Urban Development of Bayn Al-Haramayn Zone Based on 25-Year Estimation of Al-Arbaeen Crowd Density

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Abstract. Karbala city is known to host one of the largest annual human gatherings in the world, where a diverse group of visitors congregates in the Karbala old city to participate in the Al-Arbaeen rites. This significant event peaked on Safar 19th, resulting in mobility issues, particularly in the Bayn Al-Haramayn zone. To address this concern, this study proposes a plan that estimates the number of visitors over the next 25 years and presents a solution for the vertical expansion of the zone while maintaining its urban fabric. The proposal includes estimating the areas required to accommodate the visitors based on an average crowd density of 3.5 individuals per square meter. The authors predict that the number of pilgrims will continue to increase over the next 25 years, and by 2046, an area of 148 square kilometers will be necessary to accommodate them. Expanding the Bayn Al-Haramayn zone is crucial as it is a vital destination for many visitors, and its spiritual significance adds value to the experience of performing the Ziyarat-Alarbaeen rituals. The proposed solution focuses on vertical expansion, providing a total area of 10,116 m^2 and can accommodate up to 35,500 capita. Moreover, the proposed solution also integrates mobility paths that align with the urban scene of the area.

Keywords: Urban planning; statistical forecasting; Crowd density; Ziyarat-Alarbaeen; Karbala.

1. INTRODUCTION

Crowds are a feature of cities that receive important events, where many people gather at a particular event location, such as historical ceremonials, pilgrimage seasons, religious rituals, etc. One massive, crowded, and distinctive event is the Al-arbaeen rite held annually in Karbala, Iraq. Karbala is of great importance in receiving large crowds during religious rituals, leading to overcrowding of the area to an all-year high. This is due to the uniqueness of its urban center, which is the presence of the tombs of Imam Hussein and his brother Abbas (peace be upon them) [1]. Therefore, it is necessary to shed light on this mass gathering by examining and predicting areas to be occupied by the Visitors as well as setting forth a design proposal for the transportation of Visitors to and from Karbala.

Seldom have previous studies investigated the crowd during Arbaeen in terms of crowd modeling, smart scheduling, statistical estimation, occupied areas, crowd density, and so forth. On the other hand, which is of interest to this study, studies have focused on various topics from another perspective: Merie and Farhan [2] reevaluated the relationship between architecture and social-cultural traditions, particularly in the old center of Karbala city surrounding the two holy Shrines. The city's core consists of mosques and shrines occupying over a square kilometer within the Al-Muheet Road ring. Unlike other Islamic cities, the shrines represent the heart of Karbala, making it distinct. Despite its religious significance, Karbala has maintained its social-cultural and heritage identity, partly due to the surrounding green areas and its ability to attract millions of Muslim pilgrims annually. According to Nikjoo et al. [3], Iraq hosts one of the world's largest annual pilgrimages, which approximately 20 million Shia Muslims attend. Many pilgrims commence their spiritual journey on foot from various locations, mainly Najaf and Basra, to reach Karbala for the Arbaeen commemoration. The study revealed that pilgrims arrive at Karbala at different times, and not all of them stay until the day of Arbaeen. This suggests a need for further investigation into the peak crowd and its occurrence day. Moufahim and Lichrou [4] stated that UNWTO estimates indicate that approximately 600 million religious trips are taken annually worldwide, with around 300-330 million tourists visiting major religious sites.

Arbaeen is the biggest annual pilgrimage in the world, and Karbala hosts millions of domestic and foreign pilgrims who generate high demand for services such as housing and transportation. Therefore, managing the safety and comfort of pilgrims is crucial and cannot be ignored. This makes Karbala an excellent context for studying pilgrimage crowds. Sharma [5] reviewed advancements in crowd management technology, including crowd modeling, data collection and analysis, and crowd control measures. Managing crowds requires collaboration across various fields of engineering and science, and ineffective management can result in fatalities. It is an interdisciplinary field that requires an understanding of engineering and technological factors and psychological and sociological factors affecting crowd behavior and flow. Planning public infrastructure in areas with expected heavy crowding should also consider crowd management. Karbovskii et al. [6] proposed a new method to predict short-term crowd flow and highlighted the safety risks associated with large-scale mass gatherings. Recent history has witnessed serious incidents such as the Hajj crush in Mecca, Saudi

Arabia (2006 and 2015), the Love Parade disaster in Duisburg, Germany (2010), and the Kumbh Mela stampede in Allahabad, India (2013). Safety assurance at such events relies heavily on crowd control and understanding the crowd's behavior. A fundamental challenge in comprehending crowd dynamics is the ability to forecast crowd flows based on past/present flows at a particular location.

Alghamdi et al. [7] addressed the need for practical smart modeling solutions based on IoT to manage crowding effectively during religious gatherings, such as the Hajj, where proximity of pilgrims during prayer, tawaf, and hotel stays can lead to the spread of infections and diseases. Altering crowd flow and smart scheduling can reduce the spread of contagious diseases and prevent stress and injuries resulting from collisions between pilgrims, particularly affecting older travelers and female pilgrims. Gayathri, Aparna, and Verma [8] conducted various studies to understand and simulate individual and collective pedestrian behavior in various situations, which can enhance safety during crowd events. However, pedestrian behavior in public spaces during everyday situations differs significantly from behavior during mass gatherings. A mass gathering is an event where more people than a predetermined number gather at a predetermined location for a predetermined reason for a predetermined period. Mass gathering events have the potential to cause severe disasters due to a combination of densely populated areas, physical barriers preventing access, inadequate crowd control, and incomplete information about the surroundings and activities, particularly during communicable disease alerts and responses.

Notwithstanding, the previous studies did not estimate the number of pilgrims and required areas for the upcoming 25 years in the city of Karbala, particularly for the Arbaeen crowds. This research aims to collect and analyze previous data, forecast the number of pilgrims, and determine the relation between pilgrims and required areas to propose a forward-looking plan.

2. PROBLEM DEFINITION

The Arbaeen pilgrimage, observed annually from the 1st until the 20th of Safar, experiences the highest crowd density on the 20th of Safar due to the Ziyarat-Alarbaeen rituals. This leads to congestion around the holy shrines and their surroundings, resulting in hindrances to pilgrim movement. As depicted in Figure 1, the increasing number of visitors necessitates the provision of adequate space to avoid overcrowding and ensure a conducive atmosphere for the performance of the Ziyarat-Alarbaeen with utmost spiritual significance.

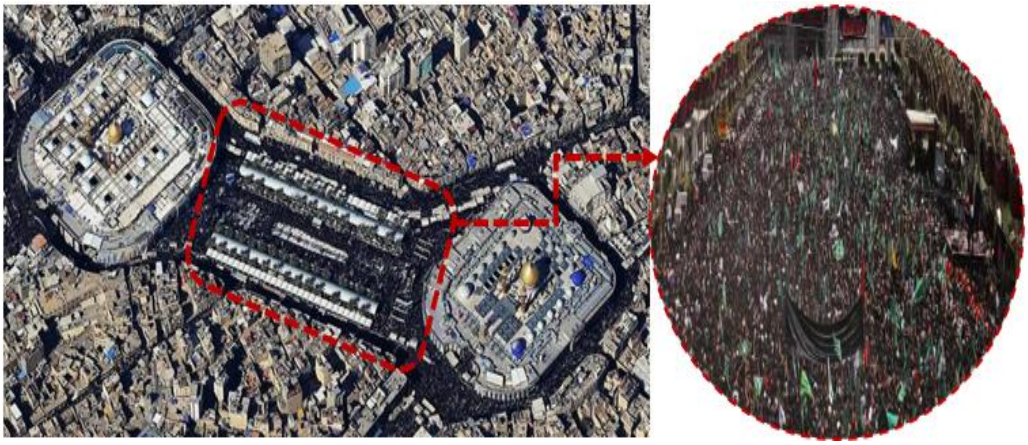


Figure 1: An elevated view of the crowd at the holy shrines and Bayn Al-Haramayn zone.

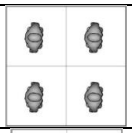
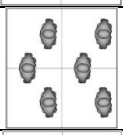
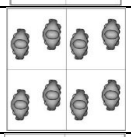
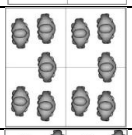
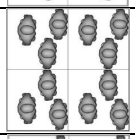
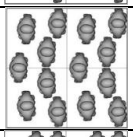
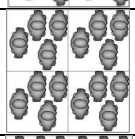
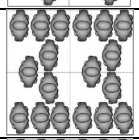
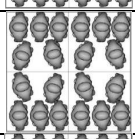
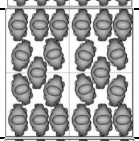
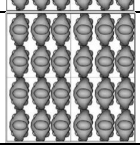
3. METHODOLOGY

3.1 Approach Method

This study aims to estimate the number of pilgrims expected to attend the Arbaeen pilgrimage over the next 25 years, along with the required space to accommodate them. The crowd density method has been chosen to achieve this due to its relevance and accuracy in simulating the case study. This method calculates the number of people per square meter and determines the maximum number of pilgrims occupying a single square meter before the area becomes congested.

Using the crowd density method, the standard dimensions of a standing human projection were measured as 50cm by 30cm in a horizontal plane [9]. This allows the estimation of the maximum number of people that can occupy a single square meter and, in turn, determines allowable crowd densities, as presented in Table 1.

Table 1: Expected values of crowd densities [10] (modified).

Graphic Density	No. of Capita/m²	Level	Remarks
	1	Free movement	Each individual has a space of 1m, free movement
	1.5	Free movement	Space available for each individual is about 0.5 to 1m, free movement
	2	Channels movement	Space between individuals is less than 0.5 m, and channels forming
	2.5	Channels movement	Space between individuals is less than 0.4 m, and channels forming
	3	Channels movement	Space between individuals is less than 0.3 m, and channels forming
	3.5	Moderate movement	Space between individuals is less than 0.25 m, channels-based movement
	4	Moderate movement	Pushing others aside to move through crowd
	4.5	Moderate movement	Difficulty in movement through the crowd - s low movement case
	5	Slow movement	Highly difficult to move through crowd - inco nsiderable movement case
	5.5	Slow movement	Mass formation movement
	6	Restricted movement	No ability to move - instability state (rapid in voluntary surging)

It is important to note that, in any circumstance, no more than six pilgrims can occupy a single square meter, regardless of the difficulties that may arise in movement. This reveals that the maximum crowd density allowable is six individuals per square meter. However, to ensure ample space for the pilgrims without

compromising their movement, it is practically advisable to use the average crowd density of 3.5 individuals per square meter employed in this study to estimate the necessary area.

3.2 Crowd Volume Estimate

Following the implementation of electronic monitoring and counting systems in five axes by the Al-Abbas Holy Shrine, the number of pilgrims attending the Arbaeen pilgrimage has become readily available. It is officially announced on an annual basis. This information was first released in 1438 AH (2016 AD), and it is important to note that the statistics only include visitors present from the 10th to mid-noon of the 20th of Safar each year. For instance, Table 2 displays the number of visitors recorded during the designated period in 1444 AH.

Table 2: Statistics for the number of Visitors in 1444 AH (2022 AD).

Hijri Date	Gregorian Date	No. of Pilgrims	Remarks
10 Safar 1444	07 September 2022	318,665	
11 Safar 1444	08 September 2022	562,982	
12 Safar 1444	09 September 2022	966,449	
13 Safar 1444	10 September 2022	1,142,078	
14 Safar 1444	11 September 2022	1,951,844	
15 Safar 1444	12 September 2022	2,139,449	
16 Safar 1444	13 September 2022	2,750,252	
17 Safar 1444	14 September 2022	2,824,214	
18 Safar 1444	15 September 2022	2,942,787	
19 Safar 1444	16 September 2022	4,404,807	Peak value
20 Safar 1444	17 September 2022	1,195,113	
Total no. of Pilgrims		**21,198,640**	

It is worth noting that the largest number of pilgrims, accounting for approximately 21% of the total, visit Karbala on the 19th of Safar to observe the night and day of Arbaeen. Moreover, the number of visitors has been recorded in previous years and compiled in Table 3 to estimate the number of visitors over the upcoming 25 years. Applying the forecasting technique in MS Excel, with a confidence interval of 95%, yielded accurate predictions for the number of Visitors, enabling the determination of the peak crowd density on the day of Arbaeen, as presented in Table 4. Furthermore, as depicted in Figure 2, the crowd volume progressively escalates over time, indicating the necessity of sufficient area to accommodate the growing number of pilgrims in the future.

Table 3: Enumeration of Visitors for the last six years.

Hijri Date	Gregorian Date	Total no. of Pilgrims	Peak Value on 19th of Safar
1438	2016	11,210,367	2,329,371
1439	2017	13,874,818	2,883,010
1440	2018	15,322,949	3,183,913
1441	2019	15,229,955	3,164,590
1442	2020	14,553,308	3,023,992
1443	2021	16,327,542	3,392,655
1444	2022	21,198,640	4,404,807

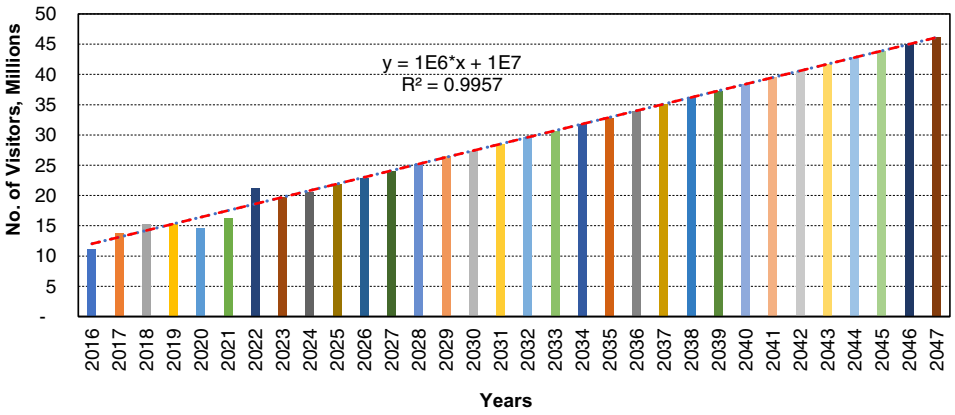


Figure 2: Crowd volume announced and estimated.

Table 4: Estimation of Visitors enumeration over the upcoming 25 years.

Hijri Date	Gregorian Date	Total no. of Pilgrims	Peak Value on 19th of Safar	Remarks
1445	2023	19,757,277	4,105,310	Peak value estimated based on 21% of the total no. of Pilgrims.
1446	2024	20,649,613	4,290,726	
1447	2025	21,830,395	4,536,078	
1448	2026	22,919,878	4,762,458	
1449	2027	24,044,971	4,996,238	
1450	2028	25,170,065	5,230,018	
1451	2029	26,503,831	5,507,158	
1452	2030	27,388,608	5,691,003	
1453	2031	28,484,478	5,918,711	
1454	2032	29,581,936	6,146,749	
1455	2033	30,680,723	6,375,063	
1456	2034	31,780,621	6,603,608	
1457	2035	32,881,452	6,832,346	
1458	2036	33,983,070	7,061,248	
1459	2037	35,085,354	7,290,289	
1460	2038	36,188,208	7,519,448	
1461	2039	37,291,552	7,748,709	
1462	2040	38,395,321	7,978,058	
1463	2041	39,499,462	8,207,484	
1464	2042	40,603,931	8,436,979	
1465	2043	41,708,693	8,666,534	
1466	2044	42,813,718	8,896,145	
1467	2045	43,918,980	9,125,804	
1468	2046	45,024,459	9,355,508	
1469	2047	46,130,137	9,585,254	

4. AREA CAPACITY ESTIMATE

The Visitors' destination is consistently the old city, which is approximately 1,000,000 m^2 [2] and offers numerous spaces for Visitors. However, it is rare to find an area vacant while performing worship rituals due to the significance of the urban center, where the holy shrines are located, as well as the area's urban and historical values. The areas can be classified into two categories based on crowd density: extremely congested areas, such as the Bayn Al-Haramayn zone [11] and the holy shrines themselves, and moderately crowded areas, such as other adjacent zones that include public facilities. Moreover, under-construction areas are expected to contribute to reducing the crowd density in the future, as illustrated in Figure 3.

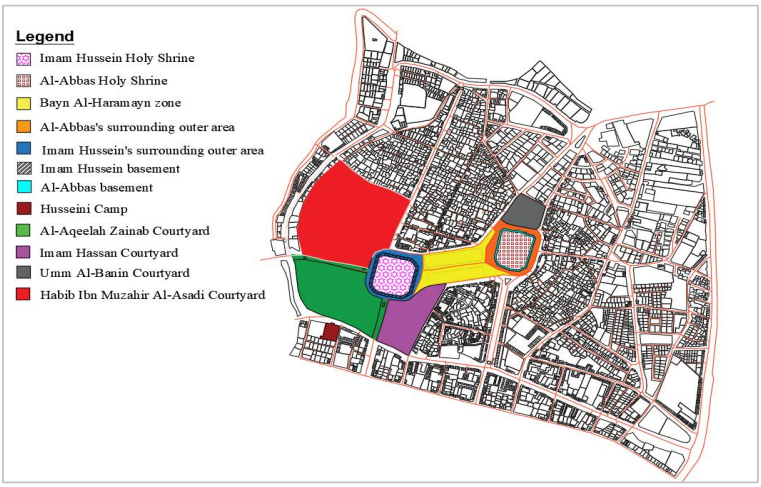


Figure 3: Areas specified for Visitors in Karbala old city.

The current areas occupied by visitors comprise multi-story buildings, public lands, and multipurpose lands and are estimated to cover about 1,056,793 m^2. Moreover, expansion areas are currently being constructed for horizontal and vertical urban expansion, amounting to approximately 231,411 m^2. The combination of these existing and expanding areas results in a total estimated area of approximately 1,288,204 m^2, as detailed in Table 5. These data underscore the magnitude of development and growth in the region, reflecting the continuous transformations in urban landscapes and the escalating need for space in these areas.

Table 5: Area details and information collected from Imam Hussein and Al-Abbas holy shrines.

Region	Total area (m^2)	Area for Pilgrims (m^2)	Remarks
Imam Hussein's holy shrine	15,000	6,000	Existing areas
Al-Abbas holy shrine	10,973	6,483	
Bayn Al-Haramayn zone	23,722	23,722	
Al-Abbas's surrounding outer area [1]	11,304	11,304	
Imam Hussein's surrounding outer area [1]	10,681	10,681	
Imam Hussein basement [2]	4,000	4,000	
Alhayir Al-Husseini [3]	24,000	24,000	
Al-Abbas basement [4]	1,728	1,728	
Husseini camp	5,000	5,000	
Public and multipurpose lands [5]	385,000	385,000	
Hotels	771,833	578,875	
Total	**1,263,241**	**1,056,793**	
Al-Aqeelah Zainab Courtyard [6]	208,000	156,000	Under-construction areas or to be constructed
Imam Hassan Courtyard [7]	22,000	16,500	
Umm Al-Banin Courtyard	20,000	20,000	
Habib Ibn Muzahir Al-Asadi Courtyard [8]	77,821	38,911	
Total	**327,821**	**231,411**	-
Grand total	**1,591,062**	**1,288,204**	-

[1]The boundaries of the shrine, associated with Bayn Al-Haramayn zone.
[2]Total area of 4 basements, namely, Qibla, Hujjah, Al-Shuhadaa, and Al-Raes Al-Sharif.
[3]Total area of 4 floors mostly specified for Visitors.
[4]Total area of 2 basements, namely, Imam Muhammad Al-Jawad and Imam Hussein.
[5]38.5% of the old city area (1,2).
[6]Total area of 4 floors, 75% of which is dedicated to Visitors.
[7]Area allocated to Visitors is 75% of the total area.
[8]Area allocated to Visitors is 50% of the total area.

5. DISCUSSION AND CONCLUSIONS

As the number of Pilgrims is consistently increasing annually, providing more spaces is in high demand to assist in accommodating Visitors. It can also be pointed out that the state of the crowd density, as explained in Table 6, tends to shift from the level of moderate movement to the level of restricted movement due to the increasing numbers of Visitors as well as the insufficient existing areas.

Table 6: Crowd density estimation over the upcoming 25 years.

Hijri Date	Gregorian Date	Peak Value (Capita)	Existing Area (m^2)	Crowd Density (Capita/m^2)	Remarks
1445	2023	4,105,310	1,056,793	3.9	Existing area
1446	2024	4,290,726	1,056,793	4.1	
1447	2025	4,536,078	1,212,793	3.7	Expected completion of Al-Aqeelah Zainab Courtyard
1448	2026	4,762,458	1,212,793	3.9	
1449	2027	4,996,238	1,212,793	4.1	
1450	2028	5,230,018	1,232,793	4.2	Expected completion of Umm Al-Banin Courtyard
1451	2029	5,507,158	1,288,204	4.3	Expected completion of both Imam Hassan & Habib Ibn Muzahir Al-Asadi Courtyards
1452	2030	5,691,003	1,288,204	4.4	
1453	2031	5,918,711	1,288,204	4.6	
1454	2032	6,146,749	1,288,204	4.8	
1455	2033	6,375,063	1,288,204	4.9	
1456	2034	6,603,608	1,288,204	5.1	
1457	2035	6,832,346	1,288,204	5.3	
1458	2036	7,061,248	1,288,204	5.5	
1459	2037	7,290,289	1,288,204	5.7	
1460	2038	7,519,448	1,288,204	5.8	
1461	2039	7,748,709	1,288,204	6.0	
1462	2040	7,978,058	1,288,204	6.2	
1463	2041	8,207,484	1,288,204	6.4	
1464	2042	8,436,979	1,288,204	6.5	
1465	2043	8,666,534	1,288,204	6.7	
1466	2044	8,896,145	1,288,204	6.9	
1467	2045	9,125,804	1,288,204	7.1	
1468	2046	9,355,508	1,288,204	7.3	
1469	2047	9,585,254	1,288,204	7.4	

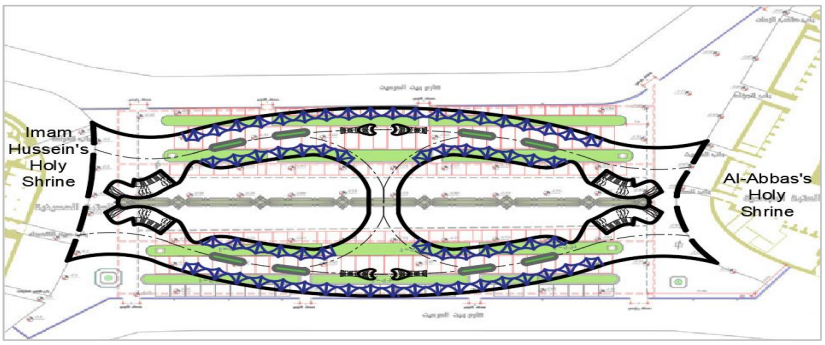
Despite the planned expansion space that is expected to be operational by 2025, it will not be sufficient to facilitate a moderate level of movement. Consequently, the high density of visitors causes significant overcrowding, resulting in difficulties in accessing the holy shrines during the Ziyarat-Alarbaeen. Based on the adopted average crowd density of 3.5 capita/m^2 in this study, Table 7 presents the additional area required to alleviate the congestion in the existing area. The expansion should be carried out vertically to preserve the urban fabric of Karbala's old city as an utmost priority factor, in line with the requirements of pilgrims without indiscriminate transformation, which greatly impacts the traditional urban fabric. One of the urgent areas for redevelopment is called Bayn Al-Haramayn zone for its special significance as it is the destination for many Visitors, where the Ziyarat-Alarbaeen is performed. This study proposes to vertically develop the Bayn Al-Haramayn zone so that the expansion does not affect the city's shape, as illustrated in Figure 4.

The concept for the design was inspired by a saying of the Prophet, in which Imam Hussein is likened to a ship of salvation. As a result, the proposal was to create a structure resembling a ship, seemingly floating between the two holy shrines, serving as a conduit for pilgrims from one sacred site to another. This design concept also captures the spiritual essence of the place, evoking a sense of reverence and awe in its vastness. From an urban design perspective, the ship-like structure, with its expansive space, harmoniously integrates with the surrounding landscape, preserving the visual integrity of the area and mitigating visual pollution. This approach prioritizes the preservation of the unobstructed view towards the golden domes, maintaining the paramount visual pathway while enhancing the overall aesthetics of the urban environment. The design was created using SketchUp software, with dimensions providing a total area of 10,116 m^2. This area is intended to accommodate approximately 35,500 capita, based on a crowd density of 3.5 capita/m^2. The primary materials used in construction include reinforced concrete, bricks, marble, Islamic mosaic tiles …etc.

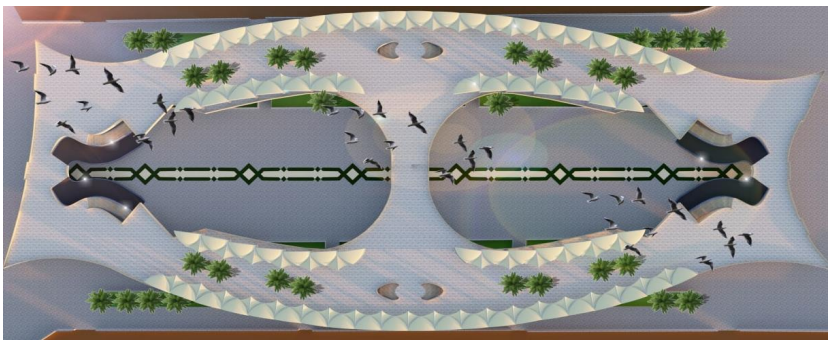
Table 7: Estimating the required areas based on the average crowd density over the next 25 years.

Hijri Date	Gregorian Date	Peak Value (Capita)	Existing Area (m^2)	Total Area(*) (m^2)	Area required (m^2)
1445	2023	4,105,310	1,056,793	1,172,946	116,153
1446	2024	4,290,726	1,056,793	1,225,922	169,129
1447	2025	4,536,078	1,212,793	1,296,022	83,229
1448	2026	4,762,458	1,212,793	1,360,702	147,909
1449	2027	4,996,238	1,212,793	1,427,497	214,704
1450	2028	5,230,018	1,232,793	1,494,291	261,498
1451	2029	5,507,158	1,288,204	1,573,474	285,270
1452	2030	5,691,003	1,288,204	1,626,001	337,797
1453	2031	5,918,711	1,288,204	1,691,060	402,856
1454	2032	6,146,749	1,288,204	1,756,214	468,010
1455	2033	6,375,063	1,288,204	1,821,447	533,243
1456	2034	6,603,608	1,288,204	1,886,745	598,541
1457	2035	6,832,346	1,288,204	1,952,099	663,895
1458	2036	7,061,248	1,288,204	2,017,499	729,295
1459	2037	7,290,289	1,288,204	2,082,940	794,736
1460	2038	7,519,448	1,288,204	2,148,414	860,210
1461	2039	7,748,709	1,288,204	2,213,917	925,713
1462	2040	7,978,058	1,288,204	2,279,445	991,241
1463	2041	8,207,484	1,288,204	2,344,995	1,056,791
1464	2042	8,436,979	1,288,204	2,410,565	1,122,361
1465	2043	8,666,534	1,288,204	2,476,153	1,187,949
1466	2044	8,896,145	1,288,204	2,541,756	1,253,552
1467	2045	9,125,804	1,288,204	2,607,373	1,319,169
1468	2046	9,355,508	1,288,204	2,673,002	1,384,798
1469	2047	9,585,254	1,288,204	2,738,644	1,450,440

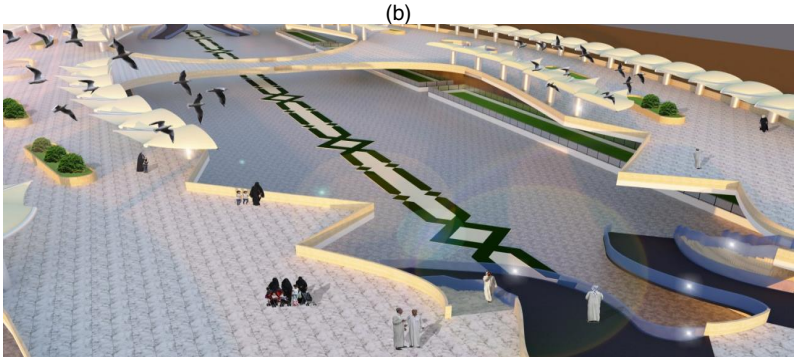
*Calculated based on a crowd density of 3.5 capita/m^2.



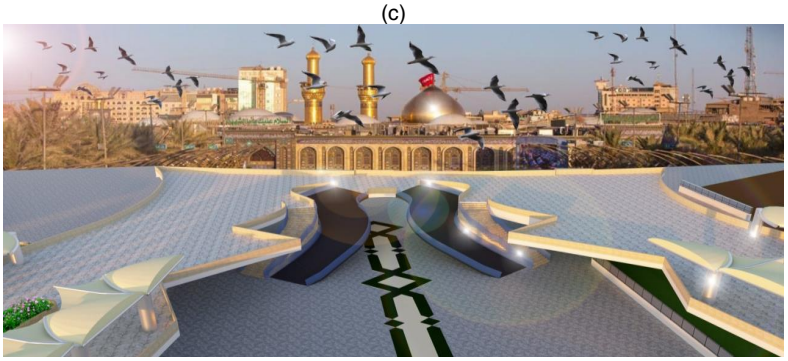
(a)



(b)



(c)



(d)

Figure 4: Proposal for expanding Bayn Al-Haramayn zone: (a) Site plan, (b) Top view, (c) Close-up view, (d) Elevated view.

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