

**Pedestrians' Movement to the Holy Mosque**

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**A case study for developing the pedestrians' routes using GIS**

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**Abstract:**

Makkah, a city of profound religious significance, annually hosts the Hajj pilgrimage and continuously accommodates Umrah visitors, resulting in a surge of millions of pilgrims. This extraordinary influx places immense pressure on transportation infrastructure and demands efficient management of people flows within the city's constrained boundaries. This research paper provides a scientific background to address the challenge of managing large pilgrim flows in Makkah through innovative transportation solutions. By analyzing the unique characteristics of pilgrimages, urban dynamics, and the complexities of pedestrians' movement, and aim to propose strategies for sustainable, safe, and efficient transportation in this spiritually significant environment.

**Keywords: GIS, Pedestrians movement analysis, Crowd Management, Urban Development**

**1. Background:**

Makkah's hosting of the annual Hajj pilgrimage and year-round Umrah visitors has transformed the city into one of the most densely populated urban areas globally during certain periods. As such, the necessity to manage the transportation of millions of pilgrims within a confined space has become a pressing concern. The pilgrimage activities form the driving force behind the urgent need for improved transportation solutions in Makkah.

**2. Challenges for improving transportation system in the Holy Mosque Surrounding Areas:**

**2.1 Unique Characteristics of Pilgrimages:**

Pilgrimage activities, marked by specific rituals and time-sensitive obligations, create a distinctive set of challenges for transportation management. Understanding the spatial-temporal patterns of pilgrim movements, including peak arrival and departure times, is essential to design effective transportation strategies.

### **2.2 Urban Dynamics and Limited Space:**

Makkah's urban environment presents a constrained landscape for accommodating the surge in pilgrim numbers. Balancing the requirements of pilgrim transportation with the city's existing infrastructure, resident needs, and historical significance requires meticulous urban planning and innovative transportation designs.

### **2.3 Crowd Dynamics and Safety:**

Managing large crowds in confined spaces necessitates an in-depth understanding of crowd behavior, flow dynamics, and safety considerations. The integration of crowd management principles with transportation solutions is vital to prevent overcrowding, ensure pilgrim safety, and maintain a spiritually enriching experience.

### **2.4 Technological Interventions:**

Modern technologies such as GIS and real-time data analytics, crowd simulation modeling, and digital wayfinding systems offer valuable tools for optimizing transportation solutions. By harnessing data-driven insights, authorities can proactively manage pilgrim flows, predict congestion points, and ensure efficient resource allocation.

### **2.5 Sustainable Transportation:**

Addressing the environmental impact of pilgrim transportation is imperative. Implementing sustainable transportation modes, promoting pedestrian-friendly infrastructure, and exploring green mobility options align with the principles of responsible urban development. The integration of multiple transportation modes, including buses, trains, pedestrian pathways, and potential future innovations, presents an opportunity to create a seamless and

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efficient transportation network that caters to diverse pilgrim needs.

### **3. The Study Area:**

#### **3.1 The Development of The Central Area:**

Centralization is related to directing functions and services towards a specific area. During the forties of the last century, the central area surrounding the Holy Mosque was dominated by all parts of the city. The area controlled all religious, educational, and commercial activities. The heart of Makkah contains the Holy Mosque, which is frequently visited by people from various areas of the city. This explained by the absence of the neighborhood's mosques on one hand. On the other hand, the institutes of science, the commercial markets around, and the governmental institutions centers and departments were in this area. Therefore, the central region had a strong influence in the Holy City.

Figure 1: Satellite imagery for Makkah city 1966



Figure 2: Satellite imagery for Makkah city 2015



After 1955, following the Saudi's expansion of the Holy Mosque and the surrounding areas, urban development began to move towards the surrounding neighborhoods. Then the urban-expansion began to move towards the outskirts of the city, extending to Al-Zaher and Al-Nozha in the northwest and then to Al-Azizia in the southeast, exploiting the absence of mountains

and the opening of the area. This extension is produced along the arteries of the transport routes to the outside of the Holy City. The city grew steadily towards the sides. It extended to about 14 km on the Medina Road in the north and 8 km on the south side of Al-Layth road. On the west side, the urban-expansion covered the interstellar spaces in-between Al-Tandabawi and Hindawiah and extended westward to Al-Rusayfah. In the east, urbanization has entered the area of the Holy Sites (Mina, Muzdalifah, and Arafat).

If we try to describe the shape of the present city, the task could be very hard: it looks like a star with a central area surrounding by other areas of the former parties; these parties were densely populated and followed by radiological axes of buildings along the main external roads. This growth came because of the irregular topography that imposed itself on the growth of the city. The growth extended in the valleys and open areas, which attracted the roads network which are linking the city its environment. Then the open, radial, or angular shape replaced the circular shape that existed in the Holy City in the previous periods.

### **3.2 Demographic Data**

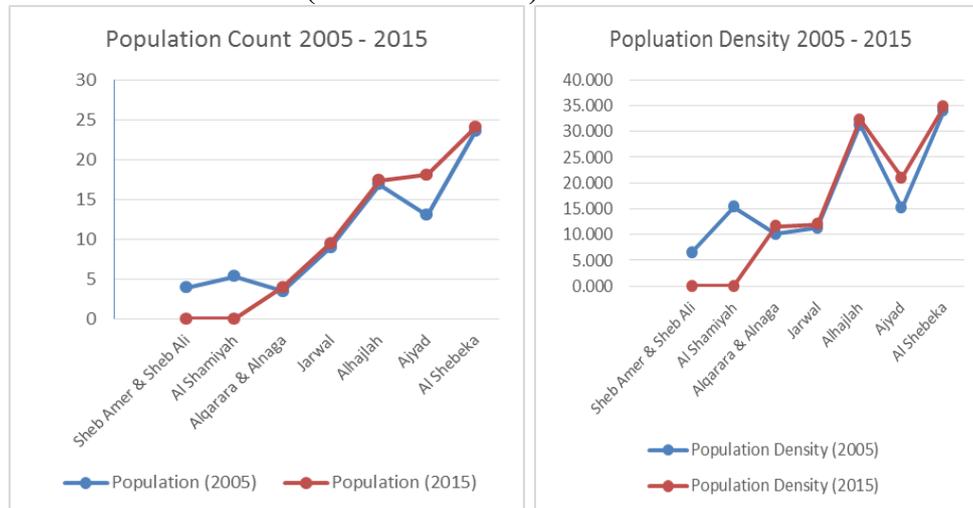
According to the latest effort to update Makkah structural plan, the population in Makkah in the year 2004 was around 1.375 million, spread over an urbanized area of close to 152 km<sup>2</sup>, and is expected to reach 2.9 million in the year 2029. The highest population density exists in the city center (about 6 km<sup>2</sup> within the Second Ring Road), while densities in the new modern residential areas in the central area was estimated at 128,000 in 2004 and expected to reach 621,000 in 2029 of which 183,000 would be permanent residents.

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**Table 1: Population count and population density for the surrounding districts 2005 – 2015. (Source: Author)**

District name	Area Km <sup>2</sup>	Population (2005)	Population (2015)	Population Density (2005)	Population Density (2015)
Sheb Amer & Sheb Ali	0.596932	3.889	0	6.515	0
Al Shamiyah	0.348464	5.344	0	15.336	0
Alqarara & Alnaga	0.341921	3.459	3.966	10.116	11.599
Jarwal	0.789913	8.948	9.455	11.328	11.970
Alhajlah	0.539478	16.882	17.389	31.293	32.233
Ajyad	0.861874	13.033	18.04	15.122	20.931
Al Shebeka	0.691989	23.503	24.01	33.964	34.697

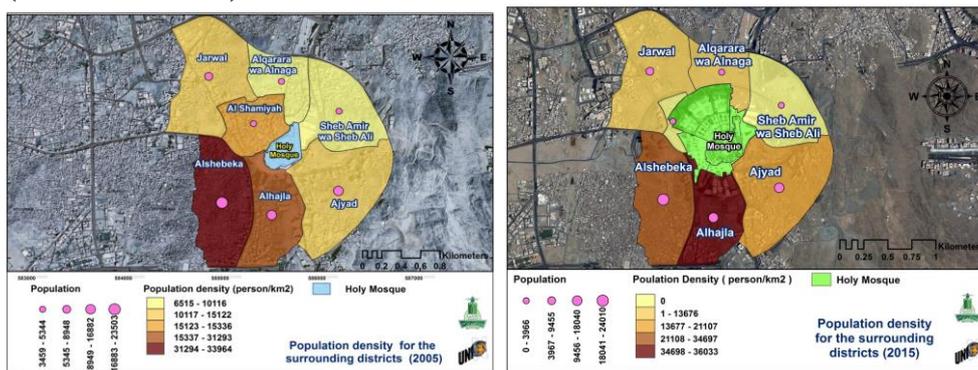
**Figure 3: Population count and population density for the surrounding districts 2005 – 2015. (Source: Author)**



People of the same ethnic origin tend to live together in quarters surrounding Al Haram area. Expatriates, who have the past played a significant role in the development of Makkah in the past periods, represent 27% of Makkah's population. But there is

an enormous fluctuation in the population size according to religious seasons. The peak is during the months of Du al-Hijjah (during which Hajj is performed) and Ramadan, when the city receiving more than 2 million worshipers from all over the Islamic world. In fact, in 2005, the number of Umrah visitors was about 2.78 million people, 38% of whom visited the Holy City during Ramadan and 21% during Sha'ban (the month preceding Ramadan). This number is projected to grow to nearly 3.28 million persons by the year 2019 and 4.2 million persons by the year 2029. In 2008, the total number of Hajj pilgrims from outside Makkah was 2.45 million, in addition to 0.5 million pilgrims who are permanent residents of Makkah. By the year 2030, the number of pilgrims is expected to grow up to 30 million including pilgrims for Hajj seasons and the visitors during Umrah seasons (Note that Hajj season is one month in a year while the Umrah season is opened for the whole year), excluding pilgrims from inside Makkah. Residence in Makkah is permitted only to followers of Islam. It is, however, a cosmopolitan city, hosting Muslims from many countries around the world [Source: *Center of Research Excellence in Hajj and Umrah, Umm Alqura University*].

**Figure 4: Population density for the surrounding districts 2005 – 2015.**  
(Source: Author)



### 3.3 The Expansion of The Holy Mosque and The Surrounding Areas:

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Terrain represents a major obstacle to the provision of large spaces to expand the Holy Mosque in Makkah and the surrounding areas from all directions. Wadi Ibrahim and its natural shape along with the rest of the surrounding hills and mountainous areas represent a combination of restrictions on the development of integrated and interconnected, especially in the central area.

There is also a slightly sloping land surrounding the Holy Mosque and the area around it, surrounded by mountainous areas and areas with many narrow side slopes and sharp points of convergence tight. There is no doubt that one of the main determinants of the currently movement flow plans during hajj season is the ability of the central area to support the smooth flow of the arrival and departure of pilgrims interested in performing Tawaf. Currently the Holy Mosque has a maximum capacity of (600,000) worshipers and a maximum capacity of (52,000) person/hour performing Tawaf. The areas surrounding the Holy Mosque have nearly a total of (100,000) square meters, with a maximum capacity of (200,000) worshipers. In addition to the roads connected to those areas surrounding the Holy Mosque of (250,000) square meter with a maximum capacity of (350,000) worshipers.

To solve the problem of pedestrian movement flow, it will be necessary to provide enough open spaces in the central area to support the arrival and departure of the pilgrims and worshipers to the Holy Mosque smoothly and safely. There is also a need to provide smart systems for crowd management to monitor the flow in and the flow out of the pedestrians, and to provide a better pedestrian movement pattern.

We must consider the importance of these movements to think about the main transportation tracks, and the future

improvements and development of other transportation means to assure the smoothness of pedestrian movement flow especially in the central area including the areas in between the Holy Sites (Mina, Muzdalifah, and Arafat) and the Holy Mosque. Due to the increasing number of pilgrims, Umrah pilgrims, and the worshipers who come to the Holy Mosque especially in the last ten days of Ramadan, and the 8th, 9th, 10th, 11th, 12th, 13th of Dhu al-Hijjah, the Holy Mosque and the surrounding areas must be upgraded to their maximum capacity to accommodate the increasing number of pilgrims and worshipers within a system which allows easy and smooth movements from and to the Holy Mosque.

In 2007 King Abdullah bin Abdulaziz ordered that a massive expansion of the Holy Mosque and the surrounding areas to be undertaken. The ongoing expansion covers the Holy Mosque and its surrounding areas starting in the northern side to enable it to accommodate about 2.5 million worshipers at the same time. In addition to erecting new buildings, King Abdullah's expansion includes the expansion of the external surrounding areas of the Holy Mosque as well as the passageways, the pedestrians' tunnels, and other facilities. Upon its completion in 2020, this expansion project will increase the area of the Holy Mosque to approximately (1000, 000) square meters.

As part of the latest expansion of the Holy Mosque, the entire districts around the Holy Mosque were developed on an unprecedented scale which makes the central area more accessible. Consequently, the government of Saudi Arabia afforded soaring prices to acquire the lands in these central districts, so that the people who lived in those districts could move to newly developed districts. As a result of this operation, the area that Makkah covers has dramatically expanded.

#### **4. Major Congestions areas during hajj seasons:**

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When pilgrims notice the intensity of the congestion at the entrance to Al-Rahma Street, they begin to search for alternative routes to reach the Holy Mosque, careless to their personal safety and the safety of other pilgrims, where they walk through a non-pedestrian route, creating several traffic jams. We have chosen several places to explain the congestions areas along the way to the Holy Mosque.

**4.1 Al Rahma Street:** The entrance of the pedestrian tunnel after the departure of the pilgrims directly from Al Jamarat facility towards the holy mosque Sep 10<sup>th</sup>, 2016.

**Figure 5: 2n aerial photograph of Al Rahma Street showing the pedestrians' congestion Sep 10<sup>th</sup> during 2016 Hajj Season. (Source: Makkah Municipality).**



**4.2 Hajj Street:** This street starts at the end of Al Jamarat facility, making it one of the most popular alternative routes for pilgrims when congestion takes place in the pedestrian tunnel at Al Rahma Street Sep 10<sup>th</sup>, 11<sup>th</sup>, 12<sup>th</sup>, 2016.

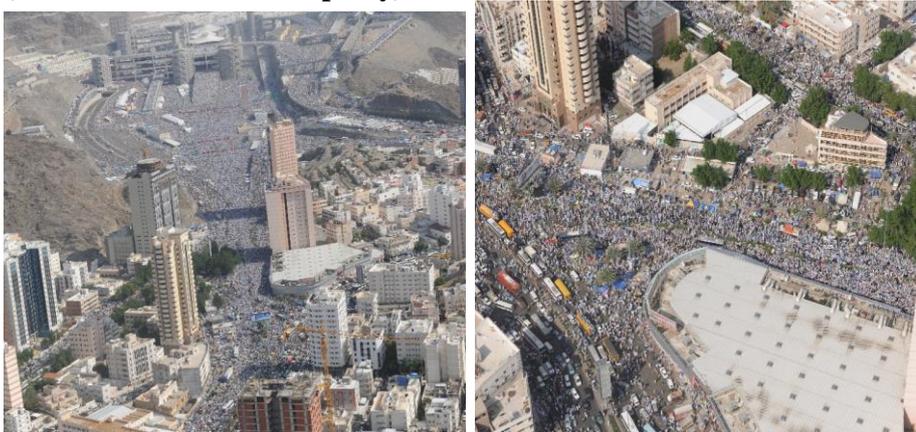
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**Figure 6: An aerial photograph shows the pedestrians' congestion at Hajj Street from different angles Sep 11<sup>th</sup>, during 2016 Hajj Season. (Source: Makkah Municipality).**



**4.3 Al Rowdah Square:** Located near Al Jamarat facility, considered one of the most used routes by pilgrims when the congestion takes a place at the pedestrian tunnel during pilgrims' movement towards the holy mosque. This creates traffic congestion affecting the surrounding neighborhoods such as Al-Ma'abdah neighborhood.

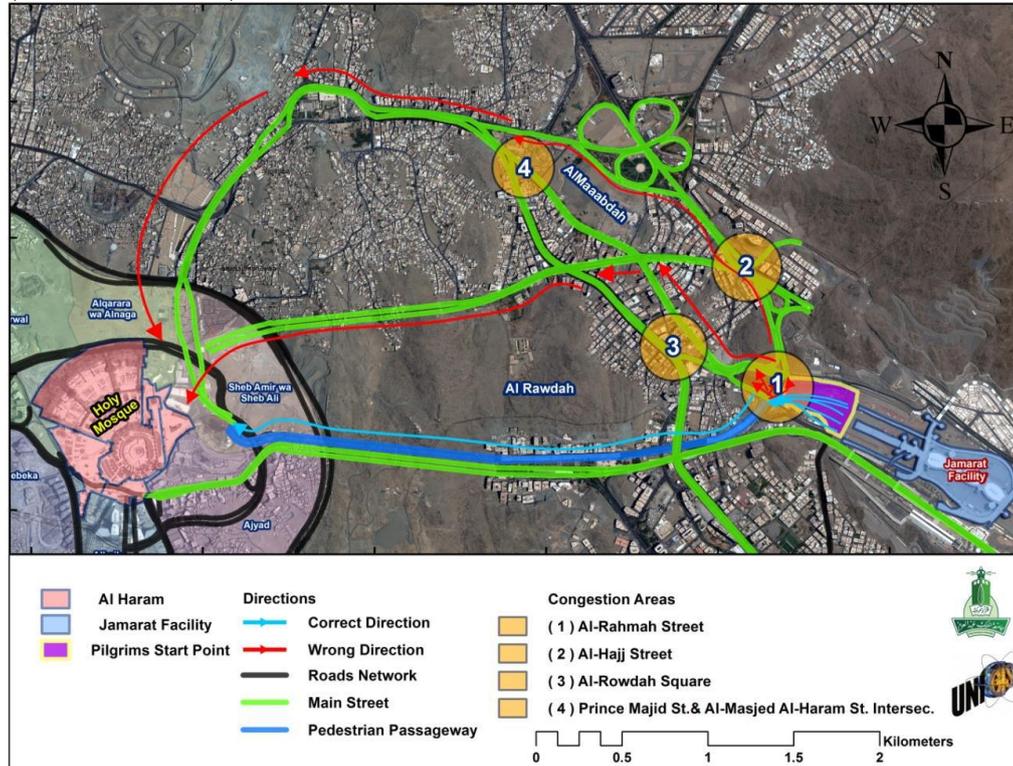
**Figure 7: An aerial photograph shows the pedestrians' congestion at Al Rowdah Square from different angles Sep 10<sup>th</sup>, during 2016 Hajj Season. (Source: Makkah Municipality).**



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Figure 8: Pilgrims' movement from Al Jamarat facility in Mina towards the Holy Mosque shows the major congestion areas.

(Source: Author).



## 5. Proposed solutions for the pedestrians' congestion during hajj seasons:

- Creating metro network, which links the holy mosque with the surrounding areas, as well as linking the holy sites (Muzdalifah, Mina, and Arafat), which helps to transport pilgrims and visitors. This network will be able to accommodate the huge numbers of pilgrims, which may reach 8 million pilgrims according to the 2030 vision. [1]([Source: Saudi Vision 2030](#)).
- Create a parallel road to (Al-Rahma Street), which run through Al-Rowdah Square to the Holy Mosque. This proposed road is important if we consider that pilgrims are

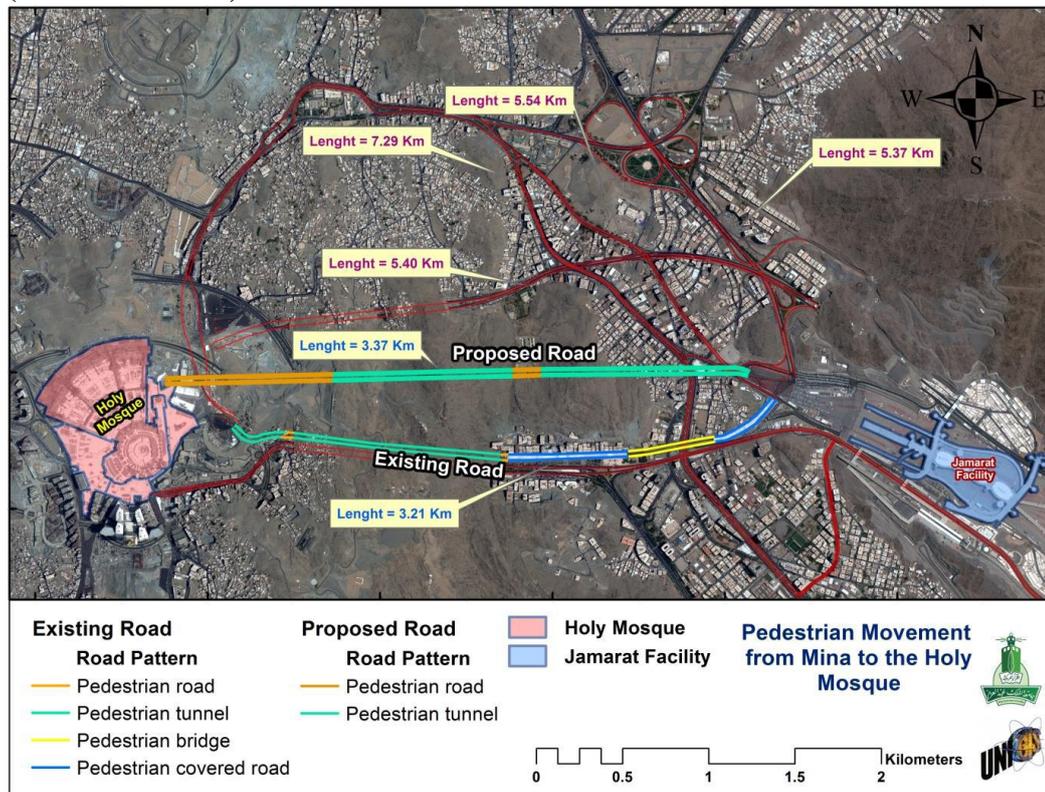
walking long distances from the Holy Sites (Muzdalifah, Mina, and Arafat) to the holy mosque, sometimes twice the distance of the proposed parallel road.

- Pedestrians' movement starts at the end of Al Jamarat facility, passing through Al Rowdah Square towards the Holy Mosque, the proposed parallel road is considered the optimal solution for the current situation for several reasons:
  - The safety of pilgrims and pedestrians, where the proposed route will reduce the congestion of pilgrims in the current road, which can cause many cases of stampede.
  - Shorter route, when congestion begins at the beginning of the current road, many pilgrims are forced to walk long distances to reach the Holy Mosque.
  - The use of non-pedestrian routes by pilgrims considered the main reason for the traffic jams that usually occur during the pilgrimage season.
  - This road will reduce the pressure on the proposed metro network of Makkah city, which is planned to be completed within the 2030 vision. [1]([Source: Saudi Vision 2030](#)).

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Figure 9: The proposed road to solve the pedestrians' congestion.

(Source: Author)



## 6. Crowd Control and Management:

### 6.1 Crowd Management Strategies:

The intricate orchestration of crowd dynamics during the annual Hajj pilgrimage presents a multifaceted and pivotal endeavor. This complexity arises from the convergence of an extensive multitude of pilgrims upon the sacred locales in Makkah. The efficacious administration of crowd dynamics holds paramount importance in safeguarding the security, overall welfare, and seamless engagement of these pilgrims. The task of crowd management in the context of the Hajj season necessitates a nuanced and comprehensive approach encompassing strategic coordination, meticulous planning, cutting-edge technological interventions, and unwavering vigilance. The primary objective

entails ensuring the physical security, emotional well-being, and spiritual enrichment of the entire pilgrim cohort, while concurrently mitigating the inherent perils associated with congregations of such vast proportions.

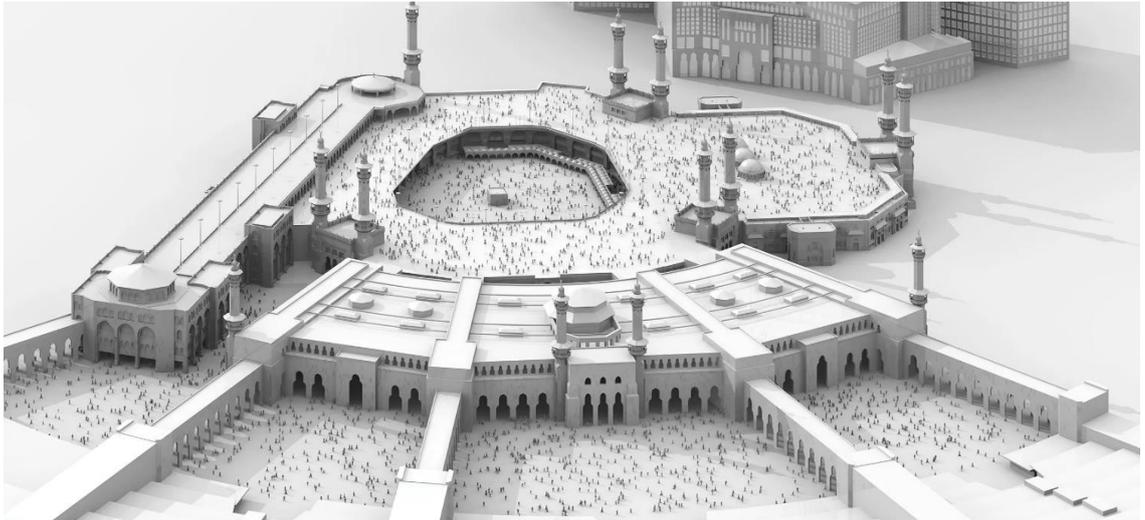
### **6.2 Human Masses Fragmentation:**

The concept of "Human Masses Fragmentation" refers to a strategy employed in the management of crowds at the holy Mosque in Makkah, Saudi Arabia, especially during the Hajj season. Given the immense number of pilgrims who visit the Grand Mosque, managing the movement of such large crowds is a complex challenge. The concept of Human Masses Fragmentation aims to break down these large crowds into smaller, more manageable groups or "fragments." This approach helps prevent overcrowding, congestion, and potential stampedes, which could pose serious safety risks to pilgrims and pedestrians.

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**Figure 10: Pedestrians tunnels from Alotaibiah side being developed to help the authorities employed the human masses fragmentation strategy. (Source: Makkah Municipality, Modified by: Author).**



### 7. Discussion

After conducting this study, the researcher found that there is a major reason that affects the decisions taken by pilgrims and pedestrians when choosing the optimal path to reach their destination. The narrowness of the roads and their inability to

absorb the huge numbers of pilgrims. Indeed, this situation implies wrong decisions made by pilgrims to reach their destination, creating traffic jams in several locations which makes the pilgrims' journey unsafe and inconvenient. The researcher suggests that more GIS studies for improving the pedestrians' walking environment to be conduct and expand our understanding of environmental characteristics affecting walking behavior.

### **8. Conclusion:**

Effective management of pilgrim transportation requires collaboration between government agencies, local authorities, transportation experts, and religious institutions. A multidisciplinary approach ensures the development of holistic solutions that consider cultural, social, and religious aspects. The annual Hajj and Umrah pilgrimages generate a unique challenge for transportation management in Makkah. Addressing this challenge requires a scientific approach that considers the distinct characteristics of pilgrimages, urban dynamics, crowd behavior, technology integration, sustainability, and collaborative governance. By adopting innovative transportation strategies, Makkah can enhance the pilgrimage experience, ensure safety, and preserve its status as a sacred destination while fostering harmonious coexistence with the city's residents.

### **9. Acknowledgment:**

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### **10. Refences:**

[1] Saudi Vision 2030, (2015). <http://vision2030.gov.sa/en> .