Identifying Courtyard Locations in Mosul's Old City through Advanced Image Processing Techniques

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***Abstract*-In the aftermath of conflict, urban environments frequently sustain substantial damage, necessitating concerted efforts to reconstruct the affected urban fabric. The absence of comprehensive documentation for reconstruction often mandates the deployment of innovative techniques and methodologies to facilitate the reimagining and subsequent reconstruction of significant urban elements. Aerial photography serves as a critical tool in documenting urban fabric components. In 2017, extensive destruction occurred across various districts of Mosul's Old City (MOC), resulting in the obliteration of key urban fabric features. MOC is distinguished by its dense urban fabric and the prevalence of internal courtyards within its buildings, which function as essential outlets for lighting and ventilation, in addition to their aesthetic, social, and functional roles. This study leverages historical aerial photographs to identify the positions of building courtyards within a section of MOC's urban fabric, constituting an initial step in a comprehensive plan to represent these features in the absence of requisite documentation and surveys. The proposed methodology involves a series of sequential phases utilizing advanced image processing techniques (AIP) to achieve the desired outcomes, enabling the determination of courtyard positions in a network format whose geo-locations can be readily ascertained.**

1. Introduction

Understanding a city urban structure is linked with perception the association between different features and qualities of the residents' context, characteristics, movement and connections. There is a necessity to examine various disciplines, to study the cities form. These disciplines concentrate on different hypotheses and methodologies, guiding to a thorough understanding of the urban configuration (Furlan and Faggion, 2017). Urban designer and heritage specialists constantly demand dynamic spatial documentations of the built heritage that supply adaptable and multipurpose instrument to interactively understand data of heritage constructions within its surroundings (Doneus, et al., 2017).Preparing process for the consequences of natural disasters and human conflicts and means to alleviate their impact requires accurate data and appropriate documents of all structures, facilities and infrastructure that may be damaged or destroyed (Susaki, 2013).

Post-conflict reconstruction of a multipart urban contexts serious damage of its infrastructure is a critical challenging theme for the experts of the construction field, urban designers, and decision makers (Saeed, et al., 2021) (Hamad and Ismaeel, 2023). To determine their urban fabric when most of their arrangement is destroyed or significantly damaged, it is difficult to explore the urban design of historic cities (Al-Harami and Furlan, 2019).During the military operations in 2017, the urban fabric of MOC was subjected to a large percentage of destruction. The damage rate in some areas reached 100% and the features of many buildings and landmarks completely disappeared (UNEP, 2018), which requires the development of plans to redraw the borders of these buildings and facilities in a way that guarantees their reconstruction on its original form. Currently, part of city urban fabric still suffers from restricted efforts for reconstruction due to economic and political motives, (UN-Habitat and UNESCO, 2018).The lack of detailed documents, records and spatial information of these areas is the major obstacle in their reconstruction process(Hussein and Ismaeel, 2021).

Globally, in similar experiments, many methods and techniques were used to obtain documents and plans that contribute to the revival of such buildings. The current research aims to benefit from the process of analyzing aerial images as a means of geo-locating the positions of the courtyards of the buildings in the urban fabric of a completely destroyed sector in MOC. For this paper, it has been assumed that no available document clarifies the features of the urban area under study. With the existence of many studies and research on MOC, there are not yet complete surveys of the city's areas comprehensively and accurately, as there are many studies that cover the city's districts partially or incompletely of all the city components. This is what the current paper is looking for to achieve its first steps in the prospects of providing comprehensive and accurate documentation for all parts of the city.

2. The Urban fabric of MOC

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 the buildings. They serve,

DOI: http://doi.org/10.24086/icace2025/paper.1697

in addition to their aesthetic, social and functional tasks, as an outlet and an element for lighting and ventilation. The religion rules, socio-cultural and economic aspects are the foremost elements that formed the urban fabric MOC (Ismaeel, 2023). Its structure resulting integrated factors including the urban spatial form, the architectural form and the community lifestyle, to achieve the requirements of their inhabitants (Al-Harami and Furlan, 2019). The new developing social, economic and behavioral changes in the nature of its community resulting from social modifications and functional developments led to the emergence of additional problems and issues for the heritage districts of such old cities (Al-Bishawi and Ghadban, 2015).

3. Courtyard Buildings in MOC

A courtyard is regularly the open space in densely enclosed area (Pelorosso, et al., 2017). World widely, the courtyard pattern is an old architectural form that had been constructed in hot zones from ancient civilizations till the last decades (Al-Hafitha, et al., 2017); (Naseri & Amini, 2022). Its design had been used in the Neolithic settlements (Zakaria and Kubota, 2014). Mosul heritage buildings within their courts reveal construction essential attitudes. It is the architectural mass style harmony, which relies on its design's conformity. It was the common model of housing design (Haraty, et al., 2019). MOC courtyard buildings style 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 (Baiz, et al., 2016). Such building engages inward oriented rather than modern outward oriented construction patterns. Its plot offer access to natural lighting and ventilation for the enclosed rooms (Gupta, et al., 2017); (Kamelnia & Hanachi, 2022); (Mohammed, 2023). Its design simplicity reduces the needless items that might expand the construction budget (Haraty, et al., 2019). In MOC house designing, privacy is significantly an essential cultural demand that courtyard has been used to fulfill. As well, it was utilized as the main meeting spaces for multiple uses in public buildings (Baiz, et al., 2016). Only some architectural items are more closely related with comfort, protection, and security than the courtyard; (Guedouh and Zemmouri, 2017). Yet, the previous researches on MOC courtyard buildings are still limited. Nevertheless, they dealt with courtyard environmental functions; the courtyard form impact on indoor thermal environments; courtyards ventilation results; or developing passive approaches and energy assessment by courtyards, (Zakaria, and 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 re-locating the positions of the buildings courtyards in a part of 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 AIP to reach the desired results.

4. Aerial Photography and Built Heritage Documentation

Aerial photography is an essential element in documenting any urban fabric components. The growth in concern for documentation is a helpful progress in the archiving of many heritage buildings (Murtiyoso, et al., 2019). The study and analysis of image databases has become an increasingly effective field in return to the rising need for multimedia information in urban and infrastructure management (Zou, et al., 2012). In the field of built heritage and environmental research, aerial images are broadly acknowledged as a helpful source of information. Old and historic aerial photographs are used in the integrated studies within a multi-disciplinary scientific heritage project for the protection, analysis and research purposes (Zapłata and Rożycki, 2015). Currently, these images are scientifically taken of cities and may simply become accessible. Thus, the documentation of heritage can obtain benefit of these information sources (Höhle, 2013). In many cases of the damage built area, the only existing data resource maybe the archival old, or historic aerial images. Aerial photographs for heritage support documentation of the former status of historic buildings, giving spatial resolution that facilitates the recognition of elements of one meter, and assisting the understanding of new aerial photographs, satellite images or Airborne Laser Scanning data (Zapłata and Rożycki,2015). Using aerial images and photographs to record and document historic buildings has grown to be a widespread alternative, producing an extraordinary amount of collections of high-resolution and geo-reference image of historic site details. These databases offer innovative means for the specialists to capture, store, process, distribute, and imagine related documents and information (Themistocleous, et al., 2015). They are utilized for the creation of three dimensional photorealistic models with clarifying the building materials (Höhle, 2013). Precise examination of accumulated image data could expose vital damage to the building elements (Zou, et al., 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 very important limitation particularly for the heritage field. For example, the laser scanner offers easy, fast and precise outcomes, however, it requires high expenses (Murtiyoso, et al., 2019).

4.1. Automatic Image Processing - AIP

Because of the technical difficulties and their complication in several disciplines, experts do their best to obtain useful algorithms that assist to discover alternative results suitable to attain prompt solution of the problems (Sundus, 2014). Digital image processing is the analysis of representation and manipulation of illustrative data by a computer (Kumar, 2014). It relates to techniques to carry out processing on an image, to acquire an improved image, or to obtain various helpful information from it to make decisions derived from it. (Tyagi, 2018). Image computational analysis is experimenting as it typically engages tasks such as segmentation, extraction of representative aspects, matching, alignment, tracking, noise removal, geometric correction, edges and contrast enhancement, illumination correction and three dimensional reconstruction. Executing these tasks requires a

DOI: http://doi.org/10.24086/icace2025/paper.1697

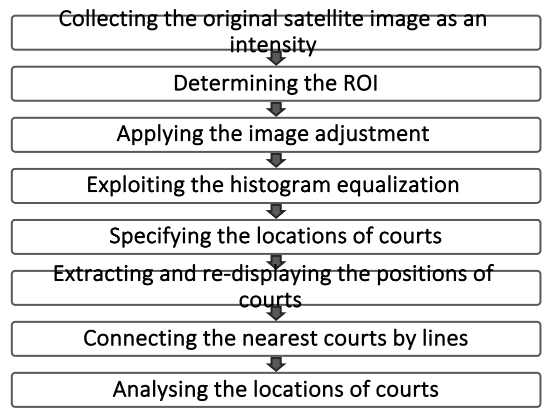
fully automated and effective method. Regardless of the difficulties, image processing and analysis are appropriate for a broad scope of applications. Applications about 2D, 3D or 4D information could be noticed in surveillance, VR, medicine, engineering, and materials sciences (Tavares, 2010), (Daeyoon, et al., 2022). Conventional cases of digital image processing are "fingerprint recognition, processing of aerial images, weather prediction, character recognition, face recognition, product inspection and assembly" (Tyagi, 2018), (Ming, et al. 2023).

4.2 Aerial Image Quality and AIP

The input image quality performs a critical role in the image analysis achievement. The more useful information the original image contains, the more valuable information will be produced by the image processing analysis (Zou, et al., 2012). The higher image quality, the easier and simpler the tasks are. Consequently, appropriate manners of image processing are necessary (Tavares, 2010). With many quickly accessible methods, the task of image preprocessing and attribute extraction necessitates the presenting of particular algorithms for certain problems under study by mixing integrated functions with modifying their parameters (Cazacu, 2021). Scientifically, a digital image is a matrix representation of a 2D image with a limited amount of points cell elements, typically indicated to as pixels, which is symbolized by numerical values (Tyagi, 2018). The majority of the image processing operations are carried out in grayscale mode. A color image, for color image processing, can be decomposed into Red, Green and Blue constituents, that are handled separately as a grayscale image. Few levels of image processing operations are defined, including: Low-Level, that includes primitive operations on images; Mid-Level, with operations involving extraction of characteristics; and, High-Level, that related to examination and understanding of the subject for decision making (Tyagi, 2018). Concentration in digital image processing systems arises from two principals applications fields: development of pictorial data for human understanding; and processing of image information for storage, transmission, and representation for independent instrument perception (Kumar, 2014). To develop modeling precision, several experts have combined airborne information with a digital map. These methods may need a pre-existing building map, and are often expensive to utilize to large urban regions. Additional sources of information have been investigated as alternatives to digital images, such as aerial or satellite images. Aerial images are potential to offer data that illustrates specific structures in complex urban areas. Current research demonstrates that a main feature of effective data integration in 3D modeling is acquiring geo-location and building shape data from 2D images, as well as attaining 3D coordination 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 highlight competence rather than precision, location and size of buildings (Yuki and Junichi, 2010).

5. The Practical study

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 geo-locate the buildings (their courtyards in particular). The selected part is located south of the historic city and includes a large number of traditional buildings. In the practical study, an AIP procedure for identifying courts locations of a group of houses in an aerial image of MOC is adopted. The proposed automatic procedure contains multiple image processing stages, as follows:



Source: Authors

Figure 1. The adopted multiple image processing stages

5.1. Collecting the original aerial image as an intensity

This step concentrates 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. Any aerial image is usually coloured. The colour of each pixel in the image is basically a combination between the (Red, Green and Blue) 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 coloured image $IRGB(x, y, z)$. To convert the coloured image into the gray scale or intensity image, the following equation can be used(MATLAB, 2001):

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

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.

DOI: http://doi.org/10.24086/icace2025/paper.1697

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

Figure 2. The intensity view of an original aerial image

5.2. Determining the ROI

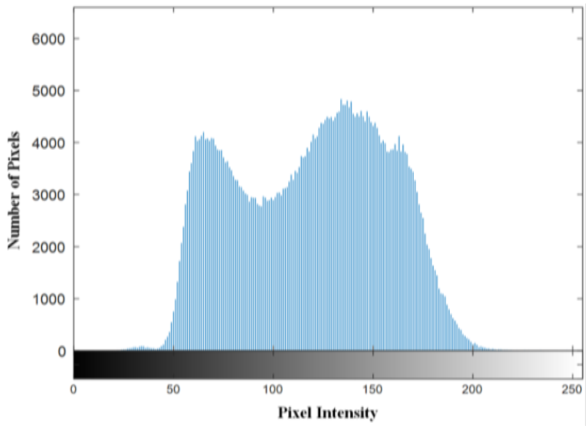
This step concentrates on determining the ROI of the original aerial image. This can simply be implemented by cropping the insignificant regions of the original image(Al-Nima, 2017). The cropped image is given in Figure.3. It focuses on the region that has massive number of courts. The coordinates of intensity image Igray(x, y) have been updated. The resulted image is here identification by I(x, y).

Source: Authors

Figure 3. The ROI image that focuses on the region with massive number of courts

5.3. Applying the contrast adjustment

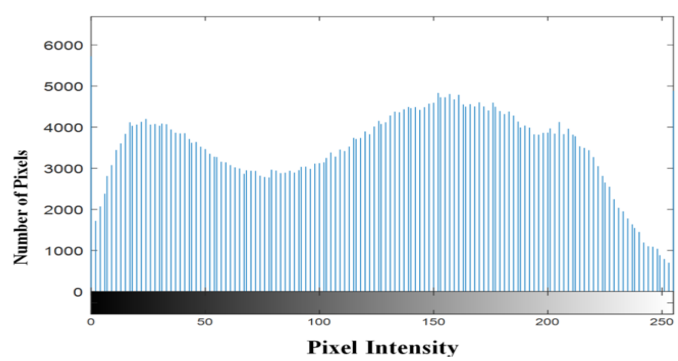
The problem in I(x, y) is that it has a low contrast view. This can be clearly demonstrated by analysing the histogram of the image, see Figure.4.Histogram is utilized to analyse images (Al-Nima, et al., 2015), it shows the relationship between the pixel intensities (grayscale values of pixels) and the number of pixels in the images.



Source: Authors

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 is covered by all the image pixels. There are greyscale 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 exploited. This process can adjust the pixel values to cover all the greyscale intensities. As shown in Figure.5. According to this figure, it can be expected that the resulted image J(x, y) has better contrast than the I(x, y). This is because that all the greyscale intensity range [0,255] is covered by the resulted pixel values. Figure.6 shows the resulted J(x, y) image.



Source: Authors

Figure 5. The histogram of the contrast adjusted image

DOI: http://doi.org/10.24086/icace2025/paper.1697

Source: Authors

Figure 6. The contrast adjusted image

5.4. Applying the histogram equalization

Now, the contrast adjusted image J(x, y) requires illumination adjustments. As it can be seen from Figure.6 that some regions in the image are dark and others are light. Therefore, equalizing the illuminations overall the image is needed (Mustafa and Al-Nima, 2009). Histogram equalization is a good selection to solve this issue.Histogram equalization is an example of histogram modelling techniques (Lim, 1990). It can distribute the illumination of an intensity image by equalizing the number of pixels over the greyscale intensities. Figure.7 and Figure.8 show the resulted histogram equalization images and its updating histogram, respectively. The resulted image, which is denoted as H(x, y), has better illumination distribution than the I(x, y) and J(x, y) images.

Source: Authors

Figure 7. The resulted image after applying the histogram equalization

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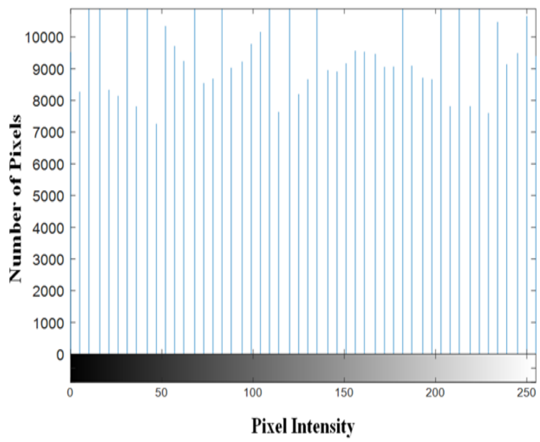


Source: Authors
Figure 8. The histogram after applying the histogram equalization

5.5. Specifying the locations of courts

To specify the locations of courts, it is important to follow their features. The intensity level of courts appears to be the best choice that can be used to specify the positions of courts. Empirically, it has been found that the locations of x and y can be highlighted if H(x,y) < 100. Here, the resulted image is identified as L(x,y). It is a combination between the H(x,y) image and the determined courts' locations. The produced L(x,y) imageis given inFigure.9.

Source: Authors
Figure 9. The resulted image after specifying court locations

5.6. Extracting and re-displaying the positions of courts

In order to provide better analysis for the positions of courts, it would be helpful for the positions to be extracted and re-displayed in a new image. The new image can be identified as P(x,y). The following equation can be utilized for this matter:

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

The resulted image has a black-background with the specified courts locations (Figure.10). Thus, at this stage, any color with a value less than 100 is removed, as this value is saved for the required locations with a black background provided, and the values of all other pixels less than 100 are converted to zeros.

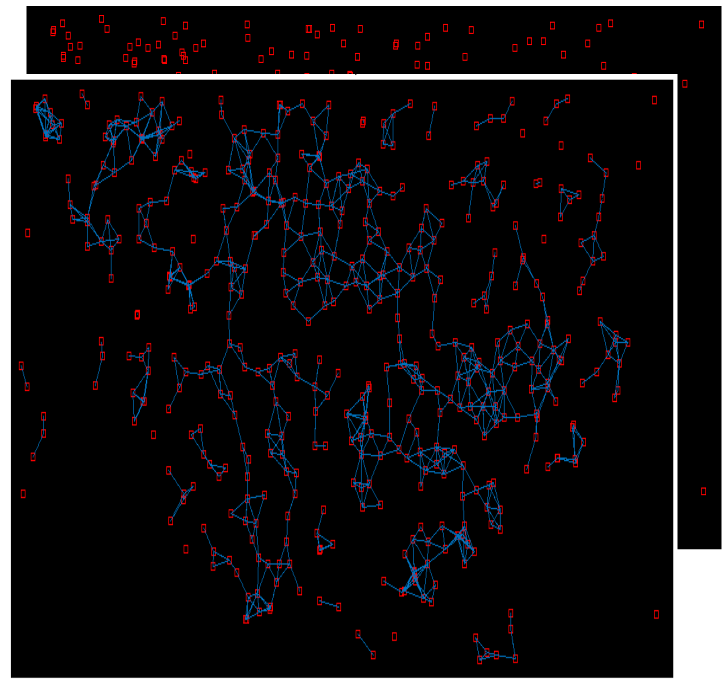
Source: Authors
Figure 10. The courts' locations with a back-background

5.7. Connecting the nearest courts by lines

From this point, the nearest positions of courts can be determined. Euclidian distance has been employed in this work (Mustafa and Al-Nima, 2009). So, the distance D between any two courts has been calculated according to the following distance equation:

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

Consequently, the nearest distances have been determined according to a suitable tolerance. Experimentally, the tolerance is considered here less than 30 pixecls, see Figure.11, which is obtained after connecting the nearest courts, hence, by practices, it was found that the closest appropriate distance is no more than 30 pixels. Finally, what has been set are the pixel positions of the courtyards of the houses within the aerial image, and in the later stage it is possible to determine the



geo-reference position on the MOC map, so that the geo-location of all elements of the image can be accurately assigned.

Source: Authors
Figure 11. The resulted image after connecting the nearest courts

6. Conclusions

The reconstruction of heritage buildings and environments is often impeded by the scarcity of adequate documentation. Consequently, the restoration of damaged urban fabric in historic cities necessitates the deployment of diverse techniques and methodologies to facilitate the reimagining and subsequent reconstruction of significant urban elements. This study utilized aerial photography to identify the positions of heritage buildings within Mosul's Old City (MOC), constituting a critical step in a comprehensive documentation plan in the absence of requisite documentation and surveys. The methodology encompassed a series of sequential phases employing advanced image processing (AIP) techniques to achieve the desired outcomes. These phases included: acquiring the original aerial image as an intensity map; defining the region of interest (ROI); applying image adjustments; employing histogram equalization; identifying courtyard locations; extracting and visualizing courtyard positions; connecting proximal courtyards with lines; and analyzing

DOI: http://doi.org/10.24086/icace2025/paper.1697

courtyard locations. The integration of modern automated image processing technologies is essential for the preservation of historic urban fabric, serving as a vital component of digital and descriptive information management in the realm of preventive conservation. Advanced image processing techniques are an effective tool in identifying the locations of courtyards in the old city. This emphasizes the importance of using modern technology in preserving and documenting urban heritage, especially in cases where the necessary documentation for reconstruction is absent. These techniques can provide accurate and usable information in planning and implementing restoration and preservation projects for historical sites.

7. Acknowledgments

The researchers would like to acknowledge and appreciate the support of the University of Mosul - College of Engineering - Department of Architectural Engineering and the Northern Technical University in Mosul in facilitating the completion of the research by providing the data bases required in establishing the theoretical framework, as well as conducting practical tests within its scientific laboratories throughout the period of work on the research.

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DOI: http://doi.org/10.24086/icace2025/paper