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Automatic Image Processing for Detecting Courtyards Geo-Locations of Urban Fabric of Mosul Old City

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Abstract

In the post-conflict periods, cities often suffer significant damage, requiring more effort to rebuild. However, proper reconstruction requires documentation of the previous urban fabric. Aerial photography is an important element in documenting the components of the urban fabric. In 2017, extensive destruction occurred in many areas of Mosul's Old City (MOC), with some districts suffering so much damage that the distinctive urban fabric was lost. The MOC is characterized by its dense urban structure and the presence of internal courtyards within its buildings. This paper aims to utilize historical aerial photographs to relocate the position of building courtyards in parts of the MOC urban fabric, as one of the first steps in a comprehensive plan to represent them in the absence of the necessary documents and surveys. The methodology proposed in this paper involves a series of automated image processing (AIP) stages, where the position of the courtyard can be determined in the form of a network whose geolocation can be easily identified. This study offers a stepwise and semi-automated methodology for courtyard location determination. Furthermore, this study demonstrates the efficacy of applying automated image processing techniques in the context of preventive conservation and protection of urban structures in historic cities. However, the study encountered limitations related to the type and accuracy of the available aerial images. Additionally, the potential use of more advanced software could yield more accurate results or facilitate the generalization of findings to other cities, a direction suggested for future research.

1. Introduction

Mosul Old City (MOC), as one of the historic Islamic Arabic cities, is characterized by its compact urban fabric, organic pattern, and the presence of internal courtyards in buildings. These courtyards serve not only aesthetic, social, and functional purposes but also act as outlets and elements for lighting and ventilation. Religious rules, socio-cultural aspects, and economic factors are the foremost elements that shaped the urban fabric of MOC (Ismaeel, 2023). Its structure results from integrated factors, including urban spatial form, architectural form, and community lifestyle, to meet the requirements of its inhabitants (Al-Harami & Furlan, 2019). The emerging social, economic, and behavioral changes in the nature of its community, resulting from social modifications and functional developments, have led to additional problems and issues for the heritage districts of such old cities (Al-Bishawi & Ghadban, 2015; Alnaim, 2024).

Understanding a city's urban structure is intrinsically linked to the perception of the associations between various features and the qualities of the residents' context, characteristics, movement, and connections. It is essential to examine multiple disciplines to study the form of cities. These disciplines focus on different hypotheses and methodologies, leading to a comprehensive understanding of urban configuration (Furlan & Faggion, 2017). Urban designers and heritage specialists consistently require dynamic spatial documentation of built heritage that provides adaptable and multipurpose instruments to interactively understand data on heritage constructions within their surroundings (Al-Ruzouq, 2012; Doneus et al., 2017). Preparing for the consequences of natural disasters and human conflicts, and devising means to alleviate their impact, necessitates accurate data and appropriate documentation of all structures, facilities, and infrastructure that may be damaged or destroyed (Susaki, 2013). Post-conflict reconstruction of multipart urban contexts with serious infrastructure damage presents a critical challenge for construction experts, urban designers, and decision-makers (Saeed et al., 2021; Hamad & Ismaeel, 2023). Determining the urban fabric when most of its arrangement is destroyed or significantly damaged makes it difficult to explore the urban design of historic cities (Al-Harami & Furlan, 2019). During the military operations in 2017, the urban fabric of Mosul Old City (MOC) was subjected to extensive destruction, with some areas experiencing a damage rate of 100%, leading to the complete disappearance of many buildings and landmarks (UNEP, 2018).

This necessitates the development of plans to redraw the borders of these buildings and facilities to ensure their reconstruction in their original form. Currently, parts of the city's urban fabric still suffer from limited reconstruction efforts due to economic and political motives (UN-Habitat & UNESCO, 2018). The lack of detailed documents, records, and spatial information on these areas is a major obstacle in their reconstruction process (Jasim, & Ismaeel, 2025). Globally, in similar contexts, various methods and techniques have been employed to obtain documents and plans that contribute to the revival of such buildings (Ismaeel, & Alabaachi, 2024).

The comparative analysis of research methodologies in urban studies and remote sensing reveals significant advancements in detecting and analyzing urban features, particularly interior courtyards and broader urban fabrics. Yazdi et al. (2021) and Chen et al. (2022) exemplify the use of deep learning techniques for identifying and segmenting interior courtyards from aerial and remote sensing images. Yazdi et al. (2021) employ deep learning for object detection and image segmentation to extract central courtyard features, facilitating the automatic identification of courtyard geo-locations within urban fabrics across various historical cities in Iran. This study highlights the efficacy of deep learning in feature extraction and underscores a significant correlation between the length and width of courtyards, providing valuable insights into urban morphological patterns. Similarly, Chen et al. (2022) utilize Mask Region-based Convolutional Neural Networks (Mask R-CNN) to automatically extract spatial objects, including courtyards, from high-resolution remote sensing images. The success rate of 92% in location perception achieved by Chen et al. (2022) demonstrates the robustness of Mask R-CNN in geographical location recognition, showcasing the potential of advanced neural network architectures in enhancing the accuracy and efficiency of urban feature detection. While Ismaeel, et al. (2022) employed GIS software to predict the locations of the shortages in high school buildings in a part of Mosul.

In contrast, studies focused on automatic image processing for urban fabric classification and detection employ diverse methodologies, each contributing uniquely to the field. Fang et al. (2020) introduce a novel CNN-based model for classifying urban fabric types, city origins, and construction periods using a multi-spatial scale dataset. This model's effectiveness in classifying urban fabric patterns and construction periods highlights the versatility of CNN architectures in handling complex urban datasets. The use of multi-spatial scale data further enhances the model's ability to capture intricate urban patterns, providing a comprehensive framework for urban fabric classification. Sirmacek & Unsalan (2011) propose a probabilistic framework for detecting urban regions using local features, adaptable for identifying courtyards' geo-locations within urban fabrics. The robustness of this method, confirmed through extensive testing, underscores the practical usefulness of probabilistic frameworks in urban region detection. The introduction of four local feature extraction methods and variable kernel density estimation for probability function further enhances the method's adaptability and accuracy. Shi et al. (2015) and Shi & Mao (2017) contribute to the field by developing methods for automatic urban area detection using multiple features and improved D-S evidence theory, respectively. Shi et al. (2015) employ a two-stage method utilizing multiple features with different resolutions for detection and a weighted Gaussian voting matrix for corner point integration. This approach improves the accuracy of urban area detection and reduces false negatives effectively, demonstrating the potential of multi-feature fusion techniques in enhancing detection performance.

Shi & Mao (2017) introduce improved D-S evidence theory (IDSET) for automatic detection of urban areas, achieving full automation without requiring parameter adjustments. The enhanced urban area detection capability of IDSET highlights the advantages of evidence theory in handling uncertainty and improving detection accuracy in complex urban environments. The comparative analysis of these studies reveals key insights into the advancements and applications of technology in urban feature detection and classification.

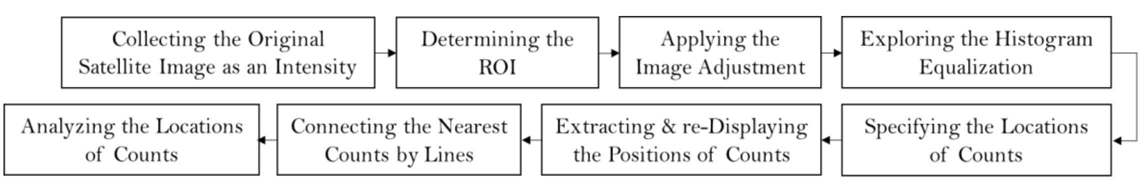
The use of deep learning and CNN models in the studies by Yazdi et al. (2021) and Chen et al. (2022) demonstrates the potential of advanced neural network architectures in enhancing the accuracy and efficiency of feature extraction and geographical location recognition. The application of probabilistic frameworks and multi-feature fusion techniques in the studies by Sirmacek & Unsalan (2011), Shi et al. (2015), and Shi & Mao (2017) further underscores the versatility and robustness of these methodologies in handling complex urban datasets and improving detection performance. The integration of these advanced technologies and methodologies provides a comprehensive framework for urban feature detection and classification, offering valuable insights into urban morphological patterns and enhancing the understanding of urban environments.

The existing literature primarily addresses urban fabric classification, buildings detection in various historic cities, and the use of advanced techniques and neural network architectures for feature extraction and geographical location recognition. However, none of the studies explicitly target the intricate and culturally significant urban fabric of Mosul Old City, which presents distinct challenges and opportunities due to its historical layers, architectural diversity, and the impact of recent conflicts

The current research aims to leverage the process of analyzing aerial images as a means of geolocating the positions of building courtyards within the urban fabric of a completely destroyed sector in MOC. For this study, it is assumed that no available document clarifies the features of the urban area under investigation. Despite the existence of numerous studies and research on MOC, there are no complete surveys of the city's areas that are both comprehensive and accurate, as many studies cover the city's districts partially or incompletely. This is what the current paper seeks to achieve in its initial steps toward providing comprehensive and accurate documentation for all parts of the city.

2. Data and Methods

At this stage, one of the aerial photographs of a part of MOC urban fabric was selected to test the efficiency of the methodology used to geolocate the buildings, particularly their courtyards. The selected area is located south of the historic city and includes a large number of traditional buildings. In the practical study, an Aerial Image Processing (AIP) procedure for identifying the locations of courtyards within a group of houses in an aerial image of MOC is adopted. The proposed automatic procedure comprises multiple image processing stages, as follows (Figure 1):



Source: Authors, 2025

Figure 1. The Adopted Multiple Image Processing Stages

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2.1. Courtyard Buildings in MOC

A courtyard is typically an open space within a densely enclosed area (Pelorosso et al., 2017). Worldwide, the courtyard pattern is an ancient architectural form that has been constructed in hot zones from ancient civilizations to recent decades (Al-Hafitha et al., 2017; Naseri & Amini, 2022; Yu et al., 2023). Its design has been utilized since the Neolithic settlements (Zakaria & Kubota, 2014). The heritage buildings of Mosul, with their courtyards, reveal essential construction attitudes. They exhibit architectural mass style harmony, which relies on design conformity. This was the common model of housing design (Haraty et al., 2019). The courtyard building style in Mosul's Old City (MOC) continued without major changes for several centuries due to its fulfillment of many cultural, societal, and environmental requirements, and its acceptance by the local community as a successful architectural solution (Karofa, 2011; Baiz et al., 2016). Such buildings are inward-oriented rather than following modern outward-oriented construction patterns. Their plots offer access to natural lighting and ventilation for the enclosed rooms (Gupta et al., 2017; Hussein & Ismaeel, 2022; Kamelnia & Hanachi, 2022; Mohammed, 2023; Sun, 2024).

The simplicity of their design reduces unnecessary items that might expand the construction budget (Haraty et al., 2019). In MOC house designing, privacy is significantly an essential cultural demand that courtyards have been used to fulfill. Additionally, courtyards were utilized as the main meeting spaces for multiple uses in public buildings (Baiz et al., 2016). Few architectural elements are more closely related to comfort, protection, and security than the courtyard (Guedouh & Zemmouri, 2017; Xu et al., 2024). However, previous research on MOC courtyard buildings remains limited. These studies have primarily dealt with courtyard environmental functions, the impact of courtyard form on indoor thermal environments, ventilation results, or developing passive approaches and energy assessments by courtyards (Al-Hafith et al., 2019; Zakaria & Kubota, 2014). Hence, for such considerations, this paper adopts the MOC courtyard buildings as a case study. It seeks to experiment with the use of aerial photographs in relocating the positions of the building courtyards in a part of the urban fabric of MOC, as one of the first steps of a comprehensive plan to represent it in the absence of the required documents and surveys. The work methodology includes a set of successive phases of aerial image processing (AIP) to achieve the desired results

2.2. Aerial Photography and Built Heritage Documentation

Aerial photography is an essential element in documenting the components of any urban fabric. The growing concern for documentation represents a helpful advancement in the archiving of many heritage buildings (Vo et al., 2013; Murtiyoso et al., 2019). The study and analysis of image databases have become an increasingly effective field in response to the rising need for multimedia information in urban and infrastructure management (Khaleel, & Kasim, 2019). In the field of built heritage and environmental research, aerial images are broadly acknowledged as a valuable source of information. Old and historic aerial photographs are used in integrated studies within multidisciplinary scientific heritage projects for protection, analysis, and research purposes (Zapłata & Rożycki, 2015). Currently, these images are scientifically captured and may be readily accessible. Thus, the documentation of heritage can benefit from these information sources. In many cases of damaged built areas, the only existing data resource may be archival or historic aerial images. Aerial photographs support the documentation of the former status of historic buildings (Kharoufa, 2016), providing spatial resolution that facilitates the recognition of elements of one meter and assisting in the understanding of new aerial photographs, satellite images, or Airborne Laser Scanning data (Zapłata & Rożycki, 2015).

Using aerial images and photographs to record and document historic buildings has become a widespread alternative, producing an extraordinary amount of collections of high-resolution and georeferenced images of historic site details. These databases offer innovative means for specialists to capture, store, process, distribute, and visualize related documents and information (Themistocleous et al., 2015). They are utilized for the creation of three-dimensional photorealistic models that clarify building materials (Mohammed & Yahya, 2022). Precise examination of accumulated image data could expose vital damage to building elements (Al-Ruzouq, 2012). In the field of urban heritage documentation, although 3D techniques provide more complete and objective documentation of the items under study than similar 2D technologies, they are often more expensive. Cost is often a significant limitation, particularly in the heritage field. For example, laser scanners offer easy, fast, and precise outcomes; however, they require high expenses (Murtiyoso et al., 2019).

2.3. Automatic Image Processing - AIP

Due to the technical difficulties and complexities across several disciplines, experts strive to develop useful algorithms that assist in discovering alternative solutions suitable for achieving prompt resolutions to problems (Sundus, 2014). Digital image processing involves the analysis, representation, and manipulation of illustrative data by a computer (Kumar, 2014). It pertains to techniques for performing operations on an image to acquire an enhanced image or to extract various helpful information from it for decision-making purposes (Tyagi, 2018). Image computational analysis is experimental, as it typically involves tasks such as segmentation, extraction of representative features, matching, alignment, tracking, noise removal, geometric correction, edge and contrast enhancement, illumination correction, and three-dimensional reconstruction (David, 2008; Schindler et al., 2008; Bocher et al., 2018; Pasupuleti, 2024;). Executing these tasks requires a fully automated and effective method. Despite the challenges, image processing and analysis are suitable for a broad scope of applications. Applications involving 2D, 3D, or 4D information can be observed in surveillance, virtual reality, medicine, engineering, and materials sciences (Tavares, 2010; Bocher et al., 2018; Chen et al., 2021; Moon et al., 2022). Conventional examples of digital image processing include "fingerprint recognition, processing of aerial images, weather prediction, character recognition, face recognition, product inspection, and assembly" (Tyagi, 2018; Kirwale et al, 2021; Li et al., 2023).

2.4. Aerial Image Quality and AIP

The quality of the input image plays a critical role in the success of image analysis. The more useful information the original image contains, the more valuable information will be produced by the image processing analysis (Al-Ruzouq, 2012). Higher image quality simplifies tasks, making them easier to perform. Consequently, appropriate methods of image processing are essential (Tavares, 2010). With many readily accessible methods, the task of image preprocessing and attribute extraction necessitates the development of specific algorithms for particular problems under study by combining integrated functions and modifying their parameters (Bernard et al., 2024; Cazacu, 2021). Scientifically, a digital image is a matrix representation of a 2D image with a finite number of pixel elements, typically referred to as pixels, which are represented by numerical values (Tyagi, 2018). Most image processing operations are carried out in grayscale mode. For color image processing, a color image can be decomposed into red, green, and blue components, which are handled separately as grayscale images. Several levels of image processing operations are defined, including (1) Low-Level: Involves primitive operations on images; (2) Mid-Level: Involves operations for extracting characteristics; and (3) High-Level: Related to the examination and understanding of the subject for decision-making (Tyagi, 2018).

Focus in digital image processing systems arises from two principal application fields: the development of pictorial data for human understanding and the processing of image information for storage, transmission, and representation for autonomous machine perception (Kumar, 2014). To improve modeling precision, several experts have combined airborne information with digital maps. These methods may require a pre-existing building map and are often expensive to apply to large urban regions. Additional sources of information have been investigated as alternatives to digital images, such as aerial or satellite images. Aerial images have the potential to provide data that illustrates specific structures in complex urban areas. Current research demonstrates that a key feature of effective data integration in 3D modeling is acquiring geolocation and building shape data from 2D images, as well as obtaining 3D coordinate data from airborne methods (Susaki, 2013). Detailed 3D models in dense urban areas are not often available due to inappropriate measurement settings. Several researchers have used an effective methodology to create 3D building models in complicated urban regions, which emphasize competence over precision, location, and size of buildings (Ota & Susaki, 2010).

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3. Result and Discussion

3.1. Collecting the Original Aerial Image as an Intensity

This step focuses on collecting and converting the original aerial image into a greyscale or intensity type. The original image can be obtained from the internet or from any aerial acquisition device. Typically, any aerial image is colored. The color of each pixel in the image is essentially a combination between the Red, Green, and Blue (RGB) levels of image values. The combination between the red channel IR (x, y, 1): Z2[0, 255], green channel IG (x, y, 2): Z2[0, 255] and blue channel IB (x, y, 3): Z2[0, 255] produces the colored image IRGB (x, y, z). To convert the colored image into the grayscale or intensity image, the following equation (Equation 1) can be used (Matlab, 2001):

$$Igray\ (x, y) = 0.2989 * IR\ (x, y, 1) + 0.5870 * IG\ (x, y, 2) + 0.1140 * IB\ (x, y, 3) \ \ldots\ldots.. \ (Equation.1)$$

where Igray (x, y) is the resulted grayscale or intensity image Igray (x, y) : Z2[0, 255]. The intensity view of an original aerial image is given in Figure.2. This equation effectively transforms the RGB image into a grayscale image by calculating the weighted sum of the red, green, and blue components of each pixel.

3.2. Determining the Region of Interest (ROI)

This step focuses on determining the Region of Interest (ROI) within the original aerial image. This can simply be effectively implemented by cropping the insignificant regions of the original image (Al-Nima, 2017). The cropped image is illustrated in Figure 3. It emphasizes the region that contains a substantial number of courtyards. The coordinates of intensity image Igray (x, y) have been updated accordingly. The resulted image is identified here as I (x, y).

Source: https://www.ucl.ac.uk/archaeology/ucl-institute-archaeology

Figure 2. The Intensity View of an Original Aerial Image

Figure 3. The ROI Image that Focuses on the Region with Massive Number of Courts

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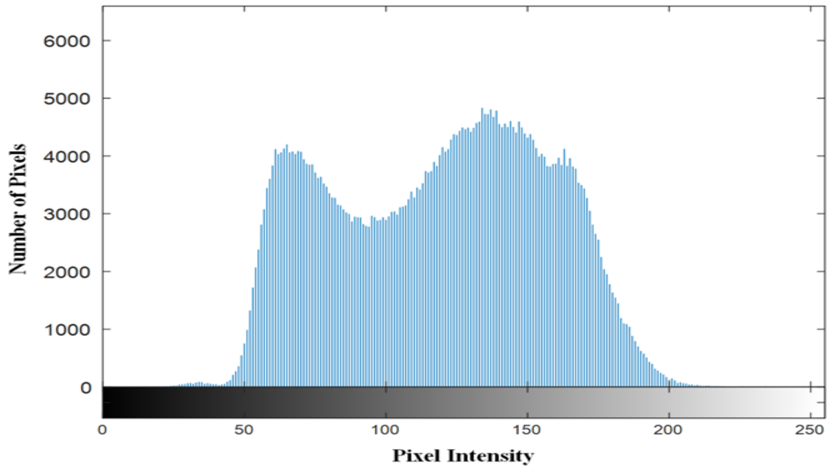
3.3. Applying the Contrast Adjustment

The issue with I(x, y) is that it exhibits a low contrast view. This can be clearly demonstrated by analyzing the histogram of the image, as shown in Figure 4. A histogram is utilized to analyze images (Al-Nima et al., 2015); it illustrates the relationship between the pixel intensities (grayscale values of pixels) and the number of pixels in the image.



Source: Authors, 2025

Figure 4. The Histogram of the Cropped Image

From Figure 4, it can be observed that the I(x, y) image has a low contrast view. This is because its histogram shows a limited range of pixel intensities that are covered by all the image pixels. There are grayscale intensities that have not been covered by image pixel values (such as the white and black intensities, which respectively have the values of 255 and 0). To address this issue, image contrast adjustment is employed. This process can adjust the pixel values to cover all the grayscale intensities, as shown in Figure 5. According to this figure, it can be expected that the resulting image J(x, y) has better contrast than I(x, y). This is because the entire grayscale intensity range [0, 255] is covered by the resulting pixel values. Figure 6 shows the resulting J(x, y) image.

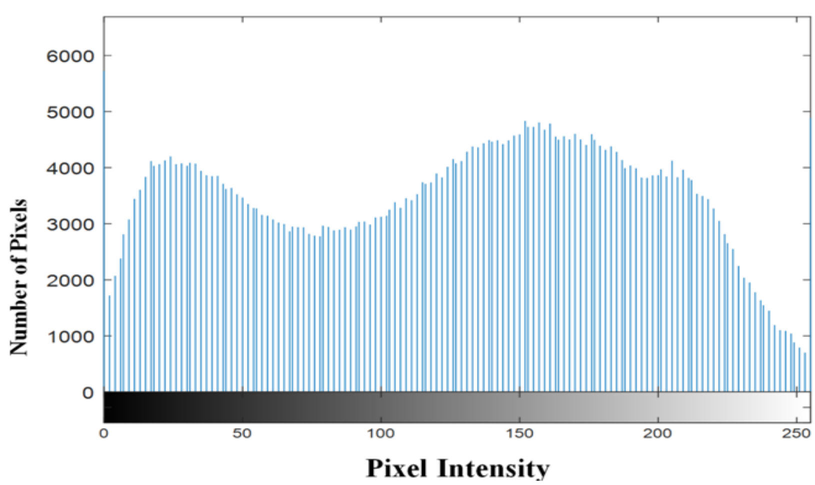


Figure 5. The Histogram of the Contrast Adjusted Image

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Source: Authors, 2025

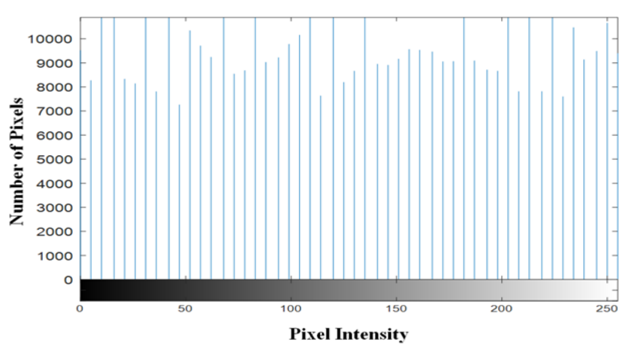
Figure 6. The Contrast Adjusted Image

3.4. Applying Histogram Equalization

The contrast-adjusted image J (x, y) necessitates illumination adjustments. As illustrated in Figure 6, certain regions within the image exhibit darkness, while others are overly illuminated. Consequently, equalizing the illumination across the entire image is essential (Mustafa, 2009). Histogram equalization presents a viable solution to this issue. As a technique within the realm of histogram modeling (Lim, 1990), it effectively distributes the illumination of an intensity image by equalizing the number of pixels across various grayscale intensities. Figures 7 and 8 depict the resultant image post-histogram equalization and its corresponding updated histogram, respectively. The resultant image, denoted as H (x, y), demonstrates a superior illumination distribution compared to the I (x, y) and J (x, y) images.

Source: Authors, 2025

Figure 7. The Resultant Image Following the Application of Histogram Equalization



Source: Authors, 2025

Figure 8. The Histogram Subsequent to the Application of Histogram Equalization

3.5. Specifying the locations of courts

To accurately determine the locations of courts, it is imperative to adhere to their distinctive features. The intensity level of the courts emerges as the optimal criterion for identifying their positions. Empirical findings indicate that the locations of x and y can be accentuated if H(x, y) < 100. The resultant image, identified as L (x, y), amalgamates the H (x, y) image with the determined court locations. The resultant L (x, y) image is presented in Figure 9.

Source: Authors, 2025

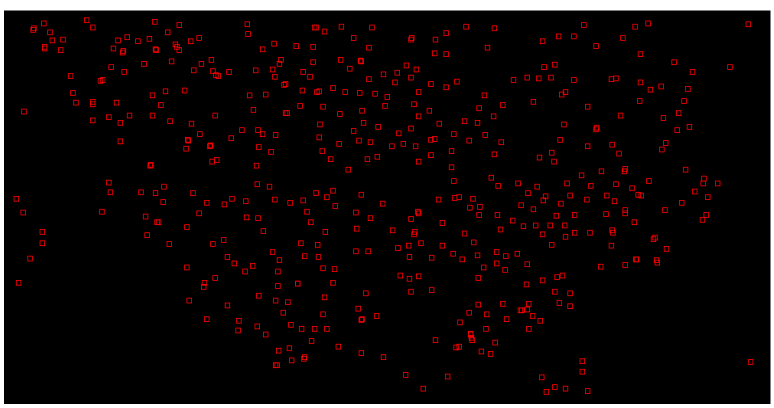
Figure 9. The Resultant Image Following the Specification of Court Locations

3.6. Extracting and re-Displaying the Positions of Courts

To facilitate a more comprehensive analysis of the court positions, it is beneficial to extract and re-display these positions within a new image. This new image can be designated as P(x, y). The following equation (Equation 2) can be employed for this purpose:

$$P(x,y)=\begin{cases} L(x,y) \text{ if } L(x,y)<100 \\ 0 \text{ Otherwise} \end{cases} \quad \text{...........(Equation. 2)}$$

The resultant image features a black background with the specified court locations (Figure 10). At this stage, any color with a value less than 100 is eliminated, as this value is reserved for the required locations with a black background provided, and the values of all other pixels less than 100 are converted to zeros.



Source: Authors, 2025

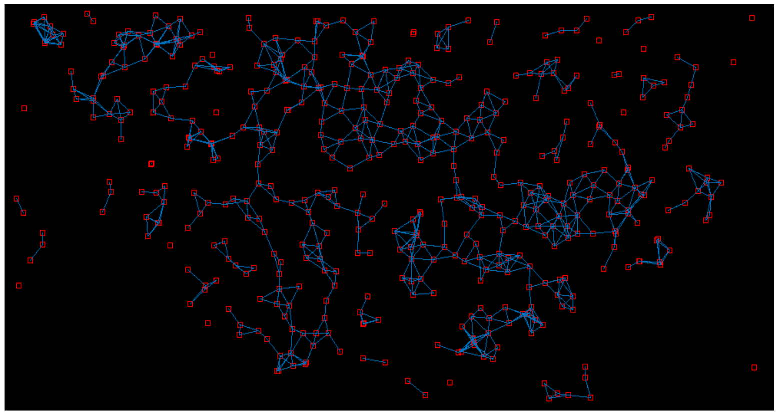
Figure 10. The Court Locations with a Back Background

3.7. Connecting the Nearest Courts by Lines

At this juncture, the nearest positions of the courts can be ascertained. Euclidean distance has been employed in this study (Mustafa & Al-Nima, 2009). Thus, the distance D between any two courts has been calculated according to the following distance equation (Equation 3):

$$D = \sqrt{(P(x1) - P(x2))^2 + (P(y1) - P(y2))^2} \quad \ldots\ldots\ldots \text{(Equation.3)}$$

Consequently, the nearest distances have been determined according to a suitable tolerance. Experimentally, the tolerance is considered here to be less than 30 pixels, as depicted in Figure 11, which is obtained after connecting the nearest courts. Through practical application, it was found that the closest appropriate distance is no more than 30 pixels. Finally, the pixel positions of the courtyards of the houses within the aerial image have been established, and in the subsequent stage, it is possible to determine the geo-reference position on the MOC map, thereby accurately assigning the geo-location of all elements within the image.



Source: Authors, 2025

Figure 11. The Resultant Image Following the Connection of the Nearest Courts

Based on the research findings, it can be concluded that identifying the locations of destroyed buildings and their components at both urban and planning levels is crucial for the efficient and effective reconstruction of cities following war and conflict. This process aids strategic planning by providing a clear understanding of the post-destruction landscape, thereby enabling the prioritization of areas in urgent need of reconstruction. Additionally, it assists in the optimal allocation of resources, ensuring that efforts are concentrated on the most critical areas. Moreover, this process supports the preservation of historical and cultural heritage by identifying significant buildings that can be restored. Furthermore, it enhances coordination among various stakeholders, including government agencies, urban planners, and construction teams, thereby fostering participatory reconstruction efforts. This approach contributes to creating resilient urban environments that are better equipped to face future challenges.

4. Conclusion

In many cases, it is difficult to have appropriate and sufficient documents for the reconstruction of heritage buildings and environments. For rebuilding the damaged urban fabric of historic cities, it has become necessary to employ an array of techniques and methods that aid in re-imagining the significant parts with a view to their reconstruction. This paper used aerial photographs to re-locate the positions of the heritage buildings in MOC, as a step of a comprehensive documentation plan in the absence of the required documents and surveys. The work methodology includes a set of successive phases of AIP to reach the desired results, including: collecting the original aerial image as an intensity; determining the ROI; applying the image adjustment; exploiting the histogram equalization; specifying the locations of courts; extracting and re-displaying the positions of courts; connecting the nearest courts by lines; and analyzing the locations of courts. It is necessary to employ modern technologies used in automated image processing for the purposes of protecting the urban fabric of historic cities as one of the types of digital and descriptive information management required in the field of preventive preservation. However, the study encountered limitations related to the type and accuracy of the available aerial images. Additionally, the potential use of more advanced software could yield more accurate results or facilitate the generalization of findings to other cities, a direction suggested for future research.

5. Acknowledgments

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