Exploring the Transformative Power of 3D GIS in Urban Planning and Management

Zainab T. Al-Ars
Department of Remote Sensing and GIS, College of Science, University of Baghdad, Baghdad, Iraq

Moaz H. Ali
AlSafwa University College, Scientific Advisor in Karbala Center for Studies and Research, The Husseini Holy Shrine, Karbala, Iraq

Zainab.t@sc.uobaghdad.edu.iq

Abstract

The utilization of three-dimensional (3D) technology has led to significant progress in the analysis and comprehension of geographical data within geographic information systems (GIS). This study used the Al-Jadriya area in Baghdad, Iraq, as an example of how 3D GIS may be used to analyze and manage urban environments. By integrating 3D models of buildings, landscape, and infrastructure, urban planners and decision-makers can obtain vital insights into the potential implications of proposed developments, simulate traffic patterns, and discover hiding threats. We can strengthen disaster management and emergency response skills by giving complete insights into the built environment and possible risks.

This research aims to investigate the benefits of 3D GIS while emphasizing the need of enhancing urban planning and management approaches. Stakeholders may improve urban development plans, increase the safety and efficacy of Zeyart AL-Arbaeen, and much more by using the potential of 3D GIS technology. Population control, population movement management, and the security of millions of people attending this massive event are all advantages of 3D GIS.

1. Introduction

The rapid advancement of information technologies has revolutionized the creation of virtual worlds, enabling 3D landscape modeling and visualization. These technologies have facilitated the generation of attractive representations of the environment based on diverse digital data types, including geographic, geological, architectural, and biological data [1, 2]. The availability of geospatial datasets with global coverage, improved resolution, and thematic content has further fueled the growth of 3D modeling and mapping applications [3].

Recent advancements in accurate landscape modeling and mapping have expanded the possibilities for generating 3D maps and visualizations, making them indispensable in a variety of fields such as city planning, landscape monitoring, utility and transportation management, tourist maps, and 3D mapping services [4]. Furthermore, 3D models have proven valuable in areas including tourism, scientific presentations, regional planning, and management due to their ability to provide a better understanding of spatial linkages in the landscape [5].

To enhance the efficacy and expressiveness of 3D landscape modeling and mapping, researchers have explored various aspects such as cartographic standards, design principles, and visualization techniques. These efforts have contributed to the development of integrated data models that support 3D geometry and topology, enabling extended spatial analysis and interactive visualization [6]. The integration of 3D models with Geographic Information Systems

(GIS) has demonstrated numerous advantages, including applications in machine learning, restoration projects, shadow analysis, 3-dimensional urban planning, virtual cities, visual analysis, emergency planning, and landscape planning [7].

Accurate and reliable 3D models play a crucial role in landscape management, planning, and analysis. These models incorporate various GIS datasets such as relief, land cover, hydrography, structures, roads, and tourist infrastructure, as well as remote sensing data from satellite imagery, orthophotos, Radar, and LiDAR [8]. The creation of 3D models involves processing remote sensing data to generate a terrain model and integrating fundamental data for landscape simulation, including geology, soil, vegetation, and hydrography. The choice of presentation software depends on whether dynamic or static viewing of the 3D models is desired, offering advanced outcomes like flying simulations for landscape observation [9].

Despite the advancements in 3D GIS, challenges remain in representing complex 3D objects and achieving comprehensive 3D cadastral registration. Efforts to address these issues are ongoing, with limited progress in geographic analysis and attribute handling within the context of 3D GIS [10]. Three-dimensional photo-models have emerged as a viable approach, combining topology structures with geometry to create coherent 3D models of buildings in metropolitan regions [11].

In the context of spatial strategies, flood protection and the management of flood-endangered land are critical concerns for

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municipalities. GIS technology, coupled with 3D models and mathematical models utilizing neural nets, facilitates spatial analysis, monitoring changes, and protecting flood risk land. Thorough and trustworthy information plays a vital role in decision-making processes related to land use planning and landscape protection [12].

In this study, we propose an integrated modeling strategy for 3D GIS to address the challenges in managing geo-information about urban regions. Our approach aims to create a 3D model that supports 3D topology and incorporates a user interface for querying and visualization using ArcGIS. By establishing the connection between model design and data collection techniques, we aim to contribute to the development of a flexible and operational urban 3D GIS system.

2. 3D GIS in Zeyart AL-Arbaeen of Imam Hussein

The Arbaeen visit of Imam Hussein in Karbala draws millions of pilgrims from around the world, making it one of the largest gatherings globally. Ensuring the safety, efficiency, and smooth management of this significant event is a paramount concern for the organizers and authorities involved. The application of three-dimensional (3D) Geographic Information Systems (GIS) emerges as a transformative solution in achieving these objectives.

This study explores the implementation of 3D GIS technology in the context of the Arbaeen visit to Imam Hussein, focusing on the Al-Jadriya region in Baghdad, Iraq, as a representative example. By integrating 3D models encompassing buildings, terrain, infrastructure, and crowd data, urban planners and decision-makers gain valuable insights into potential impacts, traffic patterns, and latent hazards.

The benefits of 3D GIS extend beyond spatial data analysis and understanding. It plays a pivotal role in enhancing disaster management and emergency response capabilities by providing comprehensive insights into the built environment and potential risks. Stakeholders can leverage the power of 3D GIS to make informed decisions, improve urban planning strategies, and ensure the safety and efficiency of the Arbaeen visit.

With its capacity to reduce congestion, control crowd movements, and enhance safety measures, 3D GIS proves to be an indispensable tool for managing large-scale events like the Arbaeen visit of Imam Hussein. The research sheds light on the transformative potential of 3D GIS technology in advancing urban planning and management practices, fostering a safer and more organized experience for millions of visitors participating in this significant event.

3. Background on 3D Modelling Techniques and Technologies

Photogrammetry, a non-contact measurement technique, is a scientific discipline that enables the measurement and analysis of surface characteristics and objects without direct physical contact [13]. It involves the use of pictures as its primary medium for measuring three-dimensional coordinates, based on the principle of triangulation, specifically aerial triangulation [14]. This technique allows for the creation of accurate three-dimensional models by overlapping the line of sight.

There are two main categories of photogrammetric techniques: terrestrial and aerial. Aerial photogrammetry involves capturing pictures from cameras positioned in the air, typically mounted on aircraft or unmanned aerial systems, to collect data [15]. Terrestrial photogrammetry, on the other hand, relies on capturing pictures using cameras physically located on the Earth's surface.

Aerial photogrammetry, with its ability to cover large areas and capture detailed imagery from an elevated perspective, is particularly suitable for creating orthophotos, 3D models, and other photogrammetric products [16]. It offers a faster and more convenient approach to 3D modeling, with drones becoming increasingly popular for capturing images and data for various applications, including buildings and objects (Figure 1) [15].

In addition to aerial photogrammetry, another technique commonly used in 3D modelling is LIDAR (Light Detection and Ranging). LIDAR is a remote sensing technique that utilizes pulsed laser light to measure ranges to the Earth's surface and other features, providing highly accurate and precise three-dimensional data [16].

Overall, photogrammetry, including both aerial and terrestrial approaches, along with LIDAR, plays a significant role in generating 3D models and capturing detailed information about surfaces and objects. These techniques offer valuable tools for a wide range of applications, from mapping and surveying to urban planning and infrastructure management.

Figure 1. Aerial photogrammetry using drones [15]

4. Methodology

4.1. Introduction to 3D GIS

The advent of Geographic Information Systems (GIS) in the mid-1960s revolutionized the field of mapping and geographic information management [17]. Initially focused on 2D mapping and analysis, GIS has found numerous applications in various industries such as forestry, natural resources management, planning, and military [17]. However, the traditional 2D GIS approach neglects the inherent three-dimensional nature of the real world [18]. Only in the past few years has the serious integration of 3D capabilities in GIS gained attention, although its acceptance among the broader GIS community has been limited [18]. The concept of 3D GIS involves associating spatial information with three-dimensional phenomena and aims to perform similar tasks as 2D GIS [19]. While current 2D GIS software can handle basic 3D tasks, more advanced 3D operations require specialized tools and techniques [20].

4.2. Understanding Dimensionality

Dimensionality is a fundamental concept in geometry that defines the number of values required to determine a position in space. In the context of GIS, primitives such as points, lines, areas, and volumes represent the basic geometric elements, each requiring a specific number of dimensions for description. A point, having zero dimensions, represents a position in space. A line extends in one dimension, while an area requires two dimensions to define its length and width. A volume, described by three dimensions, possesses length, width, and depth [21].

4.3. Representation in 2.5D

In addition to the primitive features, the surrounding environment plays a role in determining the dimensionality of objects. Internal dimension refers to the object's own dimension based on the primitives it represents, while external dimension refers to the space surrounding the object [22]. The external dimension can be projected onto a plane (R^2) or extended into higher dimensions (R^3, R^4, etc.), creating a 3D model or a dynamic 3D model over time. This concept of dimensionality allows for the representation of 2D objects in extended spaces, commonly referred to as 2.5D [23]. In 2.5D, -values are often represented as attributes in a table, enabling the simulation of a 3D model while geometrically describing the objects as 2D features [24].

4.4. 'True' 3D Representation

Unlike 2.5D features, 'true' 3D features are geometrically described using xyz-coordinates without relying on -values as a function of xy-coordinates [22]. 'True' 3D features allow for the storage of complex objects in GIS databases. Examples include Triangulated Irregular Networks (TINs), which describe surfaces with varying heights, and solids, which represent enclosed volumes composed of polygonal faces.

The representation of solids in GIS is challenging due to the complex nature of determining vertex order and connectivity [23]. Various categories of 3D primitives, such as polyhedrons, polyhedrons combined with curved patches, tetrahedrons, and CAD objects, have been proposed for modeling 3D spatial objects [25]. Each category has its advantages and limitations, depending on specific criteria and application requirements [26].

4.5. Applications and Advantages of 3D GIS

The availability of 3D GIS data has expanded significantly, ranging from LiDAR captured by drones to high-resolution textured models of buildings and subsurface information [27]. The adoption of 3D GIS offers intrinsic value beyond traditional mapping techniques, providing more accurate representations of the real world and enabling better communication with stakeholders [27].

3D GIS facilitates advanced spatial analysis, visualization, and simulation, supporting a wide range of applications such as urban planning, virtual city modeling, visual analysis, telecommunications, emergency planning, and landscape planning [28-30]. The integration of 3D GIS with Building Information Modeling (BIM) allows for comprehensive building management, detailed analysis, and preservation of historical structures. Additionally, 3D GIS aids in the assessment of environmental impacts, such as wind farm development, by analyzing factors like migratory paths and noise propagation [27].

4.6. Study Area: Al-Jadriya, Baghdad, Iraq

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The neighborhood of Al-Jadriya is located along the Tigris River in Baghdad, Iraq. Situated at the southern tip of the peninsula where the river makes a significant turn, Al-Jadriya shares its space with the Karrada neighborhood [27]. The neighborhood is notable for its quality of life and presents an interesting case study for implementing 3D GIS and spatial modeling techniques, Figure 2 shows the study area of this research (Al-Jadriya Region).

Figure 2. Al-Jadriya Region (Case Study)

4.7. The Proposed Method

The methodology for creating the 3D model of the study area in Al-Jadriya, Baghdad, Iraq involved the following steps:

Data collection: Relevant data, including Esri imagery, elevation data, and vector data representing roads, buildings, and other features, was collected for the study area.

Data preparation: The collected data underwent necessary preparation and organization to ensure its suitability for 3D modeling in ArcGIS. This involved tasks such as data cleaning, conversion, and editing.

Creation of a new 3D scene: A new 3D scene was opened in either ArcScene or ArcGIS Pro, and the required data layers, such as Esri imagery, elevation data, and vector data, were added to the scene.

Data adjustment: The data layers were adjusted to align with the correct location, scale, and orientation. Georeferencing tools in ArcGIS were utilized to align the data layers accurately.

Feature extrusion: The buildings and other features in the vector data were extruded to create a 3D representation of the study area.

Texture addition: Textures, such as the Esri imagery, were added to the 3D model to enhance its realism and provide a more accurate representation of the study area.

Analysis: Once the 3D model was created, various spatial analyses were performed, including viewshed analysis, terrain analysis, and hydrological analysis.

5. Results

The results of the 3D modeling process in Al-Jadriya, Baghdad, Iraq are presented in Figures 3, 4, 5, and 6. These figures showcase the three-dimensional representation of the study area, highlighting the buildings and other features that were extruded in the modeling process. The addition of textures, such as the Esri imagery, contributes to a more realistic visualization of the study area.

These 3D models can serve as valuable tools for visualization, allowing for virtual tours, simulations, and informed decision-making regarding the study area. The models provide a comprehensive understanding of the spatial characteristics and features of Al-Jadriya, enhancing the analysis and planning processes. Figure 3 demonstrates the process of drawing the features in the 3D model, illustrating the extrusion of buildings and other elements. The subsequent figures (4, 5, 6 and 7) showcase the completed three-dimensional representation of Al-Jadriya, emphasizing its spatial characteristics and enabling in-depth analysis. These results highlight the effectiveness of the methodology in creating a detailed and accurate 3D model of the study area, which can support various applications in urban planning, decision-making, and virtual visualization.

Figure 3. Features Drawing

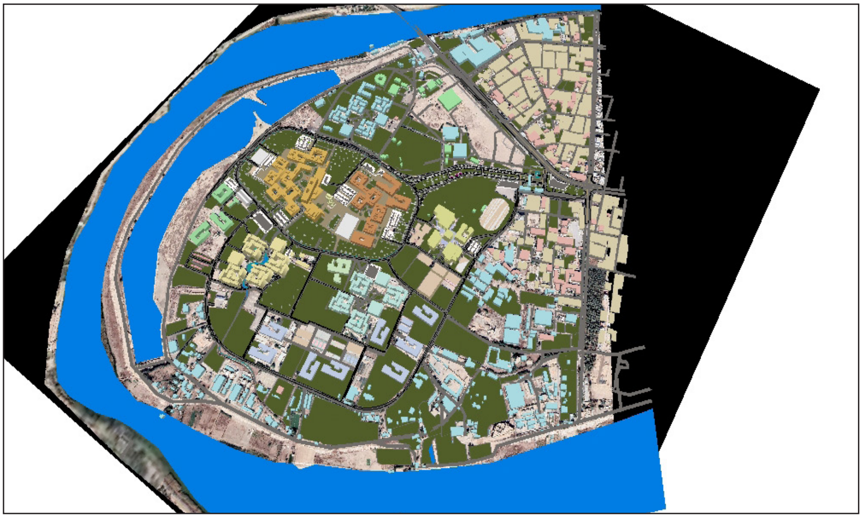

Figure 4. 3D Al-Jadriya Model (1)

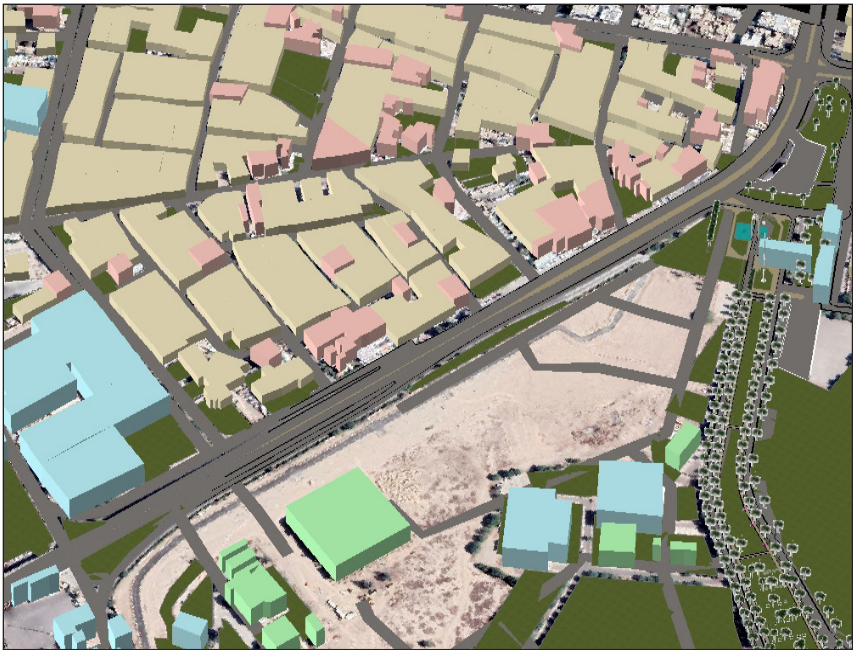

Figure 5. 3D Al-Jadriya Model (2)

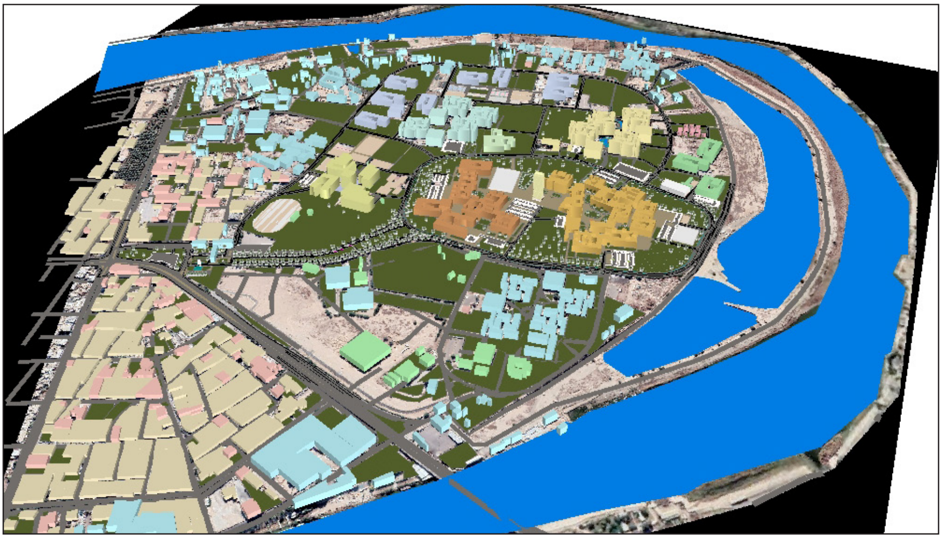

Figure 6. 3D Al-Jadriya Model (3)

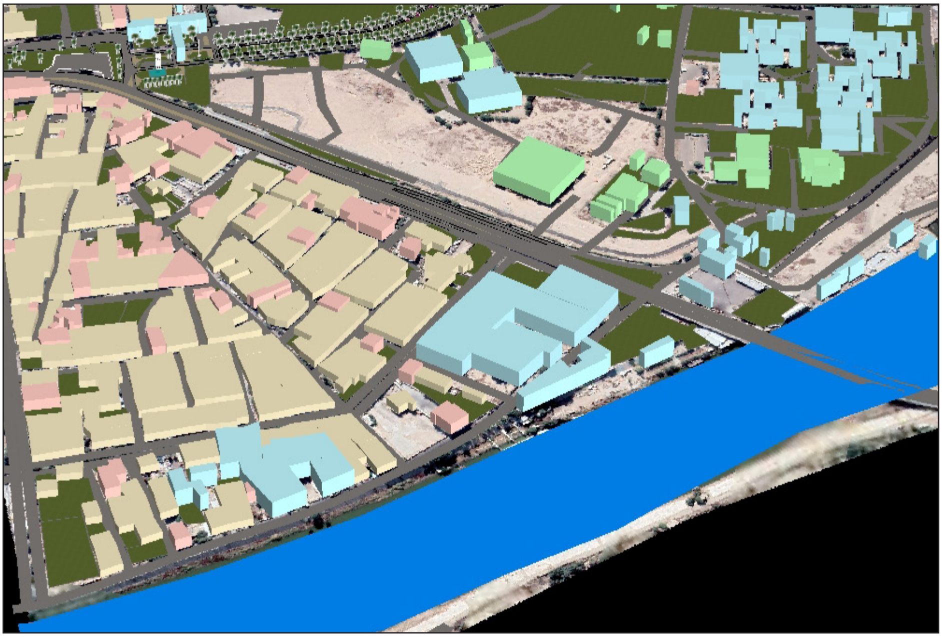

Figure 7: 3D Al-Jadriya Model (4)

6. Conclusion

The application of three-dimensional (3D) Geographic Information Systems (GIS) in the context of the Arbaeen visit of Imam Hussein has demonstrated its transformative power in advancing urban planning and management practices for one of the largest gatherings in the world. Through the case study of the Al-Jadriya region in Baghdad, Iraq, this research has revealed the numerous benefits and potential of 3D GIS technology in comprehending and managing complex urban environments during this significant event.

By integrating 3D models encompassing buildings, terrain, infrastructure, and crowd data, decision-makers and urban planners gain crucial insights into proposed developments, traffic patterns, and latent hazards. This enhanced understanding enables them to make informed decisions and devise strategies to ensure the safety and efficiency of the Arbaeen visit. Moreover, 3D GIS has proven to be an indispensable tool in disaster management and emergency response capabilities, providing comprehensive insights into the built environment and potential risks.

The use of 3D GIS not only enables precise spatial data analysis but also fosters effective communication among stakeholders. This leads to a more collaborative approach to managing the Arbaeen visit, as authorities, organizers, and relevant entities can work together with a shared understanding of the spatial challenges and opportunities.

Furthermore, 3D GIS technology has shown promising results in reducing congestion, controlling crowd movements, and enhancing safety measures. By simulating various scenarios, decision-makers can proactively plan for the event and implement measures to optimize crowd flow and reduce potential risks. As technology continues to evolve, the potential of 3D GIS in managing large-scale events like the Arbaeen visit will only expand. With advancements in data collection methods, real-time data integration, and improved modeling techniques, the application of 3D GIS will become even more effective in meeting the dynamic challenges posed by such events.

In conclusion, the utilization of 3D GIS in the Arbaeen visit of Imam Hussein represents a significant step forward in urban planning and management. This technology's ability to provide comprehensive spatial insights, enhance disaster management capabilities, and improve decision-making processes makes it an invaluable asset for ensuring the safety, efficiency, and success of this revered event. As urban environments continue to evolve and grow in complexity, 3D GIS will play an increasingly critical role in enhancing the planning, management, and overall experience of the Arbaeen visit and similar large-scale gatherings.

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