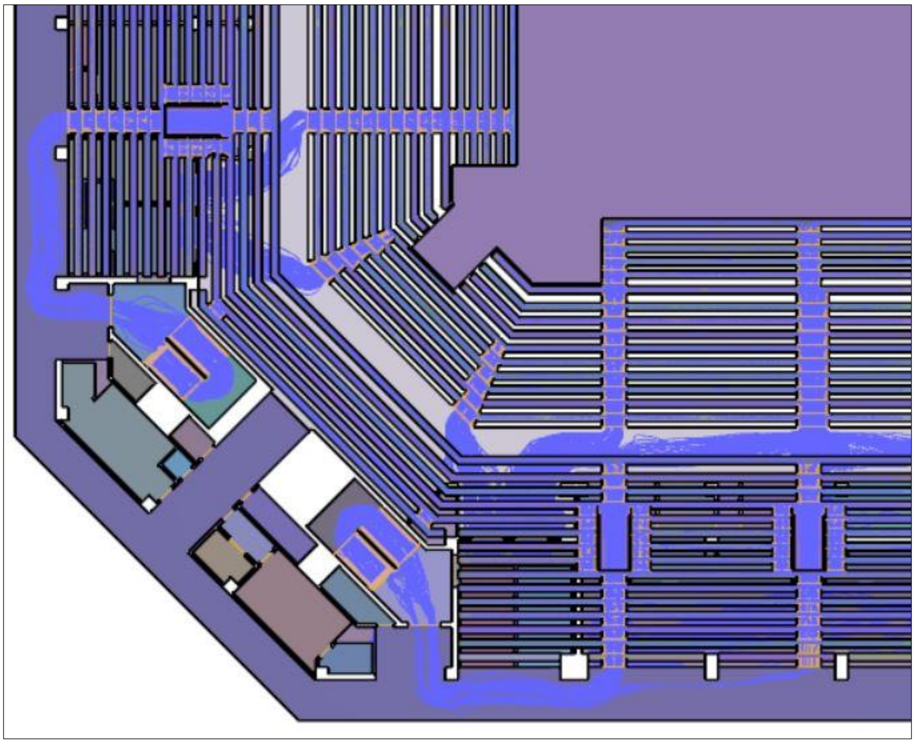


Figure 4.18. Detailed Occupant paths in 3 scenarios

The paths that occupants take are listed below:

- Upper floors:

Spectator seats> spectator stairs between seats> spectator corridors> accumulation spaces in front of stairways> stairways> exits from the ground floor

- Ground floors:

Spectator seats> spectator corridors> exits from ground floor

- Lower floors:

Spectator seats> spectator stairs between seats> spectator corridors> exits from ground floor

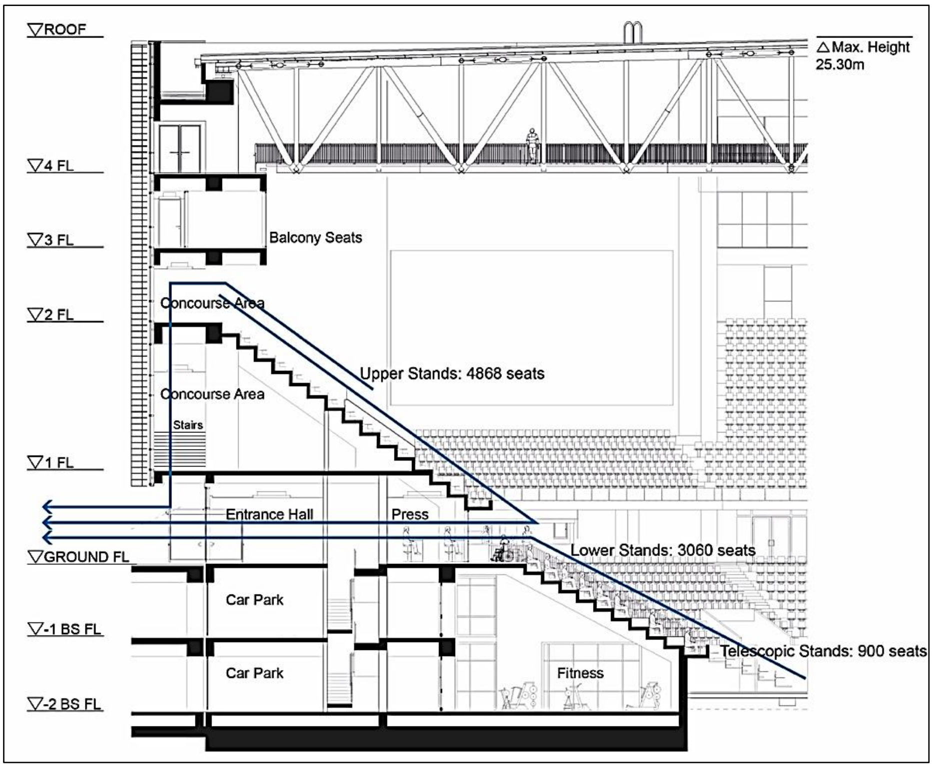


Figure 4.19. Section of the occupant paths

Even though the basement and fourth floors of the building are not included in the study, they are shown in sections to help understand the sports arena's escape routes. If they are close to the 2nd floor concourse areas, spectators in the upper stands prefer exits to the concourse areas and then to the exit stairs. If they are close to the ground level, they prefer exits to the entrance hall on the ground floor.

If they are close to the ground level, spectators in the lower stands (3 060 seats) prefer exits to the entrance hall on the ground floor. If they are close to the field level, they can prefer exits to the indoor car park. Because the project's indoor car park is not included in the study, the simulation software directs the occupants on the lower stands and telescopic stands, to the ground level concourse areas, and finally to the exit gates.

The occupant load is calculated as 7 778 people according to TRFP and 8 828 people according to the IBC and NFPA. The number of the fixed seats, 8 828, is defined to the program according to the original design.

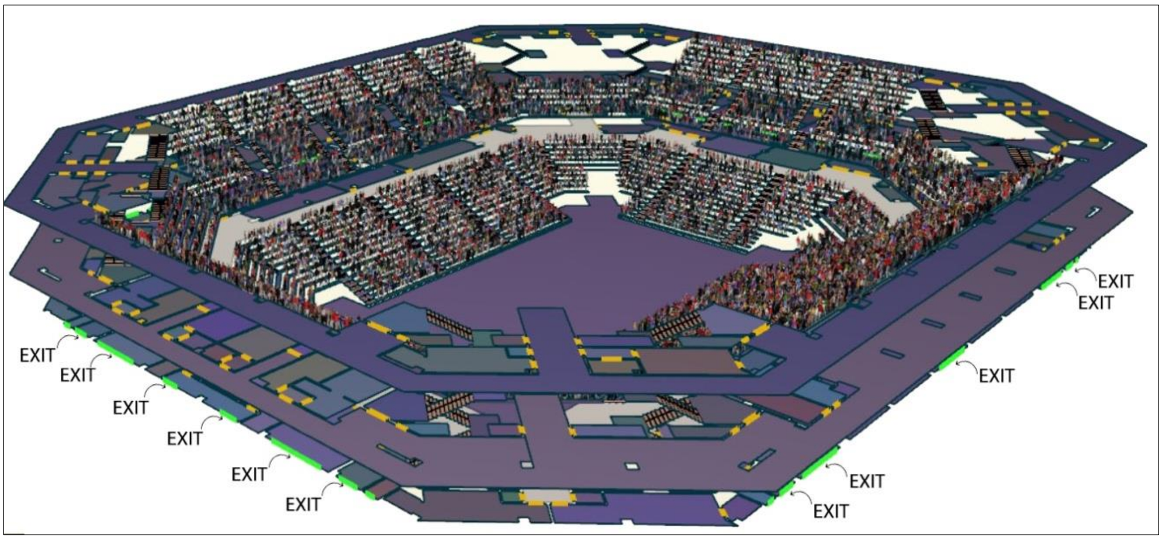


Figure 4.20. Perspective view of the model

The distribution of occupants between floors is not uniform. Because of the height of 7.20 m, the 1st floor has the most fixed seats and as a result spectator. The 2nd floor has the least spectators because it is the circulation part of the building and does not have fixed seats.

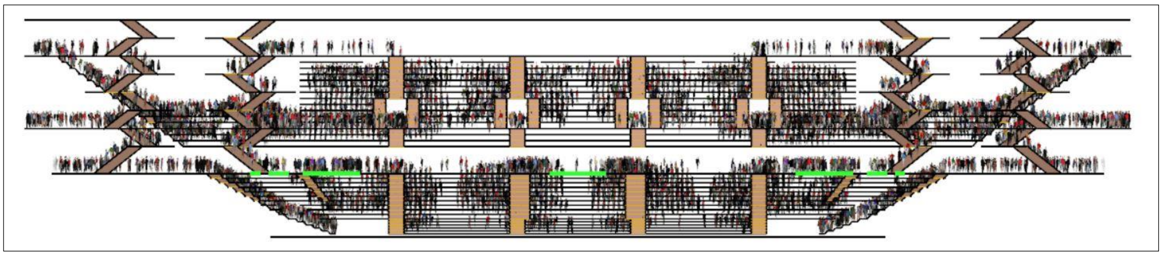


Figure 4.21. Front view (exit doors are shown with green lines)

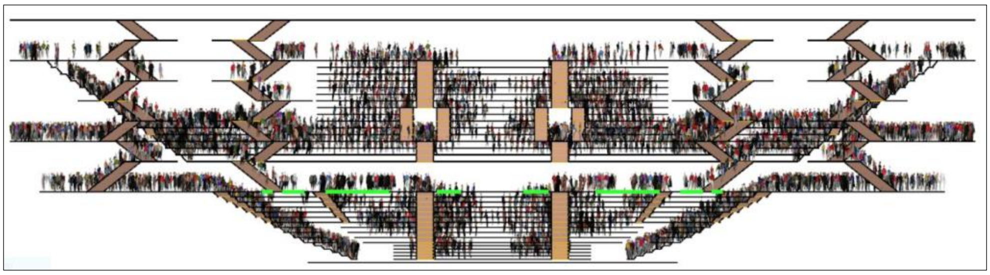
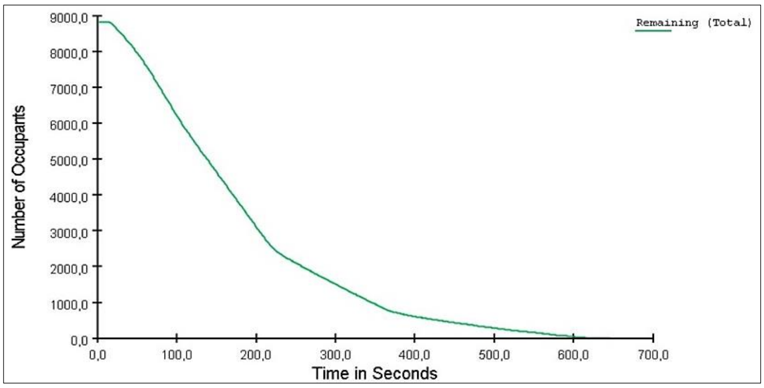


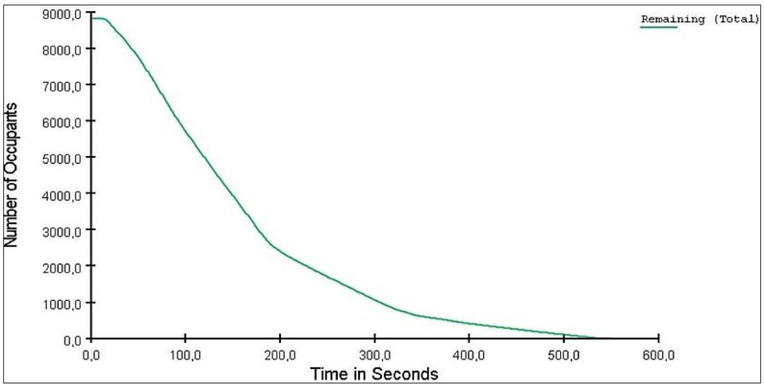
Figure 4.22. Side view (exit doors are shown with green lines)

Because the model has occupants only on fixed seats, there are no occupants on the 3^{rd} floor.

Evacuation times and graphics for 3 scenarios are given below as the results of simulations of the scenarios mentioned above. It can be seen that the evacuation times of scenario1 is 644.5 s (10.74 min), scenario2 is 548.5 s (9.14 min) and scenario3 is 428.8 s (7.14 min).

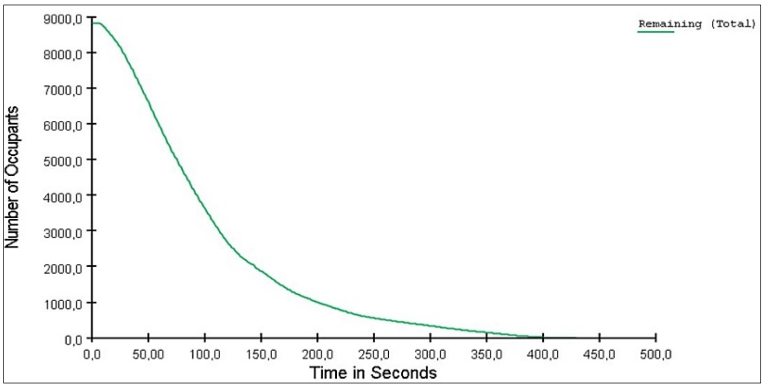


w.s.:1.19 m/s



w.s.:1.384 m/s

Figure 4.23. Time-dependent graphics of the occupant's number leaving the building in 3 scenarios



w.s.:2.5 m/s

Figure 4.23. (continued) Time-dependent graphics of the occupant's number leaving the building in 3 scenarios

As expected, the shortest evacuation time belongs to the fastest walking speed scenario with 2.5 m/s.

In the 1st scenario with 1.19 m/s walking speed and in the 2nd scenario with 1.384 m/s walking speed, the evacuation time values are close to each other. The rate between the number of evacuees of 1st and 2nd scenarios decreases as the number of remaining users decreases as time progresses. In the 3rd scenario, the evacuation timeline is the shortest of all and the evacuation of 8 828 occupants ends before 500 seconds.

The change of evacuation time between 1st – 2nd and 3rd scenarios is more effective than the change of evacuation time between 1st and 2nd scenarios. This also supports the change rates between the 1st scenario with 1.19 m/s walking speed and the 3rd scenario with 2.5 m/s walking speed.

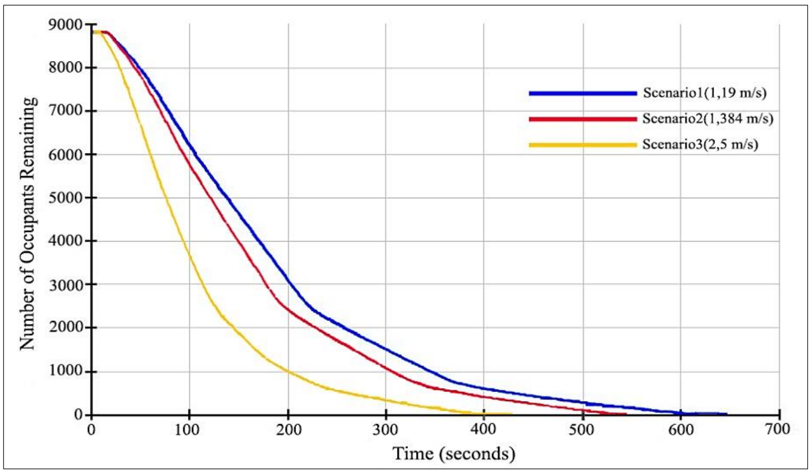


Figure 4.24. Unified Time-dependent graphics of the occupant's number leaving the building in 3 scenarios

There are elbow points and constant areas where the evacuation speed changes or stabilizes. The first elbow point in three scenarios is seen in the first 20 seconds. Up to this interval, there is stagnation in scenarios. The elbow points are at 16th second in the 1st scenario, at 14th second in the 2nd scenario, and 8th second in the 3rd scenario. The evacuation curve remains steady for a long time after that. In these constant regions, individuals from various floors follow the evacuation route at a steady speed until the second elbow point.

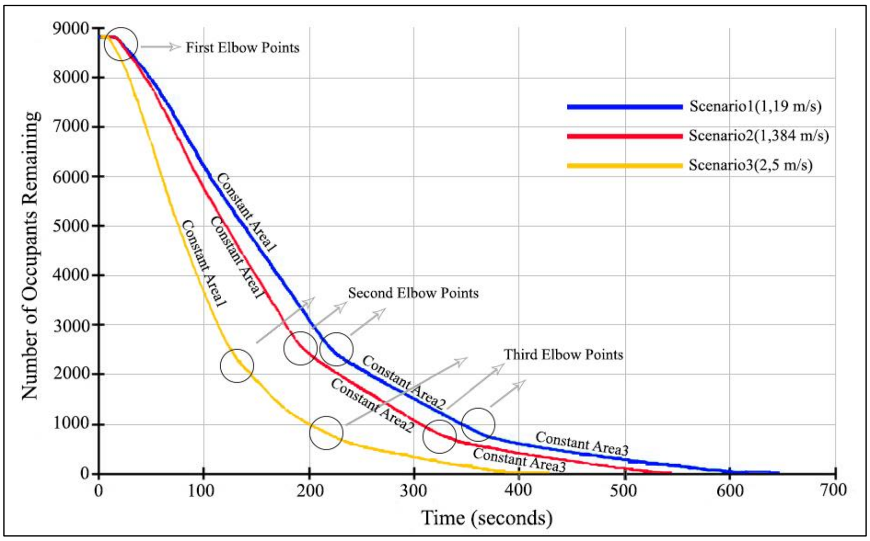


Figure 4.25. Unified Time-dependent graphics of the elbow points and constant areas

In the first constant area, the 3rd scenario with a speed of 2.5 m/s evacuated more persons than the 1st and 2nd scenarios. The 1st and 2nd scenarios' evacuation lines are close to each other and slower than the 3rd scenario. There is an efficient shift between 1st - 2nd and 3rd scenarios timelines.

Figure 4.26. 1st elbow point (queueing on the spectator seats corridor)

The second elbow points are seen near one-third of the evacuation timeline. They occur when people on the mezzanine floor meet people on the upper floor at the intersections of stairways and corridors. These elbows are steeper than the first elbows. The remaining occupant's number (2 469 and 2 452) are very close in the 1st and 2nd scenarios. The 3rd scenario evacuates 6 884 occupants when it comes to the second elbow. The elbow points are at 224th second in the 1st scenario, at 197th second in the 2nd scenario, and 147th second in the 3rd scenario.

In the second constant area, the 3rd scenario with a speed of 2.5 m/s put more distance between the 1st and 2nd scenarios. The reason for this consistency is that the merging of stairway halls and corridors has come to an end, and occupants are appropriately using the eight stairs.

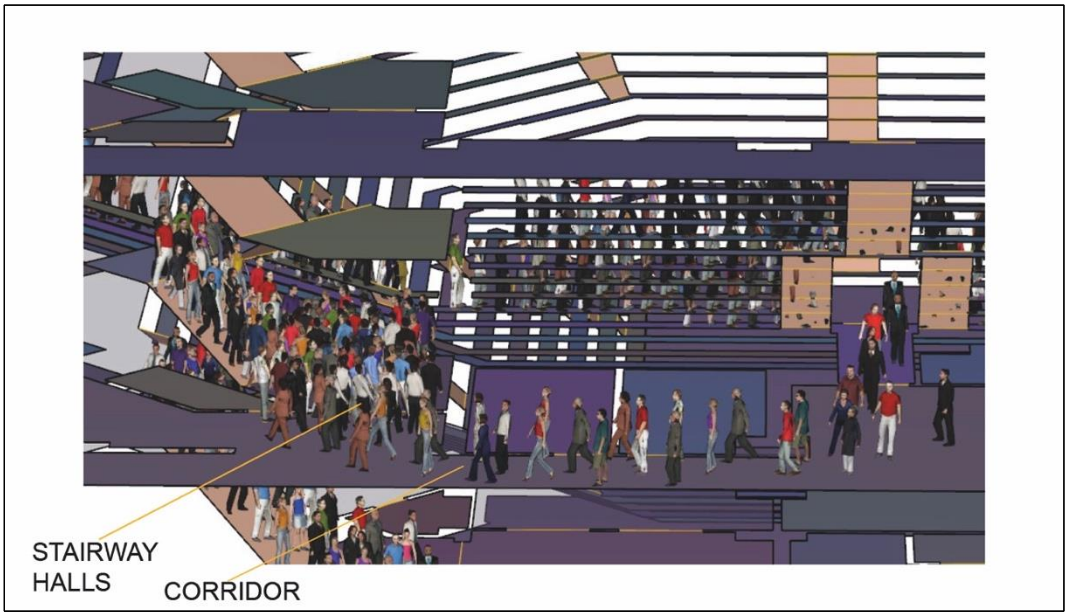


Figure 4.27. 2nd elbow point (merging of stairway halls and corridor)

The third elbow points are seen near the last moments of the building evacuation. They occur at four corners of the building. The corner spectators' queues are stuck at the bottom of the spectator seat stairs. The remaining occupant's numbers (720 and 645) are close in the 1st and 2nd scenarios. The 3rd scenario evacuates 8 112 occupants when it comes to the third elbow. The elbow points are at 376th second in the 1st scenario, 343rd second in the 2nd scenario, and 227th second in the 3rd scenario.

The 3rd scenario, with a speed of 2.5 m/s, behaves similarly to the 1st and 2nd scenarios in the third constant area. The reason for this consistency is because the merging of corner spectators and the bottom of the spectator stairs has ended, and occupants are using the stairs appropriately.

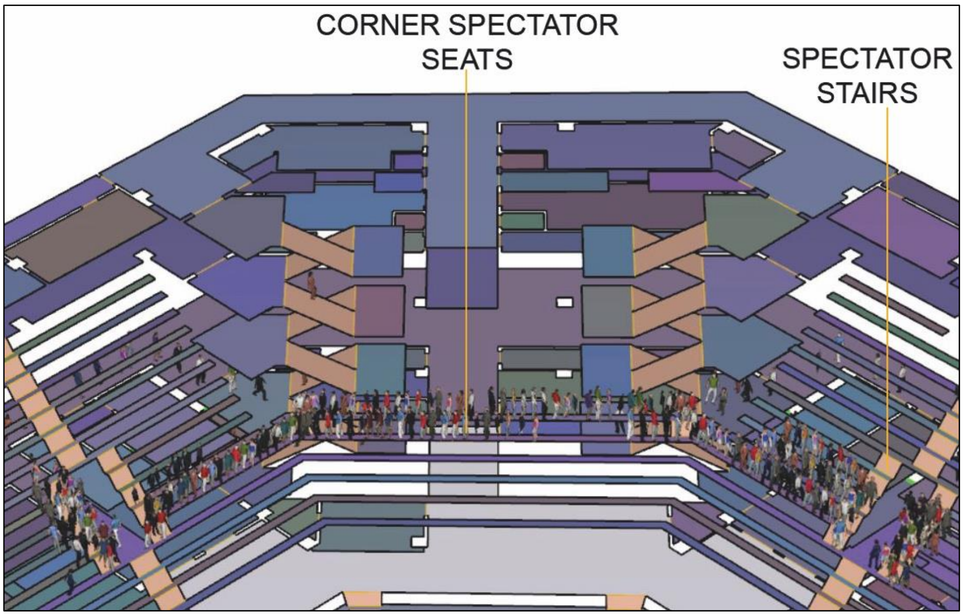


Figure 4.28. 3rd elbow point (stacking corner spectators' queues at the bottom of spectator seat stairs)

Table 4.3. The elbow points of three scenarios

Elbow Points	1.19 m/s	Number of Evacuees	1.384 m/s	Number of Evacuees	2.5 m/s	Number of Evacuees
1st Elbow	16 s	12	14 s	14	8 s	11
2nd Elbow	224 s	6 359	197 s	6 376	147 s	6 884
3nd Elbow	376 s	8 108	343 s	8 183	227 s	8 112

4.2. Evaluation of the Analysis Results of Scenario2

This subsection analyzes Scenario2 with the walking speed of 1.384 m/s. The defined walking speed for this scenario was based on researches that include the average rate of women's sports event attendance and the average walking speeds of occupants which are reviewed in subsection 3.3.2.

The graphs below show the results of scenario 2 (remaining, exited, and evacuation time).

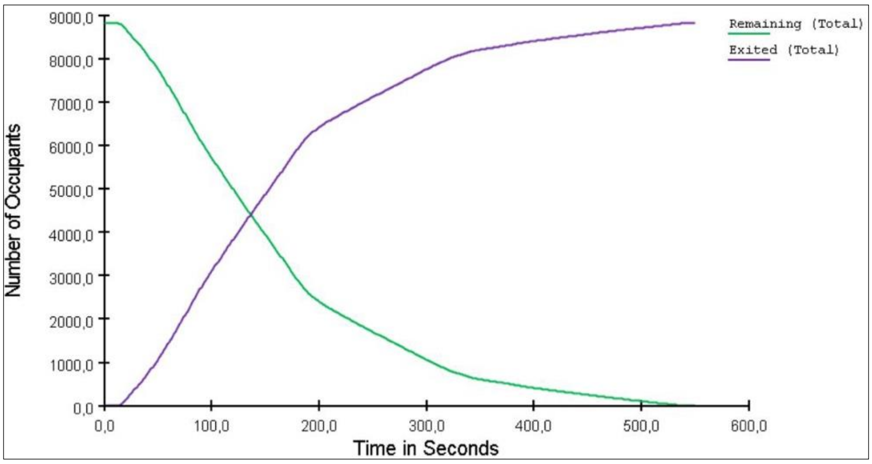


Figure 4.29. Time-dependent graphics of the occupant's number leaving the building in Scenario2

Figure 4.29. shows how many occupants left the building throughout the evacuation process and how many people remained at the same time. The evacuation time of the scenario2 is 548.5 s (9.14 min).

On the ground floor, the building has 18 main exit doors. There are 3 doors at the north entrance, 2 doors at the east entrance, 3 doors at the south entrance, and 2 doors at the west entrance, and 8 stair exits. There is further access to the electricity rooms from the outside of the building, however, these are not exit doors that occupants can use during an evacuation.

Figure 4.30. shows the İstanbul Esenler Sports Arena's main exit doors on the ground floor. The exit doors are numbered in the clockwise direction. On the entrance level, there are 18 exit doors, as previously mentioned. 10 of them are entrance gates and 8 of them are stairs exits.

Figure 4.31. shows flow rates of İstanbul Esenler Sports Arena's stair exits. It can be seen that Stair Exit_001, 004, 005, 007, and 008 show similar features. They are used more effectively with approximately 2.25 pers/s flow rate in the first 400 seconds than in the last 100 seconds of evacuation. They keep the same rate between these time intervals. The flow rate decreases to approximately 0.5 pers/s in the last 100 seconds of evacuation. The rate reaches 0 at the end of the evacuation as all occupants evacuated from the building. Stair Exit_007 behaves differently in the last 100 seconds of evacuation from nother stair exits. The flow rate reaches 0.75 pers/s at the 400th and 500th seconds of evacuation.

Stair Exit_002 and 003 show similar features in the first 200th seconds of the process. The decrease of the flow rate begins at this interval and reaches around 0.75 pers/s between 200th and 400th seconds. Between 400th and 500th seconds of evacuation, the rate is approximately 0.5 pers/s for both of these stairs. Stair Exit_006 begins to evacuate occupants later than other stairs. Its flow rate starts to increase about 50th seconds and decreases at 250th seconds.

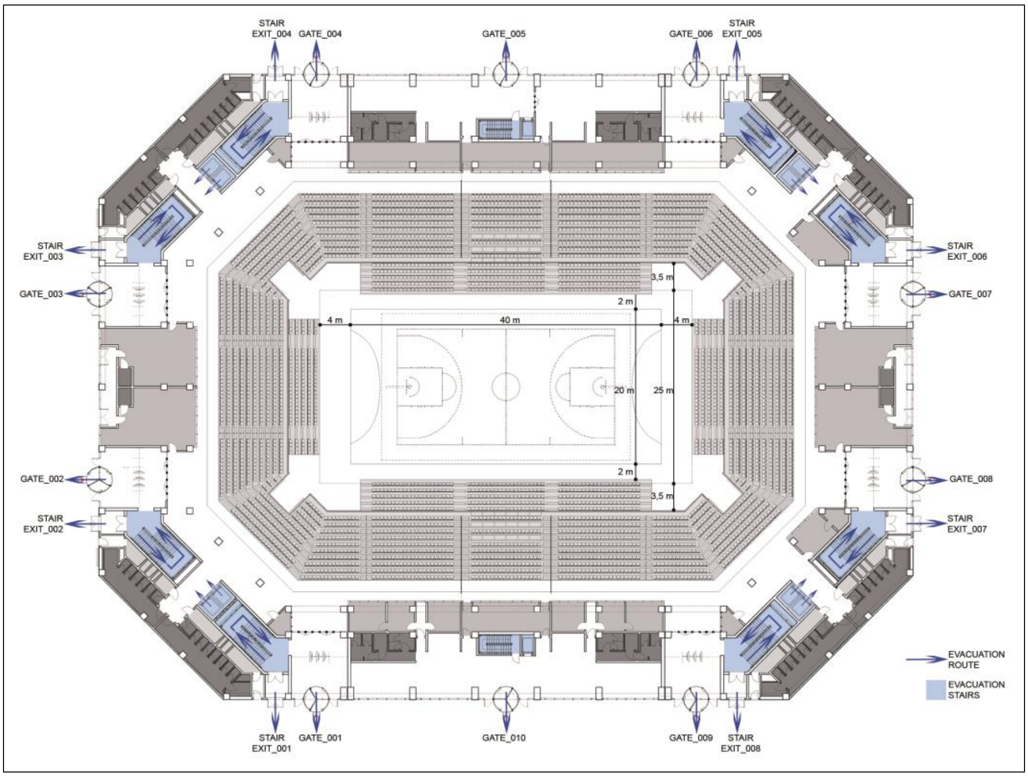


Figure 4.30. Main exit doors layout on ground floor

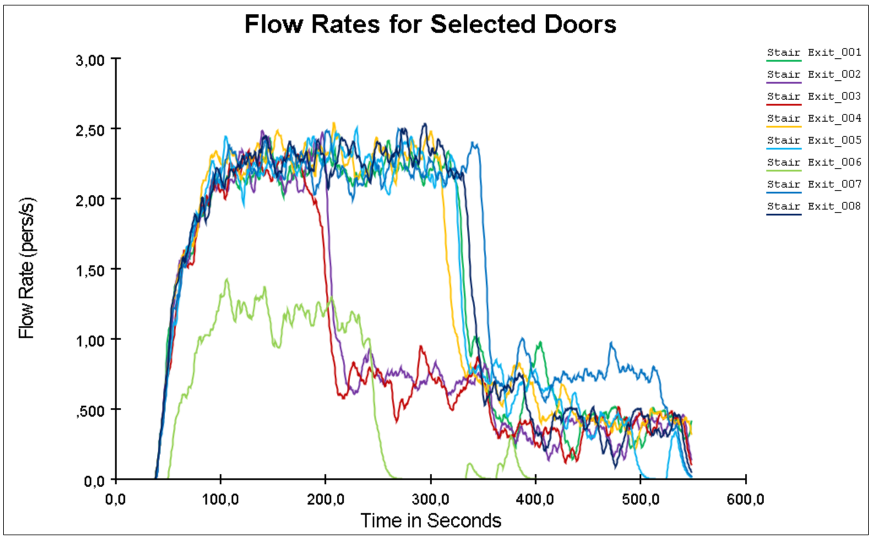


Figure 4.31. Flow rates for stair exit doors of İstanbul Esenler Sports Arena

Figure 4.32. shows flow rates of İstanbul Esenler Sports Arena's exit gates. It can be seen that Gate_002, 003, 004, 006 and 008 have similar features. The flow rate they have between the 10th and 100th seconds of evacuation is between 2.25 pers/s and 3.25 pers/s. After 100th second the rate begins to decrease and shows consistency up to 200th and decreases again up to 225th seconds. Gate_005, 007, 009, 010 have steeper rates between 50th and 100th seconds. In 100th seconds of evacuation, the decrease begins and shows consistency up to 200th seconds of evacuation with a 1.25 pers/s flow rate.

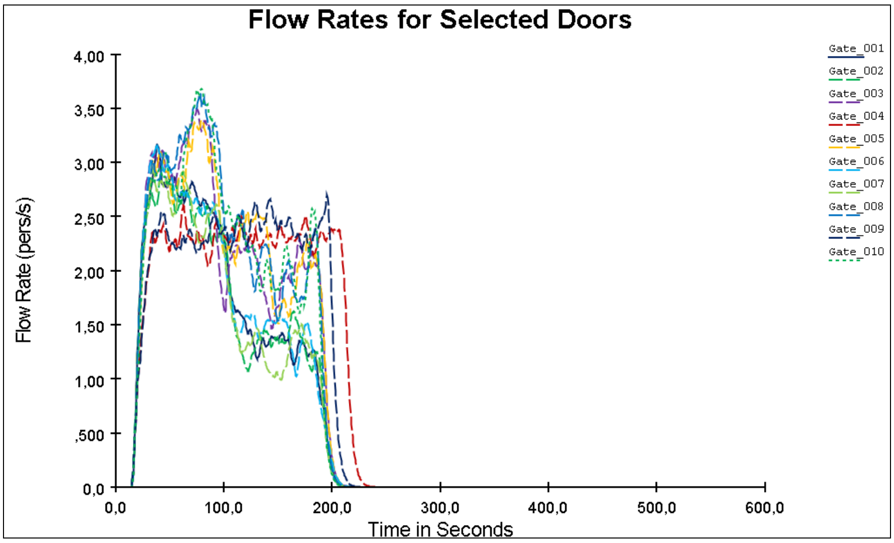


Figure 4.32. Flow rates for exit gates of İstanbul Esenler Sports Arena

4.2.1. Occupant density analysis

Figure 4.33. shows occupant density after modeling and simulation of the building in Pathfinder Software. As can be seen from the figure the red zones represent the density between 2.51 and 3 occs/m^2 and the blue zones represent between 0.55 and 1.04 occs/m^2. The landing of stairwells and stairway halls are the places with maximum density. These are the zones where the crowd merges most. The maximum density is also seen at the top of the lower spectator seating steps at ground level. These are the areas where lower-level and ground-level spectators meet. The occupant density on the stairs between the seats, whether on the upper or lower level, is between 2.51 and 2.65 occs/m^2. Because of the merging in front of the stairs, the spectator seats, especially at the corners, are shown in red.

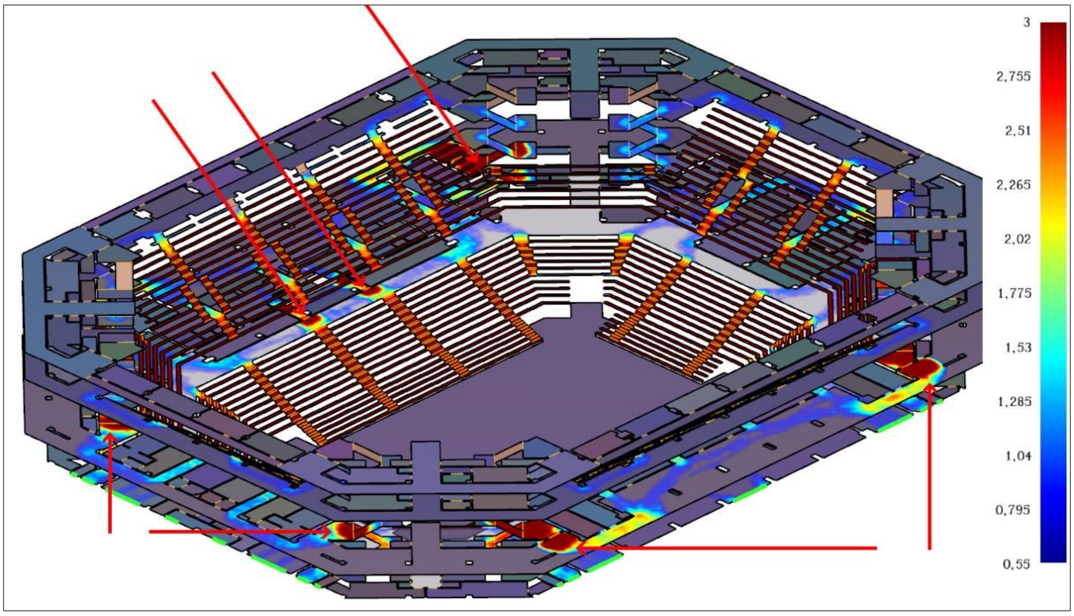


Figure 4.33. Occupant Density of İstanbul Esenler Sports Arena

4.2.2. Service queuing level analysis

As can be seen from the figure 4.34, the queuing occurs at the stairs between spectator seats. The level of queuing is higher at the top zones of upper stairs and low zones of lower stairs than in the other zones on the stairs. The spectator number is 4 868 on the upper stands and 3060 on the lower stands. The spectators on telescopic stands cannot exit from the field ground because these parts are not included in the study. Therefore, they use the exits on the ground floor and they reach these exits by the stairs between spectator seats. This creates the reason for queuing on the lower stand’s stairs. The spectators on the upper stands who are near to the 2nd floor concourse areas prefer these areas to reach the escape stairs. The spectators who are near to the 1st floor spectator corridor prefer this corridor to reach the escape stairs. Therefore, queuing occurs in the middle of spectator stairs on the upper stands.

The stairways and walkways of the case building have similarities to the service queuing level. Because the spectator stairs are the first things occupants use during an evacuation. They act in the same way in lines and on pathways. In the upper stands, there are more people than in the lower stands. The stairway and walkway lines have more densities on the upper stands because more people use them during evacuation.

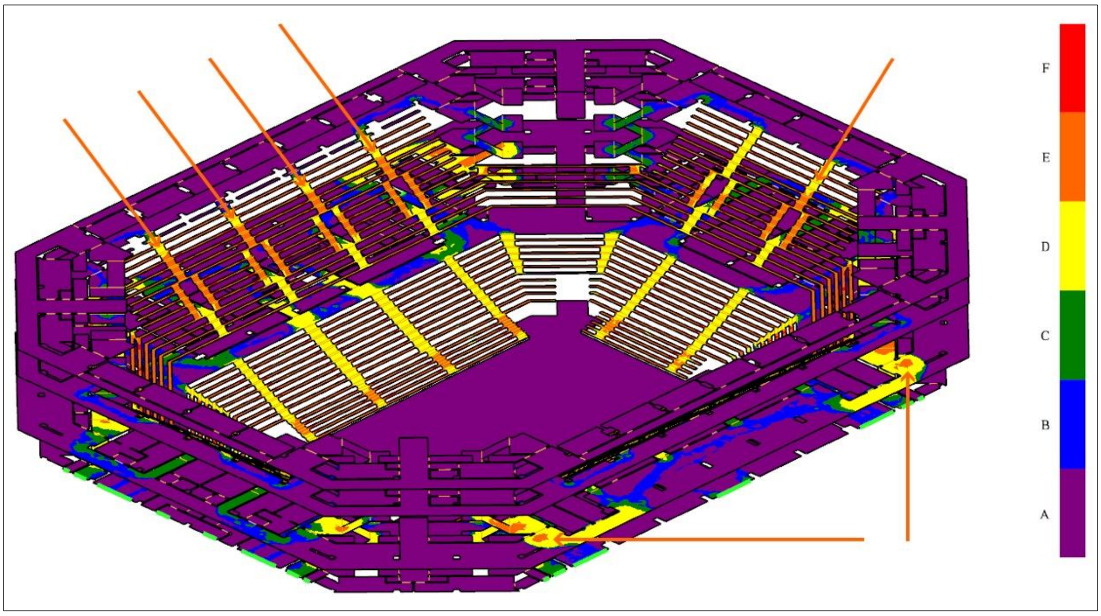


Figure 4.34. Level of Queuing of İstanbul Esenler Sports Arena

4.2.3. Exit ways' accumulated usage analysis

The accumulated usage in the stairwell halls, corner spectator seats, and spectator stairs continues to the end of the evacuation. The stair halls on the ground floor have accumulated usage even at the last moment of evacuation. The reason for this accumulation is the width of stair exits outside of the building. The stair exits are narrower than the exit gates. The usage of escape stairs during an evacuation can be more sufficient with wider exits to the outside of the building.

Queuing occurs at the top zones of the upper stairs when there is an accumulation of people. These are also the zones with the highest density. The zones on the lower levels of lower stands are the only ones where there is queuing but no accumulation.

The corridors on the concourse areas on the ground, 1st, and 2nd floors are also accumulated zones with lower densities. The spectators use these corridors to reach the escape stairs.

The accumulation on stairs does not have the same density on each floor. Even if the stairs and landings are symmetrical to each other, the software does not divide the occupants equally. Stairs 1-2 and Stairs 5-6 do not have the same accumulation densities between each other and among themselves. The first landing of Stair 5 is accumulated while Stair 6 in the opposite direction does not have any accumulation on landings.

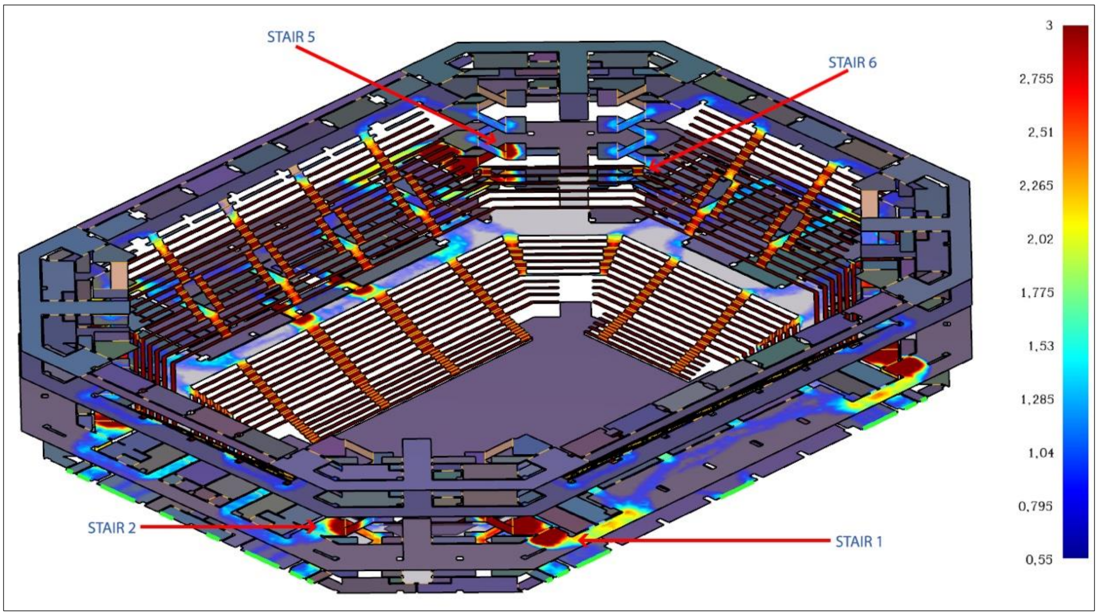


Figure 4.35. Acccumulated Usage of İstanbul Esenler Sports Arena

4.2.4. Lower and upper bowls' evacuation

Bowl-shaped stadiums and indoor sports arenas are the most common. Designing a huge number of spectators with fixed seats is a difficult task. The capacity equality of the lower and upper bowls, as well as how the spectator ratios should be compared, are issues that must be researched.

The horizontal passageways that go to the indoor car park are one of the evacuation routes of İstanbul Esenler Sports Arena's lower bowl. However, the indoor car park is not included in the study. As a result, during simulation, Pathfinder Software directs the spectators of the lower bowl to the concourse areas on the ground floor.

The lower and upper bowl evacuation times are computed using simulations of the İstanbul Esenler Sports Arena. The lower bowl is evacuated in 178.8 s =2.98 min. There are 2 936 occupants evacuated from the arena and 5 892 remaining at this time when the lower bowl is emptied. The upper bowl is evacuated in 541 s = 9.01 min., 7.5 seconds up to a total evacuation time of 548.5 s = 9.14 min. There are 8 823 evacuated occupants and 5 remaining at this time when the upper bowl is totally evacuated. It is clear that the upper bowl's evacuation time is nearly equal to the sports arena's total evacuation time.

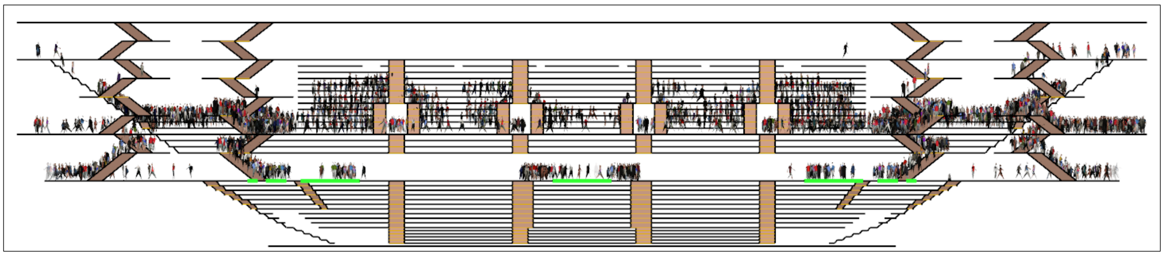


Figure 4.36. Evacuation time of lower bowl

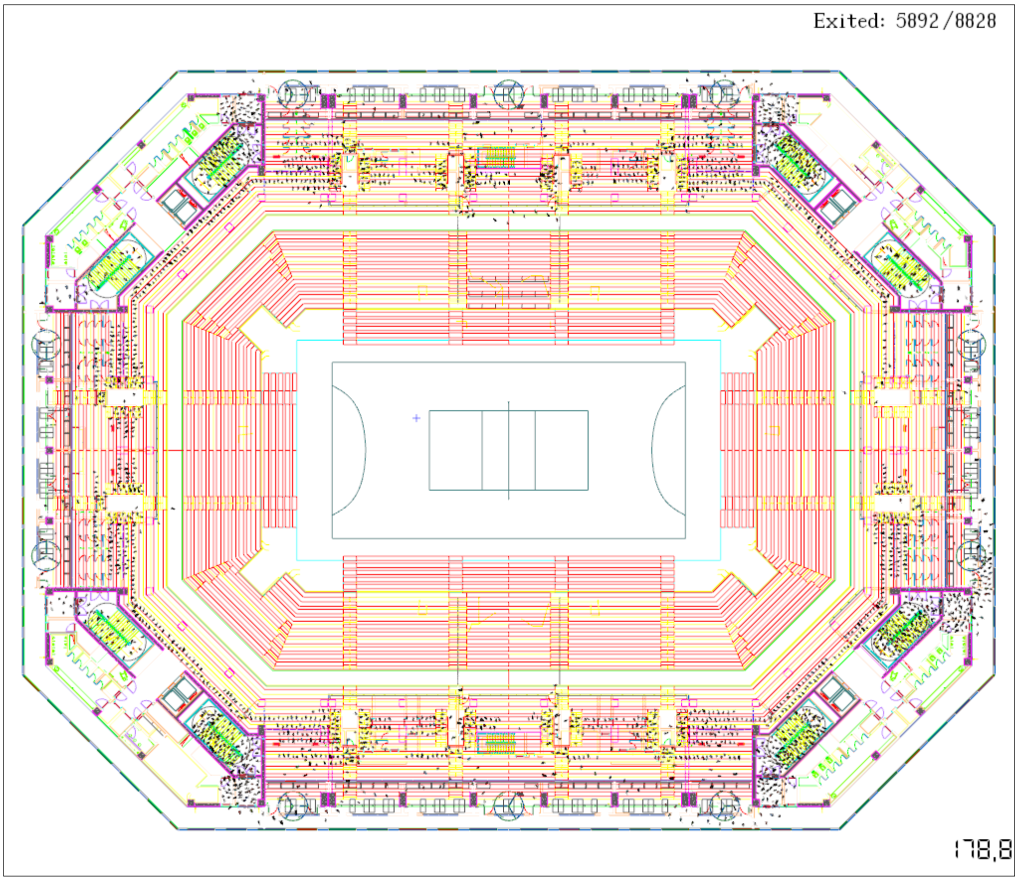


Figure 4.37. Layout of lower bowl at 178.8 s = 2.98 min

The reason for the earlier evacuation of the lower bowl is because the upper stands have more spectators and rows (upper stands = 4 868, lower stands = 3 960). As a result, queuing and merging is more efficient on the top levels. According to Klüpfel (2007), the sequence of egress from the rows is a highly important pattern that can be observed in the evacuation of venues with fixed seats. The lower rows are the first to be emptied (Klüpfel, 2007).

5. DISCUSSION

İstanbul Esenler Sports Arena, selected for this study has a rectangular and bowl-shaped plan scheme. There is a very large population of people during organizations in these types of venues. For this reason, in case of any emergency or normal evacuation situation, high-security measures are required for the occupants.

The models and simulations developed on this selected sample enabled us to compare evacuation times and the number of evacuated occupants within the context of three scenarios. The evacuation time is 10.74 min in scenario1, 9.14 min in scenario2, and 7.14 min in scenario3. When compared to the Turkish Regulation, the evacuation times resulting from the scenarios have already exceeded the safe evacuation time. Actually, according to Turkey's Regulation, the evacuation time of İstanbul Esenler Sports Arena is 1.50 minutes, which does not accurately reflect reality.

Table 5.1. Evacuation times comparison of İstanbul Esenler Sports Arena with TRFP

Pathfinder Results				TRFP
Scenarios	Content	Variables	Evacuation Time	Evacuation Time
Scenario 1	Walking Speeds	1.19 m/s	10.74 min	1.50 min
Scenario 2	Walking Speeds	1.384 m/s	9.14 min	1.50 min
Scenario 3	Walking Speeds	2.5 m/s	7.14 min	1.50 min

The result of scenario3 with 7.14 minutes is less than 8 minutes when compared to stadium evacuation times utilized in international codes and regulations. Turkey's Regulation on Fire Protection (2002) calculates evacuation times that are even shorter than international codes and regulations which is a contentious topic. It is extremely accurate that it has now been abolished.

In TRFP, the occupant load is calculated by adding the area of field and spectators (x m^2 = x people) to the area of excluding fields on each floor / 10 m^2. The occupant load is calculated in NFPA and IBC by adding the number of fixed seats. Based on these calculations, the occupant load is 7 778 in Turkey's Regulation and 8 828 in NFPA and IBC.

The architectural plan scheme is very important in the evacuation process. The egress components like stairways, doors, ramps, corridors, and elevators should be easily accessible. The parameters that influence evacuation time are the number and width of exits, as well as the capacity, width, and location of the stairs.

The exit width of the Esenler Sports Arena is 73.5 m while it should be 32.4 m according to the regulation of Turkey. The number of the exits of the Esenler Sports Arena is 18 (10 exit gates + 8 stairway exits), while it should be 17 according to the regulation of Turkey. It is seen that the case building has enough capacity for exit width and exit numbers according to TRFP.

There are 8 stairs in the building which are located at four corners alternatively. Stairs are symmetrical to each other. Each stair works as an egress stair and is open to the outside of the building with an exit door. Considering their location, they are easy to access in every aspect and open to alternatively usages. The symmetric plan scheme of the indoor hall allows each stair to be used effectively.

The width of the stairs of the Esenler Sports Arena is 205 cm without a handrail which is called ‘clean width’. According to the regulation of Turkey, the stair width should not be less than 125 cm. It is seen that the case building has enough stair width.

The tread length is 30 cm and the riser height is 15 cm in İstanbul Esenler Sports Arena. According to the regulation of Turkey, the riser height should not be more than 17.5 cm and tread length should not be less than 25 cm. It is seen that the case building has enough tread length and riser height.

The following situations are obtained during the simulation studies:

- Even though the İstanbul Esenler Sports Arena is symmetrical in terms of X and Y origins, the Pathfinder software does not give similar results on the exit doors. It can be seen from the flow rates graphics for stair exit doors and exit gates. Some exit doors are used more effectively during the evacuation process. The reason why the software directs the occupants to some of the gates more effectively is unknown. Because the software is a package program with embedded assumptions.

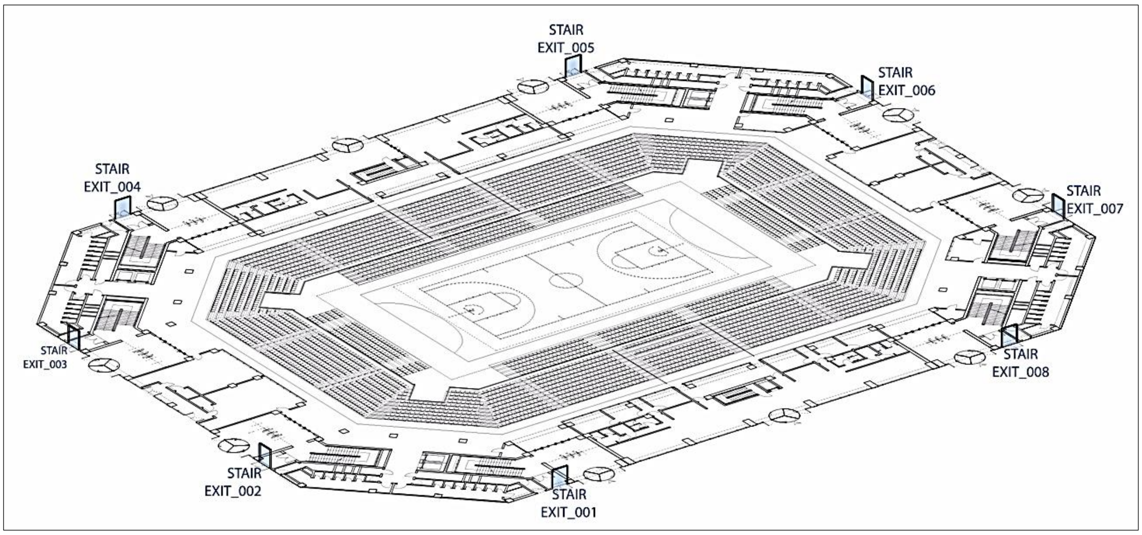


Figure 5.1. Stair exits of İstanbul Esenler Sports Arena

Figure 5.1. shows stair exits' locations of İstanbul Esenler Sports Arena. Stair Exit_001, 004, 005, 007, and 008 are used more effectively with approximately 2.25 pers/s flow rate in the first 400 seconds than in the last 100 seconds of evacuation. They keep the same rate between these time intervals. The flow rate decreases to approximately 0.5 pers/s in the last 100 seconds of evacuation. Stair Exit_007 behaves differently in the last 100 seconds of evacuation from other stair exits. The flow rate reaches 0.75 pers/s at the 400th and 500th seconds of evacuation.

Stair Exit_002 and 003 show similar features in the first 200th seconds of the process. The decrease of the flow rate begins at this interval and reaches around 0.75 pers/s between 200th and 400th seconds. Between 400th and 500th seconds of evacuation, the rate is approximately 0.5 pers/s for both of these stairs. Stair Exit_006 begins to evacuate occupants later than other stairs. Its flow rate starts to increase at about 50th seconds and decreases at 250th seconds.

As can be observed in the Pathfinder software's flow rate data, some doors are used more effectively with greater flow rates of around 2.25 pers/s while some of them have 0.75 pers/s flow rates.

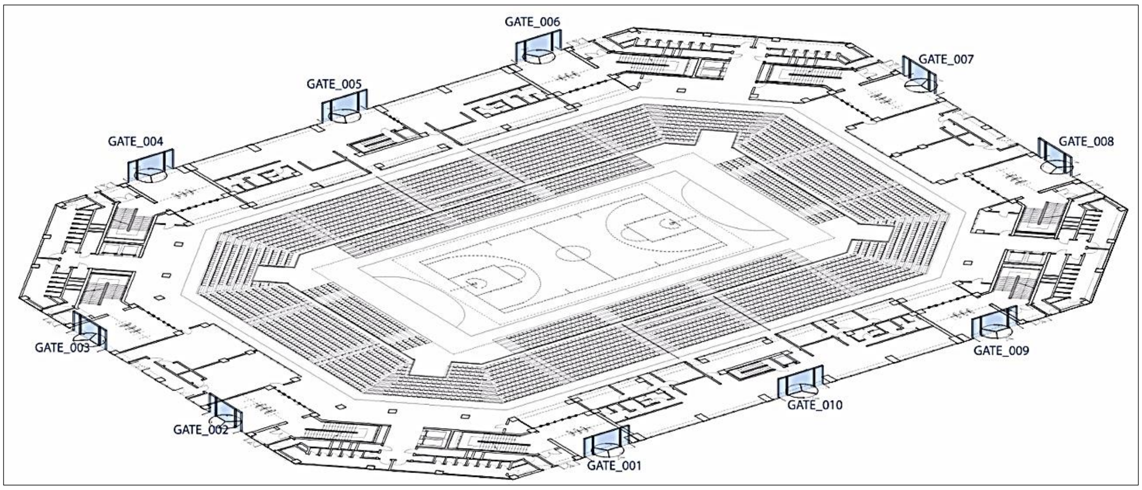


Figure 5.2. Gates of İstanbul Esenler Sports Arena

Figure 5.2. shows exit gates of İstanbul Esenler Sports Arena. Gate_002, 003, 004, 006 and 008 have similar features. The flow rate is from 2.25 pers/s to 3.25 pers/s in between 10th and 100th seconds of evacuation After 100th second the rate begins to decrease and shows consistency up to 200th and decreases again up to 225th seconds. Gate_005, 007, 009, and 010 have steeper rates between 50th and 100th seconds. In 100th seconds of evacuation, the decrease begins and shows consistency up to 200th seconds of evacuation with a 1.25 pers/s flow rate.

As can be observed in the Pathfinder software's flow rate data, some gates are used more effectively with greater flow rates of around 2.75 pers/s while some of them have 1.25 pers/s flow rates.

The reason why the software directs the occupants to some of the gates and some of the stair exits more effectively is unknown. Because the software is a package program with embedded assumptions.

- Differences in the evacuation times of lower and upper bowls have been observed during the simulation studies. The lower bowl is evacuated in 178.8 s = 2.98 min. There are

2 936 occupants evacuated from the arena and 5 892 remaining at this time when the lower bowl is emptied. The upper bowl is evacuated in 541 s = 9.01 min., 7 seconds up to the total evacuation time of 548.5 s = 9.14 min. There are 8 823 evacuated occupants and 5 remaining at this time when the upper bowl is evacuated. It can be seen that the lower bowl is evacuated

in the first third of the entire evacuation period and the upper bowl's evacuation time is nearly equal to the sports arena's total evacuation time. The horizontal passageways that go to the indoor car park are one of the evacuation routes of the arena's lower bowl. However, the indoor car park is not included in the study. If it was included, an even shorter evacuation time would have been achieved in the lower bowl of the indoor sports hall.

The lower bowl's occupant load is the cause for its faster evacuation time (upper stands =

4 868, lower stands = 3 960). The occupant load is not distributed homogeneously to the floors of the building. The lower bowl which consists of 1st and 2nd basements has lower stands and telescopic stands. The upper bowl which consists of 1st floor with 7.20 m. height has the most rows and spectators among the floors. The 2nd floor has no spectators because it is the concourse area and does not have fixed seats. The 3rd floor with balcony seats is not included in the study.

The rows and, as a result, the occupant load must be distributed equally between the lower and upper bowls to get equal evacuation times. In the evacuation process, half of the lower bowl's stands shall be directed to the basement exits and half of them shall use the ground-level exits and half of the upper bowl's stands shall be directed to the ground level exits and half of them shall use the upper level's concourse areas to reach the escape stairs.

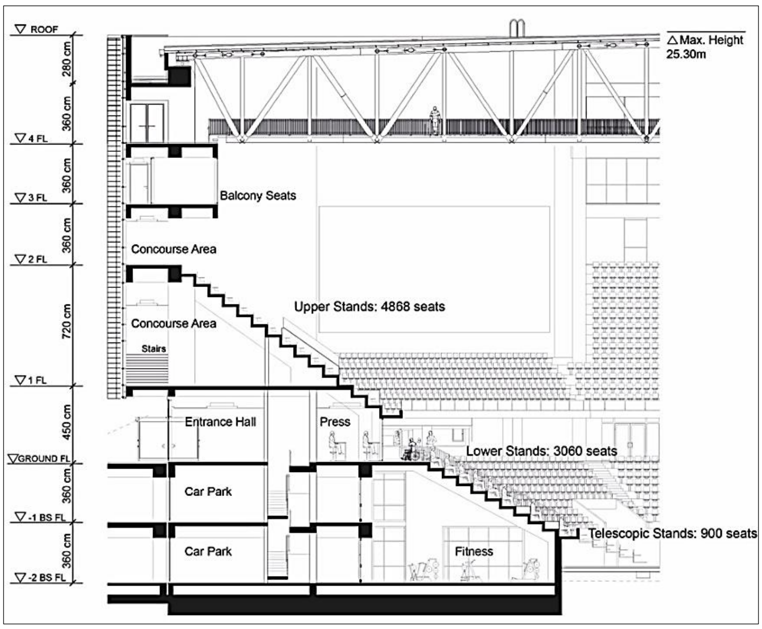


Figure 5.3. Floor heights of İstanbul Esenler Sports Arena

- Literature research about the evacuation of sports facilities were examined according to 3 approaches. These are; simulations, drills, and real situations. However, drills are not widely practiced in the literature. It has been observed that, evacuation times are shorter in real-life situations than in drills and shorter in drills than in simulation studies.

The Santiago Bernabeu Stadium in Madrid serves as a good example of this case. The stadium was evacuated on December 12, 2004, due to a bomb threat. The evacuation was completed without incident from 8:45 p.m to 8:53 p.m in just 8 minutes. A total evacuation was intended to take 15 minutes, according to drills. However, in just 8 minutes, almost 70 000 people had evacuated the building without incident.

The Spartan Stadium in Michigan, US was evacuated on August 14, 2015, due to the largest emergency evacuation drill in Spartan Stadium history. According to the drill, a crowd of 15 000 people was able to safely exit the building in 15 minutes.

El Campo Nou with 98 000 seats evacuated in 15 min., La Romareda with 34 000 seats in 10 min., and El Jose Zorilla with 3 300 seats in 4 min. As can be seen, the drills have no specific evacuation time standards as they depend on the land, the time, the number of people, and the human behavior.

Simulation studies about the evacuation of sports facilities are more common than drills in the literature. The closest case to this thesis topic is Taipei Arena which has a capacity of 14 960 spectators. Its evacuation time is 22.41 min with 0.65 m/s occupant walking speed value and it was modeled with Pathfinder software. Wuhan Sports Center Stadium, Roman Colosseum, and Gazprom Arena have closer occupant walking speeds with 2 m/s and 1.66 m/s to İstanbul Esenler Sports Arena. However, Wuhan Sports Center Stadium with a capacity of 45 000 persons is evacuated in 11.25 minutes, Roman Colosseum with a capacity of 48 000 persons in 14.5 minutes, and Gazprom Arena with a capacity of 68 000 persons in 34.6 minutes.

6. CONCLUSION

The purpose of this thesis is to analyze the evacuation effectiveness in indoor sports halls with a focus on normal evacuation conditions. A newly designed İstanbul Esenler Sports Arena with 8828 seat capacity was chosen for the case and it was modeled within a 6-month trial version of Pathfinder 2021 simulation software. The reasons why İstanbul Esenler Sports Arena was chosen for the scope of the thesis are the curiosity of the author about the newly designed building by the supervisor and the supervisor's guidance. The reason for using the pathfinder simulation program is that it is an easily accessible program that allows for academic research on evacuation analysis.

Within the scope of the thesis, three scenarios with different occupant walking speeds were modeled. The walking speeds of occupants were defined as 1.19 m/s in the 1st scenario, 1.384 m/s in the 2nd scenario and 2.5 m/s in the 3rd scenario.

The aim of the thesis was to determine how walking speeds obtained from the literature affect the evacuation. In addition, human behavior, women's sports event attendance, architectural considerations, concourse areas, upper and lower bowls, stadium safety factor, and real-life situations and drills were analyzed.

The following answers are obtained after the analysis:

<u>User walking speed</u>

The evacuation time reaches 10.74 min. with the program's default walking speed of 1.19 m/s, and when it is increased to 1.384 m/s, it takes 9.14 min. to evacuate the indoor sports hall. The evacuation time is 7.14 min. when the walking speed is increased to 2.5 m/s. The shortest evacuation time is 7.14 min. (scenario3), and the longest evacuation time is 10.74 min. (scenario1). The change rate of evacuation time is of %33.51 between 1st and 3rd scenarios. The shortest evacuation time of all three scenarios is the one with the walking speed of 2.5 m/s (scenario3) and the longest of all is the one with the walking speed of 1.19 m/s (scenario1). The walking speeds of scenarios are obtained from the literature studies of the thesis.

The 1.19 m/s is the default value of the Pathfinder Simulation software. The software defines this speed according to Fruin (1987)'s study in which he divides the population into six age and gender groups, however, for all of them, it simply produces a single normal distribution of walking speeds. The Pathfinder employs the same normal distribution across all six population groups, as well as an aggregated profile known as "Average All". The original data was reported as an absolute measurement of walking speed across several people, rather than a number that could be normalized to a given speed (1.2 m/s).

The 1.384 m/s walking speed value is based on research that include the average rate of women's sports event attendance and the average walking speeds of occupants. The average percentage of women who attend sporting events in European countries is calculated by the author and the women's rate of 0.267 = %26.7, the men's rate of 0.733 = %73.3 are found. Then, these values are multiplied by the average walking speed of men and women, and the 1.384 m/s value is found.

The 2.5 m/s walking speed value is obtained from researches based on the drill studies of Xie et al. (2018) and Klüpfel (2007).

- It is seen that if the user walking speed increases, the evacuation time decreases in sports facilities.
- The default walking speed of 1.19 m/s of the Pathfinder software is not sufficient. It is relatively slow in comparison to a pedestrian's normal walking speed. It should be increased in conformity with the intended purpose of the building. Because the user walking speed changes in different land usages such as residential, sports, retail, and commercial areas. For example, pedestrians walk faster in commercial areas than in recreational areas. There is also a relationship between speed and city size. Pedestrians in major cities walk at a faster velocity than those in smaller cities.
- The walking speed should also be increased in conformity with the general profile of users. Because the walking speed depends on age, gender, mental state, health status, physical conditions and motivation of the individual.

Human behavior

For a realistic evacuation study, it is critical to understand human behavior. These behaviours have an impact on occupants during the evacuation process and it affects the evacuation time as a result.

People make sensible decisions when they comprehend the circumstances during an emergency. But they can ignore the problem even when they hear the alarm of a dangerous situation in the absence of panic. Because of this, evacuation time can be delayed.

Because of the stress, some information is not used in the evacuation process. In a fire, for example, people may fail to notice the best exit or exit signs. This increases the likelihood of people using the exits they are familiar with.

Individual's personality and decision-making style may differ in crowds from when he/she is alone. The same reaction cannot be expected from the crowd in a stadium, a cinema, or a theatre, during an emergency situation. Even the location of the crowd during an emergency has an impact on their reactions. In a hotel, for example, users in their rooms, at the pool, or in the restaurant will not behave in the same way.

The individuals in the building generally evacuate with the routes they know and these are mostly the main exits which are the entrances of the building. The user of the building shall be familiar with the venue and the exits must be accessible for every occupant in the building.

- The thesis' evacuation scenarios do not include the human psychology and human behavior factor. The Pathfinder Software used in the thesis is a no behavior model because it measures only the movement of evacuees. But it is important to understand the human behavior in an evacuation process.
- Building evacuation studies can be made appropriately if user behavior is taken into account.

Women's sports event attendance

Men are more likely than women to participate in sports in some countries. Attendance at women's sporting events by gender may differ across countries, because 'sport' serves as a platform for the display of masculinity. The percentage of women who attend sporting events in European countries is shown in table 3.4 in subsection 3.3.2.

The Gender Equality Index (GEI) has the highest value in Sweden with a 72.8 rate and the lowest value in Italy with a 34.6 rate among 27 European countries. The Human Development Index (HDI) has the highest value in Denmark with a 0.891 rate and the lowest value in Bulgaria with a 0.749 rate among these countries. Turkey, unfortunately, is not represented in this table.

According to this table, the connection between these rates and gender equality appears to be closely related to gender equality index and human development index.

- The gender rate of the crowd will be influenced by the rate of women in the crowd.

This rate has been found to be higher for men, particularly in sports facilities. This affects the average walking speed of users, which in turn affects the evacuation time of sports venues.

<u>Architectural considerations</u>

The thesis' evacuation scenarios are based on stair evacuation. The elevators are not included in the study. The normal and escape stairs of the building are easily accessible in every way and open to alternative uses according to their locations.

There are eight stairs in the building which are located at each corner of the building. Stairs are symmetrical to each other. The riser height is 15 cm, and the tread length is 30 cm. The stair width is 205 cm. The doors of the stairs have a 200 cm. clear opening width. They are 90 degrees swinging doors. The entrance hall of the stairs has 325 cm. width and 430 cm. length.

- The architectural plan scheme is critical during the evacuation process. Stairways, doors, ramps, corridors, and elevators, among other egress components, should be easily accessible. The number and width of exit gates, as well as the capacity, width, and position of the stairs, all influence evacuation time.

- The stairwell halls on the ground floor have accumulated usage even at the last moment of evacuation. Occupants who reach the ground level congregate in the stairwell hall because they cannot leave the building quickly. The reason for this accumulation is the width of stair exits that reach outside of the building. The stair exits are narrower than the gates. The optimum width for the stair exits is beyond scope of the research.
- The stairs between spectator seats at sporting venues are just as significant as the escape stairs. Because they experience density, queuing, and accumulated usage during the evacuation process. It is seen in simulations that the accumulated usage continues to the end of the evacuation in the stairwell halls and spectator stairs.
- Queuing occurs at the top zones of upper spectator stairs when there is an accumulation of people. These are also the zones with the highest density. The zones on the lower levels of lower stands are the only ones where there is queuing but no accumulation. The accumulation on stairs does not have the same density on each floor. Even if the stairs and landings are symmetrical to each other, the software does not divide the occupants equally. The reason of this inequality is not known because the program is a package with assumptions built-in.

Concourse areas

Concourse areas are other critical parameters in the evacuation of sports venues. They surround the seating bowl. They host the majority of the stadium's serving facilities as well as function as a circulation zone between the seating bowl and the exit routes from the sports venue.

- During an evacuation, concourse areas must be able to host long lines that occur at the top of exit stairs or in front of gates. The size of these areas must be carefully determined because they must safely accommodate these queues. These areas must be smooth so that people do not get lost and they must be evacuated quickly and safely in an emergency situation.

Lower and upper bowls

One of the critical parameters encountered in the evacuation of sports venues is the distribution of the occupant load between lower and upper bowls. It is not difficult to have a large human population, but it is difficult to distribute that population homogeneously in such structures. The areas with the most fixed seats have the biggest occupant load in these types of buildings. The upper bowl usually has more spectator seats than the lower bowl.

Some of the evacuation routes of İstanbul Esenler Sports Arena's lower bowl are the horizontal corridors that reach to the indoor car park on the 2nd basement level. However, the indoor car park is not included in the study. As a result, Pathfinder Software directs the spectators of the lower bowl to the concourse areas and to the gates on the ground floor. When the lower and upper bowl evacuation times of İstanbul Esenler Sports Arena were calculated in Pathfinder, it was seen that the lower bowl takes 2.98 min. and the upper bowl takes 9.01 min. The upper bowl's evacuation time is nearly equal to the total evacuation time of the sports arena which is 9.14 min.

- The number of spectators must be distributed equally in order for them to be evacuated safely. The capacity equality of the lower and upper bowls, as well as how the spectator ratios should be compared, are all factors to consider.

<u>Stadium safety factor</u>

Mishaps are likely anywhere people congregate, especially in a situation of great passion, as in sports. The importance of safety in a sport facility cannot be overstated. At sports facilities, safety is ensured by striking a balance between competent management and appropriate design. Individual components of a sports ground, such as stairways, gangways, sitting areas, or terraces, are not sufficient to provide safety at sports grounds.

The interdependence of these and other elements is crucial. None can be treated in isolation without taking into account the impact of its design and administration on the other components. They should all be compatible and work together to make a well-balanced unit. Good management will not always make up for poor design, and vice versa. Designers should consult with those who will administer the sports field to ensure that the designs are functional.

The lack of stadium safety and security regulations can cause disasters in sports facilities. These disasters in the last century are shown in table 2.4. in subsection 2.5. There are 31 disasters in the last century which have been generated from literature. Over 10 000 people were injured and 1 735 died in these disasters. It can be observed that certain countries have more disasters than others. For example, United Kingdom saw 6 disasters between 1902 and 1989, South Africa experienced 3 between 1991 and 2001, Brazil experienced 3 between 1971 and 2000, and Egypt experienced 2 between 1974 and 2012. Turkey has had 1 disaster, which occurred in Kayseri in 1967.

- Considering the examples of England and Brazil, the number of stadium disasters in the last century may be related to the countries' interest in sports, especially in soccer. But it's also important to remember that England has its own set of rules about these high population venues. Turkey, which has no set of rules on sports facilities, has experienced one disaster in the last century. As a result, the potential security threats on a sports facility are not directly related to country regulations. The safety conditions of a sports facility are ensured by a combination of professional management and appropriate design.

Real-life situations and drills

When researching studies on the evacuation of sports facilities, it is seen that there are 3 types of methods to determine evacuation times. These are; simulation studies, drills practiced in real buildings, and real-life situations. In the literature, there are a few examples of sports venue evacuation drills. There are over twenty real-life instances from the last century, but their evacuation times are unknown. It has been observed that, evacuation times are shorter in real-life situations than in drills and shorter in drills than in simulation calculations.

- Building evacuation is a complicated process that brings people of various personalities together and causes them to respond in unexpected ways. The process is guided by the various physical and psychological characteristics of these different people, as well as their interactions with the environment. As the user and the environment change, the evacuation timing changes in different ways.
- General human qualifications such as stress and emotional factors, as well as individual qualifications such as physical state (size, age), mental state (happy, tired, drunk), knowledge of emergency situations, personality (anxiety, cowardice), and motivation (control, curiosity) are the causes of decreased evacuation time in real-life situations.

The evacuation efficiency in sports facilities will be at the highest level if the parameters summarized below are followed;

- User walking speeds that correspond to land usage must be determined accurately during the design and simulation phase.
- The effects of user behavior on evacuation timing must be considered.
- The facility’s occupant gender rate which influences the average walking speed of occupants must be calculated.
- The stairs and concourse areas must be used to their full capacity.
- The lower and upper bowls’ occupant load must be distributed equally to get equal evacuation times.

6.1. Limitations of the Study

Limitations of the thesis are;

- Parameters such as gender, age, and health status when defining building occupants are excluded from the study. Furthermore, the study excludes pre-evacuation time and user behavior.
- The negative impact of environmental effects inside or outside of the building on the user during the evacuation process are excluded from the study.
- Pathfinder Simulation Software was used to model and simulate the building. The program is a package with assumptions built-in. These can have an impact on the results.

6.2. Future Research

In comparison to international codes and regulations, Turkey's regulations, regarding the evacuation of indoor sports halls, lag far behind. The calculations for evacuation times have not been valid in Turkey’s Regulation since 2002.

- These venues with high population density require their own set of rules.
- The occupant walking speed of sports facilities could be studied more thoroughly.
- More research should be done on the parameters for disabled and elderly occupant evacuation.
- The optimum width for stair exits should be properly researched.

- The capacity equality of the lower and upper bowls, as well as how the spectator ratios should be compared, are all considerations.

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