https://doi.org/10.33261/jaaru.2025.32.4.003 *Association of Arab Universities Journal of Engineering Sciences (2025)32(4)24–34*

Association of Arab Universities
Journal of Engineering Sciences
مجلة اتحاد الجامعات العربية للدراسات والبحوث الهندسية

كلية الهندسة - جامعة بغداد

جمعية كليات الهندسة
اعضاء اتحاد الجامعات العربية

Employing Artificial Intelligence Techniques in the Analysis of Morphological Characteristics of Heritage Elements in Iraq

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Received:

Abstract— This research explores the application of artificial intelligence (AI) tools to the morphological analysis and digital documentation of heritage architectural elements, focusing on the muqarnas of the Abbasid Palace in Baghdad. A replicable workflow was developed that combines AI-based monocular depth estimation models, including MiDaS and Depth Anything, with point cloud generation, three-dimensional mesh reconstruction, and quantitative curvature analysis. High-resolution photographs were processed to produce detailed depth maps, which were transformed into dense point clouds and reconstructed into watertight meshes using the Poisson Surface Reconstruction algorithm. Per-vertex curvature metrics were extracted and visualized through color-coded maps and histograms, revealing a predominance of moderately low curvature regions interspersed with localized high-curvature zones corresponding to decorative recesses and stepped projections. Segmentation and classification of depth and curvature data enabled the surface to be divided into discrete morphological units, supporting a structured interpretation of its hierarchical design. These findings highlight the potential of integrating accessible AI-based tools with open-source 3D processing platforms to enhance the accuracy, objectivity, and reproducibility of heritage documentation. The methodology offers a scalable approach for analyzing similar historical elements and contributes to the broader discourse on digital preservation, conservation monitoring, and the interpretation of Islamic architectural heritage.

Keywords— artificial intelligence, Architecture, Abbasid Muqarnas, MiDaS, 3D reconstruction, heritage documentation.

1. Introduction

The Iraqi architectural heritage is one of the deepest cultural belongings of the Middle East which offers a unique example of artistic and technological advancement of several centuries. Muqarnas form a notable part in this heritage as the symbol of Islamic architecture. The Muqarnas are three dimensional decorative apparatuses which create multifaceted areas of ambiguity along the surfaces of architecture by creating an aesthetic poetic at the same time they are serving a functional purpose [1].

During the Abbasid era, muqarnas reached the intellectuality of geometric structures, consequently augmenting the characters of religious and civil structures in Baghdad and more [2].

Recording and reporting of these complex morphological compositions are quite superheroic tasks to the conventional survey methods and manual recording methods. The present capability to collect highly geometric and accurate data in the sub-millimeter range with three-dimensional (3D) scanning, photogrammetry, and computer vision has transformed the heritage documentation workflows over the past 20 years [3,4]. Most recently, the strategies of artificial intelligence (AI) and the machine learning approach have been built into these routines and new horizons of segmentation, pattern discovery, and morphological classification of heritage components emerged [5].

Regardless, of such technological breakthroughs, there remains a long-term demand of integrated workflows that interconnect AI-based data streams with 3D modelling, the more traditional quantitative analysis of the traditional Islamic forms. The regular chances to integrate depth estimation, point-cloud generation and analysis of curvatures have not been explored much in terms to Abbasid muqarnas. The benefits of high-resolution digital recording in conservation have already been established within pieces of research like those conducted by [3] and [6], whereas newer studies also show how AI can be used to automate feature extraction and aid in article morphological descriptors generation [5].

This research aims to employ artificial intelligence tools, depth-map computation, and advanced digital modeling techniques to investigate the morphological characteristics of the muqarnas in the Abbasid Palace in Baghdad. The project develops a comprehensive workflow that integrates image-based depth estimation, point cloud processing, and curvature analysis. By quantifying the geometric properties of this heritage element, the study contributes to a better understanding of its formal logic and provides a replicable model for heritage documentation, analysis, and preservation.

2. Literature Review

Over the last 10 years, the application of artificial intelligence (AI) technologies in the documentation and study of cultural heritage has made significant progress, which also fundamentally redefines how researchers create representations through documentation and analysis of cultural heritage sites. One such notable example is the application of depth estimation and consequent generation of point clouds, methods that have now made newer ways of exploring morphological characteristics of elements of the past.

According to Croce et al. (2023) the involvement of machine learning (ML) in the classification of point clouds is a major step toward semi-automated Scan-to-BIM processes. Their work demonstrates that manual data processing techniques such Random Forest classifiers are efficient at segmenting and labelling architectural element identified in laser scanning or photogrammetric survey data, and may allow more objective and reproducible reconstruction of heritage assets [7].

Such research direction is in accordance with the documentation of heritage architectural features, where the clear distinction and classification of complicated surfaces geometry is essential.

The article of Karadag, (2023) further bridges the applicability of AI in conservation as it proposes the application of Generative Adversarial Networks (GANs) to reconstruct missing or damaged architectural elements. Dwelling on early Ottoman tombs, Karadag proves the effectiveness of generative ML applied to formulating probable shapes and features, the principle that may be applied to other cases as well to recreate partially preserved or not complete structural elements, especially where instances of archival information are inadequate, and one is expected to generate reconstructed geometry on the basis of uneven information [8].

After a systematic review of the AI applications in the sphere of cultural heritage, Gîrbacia, (2024) pointed out to classification, 3D reconstruction, and semantic segmentation as the key spheres of investigation. Interestingly, 3D reconstruction has become one of the fastest developing directions of research, which additionally prompts the preponderance of opinion that the combination of depth estimation models with the methods of computer vision is not a matter of choice indeed further but the necessity of creating accurate digital surrogates. The findings presented above put an emphasis on the workflows starting with depth maps generated using such tools as MiDaS and ending with point clouds, mesh generation, and a related visualisation. [9].

At the same time, Yurtsever, (2023) provided case studies with mixed use of terrestrial laser scanning and photogrammetry in the documentation of Roman structures in Turkey. Even though the applied methodology was not fully based on AI, the research highlighted the importance of different data-acquisition modalities that are essential in remedying occlusions and surface complexity. Further, the work by Yurtsever pioneered initial research on using AI-based applications like ChatGPT to craft reports and to interpret documentation datasets, which will signal a larger integration between AI and heritage processes. (Yurtsever, 2023).

Sukkar et al. (2024) compared the effectiveness of a perception of Islamic architecture with the visualisations, which are products of AI. According to the authors, such tools as Midjourney and diffusion models democratise and distort the depiction of the elements of heritage at the same time as they generate highly stylised visuals that are not in line with the historical facts. [11]. This way of thinking is crucial towards any assessment of any AI-generated reconstructions and the eventual application of such in study or conservation purposes.

In conjunction with the same, Rane, (2024) outlined the larger scope of generative AI on architectural engineering with automatic model generation and structural optimisation. Evidently, the study was mainly presented with engineering-oriented workflows, but still, it supports the idea that AI can convert the 2D imagery into a 3D form and automate measurements thus serving as a valuable guideline into the AI application in cultural heritage. [12].

Abbasid muqarnas in Iraq present the perfect study exemplum of the object-level morphological analysis due to their complex geometrications. Recently presented by Chauhan et al., (2025) is a systematic workflow wherein an AI-based algorithm is incorporated to estimate binocular depth, monocular depth, and edge detection to create scaled point clouds that are furthered by generating measurement overlay compatible with quantitative morphometric analysis. (Chauhan et al., 2025). The technical precedent of their study is an assurance that their research will be able to produce effective depth maps that can be used in morphometric data analysis and should not be based on special sensors, thus serving as a methodological premise of the work in question.

When combined, these studies provide an example of an emergent intersection of AI, photogrammetry, and computer vision technologies that support the accurate, scalable recording of diverse elements of architectural heritage. Those barriers have not gone away, though: the need to ensure accuracy and reproducibility of AI-generated models, the exposure of possible biases due to training sets, and the desires to reconcile interpretive reconstruction with fidelity to the material record. The current study extends this argument by introducing the depth estimation techniques to point clouds creation in order to perform the morphological study of Abbasid muqarnas concerning the idea to show the reproducible and transparent working process contributing to the documentation and preservation of the heritage.

The literature available on the AI-powered documentation of heritage tends to revolve around either point cloud segmentation [7], the generative reconstruction methods [8], or the use of the AI in the measurement of geometric objects in general **Chauhan et al., (2025)** None apply in a systematic way to workflows that are focused on complexity of the special nature of heritage architectural components. Besides, there is still not much empirical evidence as to how this kind of workflow can be represented in terms of available tools and open-source models to facilitate reproducibility and the preservation of heritage.

The present study is thus focused on the following research question:

In what ways might outdoor artificial intelligence tools and associated replicable workflow become mutually beneficial in recording, measuring, and categorizing the morphological traits of Iraqi heritage buildings

3. Methodology

3.1 A Scope on Study

The given work is devoted to the morphological features of the concept of muqarnas in the architectural complex of the Abbasid era in Iraq, which places this feature in the very core of the local architectural legacy. The Muqarnas are a complex form of a geometric form and a artistic tool, which is also a structural strategy and an ornamental strategy at the same time. Added to Islamic architecture in the tenth and eleventh centuries, they soon became an attribute of transitional space such as domes, squinches, and cornices in which they mediate the transitional point between the plane and vault [1,2].

Muqarnas reached the apogee of its accomplishment in Abbasid Baghdad, where there is an emphasis on modular repeat and layered projection and highly defined treatment of surfaces. These arrangements served as aesthetic, as well as, symbolic purposes and represented mathematical understanding, workmanship, and a spiritual context of the Islamic Golden Period. The Abbasid Palace, the object of the current study, is a particularly interesting case study, mainly because the overall condition of its muqarnas is comparatively well preserved as well as due to the relative visibility of its geometry as opposed to the extensive deteriorations which have occurred over the centuries. FIGURE 1.

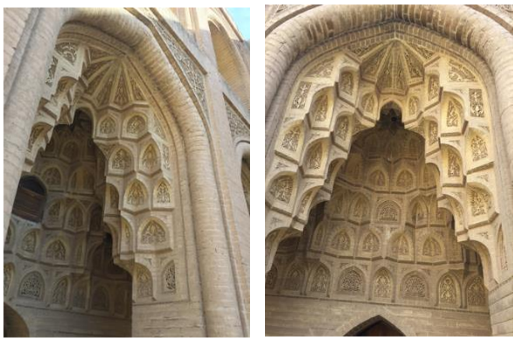

FIGURE 1. The Abbasid Palace *Muqarnas* in Baghdad, showing the layered, modular geometry and ornamental detailing characteristic of Abbasid architectural heritage. Source: author

The current research locates itself in the context of a modern intellectual debate about the interconnection of heritage-conservation issues and the rapidly developing environment of sophisticated digital technologies. Traditional documentation methods (manual surveying, photogrammetric recording and line-drawing) have provided useful information about Islamic architecture over the past several decades, but often fall short of the subtle depth and curvature displayed by the morphology of *muqarnas*. Recent progress in depth estimation with AI, point-cloud production, and three-dimensional modelling [7] [13] allows an opportunity to overcome such limitations through the creation of detailed and high-resolution digital representations.

The study hence functions in a gray area between heritage documentation, computational modelling and AI-driven analysis. It aims to represent a morpheme quantification workflow that is repeatable in the context of testing the possibilities of uniting open-source AI and typical three-dimensional reconstruction tools. Finally, the research enhances the bigger debate concerning how digital heritage tools can be used to inform conservation, education, as well as create understanding of the architectural heritage of Islam.

The discussed art of *muqarnas* of the Abbasid Palace is limited to explain how the artificial intelligence could produce objective, quantitative knowledge of the historic form and unveil the scholarly gap between old architectural historiography and the current practice of the digital world.

3.2 Data Collection and Analysis

The methodological rigor and reproducibility were secured in the present research because a systematic methodology was used. Information retrieving and processing have been planned in four main blocks, the following way:

3.2.1. Image Acquisition

Diffuse daylight was used as the source of light to ensure clarity of the image and diminish shadowing by recording high-resolution images. The photographs were saved as RAW files and later converted to quality JPEG pictures; one of them was selected to be studied in detail.

3.2.2. Depth Estimation

The depth estimation was estimated using MiDaS model, a pre-trained artificial intelligence (AI) implemented on deep learning to infer depth of a single RGB input. In order to get the data ready to use to make inferences, the size of image was reduced to 384 384 pixels and scalarized in [0 1]. An automated Python script to carry out the whole process of processing on MiDaS was created using the help of ChatGPT, which is a sophisticated AI mode that can produce human language and synthesise running code. This script has been run using the Google Colab platform that uses cloud-based acceleration with GPU to improve speed and compute throughput. The FIGURE 2 shows the output depth map given by the MiDaS model.

3.2.3. Point-Cloud Generation

Depth map resolution of MiDaS produced a point cloud representation of the muqarnas surface during a grid-based rendering method. A Python program was established to measure the produced point cloud, so the discrete geometric properties like the area of planes, average curvature, and surface apart could be estimated.

3.2.4.. Quantitative Study of Reconstructed Geometry of Muqarnas

The statistical analysis of quantitative output provided by the point-cloud script was performed with the purpose of assessing the accuracy of reconstruction. The results shows substantial coincidences between the calculated values and reconstruction values made with the help of scholisti researchers which implies that the suggested technique provided a reliable sample of muqarnas geometry. FIGURE 2.

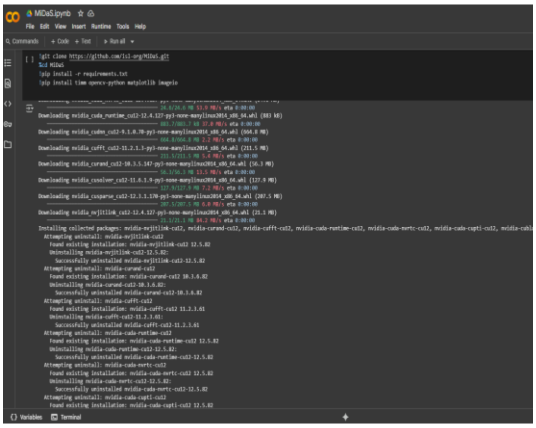

FIGURE 2. Installation of the MiDaS Depth Estimation Model and Dependencies in Google Colab Environment. Source: author

The suggested approach produced one-channel grayscale depth maps where greater pixels values related to the areas that were closer to the camera. Although the first MiDaS produced depth representations, these were not sufficiently clear and sharp especially in those areas of small geometric detail. Another deep-learning model, Depth Anything, therefore, came along to produce finetuned depth maps that provided high spatial information and general consistency. FIGURE 3.

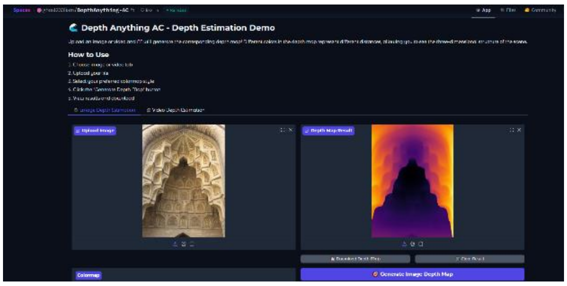

FIGURE 3. Depth Anything AI Tool Interface Showing Depth Estimation of the Abbasid Palace Muqarnas. Source: author

The enhanced-depth maps were the main input towards the building of the three dimensional point cloud data set. Postprocessing was performed by rescaling the depth values using relative proportions to keep and enhance contrast by histogram equalization. It was visually confirmed that illumination was on the right level as depth gradients recorded architectural features properly. Subsequently, the resulting depth images formed a strong quantitative basis upon which successive point clouds could be generated as well as the basis on which morphological analyses were to be performed.

3.2.5. Development of point cloud

The process involved the direct extraction of point clouds of the performed depth maps by a custom Python script developed by Open AI -ChatGPT and used to loop through pixel points extracting X and Y image coordinates and associated Z depth value. Normalization of pixel coordinates referred closely to reality on scale, given emphasis was put on relative over absolute dimensions. The individual pixel triplets (X,Y,Z) were saved as a row in a CSV file and then translated in ascii format (.ASC) which can be used interchangeably with 3D-processing programs like www.meshlab.net along with SculptGL. Random point sets were also used to plot depth maps and were compared to the original point sets to make sure the position was accurate as well. The dense point clouds which were generated at this step consisted of thousands of data points which captured the three dimensions of the muqarnas along with vivid flexibility of the surface in significant detail. FIGURE 4.

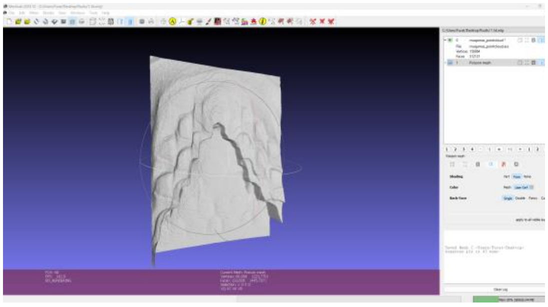

FIGURE 4. 3D Mesh Reconstruction of the Muqarnas Using the Poisson Surface Algorithm in MeshLab. Source: author

3.2.6. Three-Dimensional Model Reconstruction and Analysis

All point cloud data were imported into MeshLab where the surface was reconstructed and morphology analysed in three dimensions. The Geometry of the muqarnas was reconstructed and the poisson surface reconstruction algorithm was run: it generated a water tight mesh. Analysis of curvature was applied with MeshLab Compute Curvatures filter to the mean curvature per vertex; this data was exported as vertex qualities at the same mesh file. A Python script developed with the help of OpenAI ChatGPT was run in Google Colab, and it calculated the exported data and drew a histogram, which demonstrates how many times each of the values of curvature appeared on the surface of muqarnas.

The aim of this step was to quantify (and visualize) the geometry complexity of the muqarnas, in a way that was repeatable. The mean curvature values have been computed and a histogram plotted in which the patterns in the surface transitioning between the flat, concave and convex regions can be seen, providing objective data with which morphological interpretation can be backed by.

3.2.7. Data Interpretation

The numerical results were discussed in combination with qualitative data in order to create an in-depth insight into the muqarnas morphology. Plots of histograms were also constructed showing means of the curvature values that were used to give a quantitative overview of the proportion of surface complexity localised throughout the reconstructed mesh. The percentages of small, medium an large morphological units were computed to describe the compositional rational and modular repeatability of the muqarnas design. Table 1

Table 1. Summary of the AI-Driven Workflow for Morphological Analysis of Muqarnas. Source: author

Step No.	Methodological Step	Tool / Model Used	Scientific Purpose
1	**Image Acquisition**	High-resolution photography (RAW to JPEG)	Capturing a clear input image for depth processing and digital reconstruction
2	**Initial Depth Estimation**	MiDaS (Monocular Depth Estimation Model)	Generating the initial depth map from a single RGB image
3	**Enhanced Depth Estimation**	Depth Anything AI Model	Producing higher-fidelity depth maps for fine geometric detail
4	**Point Cloud Generation**	Custom Python Script (NumPy, OpenCV)	Converting depth maps into structured 3D (X, Y, Z) point data
5	**Point Cloud Processing & Export**	Google Colab, CSV/ASCII Format	Preparing point cloud data for mesh reconstruction and curvature analysis
6	**3D Mesh Reconstruction**	MeshLab + Poisson Surface Reconstruction	Creating a watertight 3D mesh to represent the muqarnas surface geometry
7	**Curvature Analysis**	MeshLab + Python (Open3D Library)	Extracting and analyzing per-vertex curvature values across the surface
8	**Quantitative Visualization and Interpretation**	Python (Statistical Analysis + Histograms)	Visualizing geometric complexity and categorizing morphological units quantitatively

4. Results and Discussions

It applied AI-based methods of study on Abbasid muqarnas to give the complete set of visual and quantitative artifacts explaining the sophisticated geometry of such structures. To make it clear, Table 2 outlines the key data products, extracted during the analysis to help simplify their understanding, their descriptions, and the exposition of their relevance. Taken together, these deliverables provide approximately both quantitative and qualitative views of the geometry and composition of the muqarnas and form the basis of later Figures and discussion.

Table 2. Descriptive Table Illustrating the Possible Outputs. Source: author

Output	Description	Significance
Depth Map Histogram	Displays the distribution of depth in the image	Studying topographic variations and highlighting low and prominent areas
3D Point Cloud (CSV)	XYZ coordinates of all points, converted into a 3D representation	Transforming a 2D shape into a 3D model for processing
Curvature Statistics	Mean curvature	Comparison and analysis of transformations and geometric repetition
Mesh 3D Model (OBJ/STL)	Closed 3D model ready for export	Documentation, 3D printing, integration into design datasets

FIGURE 5 illustrates an example of a depth map generated with the Depth Anything model. Overall compared to MiDaS, the method was able to produce depth images with more smooth and well defined gradients across the surface of the muqarnas specifically in areas where there were more complex stepped shapes. The visualization shows that depth estimation with AI is able to reproduce some of the nuances that are typically lost in traditional documentation of architectural design

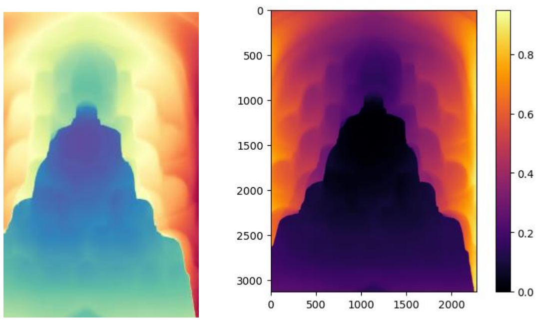

Fig 5. Depth Map of the Muqarnas Generated Using the Depth Anything AI Model. Source: author

In addition, FIGURE 6 shows a depth map produced by MiDaS to complement this analysis. As the MiDaS outcome could give a convenient overall representation of relative depth, the decrease in precision of making finer geometric distinctions was noted. Little recourses and subtle contours were made more homogenous in the output of MiDaS, thus strengthening the choice of using more accurate depth estimation tools to improve the process of point cloud creation and ensure the credibility of segmentation. An OpenAI ChatGPT-created Python program has been run, inside the Google Colab framework, to retrieve the numerical depth-based in the Depth Anything image.

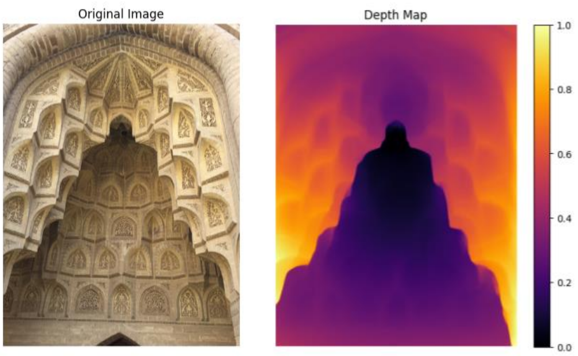

FIGURE 6. Depth Map of the Muqarnas Generated Using MiDaS AI Model. Source: author

FIGURE 7 is a histogram based on a script I wrote with Python, analysing the raw depth values produced by Depth Anything AI model. The histogram allows giving a quantitative image of depth distribution on the muqarnas surface in which a multi-modal distribution is observed with the presence of a number of distinct peaks at depths that range between 40 and 100 units. These heights reflect repetitive stepped setbacks and stratified protrusions that are characteristic of Abbasid muqarnas, and the tails of the distribution define the flattest and deepest structural areas.

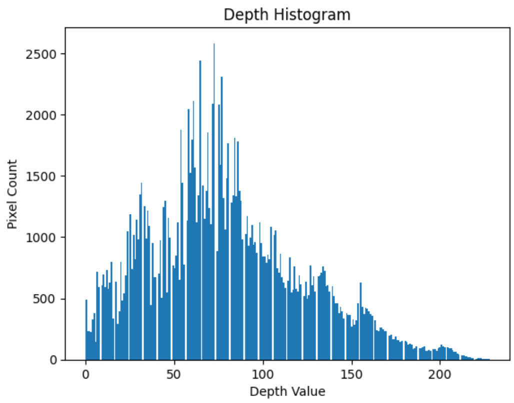

FIGURE 7. Depth Histogram of the Muqarnas. Source: author

In the current study, the generation of depth histogram deserves central place since it allows describing surface complexity in an objective way instead of visual examination only. In addition, this histogram allows converting the surface into discrete morphological layers by establishing accurate numerical values to use as the breakpoints of the surface, therefore, establishing a unified system to classify areas of various depths. The histogram can also provide a clear baseline on which subject muqarnas can be contrasted to other extant examples or with any follow-on scan, providing a chance to identify any changes wrought by erosion or repair. Analytically, the histogram supports the fact that the AI model generates a continuous and reliable depth range with no significant artifacts thus validating the applicability of the post-acquisition processing workflow to adequately capture minimal topographic change. In turn, the combination of visual depth maps and quantitative histogram analysis enhances the ability of the study to interpret, compare, and reproduce multidimensional heritages geometries in a replicable way.

Following the point cloud processing stage in FIGURE 8, the Poisson Surface Reconstruction algorithm led to the construction of a watertight three-dimensional mesh that faithfully captured the layered and stepped profile typical of Abbasid muqarnas. Visual comparison of the reconstructed mesh and original photographic images confirmed that it was an accurate representation of the volumetric attributes and spatial characteristics of the surface. Nevertheless, it is also essential to remember that the quality of reconstruction depends on other factors, including the quality and resolution of the source image, the photography lightning conditions, and even the presence of shadows that may hide the minor details or cause artifacts to appear in the depth estimation.

To further evaluate the morphological properties of the reconstructed muqarnas surface, mesh was exported via MeshLab in PLY format with the Save Vertex Quality enabled, so that the calculated per-vertex mean curvature would be embedded in file metadata. This PLY file was further read into the Python via the Open3D library wherein the values of the for the curvature was extracted into a systematic dataset. That allowed a more sophisticated statistical analysis and visualization of the curvature distribution possible than could be done with MeshLab alone. Processing the raw curvature numbers directly in program enabled the derivation of summary statistics,such as minimum, maximum, mean, and standard deviation, as well as the creation of bespoke histograms and categorization thresholds into the particular geometry of interest. This step incorporated into the flow of work increased both reproducibility and transparency as it ensured the entirety of the results were not merely interpreted visually.

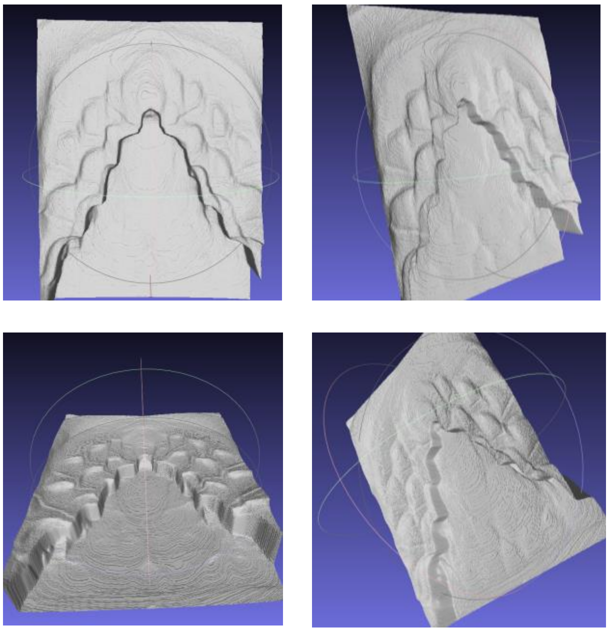

FIGURE 8. Multiple Views of the Reconstructed 3D points cloud of the Muqarnas imported in MeshLab.. Source: author

Analysis was conducted to examine the mean curvature of the reconstructed 3D mesh in detail to the quantitative assessment of the surface geometry. The resultant curvature map, shown in FIGURE 9 (left) gives variation in color that changes its hue to reflect the difference in curvature across the muqarnas. Here red areas will be those with larger positive curvature values corresponding to strongly convex ridges and edges and the blue and green will be flatter or concave areas. Such distinction allows recognizing of stepped projections and recessed sqn with reference to Abbasid muqarnas construction. To supplement this illustration, the histogram presented in FIGURE 9 (right) shows the distribution of the values of the curvature throughout the whole mesh.

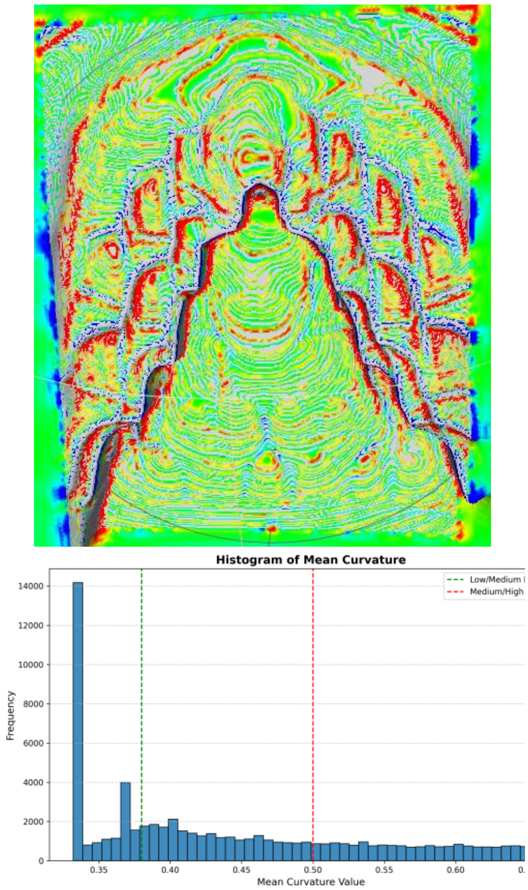

FIGURE 9. Mean Curvature Map and Corresponding Histogram of the Reconstructed Muqarnas Surface. Source: author

The analysis of the curvature of the muqarnas under investigation demonstrates that the values of curvature are rather low, with the prevailing amount of low intermediate values reaffirming the fact that a relatively low amount of elevations is occupied by gently curved areas rather than harsh protrusions. In the lower range of the curvature, evidently between 0.35 and 0.45, are a series of clusters representing transition zones of decorative tiers. The vertical dashed lines represent surfaces above which such measurements are used to demarcate areas of the surface into low, medium, and high curvature areas, making interpretation of its geometry more systematic and it is easier to segment into discrete forms via morphological units. A combination of both the curve mapping along with histogram analysis therefore offers not only visual but quantitative support to the hierarchical structure of the muqarnas. Observations of modular repetition and the emphasis on the systematic change of curvature along the vertical length of the element are strengthened by the tendency of higher-curvature zones to concentrate spatially along horizontal bands. Taken together, these data provide evidence in favor of the potential of AI-enabled workflows in not just producing faithful 3D geometry but can also yield reproducible quantitative measurements, which might be used in comparative heritage structure studies or as part of longer-term monitoring of conservation work.

Table 3: Classification of Curvature Ranges and Corresponding Surface Characteristics of the Muqarnas Mesh Source: author

Curvature Range	Geometric Description	Number of Points	Percentage (%)
Low (0.33–0.38)	Nearly flat surfaces	24,071	36.0
Medium (0.38–0.50)	Areas with moderate curvature transitions	23,487	35.1
High (0.50–0.67)	Pronounced protrusions and sharp edges	19,348	28.9

5. Conclusion

In this work, the reasonable part of documenting, analysing, and quantifying heritage architectural elements using artificial-intelligence based approaches and making it a replicable workflow is tested using the Abbasid Palace muqarnas corpus as a case. The practical implementation of the MiDaS and Depth Anythingdepth estimation models allowed creating reliable depth maps, which simplified the formation of three-dimensional point clouds and subsequent reconstruction of the mesh. This synthesis, Poisson Surface Reconstruction and curvature analyses generated high-fidelity 3D models that most precisely conducted the recursive geometry of the layered and modular Abbasid muqarnas.

The workflow provided quantitative results that could be reproduced: depth histograms, curvature distributions, and morphological segmentation of discrete objects in the surface. These findings indicated that most parts of the muqarnas surface were governed by areas of moderately low curvature, in between isolated areas of high curvature, which were linked with decorative projections and recessions. The methodology was found to be helpful in showcasing the practical use case of combining the datasets created by the use of AI and the ability provided by open-source processing tools to gain detail and precision that would have been impossible to capture with manual documentation.

Altogether, the study notes that AI-aided depth estimate and point-cloud analysis have an immense impact on the objectivity and reproducibility of the documenting of heritage. The metadata framework created here is flexible and provides a record of digital preservation as well as a quantitative standard to facilitate conservation tracking, comparative morphological interest and development of teaching or interpretive 3D deliverables. Further, it demonstrates how a complex element of heritage can be reproduced as a 3D model with only a single two-dimensional photograph, enabling downstream use like 3-D printing, electronic reconstruction, virtual-reality tours, and other computational modelling tools that further the conservation, education, and involvement with the heritage.

6. Research Limitation

The empirical tests run below show that the offered methodological pipeline of morphological analysis of muqarnas produced promising results. However, there are a number of limitations which should be explicitly identified. To begin with, depth maps produced by MiDaS and Depth Anything rely heavily on the image quality and light, with which they are launched. Areas with strong shadows or without adequate contrast were less suited to strong depth distinction and hence per force influence the ensuing point-cloud density and formal reconstruction conceit. Second, the workflow is based on single-image depth estimation, which is an approach that is easy to access and, at the same time, allows high rates of productivity but inherently entails the impossibility of achieving absolute scale, as well as geometry, referencing when compared to photogrammetry or laser scanning. Third, segmentation and classification was performed successfully, but they use thresholds to distinguish between ranges of curvature and depth which were empirically defined and could possibly require recalibration in order to analyse other case studies or more complex surfaces. Lastly, limitations in computer resources occasionally placed limitations on batch size and processing speed due to computational constraints, specifically GPU memory constraints when working with high-resolution data in Google Colab.

7. Research Recommendations:

Some of the paths of future research are clarified with the help of the presented work:

• Multi-View Data Integration:Integration of the multi-view photogrammetry techniques into monocular AI-based depth estimation can help to improve accuracy and to provide robust scale references.

Segmentation Algorithm Optimization: The application of advanced deep-learning-based semantic segmentation models will probably optimise the segmentation of geometric components of the documented facade.

Ground-Truth Comparison: It should be able to compare the proposed workflow with laser-scanning data where possible to enable the formulation of systematic accuracy decisions.

• Generalization to novel heritage settings: By expanding this approachology to other muqarnas and other similar intricate Islamic architectural compositions, one can stretch the applicability of the approachology.

• Interactive Model Construction: Connecting the reconstructed meshes to quantitative curvature data to visualisation platforms would allow facilitating educational-related outreach activities, and conservation planning and outreach to the general population.

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توظيف تقنيات الذكاء الاصطناعي في تحليل الخصائص الشكلية للعناصر التراثية في العراق

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الخلاصة –تناول هذا البحث توظيف أدوات وتقنيات الذكاء الاصطناعي في التحليل الشكلي والتوثيق الرقمي للعناصر المعمارية التراثية، مع التركيز على مقرنصات القصر العباسي في بغداد. تم تطوير منهجية عمل قابلة للتكرار تجمع بين نماذج التقدير الأحادي للعمق، مثل MiDaS وDepth Anything، وبين توليد السحب النقطية وإعادة الإعمار ثلاثي الأبعاد وتحليل الانحناء الكمي. جرى معالجة الصور عالية الدقة لإنتاج خرائط عمق تفصيلية، حُوِّلت لاحقًا إلى سحب نقطية كثيفة، ثم أُعيد تشكيلها إلى شبكات ثلاثية الأبعاد محكمة الإغلاق باستخدام خوارزمية .Poisson Surface Reconstruction كما تم استخراج مقاييس الانحناء عند كل نقطة مرئية وتمثيلها بصريًا عبر خرائط ملونة وهيستوغرامات، كاشفةً عن سيادة مناطق ذات انحناء منخفض نسبيًا تتخللها مناطق موضعية مرتفعة الانحناء ترتبط بالتجاويف الزخرفية والبروزات المتدرجة. أتاح تقسيم البيانات وتصنيفها وفق قيم العمق والانحناء تفكيك السطح إلى وحدات شكلية منفصلة، بما يسهم في تفسير منظم لطبيعة تصميمه الهرمي.

تؤكد نتائج البحث إمكانات دمج أدوات الذكاء الاصطناعي المتاحة مع منصات المعالجة ثلاثية الأبعاد مفتوحة المصدر في تعزيز دقة وموضوعية وقابلية تكرار عمليات التوثيق التراثي. وتقدّم المنهجية المقترحة إطارًا قابلاً للتوسّع لتحليل عناصر تاريخية مشابهة، كما تسهم في دعم النقاش الأوسع حول الحفظ الرقمي، ومراقبة عمليات الصيانة، وفهم التراث المعماري الإسلامي..

الكلمات الرئيسية: الذكاء الاصطناعي، العمارة، المقرنصات العباسية، MiDaS، إعادة الإعمار ثلاثي الأبعاد، التوثيق التراثي.