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Original Article

TLS–Based Documentation and Crack Detection of the Partially Collapsed Gwer Caravanserai, Kurdistan, Iraq

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ABSTRACT

Historical heritages are the identity of civilization and national identity. This study provides detailed geospatial documentation and structural condition assessment of the Gwer Caravanserai. Terrestrial Laser Scanning (TLS) was carried out using a Leica BLK360 to capture the partially collapsed structure and generate a high-resolution 3D point cloud model. In total, 46 scan positions were registered, resulting in an overall bundle error of 2.78 mm. This level of accuracy allowed for the creation of detailed 3D models, 2D floor plans, and vertical sections. The crack detection analysis highlighted significant structural deterioration. In the non-collapsed areas, crack widths were found to reach up to 20 cm, with depths of up to 25 cm, while measurements of the main walls showed inclinations of up to 16 cm, indicating serious structural instability. It also demonstrates the effectiveness of laser scanning for documenting damaged heritage structures, and possible to open and redraw for both the collapsed and non-collapsed parts by preventing sections from being taken with Civil 3D based on the TLS data. The relevant authorities have been asked to come to the aid of this historical heritage as soon as possible because it is under threat of extinction.

Keywords: Caravanserai, 3D Modelling, point cloud, 2D planning, Redraw Sections.

1 Introduction

Over the past two decades, 3D modeling of architectural and historical heritage sites has become increasingly important. Accurate as-built measurements enable effective documentation, management, preservation, and renovation planning. The generated 3D data include valuable metadata that supports information modeling, project management, and sustainable conservation of heritage structures.

Historic building preservation relies on accurate assessment techniques, with laser scanning being particularly effective for crack detection and 3D modeling. While methods like remote sensing and photogrammetry have been widely used [1]. Researchs on laser-based crack detection remains limited in Iraq, despite its importance for monitoring and structural evaluation.

Some non-governmental instituitons are working on protecting the historical buildings in terms of the archaeological and architectural manner of the world; one of them is UNESCO. Additionally, a certified list of structures having cultural significance is owned and maintained by each state. It makes sense that these structures were constructed using different materials than those that are currently available, as well as with distinct architectural knowledge and perspectives [2]. While a 100-story structure may be established in few months nowadays, religious structures like strite Vitus took several centuries to build [1]. The aim of this differentiation is to demonstrate these facts that historical buildings have complex facade elements, windows, doors, staircases, and other features.

Not a lot has been done regarding how to detect and correct the cracks in heritage buildings with complex architecture and 3D surface modeling. Moreover, there is a few research on measuring and monitoring buildings that are partially collapsed or develop cracks over time [3]. Despite this, photogrammetric methods have the same potential as laser scanners for 3D modeling of buildings with less accuracy [4]. It is fundamental to indicate that the laser scanner can detect the objects and cracks in the buildings better than the photogrammetric method [3]. Although state authorities may need it, architects and engineers typically require scaled and digital documentation.

Laser scanning generates highly detailed point clouds, but it requires significant storage and processing time, making large datasets difficult to manage and analyze [5]. Digital modeling of buildings is essential, especially when structural or architectural information is lacking, to support renovation and repair of damage over time.

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Laser scanning has been effectively used in historic places once more for the 3D modeling of Moroccan Jewish colony [6]. The entire procedure, from measuring to creating 2D floor plans, is covered in the [7] article on parametric modeling and geospatial measuring of historic structures and its construction components.

Many methods were applied for heritage documentation. [8] tried to inspect the heritage structure and detect cracks in the Wat Chai Wattanaram historical heritage using traditional and laser scanning methods. [9] tried to monitor the heritage buildings based on the data of TLS for the Mosque of Sultan Ibrahim Janek. On the other side, the Tirana clock tower was documented by [10] and the 3D model was created based on the scanner data. The capability of the scanners was tested by [11] in terms of detecting damaged parts in the historical heritages. [12] used UAV for crack detection. In other side [13] worked on the cons evaluation for the tall buildings. (14) used thermal for pedestrian semulation in Mosul accoding to the buildings.

In this research, the aim of this study is to provide accurate digital documentation of a partially collapsed historical building using TLS technology to support its preservation and future restoration. The main objectives are to acquire precise spatial data, generate reliable 3D and 2D documentation, detect and document visible cracks and structural deformations, evaluate wall plumbness, and contribute comprehensive geospatial data for conservation and reconstruction planning.

2 Case Study

2. 1 Location and Historical Background

The study area is in a small town called Gwer that is located in the southwest part of Erbil City in the Kurdistan region of Iraq, near the great Cigli Suyu River. The geodetic coordinates are longitude = 43.4950377° and latitude = 36.0483437° (see Figure 1), which are defined as an abandoned police station and used for this purpose until the previous two decades. The etymology of the word "Gwer" is not precisely documented in academic sources, but based on the Kurdish linguistic and historical patterns, it may come from "Gwerin," which means "turning" or "bending," possibly referring to the bend in the Cigli Suyu river, or it may come from "Gawir" or "Gewre," meaning "big" or "great," which could describe the river, valley, or an ancient tribal designation.

This research focused on collecting geodata and creating a 3D model of the Khan Caravanserai of Gwer, built in 1862 during the Ottoman period by Mahmut Agha Ghafuri. As a historic merchants and travelers' rest house, the structure is now in ruins and lacks as-built drawings [15]. Therefore, accurate documentation through photogrammetry or laser scanning is essential to support its future renovation and restoration.

Figure 1: Study area: a) Iraq map, b) Gwer city, c) Gwer caravanserai.

2. 2 Cultural and Architectural Significance

Gwer has cultural and architectural importance due to its historic role along regional trade routes and its blend of Ottoman and Kurdish building traditions. Landmarks such as the Khan Caravanserai of Gwer reflect traditional stone construction and courtyard-based design, highlighting the town's historical value and the need to preserve its heritage.

2. 3 Research Aspects

The caravanserai is originally built in the 19th century, and it is now partly in ruins [3]. Despite the damage, the building still retains notable technical features and distinctive architectural elements. The structure, known as the Qishla, is rectangular in layout, facing the main river, with a central entrance on the front side. At its core lies a large courtyard, around which most of the rooms are arranged. The front side of the Qishla is two stories high, while the other three sides are single-story. The back section is entirely collapsed, and the side walls are either severely leaning or have caved in. Even the front wall and floors shows serious cracks and distortions, posing a risk of total collapse. Out of around 21 rooms, 8 have been completely destroyed. The monument is in immediate danger due to neglect and ongoing degradation. Emergency stabilization efforts are planned to reinforce the most unstable parts of the structure. As a starting point, detailed documentation was carried out using laser scanning technology to record the current condition of the Qishla.

3 Methodology and Material

In this section, the proposed material and post-processing data were described. To conduct detailed analyses, the researchers utilized TLS technology. On one hand, the data was entirely collected and processed by the researchers' team.

3. 1 Data Acquisition Equipment

Geo-data from the BLK360 laser scanner was selected as the source dataset due to the scanner's high resolution, precision, and accuracy (4 mm at a distance of 10 meters), as well as its built-in camera for point cloud texturing [16]. However, using this device proved to be relatively slow, and not all areas could be documented because the scanning process took a considerable amount of time; that is why it needs numerous scan positions to avoid the gaps in the data. Each scan position required between 3 to 8 minutes, depending on whether color images were captured.

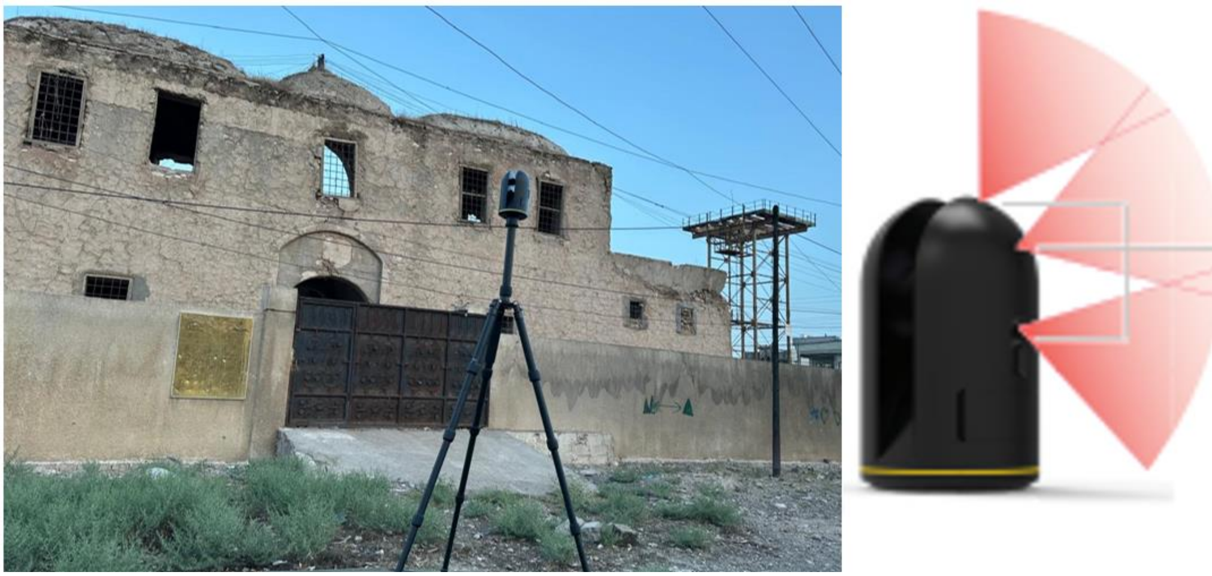

Figure 2: BLK360 Laser scanner instrument.

3. 2 Data Collection, Registration and Processing

Laser scanners were used to scan the entire caravanserai heritage from all sides, with 46 scans taken (two scans were problematic, so they were not used) inside and outside the building, as well as the courtyard and roof with all the rooms. All data were collected in two days, the outer part on 10 May 2025 and the inner part on 14 May 2025 due to large size of caravanserai and time limitation for scanning with acceptable incident angle [17]. All scans were entered into Cyclone Register 360 PLUS for registration and deletion of excess data received during the scans. As shown in Figure 3, the registration results between scans and the links between scans. The overall bundle error between the scans is 2.782 mm. The strength and the overlap between the scans are 68% and 56%, respectively. That is a strong relationship between the scans.

Figure 3: Registration between all scan locations and the overall bundle error with cloud-to-cloud registration.

Once the scans were successfully registered, multiple sections were extracted to create the model. The data generated by the software were exported in RCP format and then imported into Civil 3D for analysis and documentation. This process was carried out to:

1. Identify the geospatial information of the Qishla 3D model and define its exact location and orientation.

2. Create a 2D reconstruction of the building's floor plan from the 3D model.

3. Develop a practical workflow for reconstructing cross-sections, allowing accurate measurements and easier interpretation of the building geometry.

4. Reconstruct damaged and collapsed areas by using the remaining intact parts of the structure as a reference.

5. Locate and evaluate cracks, including their distribution, characteristics, and level of deterioration.

6. Measure the inclination of the main structural walls to assess possible deformation or instability.

7. Provide recommendations for renovation and maintenance based on the results of the analysis.

4 Results and Discussion

In this part, authors answered all the above-mentioned points based on the created high-resolution 3D model of the Gwer caravanserai.

4. 1 Gwer Caravanserai 3D Model

Using the scans and their registration, the building's 3D form was reconstructed with high accuracy and precision for historical heritage documentation. A total of 1,761,329,623 point clouds were collected, covering every part of the structure, including the collapsed sections and cracks in the remaining areas. Figure 4 presents the building from two different views.

Figure 4: Created a 3D model of the Khan based on point clouds: a) left view and b) back-top view.

4. 2 Reconstruction of 2D Floor Plans

This step derived the 2D for both floors using the entire data. The processed scan data, once imported into Autodesk Civil 3D, enabled the georeferencing of the Khan, extraction of sectional profiles, digital reconstruction, and the production of detailed 2D architectural drawings of the caravanserai. Using the point cloud data, 2D floor plans were created for both levels of the caravanserai. The plans were produced by taking horizontal slices at suitable heights and tracing the building's structural elements in Civil 3D. Areas that had collapsed were reconstructed by referencing the geometry of the remaining structures, making it possible to clearly distinguish between preserved, damaged, and fully destroyed parts of the building. Figure 5 presents the resulting 2D plans of both floors, generated directly from the original point cloud data, alongside the reconstructed drawing of the collapsed section. The comparison between the digital drawings and on-site physical contact measurements obtained using tape measurement indicates a high level of precision, with an overall drawing accuracy of approximately 1 cm. This confirms the reliability of the scan-based documentation and reconstruction process for architectural recording purposes.

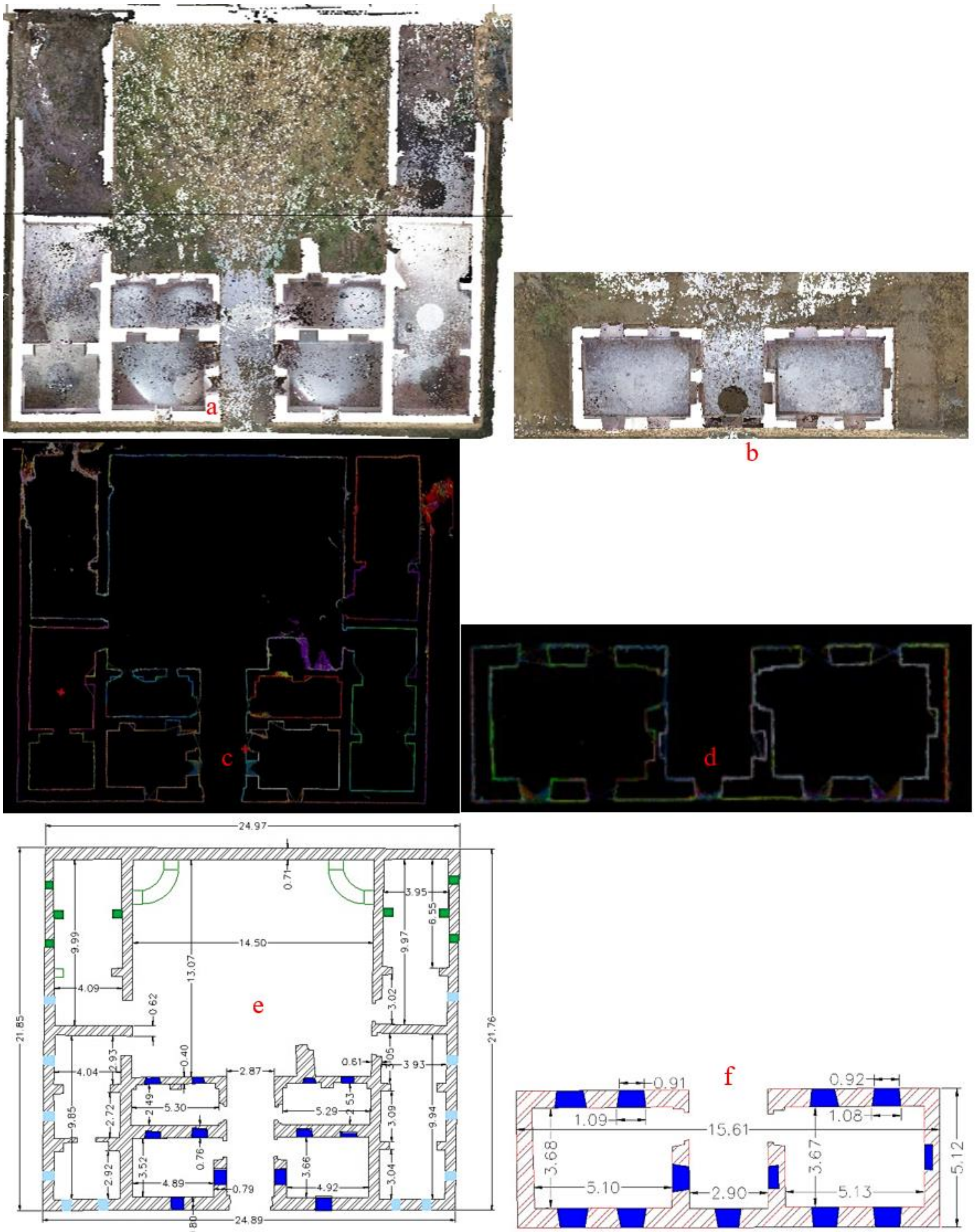

Figure 5: Reconstruction of the 2D plan of the Khan: a,b) First and second floor section plan of the data; c,d) First and second floor slice section point clouds from top view; e,f) Redrawing and reconstruction of the collapsed and non-collapsed parts of the 2D.

In the redrawing plan of the khan, shown in figure-5 (e, f), the green part illustrated the collapsed part, and the ceiling contains big cracks in both floors.

4. 3 Vertical Sections and Wall Deformation

Front and right sections were taken for the Khan, then the 3D reconstruction and redrawing of these sections were taken based on the Autodesk civil 3D software. To further illustrate the building, the two sections shown in Figure 6 have been taken. Figure 6 (a, c) shows the front of the building in terms of height, width, and shape, while Figure 6 (b, d) shows the right side of the building in terms of the design of the building and also shows the collapsed back part. On the other hand, attempts have been made to know the rate of deflection of its walls. One of the walls has been taken as a sample for this purpose. According to the results, despite the weakening of the walls due to cracks, which is the main reason for the accelerated collapse of the walls. As shown in “Figure 6 – e” the deflection rate reaches 16 cm.

Figure 6: Front and right reconstruction sections of the Khan: a,c) Front sections in planimetric view and redrawing map; b,d) Right section in planimetric section and redrawing map; and e) Represents the amount of inclination of the selected wall.

The 16 cm value corresponds to the difference between the distances measured from the reference section to the wall at its base and at its top along the same vertical alignment. The 2D coordinates of the reference section were first determined. Subsequently, the coordinates of two points located on the same vertical line, one at the bottom and one at the top of the wall were recorded. Using the Pythagorean theorem, the distances from the reference section to each of these two points were calculated. The difference between these distances represents the horizontal deflection of the wall from the base to the top. This is a method of American Petroleum Institute (API) standard to compute the deflection of the vertical objects.

$$Di = \sqrt{\Delta E_i^2 + \Delta N_i^2} \dots \dots (1)$$

Where Di is the distance from the section to the point, ΔE, and ΔN, is the difference in easting and northing between the coordinate of the sections and the measured point on the wall.

4. 4 Crack Detection and Measurement

In that section, the emphasis is on the non-collapsible part in terms of strength, durability, and longevity. According to the data obtained and the measurements taken for the cracks. Unfortunately, it can be said that the survival of the building is very close to destruction due to the large number and size of cracks that can be clearly seen on both floors. The cracks have grown to the point that the roof has completely hollowed out, posing a serious risk of collapse. Because in addition to weakening the structure of the building due to these cracks, it allows water to enter all parts of the building during rainfall, which makes the demolition easier and faster. Figure 7 shows that the width of the cracks is about 20 cm, and the depth of the cracks exceeds the walls and ceilings in some places and is about 25 cm for unpenetrated walls and ceilings.

The crack detection process was based on a comprehensive visual inspection and direct measurement of crack width and depth across all structural elements, including walls and slabs on both floors. The investigation revealed a huge number of cracks distributed throughout the building. These cracks were primarily classified into two main categories based on their depth and structural impact: penetrated cracks, which extend through the full thickness of walls and slabs, and unpenetrated cracks, which are limited to surface or partial depth. Several penetrated cracks were identified in both the walls and slabs, particularly on the second floor, where some cracks fully passed through the structural elements, indicating severe structural deterioration.

Furthermore, the cracks were categorized according to their orientation. The observed crack patterns include vertical, horizontal, diagonal, and random orientations, and they are present in both walls and slabs. The distribution of cracks in all directions suggests that the damage is not localized but affects the overall structural system. Table 1 summarizes the crack classification based on orientation, penetration condition, and location.

Table 1: Crack Classification Based on Field Investigation.

Classification Basis	Category	Description	Location
Depth / Penetration	Penetrated cracks	Cracks extending through the full thickness of walls or slabs	Walls and slabs (both floors, especially second floor)
Depth / Penetration	Unpenetrated cracks	Surface or partial-depth cracks not fully crossing the element	Walls and slabs
Orientation	Vertical	Cracks aligned in vertical direction	Walls and slabs
Orientation	Horizontal	Cracks aligned in horizontal direction	Walls and slabs
Orientation	Diagonal	Inclined cracks indicating possible shear or settlement effects	Walls and slabs
Orientation	Random	Irregularly distributed cracks without a single dominant direction	Walls and slabs

Figure 7: Crack detection and measurements on the non-collapsed part: a) Outside cracks on the wall, b) a crack in the first floor, c) cracks in the second-floor ceiling that have completely made a hole in the ceiling, and d) the depth of the crack on the second.

4. 5 Collapsed Part of Caravanserai

Unfortunately, a prominent part of the building has completely collapsed, located at the back of the building. As can be seen in **Error! Reference source not found.** approximately 50% of the roof on the right side is estimated to have collapsed, and the left side is roughly 20% collapsed. Despite the presence of many cracks in the non-collapsed part of the roof, a large amount of weeds has grown on the roof, which causes the roof to crack and damage the structure of the building due to the growth of plant roots in the roof.

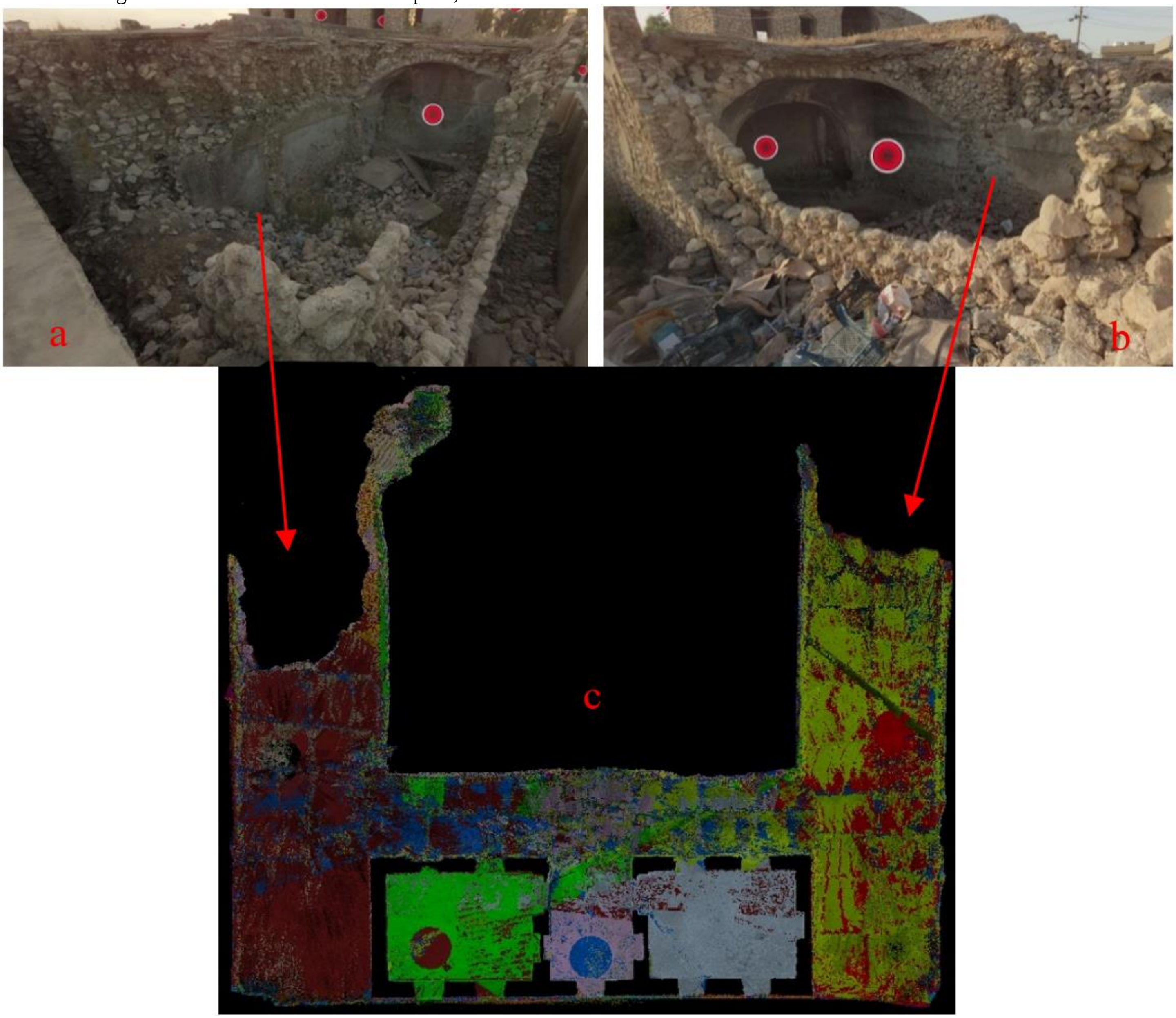

Figure 8: Collapsed part of the Gwer Caravanserai: a) Back right side collapsed ceiling, b) Back left side collapsed ceiling, and c) Top view ceiling section to show the collapsed part.

The Leica BLK360 laser scanner is a high-precision terrestrial laser scanning instrument capable of capturing object surfaces with millimeter-level accuracy. Owing to its relatively low cost, compact size, and ease of transportation, it is widely used in heritage documentation, industrial inspection, and calibration applications. The primary output of the scanner is a dense 3D point cloud representing the geometric and visual characteristics of the scanned object.

Despite these advantages, several limitations must be considered. Comprehensive documentation requires multiple scan positions to ensure complete coverage of the structure, which increases fieldwork time. The high density and texturing of the point clouds demand substantial data storage capacity and extended post-processing time.

Conclusion

In conclusion, using laser scanning for heritage documentation ensures precise geometric measurements and detailed colorized point clouds that preserve surface textures. The data can be processed in platforms such as Autodesk Civil 3D and Autodesk Revit to perform georeferencing, extract sections at any elevation, and generate accurate 2D and 3D models. Based on the scanned data, the structural model was analyzed and reconstructed using Autodesk Civil 3D, enabling a detailed assessment and precise redrawing of both the intact (uncollapsed) and failed (collapsed) sections of the structure. Advanced modeling tools facilitated accurate geometric representation, comparative evaluation of the structural conditions before and after failure, and the virtual reconstruction of damaged elements based on the geometry of the remaining structures.

With respect to the Gwer caravanserai, the results of this study demonstrate the effectiveness of laser scanning in documenting both partially destroyed and non-collapsed structural elements. The generated data enabled detailed assessment of structural damage, particularly crack detection and measurement. The scanner proved capable of identifying cracks in walls and ceilings and facilitating precise quantification of their dimensions. Crack assessment was performed by measuring crack width (horizontal separation) and crack depth (vertical penetration into the structural element).

It can be concluded that the left-back side of the first floor collapsed by approximately 50%, while the right-back side of the same floor collapsed by about 20%.

The findings reveal a substantial number of cracks distributed across both floors of the building. Several cracks fully penetrate the walls and ceilings, allowing visibility through the structural elements, and some of them unpenetrated the walls and ceilings only appeared on the surface of the elements. Measured unpenetrated cracks width reach up to 20 cm in some locations, while crack depths extend to approximately 25 cm. These dimensions indicate advanced structural deterioration and significant loss of material integrity.

Based on these observations, this study strongly recommends urgent intervention by relevant stakeholders. If the long-term preservation of the historical heritage of the Khan of Gwer is a priority, immediate structural stabilization and rehabilitation measures are essential. Without prompt conservation efforts, the building faces a high risk of progressive deterioration and potential total collapse.

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