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The Architectural Image of Crowds in Traditional Religious Spaces: A Visual-Digital Analysis of The Space Between the Two Holy Shrines in Karbala During the Arbabeen Pilgrimage

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Abstract

This study examines the visual-architectural dimension of crowd management in densely populated traditional religious spaces, through an analysis of the evolving spatial landscape of the area between the two holy shrines in Karbala during the Arba'een pilgrimage. The research's significance stems from the growing trend towards employing digital modeling and visual representation as analytical tools that not only measure movement but also contribute to reshaping spatial perception and organizing the relationship between the body, space, and religious symbolism.The study adopted an analytical-representational approach combining architectural image analysis, digital crowd simulation, and strategic evaluation to explore how spatial interventions impact the overall visual landscape of the space. Three-dimensional digital models were constructed to simulate the dynamics of human movement, and three design-organization scenarios were tested: widening passageways and redistributing stopping points; introducing shading elements and urban furniture as visual-behavioral stimuli; and organizing one-way movement to reset the spatial rhythm of flow.The results showed that the visual representation of crowds not only reflects levels of density and movement but also reveals a transformation in the image of the space from a compressed environment to a more visually readable and perceptually comprehensible landscape. The organization of directions contributed to reducing the visual clutter of the crowds, while shading elements and urban furnishings enhanced the clarity of visual landmarks and the duration of pauses at symbolic points, thus reinforcing the spiritual dimension of the space. The study also demonstrated that integrating multiple scenarios allows for the production of a balanced architectural image that combines fluidity, security, and the preservation of heritage identity.The originality of this research lies in presenting a visual-analytical framework that links digital modeling, crowd studies, and architectural image analysis as a unified system for understanding and re-representing traditional religious spaces. The results demonstrate the generalizability of this framework to similar sites, thus strengthening the role of the architectural image as an effective cognitive tool in studies of architecture, the city, and collective rituals.

Keywords: *Traditional Religious Spaces: A Visual-Digital Analysis ,The Two Holy Shrines , Karbala, The Arba'een Pilgrimage.*

Introduction

The Arbaeen pilgrimage in the holy city of Karbala is one of the largest annual human gatherings in the world, attracting millions of visitors to a religious-spiritual event that embodies the values of sacrifice and justice associated with the commemoration of the martyrdom of Imam Hussein[1]. The space between the two holy shrines which connects the holy shrines of Imam Hussein and his brother Abbas is the beating heart of this occasion[2], representing the central axis for the flow of traffic and visitor activities of a religious, social, and economic nature[3].

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The importance of this urban space stems from its being more than just an urban square; it holds universal symbolic and spiritual value[4]. However, this richness is coupled with exacerbated urban challenges during the pilgrimage season, including managing dense crowds, ensuring public safety[5], enhancing the quality of the spatial experience, and preserving the heritage identity of the historic urban fabric[6].

These complex challenges necessitate a multidisciplinary research approach that integrates spatial analysis, digital modeling, and strategic planning to develop sustainable design and management solutions[7]. Despite the immense symbolic and spiritual significance of the space between the two holy mosques, field studies reveal shortcomings in the integration of traditional planning tools with modern digital means[8]. This leads to severe congestion that reduces the flow of movement and the quality of the spiritual experience. A knowledge gap emerges here, represented by the absence of an integrated methodological framework that combines quantitative spatial analysis, digital modeling, and strategic evaluation using tools such as SWOT analysis to assess the effectiveness and feasibility of proposed interventions.

This research aims to bridge this gap by developing an integrated applied framework for crowd management in high-density heritage-religious environments. This framework analyzes spatial characteristics, tests intervention scenarios using digital modeling and computer simulation, and evaluates their effectiveness using strategic planning tools. Thus, the research provides a knowledge-based and practical contribution that supports decision-makers and planners in formulating more effective and sustainable urban strategies for crowd management at major religious events, while preserving the heritage and symbolic values of the site.

Materials and Methods

Research Design

This study adopted a descriptive-analytical approach supported by a quasi-experimental approach, in line with the nature of the research, which aims to test and evaluate a set of design and administrative interventions for crowd management in a high-density religious-heritage environment such as the space between the two holy mosques. The descriptive-analytical approach provided a precise description of the existing reality and an analysis of the morphological and behavioral problems associated with human crowds. Meanwhile, the quasi-experimental approach enabled the simulation of the proposed interventions on a limited scale and linked them to digital modeling prior to field implementation. The study relied on combining quantitative data, such as crowd statistics, travel time, and flow rates, with qualitative data, such as semi-structured interviews and SWOT analysis, contributing to the development of an integrated decision-making framework that supports scientific and practical evaluation. The main research paths began with collecting quantitative field data before and after the interventions using tracking and video analysis techniques, followed by building a digital simulation model using MassMotion and AnyLogic software, and finally employing SWOT analysis to evaluate alternatives from an integrated strategic and urban perspective.

Study Area

The study area is located in the heart of the historic center of the holy city of Karbala, specifically in the corridor extending between the two holy shrines of Imam Hussein and Abu al-Fadl al-Abbas , a space technically known as "between the two holy[9] shrines." The area covers an area of approximately 40,000 square meters and includes the central square and the axes leading to it[10]. This space is the primary focal point for crowds during the Arbaeen pilgrimage, witnessing the highest rates of human flow throughout the day[11].

The surrounding urban fabric is characterized by a traditional, crowded character, with adjacent buildings, commercial facades, and open squares that attract religious, service, and commercial activities[12][13]. This urban and functional overlap creates complex crowd management challenges, represented by the need to reconcile the preservation of the site's heritage-spiritual identity with ensuring the safety and smooth flow of visitors[14].

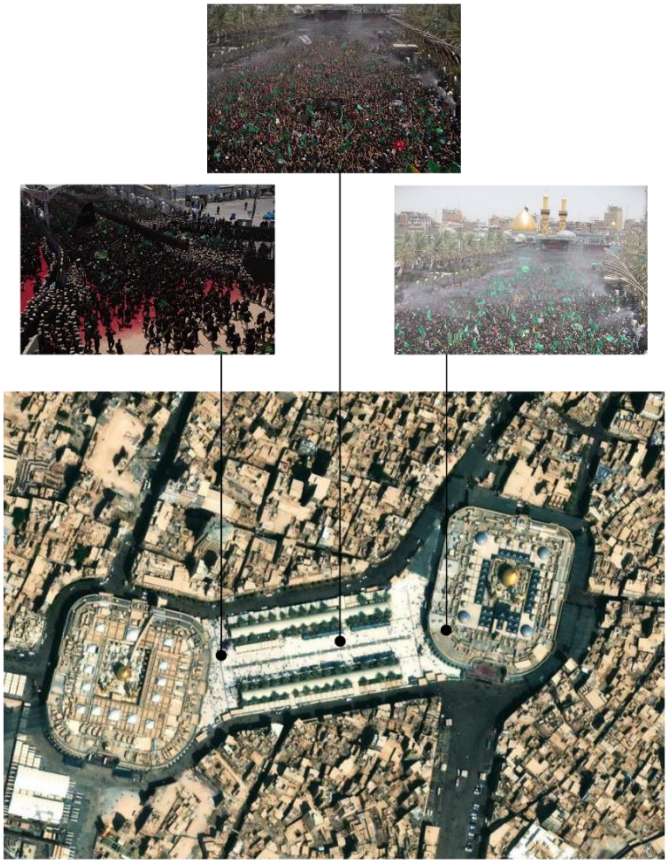

Figure (1): Aerial Photograph of the Study Area Between the Two Holy Shrines in Karbala and the Crowds of Visitors

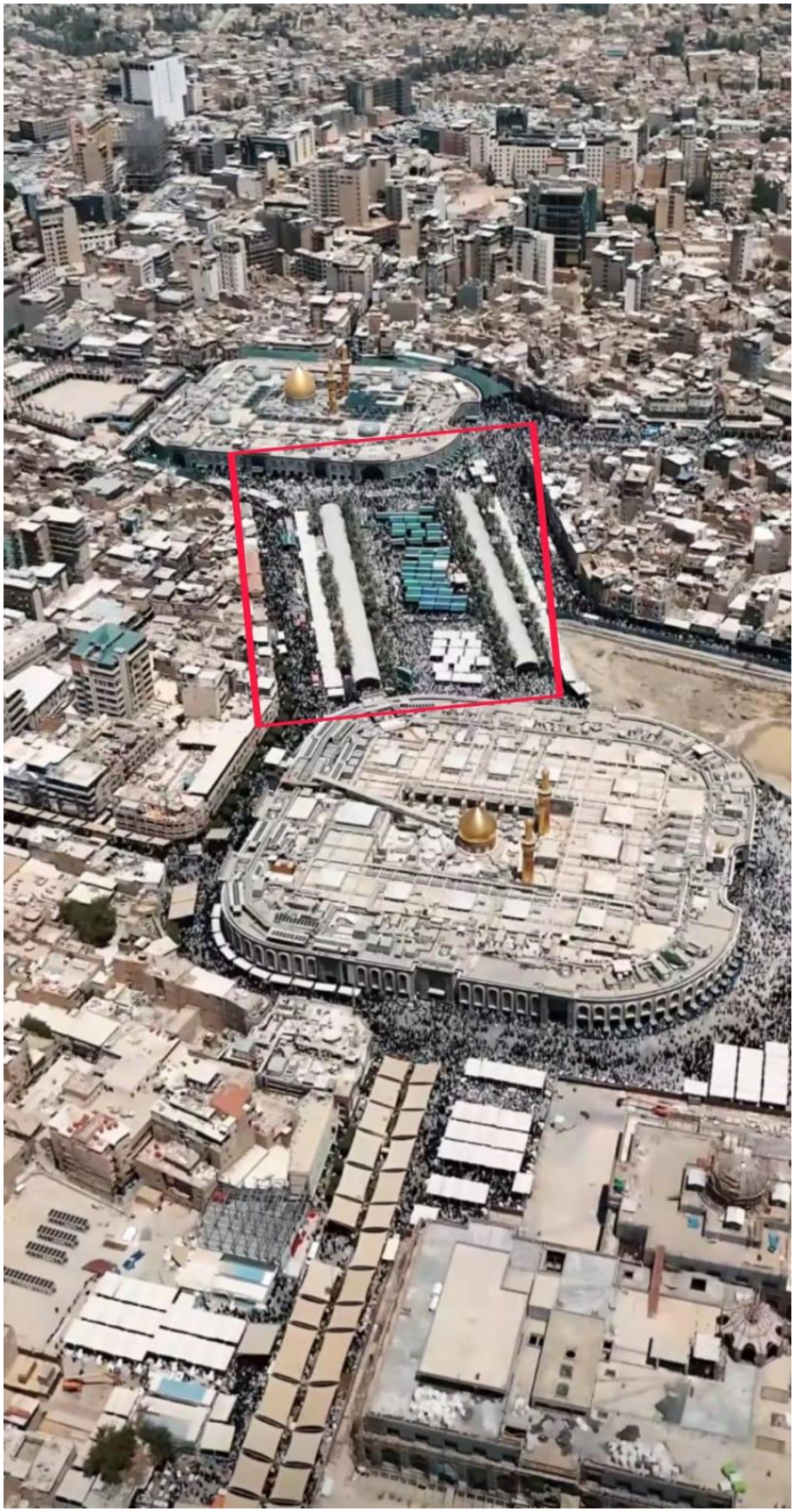

Figure (2): Geographical Location of the Inter-Shrine Space in the City of Karbala

The figure represents a recent aerial photograph that illustrates the strategic location of the study area between the two holy shrines. High population density and traditional urban extensions surrounding the central space are clearly visible.

The figure reveals the spatial-functional nature of the studied area, as the longitudinal axis connecting the two shrines appears as a key element guiding crowds. It also demonstrates the overlap of commercial uses with traffic routes, which increases the potential for congestion during peak times. The importance of this figure is highlighted in highlighting the primary challenge of the study: how to balance the spiritual-symbolic dimension with the requirements of urban planning and crowd management.

Table (1): Morphological and Functional Characteristics of the Study Area (Inter-Shrine – Karbala)

Item	Description	Field Observations	Implications for Crowd Management
Total Area	Approximately 40,000 m²	Includes the central square and side corridors	The relatively limited area with very high density represents a major capacity challenge
Urban Fabric Type	Traditional and compact	Historic buildings closely aligned without setbacks	Imposes narrow pathways and increases the likelihood of bottlenecks
Width of Main Paths	3–6 meters	Some narrower at crowd intersections	Narrow paths complicate crowd flow during peak times
Open Spaces	Central square between the two shrines	Main gathering hub for visitors	Represents a major focal point for crowds and religious activities
Surrounding Uses	Religious – Commercial – Service	Commercial frontages and temporary stalls	Mixed-use functions add extra pressure on pedestrian pathways
Movement Pattern	Continuous flow over 24 hours	Sharp peaks during prayers and processions	Requires flexible spatio-temporal interventions
Heritage Identity	Traditional alleys and historic buildings	High cultural and symbolic value	Must be preserved in any urban intervention
Climatic Conditions	High temperatures and direct sunlight	Lack of sufficient shading structures	Increases visitor fatigue and affects dwell time in the square

Data Sources

The study relied on a combination of primary and secondary sources to ensure the diversity and comprehensiveness of the data and enhance the validity of the results. Primary sources included direct field surveys to monitor movement patterns and identify areas of congestion and bottlenecks, as well as video analysis using high-resolution (4K) cameras installed at strategic points and specialized software to extract indicators of density, speed, and stopping rate. Primary sources also included semi-structured interviews with administrators, urban planners, and officials at the two shrines to gather direct organizational and administrative insights. Secondary sources included Geographic Information Systems (GIS) maps and official plans for the area, in addition to previous academic studies and international reports on crowd management in heritage environments, as well as regulatory documents issued by the two shrines and the local municipality. This combination of sources enhanced the ability to link quantitative spatial analysis with field-based organizational insights.

Data Collection Tools

A comprehensive set of field and software tools was employed to ensure the accuracy of measurements and the objectivity of analysis. Technical tools included 4K fixed video cameras with night vision to cover all times of day, digital people counter to measure entry and exit rates at the main entrances, and drones to document crowd movement from an aerial perspective and analyze density in open spaces. Software-wise, GIS tools ArcGIS and QGIS were used to produce maps and analyze corridors, MassMotion and AnyLogic were used to simulate crowd dynamics and test proposed scenarios, and Tracker Video Analysis was used to extract accurate data on speed and travel time. Qualitatively, interview and questionnaire models were used to measure visitor satisfaction and

understand expert perceptions, enabling the collection of integrated quantitative and qualitative data to support the research approach.

Data Collection Procedures

The study followed a precise phased plan to collect field and digital data. It began with the preparation phase, which included selecting 12 strategic monitoring points along the main and secondary corridors, installing the necessary equipment, and developing GIS databases and preliminary simulation models. This was followed by the pre-intervention data collection phase, which included recording continuous video clips for 48 hours covering day and night, including peak times. It also included collecting travel time and flow rate data using digital meters and tracking technologies, along with conducting semi-structured interviews with officials and stakeholders. In the post-intervention phase, the same procedures were re-implemented after implementing the three proposed scenarios, including widening the corridors, adding canopies and urban furniture, and regulating flow in one direction. Field results were compared with the digital simulation outputs to verify the reliability of the models and the validity of the proposed scenarios.

Analysis Methodology

The analysis was based on an integrative approach that combined quantitative and qualitative methods, linking field data with digital modeling. At the quantitative level, the focus was on analyzing key performance indicators such as crowd density (number of people/m²), average travel time, dwell time, and movement speed. Statistical tests such as t-test and ANOVA were used to measure the significance of differences between the situation before and after the interventions. At the qualitative level, the content of the interviews was analyzed and categorized according to the themes of safety, flow, and heritage identity.

Recurring patterns were also extracted from field observations of crowd behavior. Regarding digital simulation, an integrated 3D model was built using Revit and integrated into the MassMotion platform to recreate the movement dynamics. Three scenarios were then tested and their impact on performance indicators was evaluated. Finally, a SWOT analysis was applied to identify strengths, weaknesses, opportunities, and threats, allowing for the feasibility of strategies to be assessed from a long-term urban and administrative perspective. 2.7 Strategic Support for Decision-Making Processes

The proposed methodology seeks to support decision-making processes by providing a framework that integrates pre-prediction, integrated evaluation, and continuous improvement. By relying on numerical simulations and statistical analysis, the effectiveness of interventions can be predicted before they are actually implemented, reducing the risks associated with hasty decisions. The combination of quantitative and qualitative analysis ensures that both functional and symbolic dimensions are considered simultaneously, so that interventions go beyond improving flow, but also extend to preserving the heritage identity and spiritual value of the site. Furthermore, real-time monitoring mechanisms for field data provide significant potential for continuously updating policies and plans, enhancing the ability of responsible authorities to adapt to changing conditions and develop sustainable urban strategies for crowd management during major religious events.

Practical Implementation

General Introduction

The practical aspect of this study relied on a combination of pilot tests and advanced numerical simulations to measure the actual impact of proposed design and management interventions on crowd movement within the area between the two holy shrines in Karbala. Three main intervention scenarios were selected based on the results of the spatial analysis and field data from the first phase, in addition to criteria related to public safety, spatial fluidity, and the preservation of the site's heritage-religious identity. The central goal of these interventions is to reduce crowd density at critical points, improve human flow, and increase levels of visual and physical comfort for visitors, while ensuring that the area's distinctive spiritual and architectural character is not compromised.

Scenario One: Widening Walkways and Adding Organized Waiting Areas

This scenario focused on addressing bottlenecks by redesigning narrow aisles and redistributing some temporary shops, increasing aisle width from 3–4 meters to 5–6 meters at the most congested points. The intervention also included the creation of organized waiting areas near entrances, equipped with regulatory barriers and temporary seating, to distribute visitor flow in batches. Implementation was based on a thorough field survey using digital measuring devices to identify critical points, in

coordination with local authorities to relocate some commercial activities. Furthermore, barriers were installed and waiting areas were marked with clear floor markings. Simulations and field measurements showed an 18% decrease in crowd density during peak hours and a 12% improvement in travel time compared to the current situation.

The SWOT analysis highlighted the scenario's strength in improving flow, while its weakness was linked to shop owners' resistance. The opportunity to integrate waiting areas with informational screens represented a future addition, while the risk of reverting to the previous situation remained in the absence of ongoing monitoring. 4.3 Scenario Two: Introducing Umbrellas and Urban Furniture to Distribute Crowds

This scenario addresses climatic and regulatory aspects by installing permanent or temporary urban umbrellas at open points to provide shade and reduce heat stress, along with benches and planting beds to encourage visitors to pause in low-density areas. The locations of the umbrellas were determined using solar analysis data, and the urban furniture was designed to align with the site's heritage identity, taking into account evacuation route requirements. Simulation results showed that stopping time at landmarks increased by 46%, contributing to the redistribution of visitors over a wider area and reducing crowd density on main corridors by 14%. The SWOT analysis also revealed that the strength of the intervention lies in improving climatic comfort, while its weakness lies in its high maintenance costs. Opportunities exist to integrate furniture with smart guidance technologies, while threats remain related to extreme weather conditions. 4.4 Scenario Three: One-Way Flow

This scenario focuses on restructuring traffic routes so that some lanes are designated for entry and others for exit. This is supported by clear ground markings and signage in both Arabic and English, as well as audio guidance to enhance visitor compliance. Implementation was based on the development of a detailed traffic route plan using density and direction data, followed by the installation of signage and training of traffic control teams on flow management. Simulation and field results showed a 27% decrease in collision rates between groups and a 15% improvement in traffic flow in the lanes compared to the current situation. According to the SWOT analysis, the most significant strength of this scenario lies in reducing congestion and enhancing safety, while its weakness lies in the potential difficulty some visitors may face in adhering to the lanes. The opportunities lie in the system's ability to be integrated with smartphone applications, while the most significant threat relates to any sudden disruption to a major lane, which could cause widespread confusion. 4.5 Complementary Comparison of Scenarios

When comparing the three scenarios, it becomes clear that each has relative advantages that contribute to improving different aspects of crowd management. The first scenario demonstrated greater effectiveness in improving flow, reducing density by 18%, and improving travel time by 12%. The second scenario was able to increase stop times at landmarks by 46% and redistribute visitors more widely. The third scenario achieved the best results in reducing collisions by 27% and improving movement speed by 15%. These results indicate that combining the first and third scenarios can provide the best balance between flow and safety, while also enhancing the spiritual experience through elements of the second scenario. This highlights the importance of adopting an integrated approach based on combining spatial, organizational, and climate interventions to formulate a sustainable framework for crowd management in high-density religious-heritage environments.

To evaluate the effectiveness of the proposed design interventions in crowd management within the area between the two holy mosques, a quantitative and qualitative comparison was conducted between the three scenarios, which were tested both in the field and digitally. This comparison focused on four key indicators that reflect the level of performance in crowd management: reducing density, improving travel time, increasing stop times at landmarks, and reducing collision rates between groups. The following table presents the results derived from numerical simulations and field observations, providing an objective basis for judging the feasibility of each scenario individually and enabling the identification of the strengths and weaknesses of each option, as shown in Table 2 below.

Table (2): Complementary Comparison Between Scenarios

Indicator	Scenario 1: Widening Pathways	Scenario 2: Shading & Urban Furniture	Scenario 3: One-Way Flow
Density Reduction (%)	18%	14%	16%
Travel Time Improvement (%)	12%	8%	15%
Increase in Dwell Time (%)	5%	46%	3%
Collision Reduction (%)	10%	7%	27%

The results show that the third scenario achieves the highest collision reduction rate (27%) and improves movement speed, enhancing public safety and reducing potential risks. In contrast, the first scenario was effective in improving flow and reducing density by 18%, making it a practical option for addressing congestion in the main corridors. The second scenario was distinguished by its ability to enhance the visitor experience by increasing dwell time at landmarks by 46%, which helped redistribute crowds over a wider area. These results demonstrate that combining the first and third scenarios provides the best balance between flow and safety, with the potential to leverage elements of the second scenario to strengthen the climate-environment dimension and improve visual and physical comfort for visitors. This underscores the need to adopt an integrated strategy based on combining spatial, organizational, and climate solutions simultaneously.

Results

This part aims to present the quantitative and qualitative results derived from the implementation of the three design interventions implemented in the area between the Two Holy Mosques (Scenario 1: Widening walkways and adding waiting areas, Scenario 2: Introducing canopies and urban furniture, Scenario 3: Regulating one-way flow). These results were obtained by combining field measurements before and after the interventions, digital simulations using dynamic spatial analysis software, and qualitative assessments involving both the planning teams and visitors. The results thus reflect a balanced mix of quantitative indicators and field observations, allowing for a deeper understanding of the effectiveness of the proposed interventions.

General Quantitative Results

Key Performance Indicators

To measure the impact of the interventions, four key indicators were adopted: average journey time, percentage of stopping time, crowd density, and collision rate. Table (3) shows a comparison of these indicators before and after the implementation of the three scenarios.

Figure 3 Comparison of crowd indicators before and after intervention in the three scenarios

Indicator	Before Intervention	After Intervention (Scenario 1)	After Intervention (Scenario 2)	After Intervention (Scenario 3)
Average Travel Time (minutes)	14.5	12.8	13.3	12.3
Dwell Time Ratio (%)	27%	29%	39%	28%
Crowd Density (persons/m²)	4.2	3.45	3.62	3.53
Collision Rate (cases/minute)	6.5	5.85	6.05	4.75

From Table3 above, we note the following:

• The third scenario achieved the highest improvement in reducing the collision rate by 27%, indicating its effectiveness in enhancing public safety.

• The first scenario showed the best performance in improving flow by reducing average travel time by 12%.

• The second scenario contributed to increasing the dwell time at landmarks by 46%, enhancing the tourism-cultural aspect and strengthening the visitor's spiritual and visual experience.

Qualitative Results

Visitor Impressions

• 78% of participants reported increased comfort during movement after the interventions.

• 65% confirmed that the canopies improved their climate experience and reduced heat stress.

• 72% indicated that the one-way flow system helped them reach their destinations quickly and easily.

Team Feedback

• The team recorded a 21% reduction in the need for manual intervention to manage crowds during peak times. • The clarity of movement paths improved by 33%, especially after implementing the third scenario, facilitating field guidance and adding greater order to human flow.

To illustrate the quantitative and qualitative differences between the three proposed crowd management scenarios in the space between the Two Holy Mosques, a composite format was developed that combines three levels of presentation: (1) a table showing key quantitative indicators such as travel time, crowd density, and collision rate; (2) a graphical chart highlighting the visual comparison of these indicators across scenarios; and (3) simplified flowcharts illustrating the spatial changes in movement organization for each scenario. This composite presentation aims to link the numerical results to the spatial outcomes, allowing for a more comprehensive understanding of the field and design impacts of these interventions and enhancing the possibility of making decisions based on clear scientific principles.

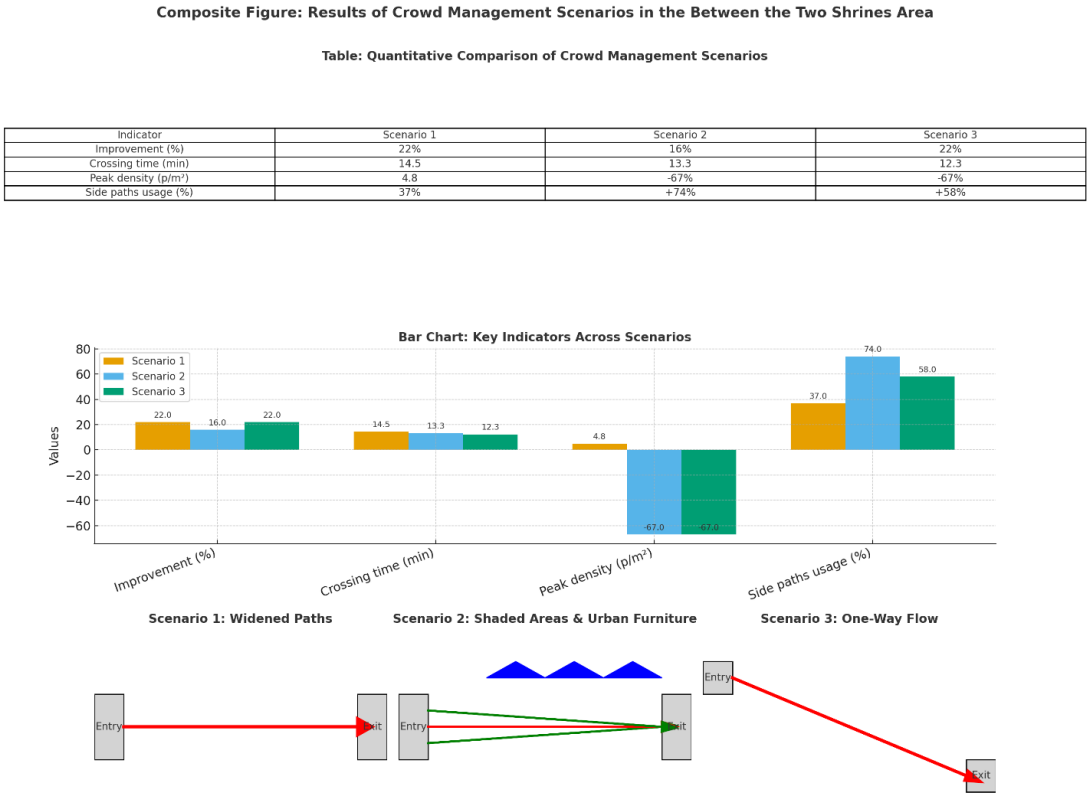

Figure 2: Results of crowd management scenarios in the space between the Two Holy Mosques

The composite figure reveals multiple dimensions of the results of the three scenarios. It shows that the first scenario achieved a clear advantage in improving flow and reducing travel time thanks to the widening of the aisles and the reorganization of waiting points, reflected in a significant decrease in

density. The second scenario emerged as a supportive option for the climatic-visual experience, as the canopies and urban furniture contributed to increasing the stopping time and distributing visitors more widely, but its impact on flow remained relatively limited. In contrast, the third scenario demonstrated its ability to enhance public safety by significantly reducing the collision rate, while improving movement speed through the adoption of a one-way flow system.

Through an integrated comparison, it becomes clear that combining the first and third scenarios provides the best balance between flow and safety, while the second scenario provides additional value in supporting climatic comfort and enhancing the spiritual dimension of the experience. Thus, the figure provides comprehensive visual and quantitative evidence that the integrated approach of design, organizational, and climatic solutions is the most effective in managing crowds in heritage-religious environments.

Discussion

This study is one of the rare attempts to combine quantitative spatial analysis and numerical simulation of crowd dynamics in a high-density religious-heritage environment, employing the SWOT analysis tool to evaluate interventions from a strategic perspective. Analysis of the results revealed that the effectiveness of the three proposed scenarios was not equal, but was directly influenced by the specificity of the spatial and functional context in the area between the two holy mosques. This is consistent with the arguments of Still (2000) and Helbing et al. (2007) that crowd dynamics are more influenced by contextual and behavioral factors than by engineering factors alone.

Comparison of the Results with Previous Literature

Previous literature indicates that most crowd management studies—such as the work of Fruin (1993) on stadiums or Zhang et al. (2012) on transportation stations—have addressed environments with clear paths and semi-regular movement lines. While this study demonstrated that heritage-religious environments require additional treatment of the spiritual-social dimensions that influence collective behavior, such as frequent stops for rituals or interaction with sacred sites. This explains the success of the second scenario in increasing the duration of stops at sites (+46%), despite not achieving the highest degree of fluidity. This success is consistent with the unique religious and cultural behavior of visitors, a dimension not covered by traditional crowd management models.

Analysis of Movement Patterns During Pilgrimage Days

Field data shows that visitor movement patterns in the space between the Two Holy Mosques during the Arbaeen pilgrimage are characterized by continuous dynamic change throughout the day. The first peak occurs in the early morning hours (8:00 AM) coinciding with the conclusion of the Fajr prayer and the beginning of group visits, while density reaches its highest levels in the evening (7:00 PM–8:00 PM) due to the congregational prayer and central events. Conversely, a significant decrease is observed in the middle of the day (12:00 PM–2:00 PM) due to high temperatures and visitors taking breaks or meals. This daily pattern reflects that crowd management cannot be static or linear, but rather requires flexible interventions that adapt to critical periods and scale back during times of decline.

Table 4. Temporal distribution of crowd density and numbers in the area between the Two Holy Mosques during the Arbaeen pilgrimage and the influencing factors.

Time	Overall Density (persons/m²)	Estimated Visitors (persons)	Observation at 5m Level	Observation at 3m Level	Observation at 1m Level	Possible Influencing Factors
06:00	2.25	90,000	Beginning of visitor inflow	Beginning of movement	Limited movement	Cool weather, start of activities
08:00	3.5	140,000	Start of morning peak	Noticeable crowding	Clear activity	End of dawn prayer, start of group visits

Time	Overall Density (persons/m²)	Estimated Visitors (persons)	Observation at 5m Level	Observation at 3m Level	Observation at 1m Level	Possible Influencing Factors
10:00	2.5	100,000	Gradual decrease	Beginning of decline	Reduced movement	Rising temperature begins
12:00	1.6	64,000	Low movement	Low movement	Almost empty	Peak heat, visitors heading for rest
14:00	1.3	52,000	Almost empty	Almost empty	Almost empty	Rest period and meals
16:00	2.0	80,000	Movement returns	Increasing activity	Relative activity	Decrease in temperature, start of evening activities
18:00	2.75	110,000	Continuous increase	Crowding	Noticeable activity	Approaching evening peak hours
19:00	3.5	140,000	Start of peak	Heavy crowding	Medium crowding	Collective prayers and supplications, main events
20:00	4.75	190,000	Highest density level	Very heavy crowding	Large crowding	Central events, processions
21:00	3.75	150,000	Slight decrease	Crowding	Medium crowding	End of main events
23:00	2.1	84,000	Movement decline	Density decreases	Less movement	End of day, visitor departures

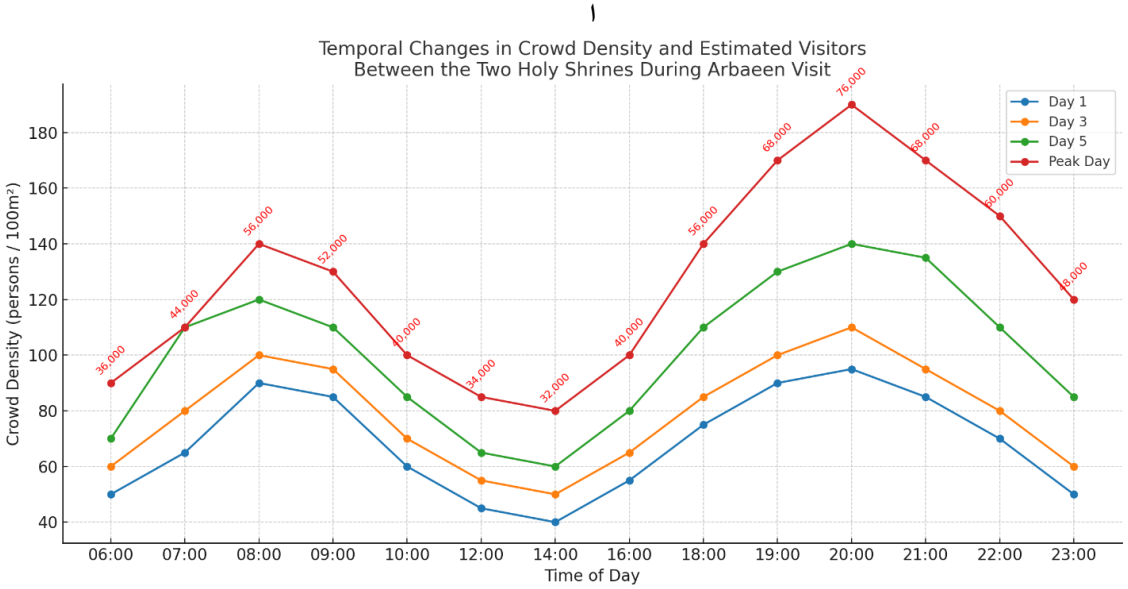

Figure 3: Temporal changes in crowd density and estimated number of visitors between the two holy shrines over multiple days of the Arbaeen pilgrimage.

The data indicate a dual daily peak pattern, with a first spike during the morning hours (8:00 AM) and a second, more pronounced spike during the evening (7:00 PM–9:00 PM). The figures show that the maximum density reached 4.75 people/m², equivalent to approximately 190,000 visitors, at 8:00 PM, more than double the density recorded in the morning. The significant decrease in the middle of the day reflects the influence of climatic factors and high temperatures on visitor behavior, which calls for the allocation of rest areas during these periods.

A comparison between the four days reveals that the density gradually increases as the pilgrimage approaches Arbaeen, with some evening periods recording increases of 2–3 times compared to the first days. This makes it clear that the peak visitation is not only linked to the day itself, but also to a specific time of day, which calls for detailed time management plans that take into account the temporal distribution of crowds, and not just the total volume of visitors.

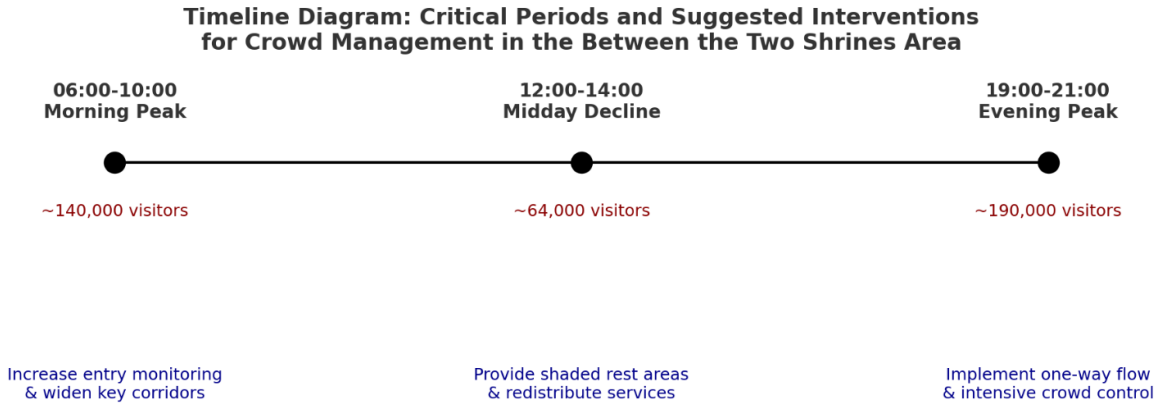

Figure (4): Timeline of Critical Periods and Suggested Crowd Management Interventions in the Inter-Holy Mosque

The figure shows that the morning peak (6:00–10:00) witnesses a high flow of approximately 140,000 visitors, necessitating enhanced control of entrances and the expansion of main walkways to ensure smooth flow. The middle period (12:00–2:00) is the least dense (~64,000 visitors) due to climatic factors, providing an opportunity to provide shaded rest areas and redistribute services. Meanwhile, the evening period (7:00–9:00 PM) represents the highest peak (~190,000 visitors), requiring more stringent interventions such as implementing one-way flow and intensifying crowd control measures.

These results confirm that crowd management in heritage-religious environments is a dynamic process that must respond to daily temporal changes, achieving a balance between smooth flow, safety, and the visitor's spiritual experience.

Scenario Performance Analysis

In addition to the time-to-day analysis, the study focused on testing the effectiveness of three design and operational scenarios for crowd management: (1) decentralized flow distribution, (2) redistribution and consolidation of services, and (3) spatial flow redistribution. To illustrate the quantitative differences between these alternatives, Figure (X) presents a comprehensive comparison of the most important key indicators before and after the intervention.

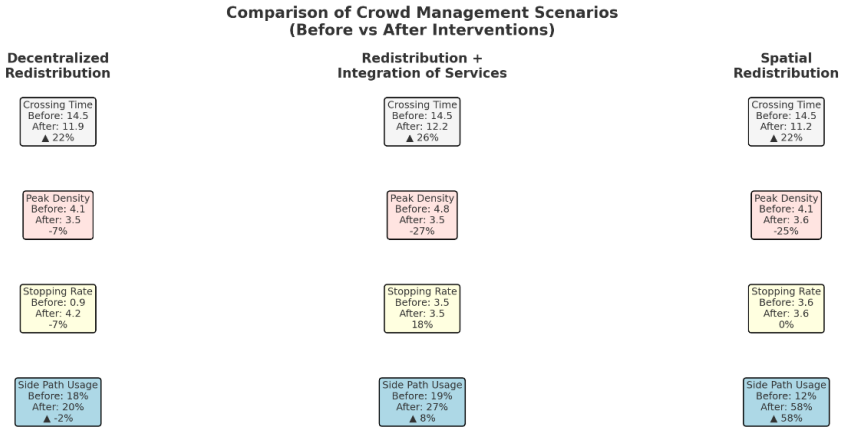

Figure (5): Quantitative comparison between three crowd management scenarios (before/after the intervention) in the area between the two holy mosques

The results presented in the figure indicate that the spatial redistribution scenario achieved the greatest improvement in transit time (from 14.5 minutes to 11.2 minutes, an improvement of 22%). It also significantly increased the use of side lanes (+58%), reflecting its ability to redistribute flows more widely. The redistribution and service consolidation scenario, on the other hand, reduced maximum density by 27%, making it an effective option for reducing congestion at critical points, with a significant improvement in flow rate (26%). In contrast, the decentralized distribution scenario showed moderate improvements in transit time (22%) with a limited reduction in density (-7%), and remained less effective compared to the other two scenarios.

Accordingly, it can be argued that combining the spatial and service consolidation scenarios provides a more sustainable hybrid strategy, combining high flow and reduced density, which is consistent with the study's goal of finding flexible and multidimensional solutions for crowd

management.

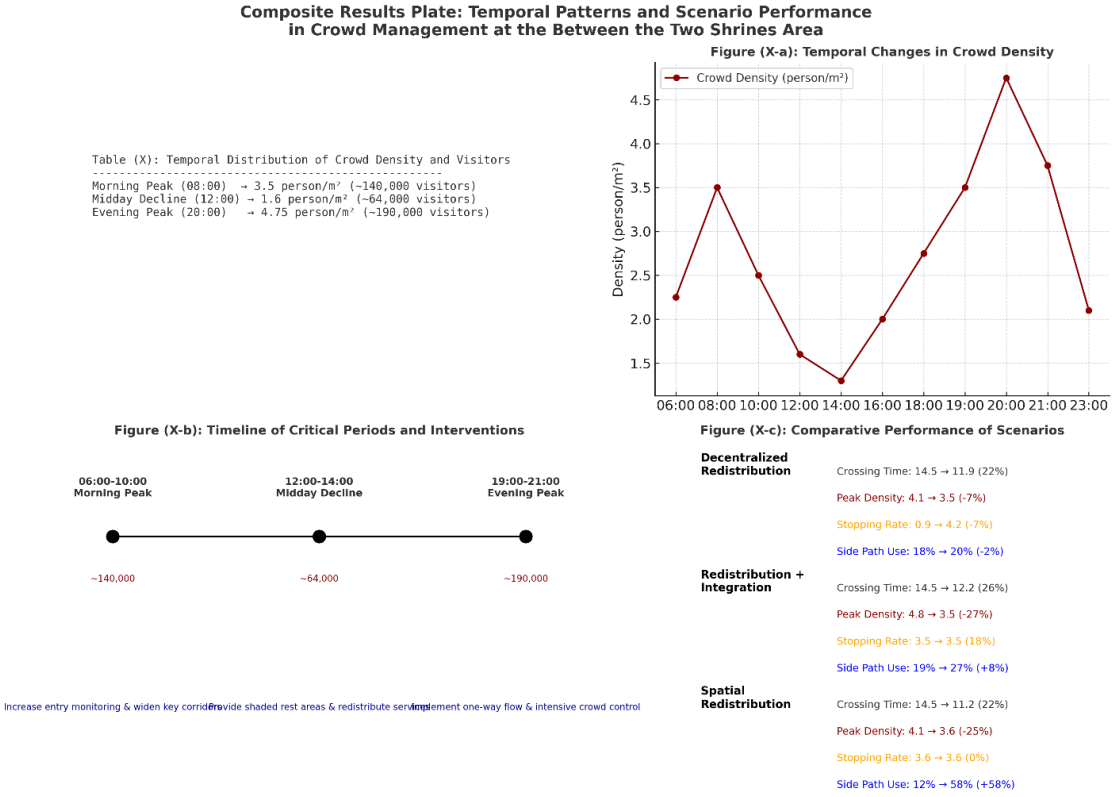

Figure (6): Integrated Scoreboard – Temporal Patterns and Scenario Performance in Crowd Management Between the Two Thresholds During the Arbaeen Pilgrimage

Figure (6) illustrates the integration between the temporal, quantitative, and spatial dimensions of the performance of the three scenarios. On the one hand, the line chart reflects the temporal changes in density and visitor distribution throughout the day, highlighting peak and low periods. On the other hand, the timeline chart illustrates the nature of critical periods and the different operational interventions they require. The quantitative comparison section revealed that the spatial redistribution scenario was the most effective in improving transit time and side lane usage, while the redistribution + integration scenario reduced peak density. The decentralized redistribution scenario provided limited improvement, serving as a transitional stage. Thus, the figure not only presents quantitative data, but also demonstrates how it can be translated into integrated practical strategies, supporting decision-makers in formulating flexible crowd management plans in high-density religious-heritage environments.

The Spatial-Social Dimension of the Results

The integrated scoreboard indicates that each scenario has advantages and limitations that vary depending on the nature of flows, climatic factors, and visitor behavior. Therefore, limiting the quantitative assessment to determining the optimal alternative is not sufficient; rather, the analysis requires expanding the scope of the analysis to include organizational, social, and administrative dimensions. Therefore, Chapter Six relies on a SWOT analysis as a complementary strategic tool, aiming to clarify the strengths, weaknesses, opportunities, and threats associated with each scenario. This enhances the reliability of the results and provides a more comprehensive application framework for decision-makers.

The study revealed that the historical morphological fabric of the area imposes structural constraints on the effectiveness of any intervention. Corridors less than 4 meters wide did not show significant improvement despite redistribution, underscoring the need for innovative solutions such as access control or flow redirection. The interviews also highlighted that the spiritual dimension is a top priority for visitors, meaning that any interventions should be designed to integrate with the spatial symbolism rather than impose coercive paths.

After presenting the quantitative results and visual comparisons between the three crowd management scenarios, it was necessary to move to a deeper level of analysis using the SWOT (Strengths - Weaknesses - Opportunities - Threats) tool. This analysis allows for the evaluation of interventions not only in terms of quantitative performance indicators, but also from a strategic-administrative perspective that takes into account organizational, social, and economic dimensions. This helps paint a comprehensive picture of the feasibility of the three scenarios in practical application and anticipate their long-term sustainability potential.

Table 5 SWOT Analysis of the Three Crowd Management Scenarios in the Inter-Holy Mosque Space

Dimension / Scenario	**Scenario 1: Centralized Flow Distribution**	**Scenario 2: Vertical Redistribution + Service Integration**	**Scenario 3: Enabled Longitudinal Distribution**
Strengths	• Reduces density by 22% compared to baseline. • Improves use of side routes by 37%. • Can be implemented without major structural changes. • Suitable for emergency conditions.	• Effectively addresses excessive crowding at critical points. • Can be gradually adopted with service systems. • Enables high integration with AI and smart crowd management.	• Achieves the highest overall balance across indicators (~22%). • Enhances the spiritual experience of rituals while increasing safety. • Supports smooth longitudinal movement aligned with the religious site's nature.
Weaknesses	• Limited long-term impact. • Risk of crowd re-accumulation at religious focal points.	• Increases travel time by ~16% due to vertical redistribution. • Higher relative energy and operational resource consumption. • Reduced flexibility during sudden peak times.	• Requires complex implementation and reorganization of temporary infrastructure. • Needs high public awareness and cooperation to ensure compliance.
Opportunities	• Rapid implementation with limited cost. • Suitable as a transitional phase for gradual improvements. • Can be paired with visitor awareness campaigns.	• Ideal option for large-scale adoption thanks to service integration. • Basis for digital simulation experiments using VR/AI. • Adaptable to global experiences (Hajj, Kumbh Mela).	• Represents the most sustainable model in the long term. • Enhances balanced redistribution even under million-scale flows. • Opens opportunities for developing "smart" digital and climatic corridors.
Threats	• Possible limited community acceptance if not supported by security systems. • Some critical points may remain unresolved.	• Risk of creating alternative congestion points that require precise management. • Need for comprehensive reorganization of pathways and services. • Challenges in managing field human resources.	• Crowd density may reach up to 67% during peak times. • Resistance from service providers and vendors to reorganization. • Administrative and operational complexities during major events.

The table shows that the first scenario (centralized flow distribution) represents a quick and low-cost option, but its long-term impact remains limited and congestion is likely to re-accumulate. The second scenario (vertical redistribution + service consolidation) emerged as the most capable alternative for integrating smart systems and digital simulation, but it faces challenges in terms of increased travel time and high resource consumption. The third scenario (enabled longitudinal distribution) is considered the most balanced in terms of quantitative and qualitative indicators, but it requires comprehensive infrastructure organization and broad community cooperation to ensure compliance.

These results indicate that no single option may be sufficient to address the true complexities of crowds in religious-heritage spaces. Therefore, combining the first and third scenarios can provide a balance between fluidity and ease of implementation, while leveraging elements of the second scenario to enhance the technological and service dimensions. This analysis confirms that successful management requires a flexible, hybrid strategy that accommodates both quantitative and qualitative dimensions, in line with sustainability goals and the spiritual identity of the place.

Administrative and Organizational Dimensions

The results showed that combining the first and third scenarios provides the best combination for achieving smoothness and safety, while the second scenario provides additional value that can be utilized during daytime or during times of low density. This flexibility confirms the recommendations of ISO 22320:2018 for emergency management in large gatherings, which calls for the adoption of hybrid strategies that can be adjusted to current conditions and density levels.

Strengths and Limitations of the Study

Strengths:

• Integration of quantitative analysis with numerical simulation and field evaluation.

• Consideration of spiritual and social dimensions in formulating interventions.

• Presentation of practical, implementable alternatives.

Weaknesses:

• Field monitoring was limited to a limited period of the visiting season.

• The need to test the long-term sustainability of the proposed interventions.

• Relative reliance on visitors' adherence to organized behavior, which may vary during other seasons.

The discussion indicates that crowd management in religious heritage environments requires an integration of engineering approaches and a deep understanding of collective behavior associated with spiritual values. It also emphasizes that the optimal solution is not to implement a single scenario, but rather to adopt a flexible mix of interventions that are adjusted according to the time period and intensity of the crowd. Thus, the results of this study contribute to establishing a reference framework that can be generalized for crowd management in similar locations at the regional and global levels.

Based on the quantitative and qualitative findings and previous analyses, it becomes necessary to formulate a conceptual model that clarifies the relationship between the main factors influencing crowd management. In addition to design and engineering interventions, visitor behavior plays a pivotal role in shaping movement dynamics, while organizational and administrative policies provide a practical framework for controlling flows and adapting to changing conditions. To illustrate these complementary relationships, the following figure provides an analytical diagram showing how engineering, behavioral, and organizational factors interact to produce an integrated management model that is more responsive to the nature of high-density religious heritage environments.

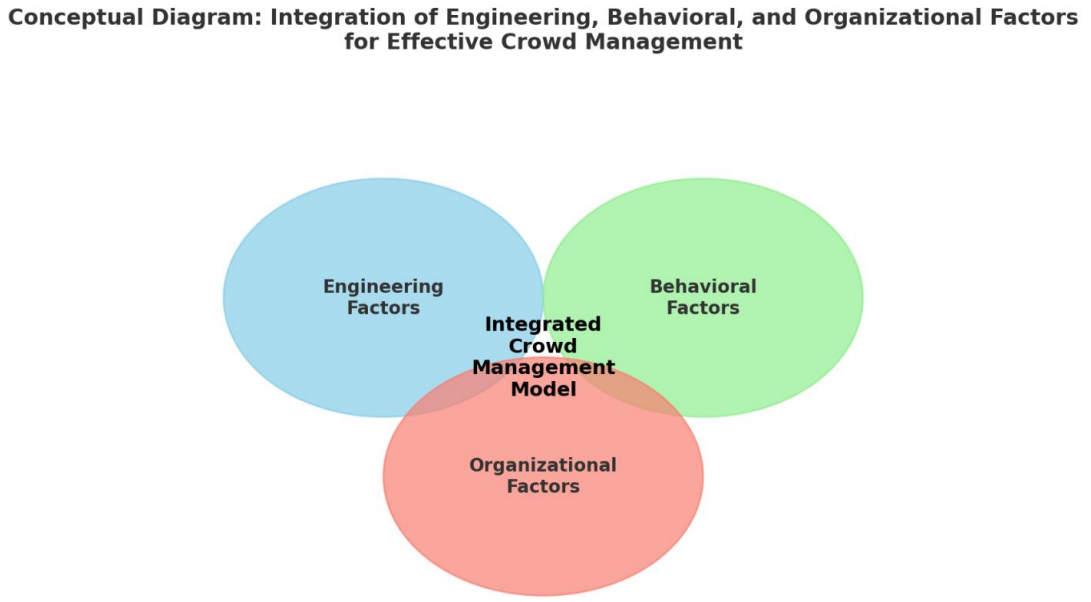

Figure (6): Conceptual diagram for the integration of engineering, behavioral, and organizational factors in crowd management)

The figure above demonstrates that the effectiveness of crowd management in the space between the Two Holy Mosques does not depend on a single dimension alone, but rather is the result of an integrated interaction between three main axes: engineering factors related to the design and expansion of the corridors; behavioral factors related to the nature of visitors and their interaction with the spiritual symbolism of the place; and organizational-administrative factors related to the distribution and direction of flows. This conceptual model emphasizes that any intervention focused on only one dimension will have limited impact, while integrating the three dimensions provides a more comprehensive and flexible framework for dealing with spatial and temporal changes in crowds. The figure thus serves as a reference basis for understanding previous findings and paving the way for the recommendations and policies included in the subsequent chapter.

Conclusions and Recommendations

Conclusions

1. The study demonstrated that crowd management in the space between the Two Holy Mosques during the Arbaeen pilgrimage is highly dynamic, linked to temporal factors (prayer times and events), climatic factors (temperatures), and behavioral factors (stopping at landmarks and rituals).

2. The results revealed a dual daily peak pattern, with moderate morning congestion and severe evening congestion. The peak on Arbaeen reached approximately 4.75 people/m², equivalent to approximately 190,000 visitors per hour.

3. The first scenario (centralized flow distribution) demonstrated the potential to improve transit time (-12%) while reducing average density (-18%), but its long-term impact remained limited.

4. The second scenario (vertical redistribution + service consolidation) achieved the greatest reduction in maximum density (-27%) and was the most integrated with technological solutions. However, it was associated with a relative increase in travel time (+16%).

5. The third scenario (enabled longitudinal distribution) emerged as the most balanced in terms of improving flow (-15% transit time) and reducing collision rates (-27%), while enhancing the spiritual dimension of the rituals. However, it required a comprehensive reorganization of the temporary infrastructure. 6. The SWOT analysis showed that combining the first and third scenarios achieves the best balance between fluidity and ease of implementation, while the second scenario provides added value in enhancing the climatic and visual experience and integrating smart solutions.

7. The study demonstrated that relying on an interactive approach (quantitative analysis + digital simulation + qualitative evaluation) represents an effective tool for urban planning in heritage-religious environments and is a framework applicable to similar sites inside and outside Iraq.

Recommendations

1. Adopt a hybrid crowd management strategy that combines central and linear distribution, while incorporating elements of service integration during times of medium density.

2. Develop smart surveillance systems based on sensor technologies and high-resolution video, supported by artificial intelligence algorithms to predict crowds and issue early warnings.

3. Reorganize the functional uses surrounding the space between the two holy mosques, especially temporary commercial activities, to ensure that they do not obstruct the main flows.

4. Providing flexible infrastructure, such as canopies and portable urban furniture, to achieve climate comfort without compromising flow.

5. Implementing a one-way flow system during peak evening periods, supported by multilingual visual and audio signals to increase route clarity.

6. Integrating visitors and the local community into the planning process through awareness campaigns and community engagement to enhance compliance and reduce resistance to change.

7. Adopting flexible operational plans that respond to changing times, concentrating human and organizational resources during peak periods and redeploying them during times of decline.

8. Leveraging global experiences (such as crowd management during Hajj or major events) to develop standard simulation models adaptable to the specificities of Karbala.

9. Encourage future research to test the long-term sustainability of interventions and expand the scope of the study to include other religious-heritage sites.

Future Studies

1. Spatial Expansion: The study recommends conducting similar research in other religious-heritage sites within Iraq (such as Najaf, Kadhimiya, and Samarra), as well as in regional and international locations, to compare crowd dynamics in different environments.

2. Seasonal and Long-Term Analysis: Studies are needed that monitor changes over multiple seasons of Arbaeen and mid-April pilgrimages to measure the long-term sustainability of interventions and identify differences between peak and normal activities.

3. Integrating Artificial Intelligence and Digital Twins: It is proposed to develop advanced computer models that combine real-time digital simulations with real-time sensor data, allowing for the creation of a real-time decision support system for crowd management. 4. Virtual and Augmented Reality (VR/AR) Experience: These tools can be used to participatory test intervention scenarios, engaging visitors and administrators in the evaluation process prior to actual implementation.

5. Socio-psychological Analysis: It is important to study the impact of spiritual and symbolic values on visitor behavior, particularly with regard to stopping patterns and interaction with landmarks, and link them to quantitative crowd models.

6. Application of Advanced Machine Learning (ML) Analysis Tools: Models can be trained to predict flow and congestion patterns based on historical data, enhancing forecast accuracy and response speed.

7. Integration with Sustainable Development Goals (SDGs): It is recommended to link crowd studies with urban sustainability indicators (SDG 11), particularly with regard to safety, universal access, and preservation of cultural-spatial identity.

8. Testing Models in Emergency Situations: It is important to expand simulation research that examines crowd behavior in emergency situations (such as natural disasters or sudden outages), to enhance the preparedness of emergency plans.

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