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Assessment of Different Archaeological Digital Surveying Techniques for Heritage Buildings and Projects

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Abstract **-Each surveying project is unique and requires a specific surveying technique. The problem lies in that not only all techniques are not suitable for all kinds of surveying projects, but also The wrong choice of the appropriate surveying method for the building can cost a lot of time and effort or cause damage to the heritage building. Individually, any surveying project depends on many factors that describe its "nature" and affect the selection of the appropriate surveying method, These factors may vary from the cost to the required degree of accuracy, or the number of existing details required to be scanned in the heritage building… etc. Therefore, this paper aims to develop a proposed methodology to choose the most suitable surveying method according to each surveying project's nature. The project's nature has been described in this paper through several factors deduced from studying modern 3D surveying methods. The paper discusses the common modern 3D surveying methods which are Laser Scanning and Photogrammetry and elicits their characteristics and affecting aspects. Complex structures may now be efficiently and correctly recorded remotely thanks to these technologies, which was not possible with earlier survey techniques. This paper, also, follows an analytical approach to prove the effectiveness of the project's nature factors in selecting the most suitable surveying method, by analyzing several case studies of surveying projects according to the project's nature factors. As a result, a methodology for choosing the most appropriate surveying method according to the project's nature has been deduced.**

Keywords: **image-based surveying, non-image-based surveying, laser-scanning, photogrammetry, accuracy level, heritage buildings.**

I. Introduction

Surveying means taking measurements, detecting, and examining a historic building's geometry, structural components, and relationships between the various components, to determine its condition of conservation, plan a viable project of conservation, consolidation, and reuse after conducting a structural examination. The survey is the first crucial step in accumulating knowledge and doing studies about the building. According to a 2011 paper, documentation is the initial step in the investigation, conservation, retrofitting, repairs, and management of heritage buildings. It may include both qualitative and quantitative assets. [1]. In Addition, the first stage to advancing fundamental modeling for building recording and documentation, according to a 2015 paper, is the collection of all relevant data. [2]. Significantly, surveying methods have been developed throughout history. Firstly, they started with measuring tapes, and hand drawings for details and later developed into 2D CAD drawings. The previously mentioned methods have many disadvantages; they consume time, have a low level of accuracy and the process of storing the outcome results of information and drawings is very poor. According to research published in 2005, the traditional method for building a 3D model is from scratch utilizing CAD software, survey data, and engineering drawings. For complex heritage monuments, this is undoubtedly time-consuming, impractical, and expensive. The produced models lack precise details and are not photo-realistic[3]. Therefore, many new Digital surveying methods have emerged recently such as Laser Scanning and Photogrammetry. Their extensive use of instruments and precise surveying methods enable them to reach a sufficient level of accuracy in the information pertaining to buildings. Consequently, the process of choosing the most suitable surveying method is a complex process and it depends on many aspects. It can be guided by taking into account the object's size, complexity, and accessibility, and restrictions can result from the budget, equipment available, and the anticipated duration of the surveying job[4]. For instance, a paper published in 2020 made a categorization of heritage buildings survey data and assessed the geometric building data collected by photogrammetry and laser scanning by cost, time, ease of use, and accuracy[5]. Besides, every historic building recording and documenting project is unique

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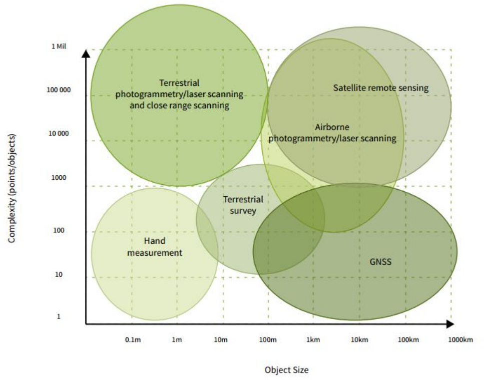

Figure 1: The relation between surveying methods according to complexity and size of an object [6].

and doesn't necessitate a high degree of accuracy. An essential component of any project involving the preservation of cultural heritage is understanding the location, scale, shape, and identity of the many elements of a historic structure or site. [4]. For these reasons, before deciding to move on with a project, it is crucial to estimate its nature independently. This paper is concerned with analyzing the different digital surveying methods and studying their properties and the most suitable uses of each method according to the above-mentioned aspects like; cost, time, complexity, size of object, Accessibility, Accuracy …. Etc. [6].

II. METHODOLOGY

Generally, The research follows theoretical and analytical methodologies. The research will go through 3 stages; the first one concerns Data collection. Then, the Analysis phase of this data. Finally, it explains the outcome resulting from those previous two stages.

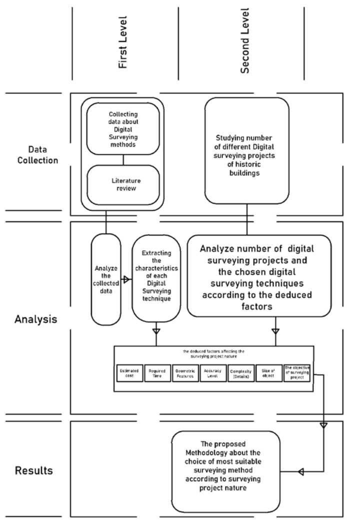

Figure 2: Methodology followed in this research

The data collection stage depends on gathering the information on two levels. Firstly, the data about Digital surveying methods accumulated from different sources and the literature review. Secondly, collecting data about real digital surveying projects that have been done in different places. Next, the analysis phase contains analyzing data collected about different digital surveying techniques in the first level and extracting the characteristics of each one. Also, the analysis phase includes deducing the factors affecting the surveying project nature according to the collected data. The second level contains analyzing the studied digital surveying projects according to the deduced factors to prove its effectiveness or ineffectiveness in the process of choosing the most suitable surveying method. Eventually, the results phase will explain the proposed methodology of choosing the most suitable surveying method according to the previous analysis.

III. LITERATURE REVIEW

1. Digital Surveying Methods:

3D scanning has evolved in recent years into a practical, non-contact tool for documenting cultural heritage and guaranteeing its long-term preservation. There has been a reevaluation of the significance of high-resolution facsimiles due to the extent of harm and loss to heritage sites and buildings brought on by mass tourism, wars, the passage of time, commercial imperatives, inadequate repair, and natural disasters[7]. There are numerous 3D scanning techniques, each with its benefits and limitations. Mainly, Images-based methods and Non-image-based methods are the two primary divisions of digital surveying techniques. The image-based category contains Close-Range photogrammetry techniques and the Non-image-based category contains Laser Scanning techniques. The two most popular methods for collecting data for heritage digital models are digital Photogrammetry and Laser scanning. [8]. Each method has unique qualities and applications. Finding the appropriate system for the appropriate application is challenging.

2. Image-Based Scanning methods/techniques (photogrammetry):

To accurately acquire data on actual items and the environment, photogrammetry is the process of taking, measuring, and interpreting photographic images and patterns of electromagnetic radiant radiation and other occurrences [9]. The definition of photogrammetry is the collection of precise measurements and three-dimensional data from images[9]. According to the height of the platform, the two main forms of photogrammetry are traditional (or aerial) and nontraditional (or close-range). A collection of overlapping stereoscopic photos is the primary requirement for a photogrammetric project.

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Almost any height or platform (from a tripod to an earth-orbiting spacecraft) can be used by a wide variety of cameras to produce stereo images. Image-based modeling is a method appropriate for regular geometric surfaces such as those found in architecture and monuments[10]. Types of the image-based survey:

1) Rectified photography (single image)

Architectural photogrammetry, particularly for historic buildings, is widely recognized for photogrammetric correction of a single digital image that results in rectified images. It is extremely well suited for use in building façades.[11]. Rectified photography is an efficient survey technique that is quick and easy to apply when the subject is flat and has a lot of textural details. [12]. Planar (flat) surfaces are best suited for single image techniques. [13]. How does it work? A software program operating inside a CAD application, such as VeCAD Photogrammetry, is used to match points in the image to surveyed points, produce a corrected image, and trace details from it. The camera determined image control points—at least four of them.[13]. To completely cover the building façade, the control points must be evenly spaced out. Knowing the X and Y coordinates of the control locations and measuring the image coordinates of those spots (x,y). As the object is thought to be flat, there is no Z coordinate. Instead, the matching process takes place, and the corrected image is created. The procedure of image rectification yields the rectified image, i.e. the procedure for transforming an image so that it is projected onto the "real" plane in the object coordinate system after the displacements caused by the camera's tilt have been corrected [11]. A corrected image, which is a geometrically accurate and undistorted digital image, is the result of this operation. There are some limitations of rectified photography. Typically, the corrected photos cannot be utilized to obtain precise proportions due to flaws brought on by one or more of the following

1) The lens of the camera has distortion. For consumer digital cameras and 35mm film cameras, especially those with wide-angle lenses, this is typically the case.
2) Areas closer to the camera appear larger than those further away because the facade of the wall is not exactly flat.
3) image plane of the camera was not perfectly parallel to the wall's facade when the photo was taken, which is why the scale changes throughout the picture [12].

Figure 3: Rectification process of a building façade [9].

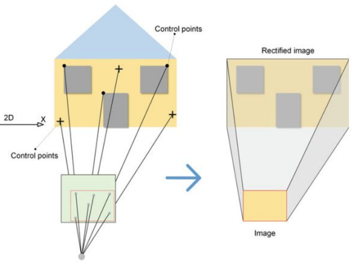

Figure 4: The representation of a façade in digital form. The control point locations are placed on the surface of the image (right). The façade of the building's corrected (rectified) image (left) [9].

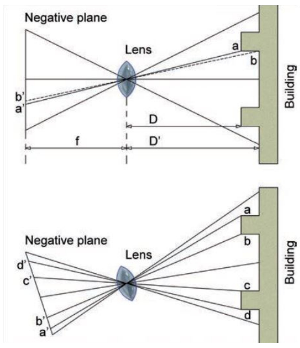

Figure 5: Due to camera tilt and the subject's shifting depth, a conventional shot may contain scale problems [10].

Figure 6: Example of photograph error due to camera tilt [11].

2) stereo-pair and multiple-image photogrammetry

The process of making exact measurements and drawings from stereographic images is called photogrammetry. Stereo photos are pictures of the same object that are overlapped and shot from slightly different viewpoints [12]. Two overlapping images, referred to as "stereo-pairs," are acquired in order to avoid the problems caused by perspective projection [12]. However, a single "stereo-pair" will typically not offer the coverage required to permit the reconstruction of the full subject [13]. As a result, a "Multiple images technique" that makes use of numerous photographs is possible. How does it work? Given that images are the

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only two-dimensional things that can be described by a 2D plane (x, y), any point in an image may be located using only two coordinates. Because the real world is three-dimensional, it is possible to define the location of any point in the object space using three coordinates, for instance by using the 3D Cartesian coordinates (X, Y, Z). In other words, photogrammetry gives all the tools and strategies to derive 3D coordinates in real space by using 2D photographs and making 2D measurements in the images. [11].The term "stereo-pair" refers to two overlapping images. they differ from a single image in that adding a second image taken from a different location enables the intersection of two rays and the determination of the point's 3D location[11]. Further photographs are needed to fully cover the subject. The overlap between the photos may then be accurately measured. The area covered by a stereo pair increases when the camera is moved further away from the subject, however, accuracy requirements rely on the final survey scale and image resolution must remain within specific constraints[12].

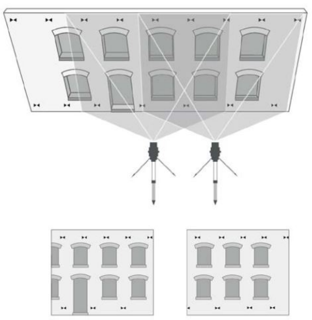

Figure 7: Typical camera configuration for a stereo pair [11].

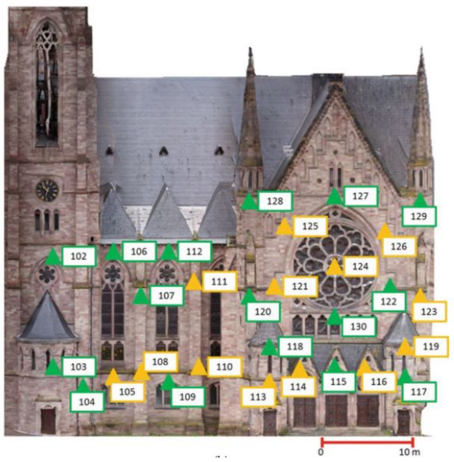

Figure 8: The St-Paul church (Strasbourg, France) control points [9].

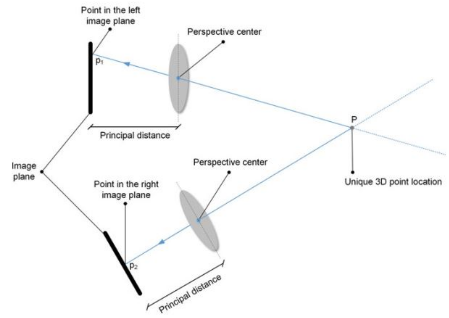

Figure 9: Collinearity principle: the identification of a point in the object space using two rays [9].

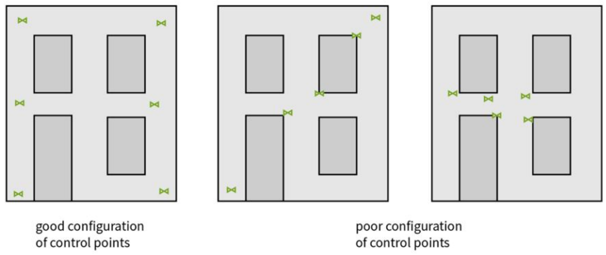

Figure 10: The distribution of control points [9].

There are some limitations of stereo-pair and multiple images which are the following

1) Cost has generally been a barrier to using photogrammetry.
2) Expertise of those using photogrammetry is required [11]
3) The object being observed is typically no farther away from the camera than 300 meters, and often not even 50 meters [14].
4) Overlap between two or more photos minimum 60%.
5) Control points specifications:
   - <u>Number</u>: There must be a minimum of three points, two of which must have 3D coordinates (i.e., x, y, and z values), and one of which need only have 1D coordinates (i.e., x, y, or z); they must also all be visible in at least two photos, though they should all be visible in many more. When compared to more geometrically complicated objects, flat facades require fewer control points for precise reconstruction.
   - <u>Distribution</u>: Instead of being clustered in one place or a straight line, control points should be dispersed around the model's surface.
6) Consistent illumination is required
7) Adding more photos to the model increases measurement accuracy [11].

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TABLE I
SUMMARY PHOTOGRAMMETRY CHARCTERISTICS AND LIMITATIONS

photogrammetry		
Type	**Rectified photography (single image)**	**stereo- pair and multiple-image photogrammetry**
Characteristics	▪ Suitable for building facades ▪ Relatively quick and simple ▪ Used terrestrially and sometimes used as Ariel ▪ Low-cost	▪ Provide more coverage than the single image ▪ Not restricted by the parallelism concept of the input image ▪ More images offer more level of accuracy ▪ Suitable for geometric surfaces not only flat or planar surfaces. ▪ Considered low-cost method
Limitations	▪ Low level of accuracy ▪ Facades are not completely flat so the nearer objects appeared to be larger ▪ The image could have some errors due to the camera tilt ▪ Can't be used for complex geometrical objects.	▪ Need skillful people ▪ A maximum of 300 meters separate the camera from the subject. The process of capturing the overlapped images is slower than the single image ▪ Affected by the existing illumination

3. Non-Image-Based Scanning methods/techniques (Laser Scanning):

According to Grussenmeyer et al. (2016), laser scanning is an active, quick, and automatic acquisition technique that uses laser light to measure the 3D coordinates of points on surfaces without making any contact and in a dense regular pattern [4]. In the most general terms, 3D laser scanning is a non-destructive, non-contact data collection technique that can be used to quickly and accurately create three-dimensional data for digital storage and processing. Although accuracy varies greatly from one scanner to another, laser scanners enable the acquisition of a great deal of tiny geometric features. In a handful of minutes, a 3D laser scanner can collect millions of precisely spaced measurements by firing a narrow laser beam at a target item. To create a 3D dense representation of the item, these scanned measurements are combined and organized into compressed point cloud databases [15]. Because laser light is coherent, a laser beam may travel great distances and be focused on extremely small areas[15]. 3D laser scanners have General characteristics which are the following

1) *Coverage:* Having a significant degree of overlap between scans is a crucial factor in determining adequate coverage. The potential accuracy can be increased by using double or multiple views, especially if a feature is only seen at a shallow angle in one view. Furthermore, compared to an angled perspective, an orthogonal view offers a greater return signal and perhaps better accuracy. It will have a poorer resolution or accuracy if there is any grazing occurrence[4]. Taller building elevations commonly have coverage issues due to balconies, recessed windows, or perhaps merely the angle's steepness. A 270° to 300° view about a horizontal axis and a 360° view about a vertical axis. That is their principal advantage over triangulation-style devices when compared to pulse and phase comparison laser scanners. Because that comes close to a full sphere of coverage. One scan position can therefore cover the majority or the entire interior of a room[4].
2) *Accuracy & Resolution:* The accuracy of the scanner determines how much detail can be observed in the object. The slightest angle variations between succeeding beams are what determine any scanner's best resolution. For static scanners, this is measured in two dimensions: The apparatus's vertical axis and the prism's horizontal axis are both rotating [4]. Range and angular accuracies are typically distinguished in terms of accuracy. The first one depends on how well the ToF recording system is engineered, while the second one depends on how well the prism and instrument rotation systems are engineered. For typical cultural heritage projects, these parameters together result in positional accuracies of 2–5 mm for tripod-based phase and pulse scanners at scan distances of 10–50 m. At the very least, the resolution and accuracy should be equal. For instance, a tool with an accuracy of 2.5mm or better should be utilized if a resolution of 2.5mm is needed[4]. Generally, Although the precision varies greatly from one scanner to another, laser scanners enable the acquisition of a significant number of microscopic geometric features [16].
3) *Scale and size:* To assist choose the ideal laser scanning regime, consider the size of the object or place. Depending on the project's scale, the accuracy level will vary. For instance, Architectural constructions should not have scanning accuracy lower than 6 mm every 15 meters[15].
4) *Accessibility:* When Thinking about the accessibility of areas that need to be scanned, it is found that this issue has always been a problem. But laser scanners made it easy. because they have a variety of ranges in long or short distances. A triangulation laser scanner would likely be the ideal choice for objects like artifacts, building fragments, and miniature statues when sub-millimeter resolution and accuracy are required. Triangulation, pulse,

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5) or phase comparison scanners may be ideal for an in-situ building feature or larger statuary, and the choice of which to utilize may depend on accessibility since triangulation scanners are more precise up close. It would be better to use a pulse or phase-comparison scanner for a building or a building elevation.

Laser scanners' way of work and uses are divided into three types which are the following

1) *Triangulation scanners:*
The triangulation scanner is frequently used in systems built for measuring distances shorter than 5 meters (see figure 11) . Systems that use triangulation can collect data with accuracy down to the micron and typically operate in the 0.5 to several-meter range. To scan certain little or medium-sized objects, inscriptions, and architectural feature details, short-range scanners are utilized. In reality, all short-range scanners are handheld/portable equipment[17].

2) *Time-of-Flight (TOF) / pulse scanners:* The TOF technique sends a laser pulse, It is followed by timing the light's journey from the scanner to the object and back, allowing the scanner to calculate the distance [15]. The benefit of this technology is the notable improvement in data capture speed, which is currently up to several million points per second. Moreover, the ability to collect data from a larger distance is the main advantage of this sort of laser scanning technology (from several hundred up to several thousand meters)[18].

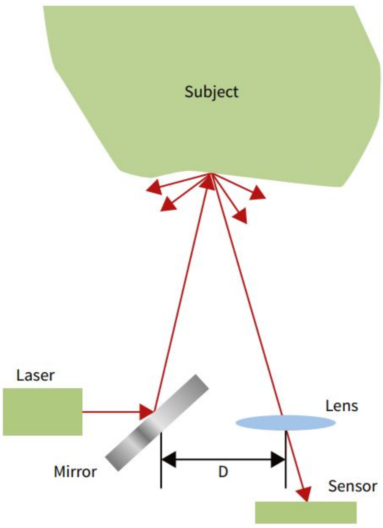

Figure 11: Triangulation system [6].

3) *Phase-comparison/Shift scanners:* PS scanners operate by continuously emitting a laser beam with an embedded modulated signal. The scanner measures the change in phase of the laser light and uses that information to compute distances by comparing the phase of the laser light before it travels to the item and is reflected to the scanner with the phase of the signal at the source [19] .PS scanners can record more points per second with higher precision than TOF scanners, although having a smaller operational range (80 meters, with some systems reaching up to 120 meters). [15].Typically, industrial applications like factories and refineries or interior architectural spaces use phase-based scanners [15].
Table No. II mentions a comparison between laser scanning systems according to the usage of each of them, accuracy, and the typical range.

TABLE II
COMPARISON BETWEEN LASER SCANNING SYSTEMS [6].

Scanning system		**Usage**	**Typical Accuracies (mm)**	**Typical Range (m)**
Triangulation	Rotation Stage	Small objects are taken to the scanner.	0.05	0.1-1
	Arm mounted	Small objects. Lab or field.	0.05	0.1-3
	Tripod mounted	Small objects in the field	0.1-1	0.1-2.5
	Close range (handheld)	Small objects, lab	0.03-1	0.2-0.3
	Mobile (handheld or backpack)	Awkward locations e.g. buildings, interiors, caves	0.03-30	0.3-20
Pulse (TOF)	Terrestrial	Buildings exteriors/interiors, drawings, analysis, 3D models	1-6	0.5-1000
	Mobile (vehicle)	Streetscapes, highways, railways drawings, analysis, 3D models	10-50	10-200
	UAS	Buildings roofscapes, archeological sites Mapping, and 3D models	20-200	10-125

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	Aerial	Large site prospecting and mapping	50-300	100-3500
Phase	Terrestrial	Buildings exteriors/interiors, drawings, analysis, 3D models	2-10	1-300

Laser scanning has several Limitations which are the following

1) The scan data may require extensive post-processing to produce the required level of results.
2) Scanners may take longer than an hour at each point if better resolutions and features are needed.
3) Laser scanning does not work through dense foliage or other obstructions since it needs a clear line of sight.
4) Scanners have minimum and maximum operating ranges, and some of them have issues with reflectance from particular materials, including marble or surfaces covered with gold leaf.
5) Since laser scanning is a high-value operation, it's possible that the necessary budget isn't always accessible[4].
6) Laser scanners typically offer great data capture accuracy, but they also produce enormous amounts of data, which might lead to processing issues.

Table No. III indicates the most remarkable characteristics and limitations of laser scanning systems.

TABLE III
SUMMARY OF LASER SCANNING CHARCTERISTICS AND LIMITATIONS

Laser Scanning			
Typ	**Triangulation scanners**	**Time-of-Flight (TOF) / pulse scanners**	**Phase-comparison scanners**
Characteristics	• Used in a close range • Have a high level of accuracy • Used in many types like; handheld, on a tripod, or articulating arm • Used in distances up to 5m • Used to scan smaller objects or fine architectural details • Provide total freedom of movement around the object	• Used in long-range scans • Have a good level of accuracy but less than triangulation • Used in longer distances from several hundred • Speedy method captures a million points per second • Less noise than other types • Provide full sphere	• Used in long-range scans but less than TOF • Have a good level of accuracy • Used in long distances usually up to 120 m • Can capture more than a million points per second
Limitations	• Need post-processing work that takes effort and time • Sometimes the higher level of accuracy required consumes a long time at each position • Triangulation Laser scanning requires a line of site (affected by any obstacles) • Each system has a minimum and maximum operating range • Some scanning systems have issues in the reflectance of some materials like marble or other • Laser scanning is a high-value operation (costly) that isn't always available • Sometimes higher level of accuracy is required to produce an enormous amount of data which leads to processing issues • The earthbound nature of laser scanners is one of their key drawbacks. For instance, high façade features or difficult-to-reach roofs sometimes have poor ground station documentation.		

IV. THE DEDUCED FACTORS AFFECTING THE SURVEYING PROJECT NATURE:

After studying the previous surveying methods and extracting the most remarkable characteristics of each method, it is found that there are main factors that could affect the process of choosing which method could be used in surveying a historic building according to each surveying project nature. The surveying project nature is proposed to be described by those main eight factors. Because these factors cover the most important aspects of each surveying project. The eight factors are the following (see figure 12) .

1) *Estimated cost*
2) *Required Time*
3) *Geometric Features*
4) *Accuracy level*
5) *Complexity (details)*
6) *Size of object*
7) *Accessibility*
8) *The objective of surveying project*

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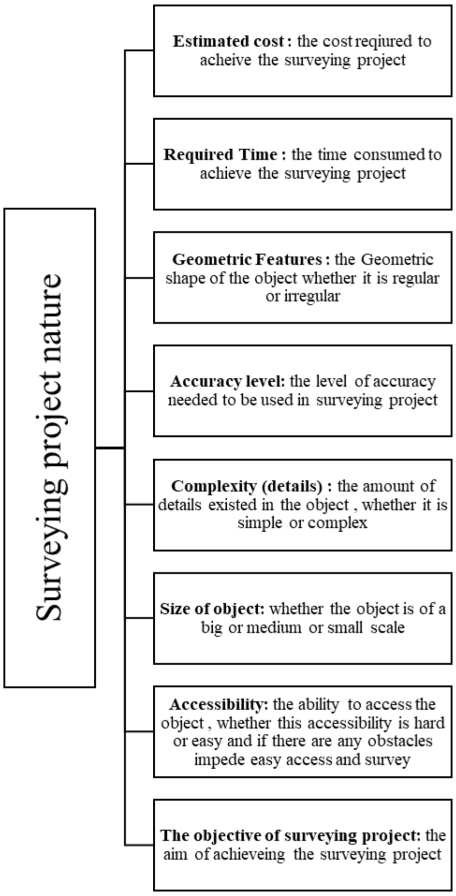

Figure 12: Factors of surveying project nature.

V. Case Studies

The other part of this paper is to analyze some of the real surveying projects according to the deduced factors affecting the project's nature. In this section, there are several examples of surveying projects from different places that have been studied and analyzed.

1. The Fish Garden and Grotto, Cairo, Egypt

Estimated cost: Unknown

Required Time: Such a large-scale project requires a long time and needs a fast scanning time

Geometric Features: contains both Soft-scape, which includes exotic plants and trees from around the world, and Hard-scape, which includes the restrooms, cafeteria, kids' area. Also, the layout of the garden revealed buildings for tanks and mechanisms that looked like little rooms and a few wooden kiosks in the garden's eastern section, which still has its early 1900s-era original elements and design. In the southeast, a fish research center and a practical laboratory are housed in four buildings.

Accuracy level: For location measurements and integral measurements of single buildings, medium resolution scanning (6mm/10m) was frequently used. For delicate parts like the grotto that require high-resolution scanning (3mm/10m), specialist detail components were scanned.

Complexity (details): There are Special characteristics of the Grotto.

Size of object: The large-scale garden contains many objects

Accessibility: Due to the large scale of the garden and different levels, some parts are impossible to reach.

The objective of the surveying project: Documentation of the garden as it has been registered by (NOUH) as a heritage garden since 2010.

3D Scanning system used: Laser TOF / pulse scanner[20].

Figure 13: Fish garden grotto (left) and fish garden map (right) [20].

2. Baron Empain Palace, Cairo, Egypt

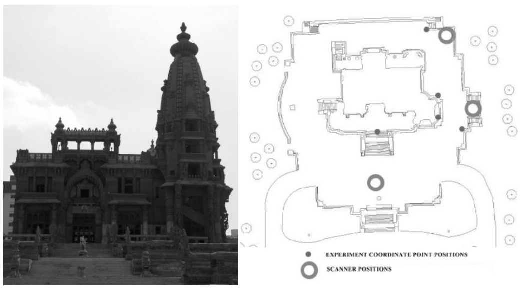

Figure 14: Baron Empain front elevation (left) and palace map with scanning spots (right) [21].

Figure 15: Laser scanning camera in baron Empain's palace [21].

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Estimated cost: Unknown
Required Time: The scanner was used in Baron Empain's palace for eight hours of fieldwork with many positions to cover most of the details.
Geometric Features: Irregular large building and has a complicated design.
Accuracy level: High level due to having a large number of details in building surfaces
The scanner has 2 accuracies: 3.2mm at 50 m or 5.9mm at 100m
Complexity (details): The palace has a complicated design with many architectural details
Size of object: Large building
Accessibility: easy as the palace has a large garden around it
The objective of the surveying project: Using the produced model as an educational tool and managing the monument conservation process through the HBIM application
<u>*3D Scanning system used:*</u> Laser scanning/ TOF[21].

3. *Basilica di Collemaggio in L'Aquila, Italy*

Estimated cost: The Basilica di Collemaggio will be restored for about 14 million euros.
Required Time: The building was in danger therefore; the surveying phase has to be as short as possible.
Geometric Features: Large building with details and regular and irregular shapes
Accuracy level: The accuracy reached was 3mm The utilized laser scanner is accurate to 3.5 mm at a distance of 25 m.
Complexity (details): Complex geometries irregularities
Size of object: Large building
Accessibility: Easy accessibility without obstacles
The objective of the surveying project: Restoration work being done on the structure that was severely damaged by the 2009 earthquake. In order to create a 3D-detailed HBIM (Historical Building Information Modeling) that can manage the project's analysis, structural behavior modeling, economic assessment, and restoration phases, a survey is a necessary component of the restoration project.

Figure 16: Basilica geometry (left) and 3d scanned interior model (right) [22].

Figure 17: Basilica rooftop 3d model [22].

<u>*3D Scanning system used:*</u> Photogrammetry is used to create ortho photographs of the external facades, internal walls, and vaults. And Phase Comparison/ Shift Laser Scanning for the general geometrical scanning using 182 scan points[22].

4. *Sille Aya-i Eleni Church, Konya, Turkey*

Estimated cost: Unknown

Required Time: There is no estimated time but it is always will be better to consume less time

Geometric Features: Generally, the building has simple geometry with plain stone surfaces and limited openings

Accuracy level: A medium level of accuracy is required therefore a Nikon D80 camera used with a 24mm lens

Complexity (details): The building facades are simple stone surfaces with some regular openings

Size of object: medium building

Accessibility: Easy accessibility

The objective of the surveying project: Surveying the building's exterior four facades

<u>*3D Scanning system used:*</u> Photogrammetry / stereo-pair[23].

Figure 18: The church general geometry [23].

Figure 19: Church small openings and plain facades [23].

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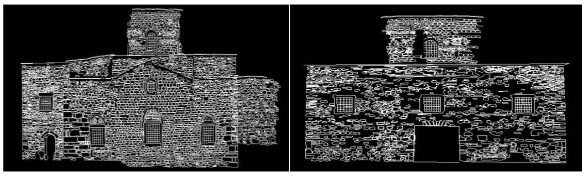

Figure 20: Basilica facades as 2D drawings extracted from scanned model [23].

5. Tout Ankh Amon Tomb, Valley of the Kings, Luxor, Egypt

Estimated cost: The documentation project aims to reduce the cost as possible
Required Time: The used Lucida scanner spends 4 hours per m² and the Time consumed to document the tomb walls was 24 days.
Geometric Features: The tomb walls are flat surfaces but full of complex details and require a close-range method to capture all these details.
Accuracy level: High level of accuracy (0.05 mm to 1 m). Lucida scanner has a capture range from 8-10 cm
Complexity (details): The tomb is full of fine complex details
Size of object: Small details on the walls
Accessibility: Some parts of the tomb were hard to access due to the narrow width of those parts.
The objective of the surveying project: Achieving a non-contact recording of the tomb restoration and making it ready for visitors. And The construction of a facsimile of the tomb.
3D Scanning system used: Laser scanning / Triangulation[24].

Figure 21: The tomb walls details (left) and the tomb 3D diagram (right) [24].

Figure 22: The tomb triangulation system [24].

6. House building in Aksaray, Turkey

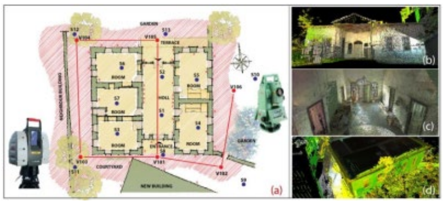

Figure 23: The house map and scanning spots (left) and the interior 3D model (right) [24].

Figure 24: The house openings and facades [24].

Estimated cost: Unknown
Required Time: 13 laser scanning stations were used for a total of 12 hours.
Geometric Features: In general, the sizes of the spaces vary in two-story masonry constructions.
Accuracy level: accuracy is 6 mm at 50 m
Complexity (details): Due to the tiny doors, a large percentage of overlapping could not be achieved. The dimensions of historic houses vary, as do the separations between the object and the scanner. As might be expected, these changes had an impact on point cloud density, although an equal scanning resolution was achieved.
Size of object: a middle-scale historical building
Accessibility: The point cloud of the building's west façades showed various noisy areas because of the close position of the historical building to its neighboring structure. Additionally, there are some dark spots and various lighting conditions around the scanner that led to overexposure or dark regions in the point cloud.
The objective of surveying project: a project to document. It was intended to repurpose this structure, which was listed as part of Aksaray, Turkey's cultural heritage, for a new use.
3D Scanning system used: Laser TOF / pulse scanner[25].

7. Historical Walls of Lagos, Portugal.

Estimated cost: Unknown
Required Time: Laser scanning was without colors to reduce the time of fieldwork. It was desired to reduce the time of fieldwork as much as possible.
Geometric Features: A number of connected medieval walls with a perimeter of approx. 1.2 KM and consists of 7 bastions.
Accuracy level: The used laser scanner has an accuracy of 2mm at 10m or 25m and has a range of up to 120m
Complexity (details): Stone large high walls with 7 bastions and have authentic materials that need to be documented.

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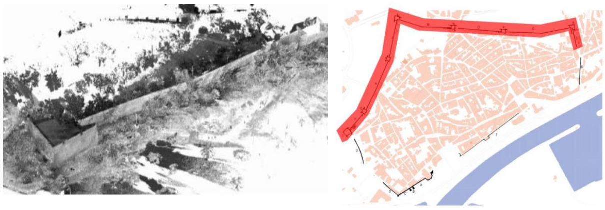

Figure 25: The walls 3d model (left) and the walls map (right) [26].

Figure 26: The walls' 3d colored model [26].

Size of object: An object has a long height and perimeter.

Accessibility: There were some difficulties in the surveying fieldwork due to:

- Rough terrain and slopes
- Vegetation interrupting direct vision of the site
- A Large number of cars parked near the walls
- Private homes are surrounded by substantial portions of walls, making ground access impossible.

The objective of the surveying project: It was intended to make a conservation project to the walls achieving the following:

- a tool to make it easier to depict new 2D documentation, like plans, sections, and elevations.
- useful instrument to facilitate many analyses, like material inspection and conservation state.
- the framework for creative design interventions that will preserve and improve historical assets while opening up the location to the local population.

3D Scanning system used: Laser Scanning Phase shift/comparison of a total of 182 scans. Photogrammetry multiple image/stereo-pair with two cameras to cover the difficult access areas and to enhance the model with real colors[26].

8. The Old Palace Seri Menanti, Malaysia

Estimated cost: Unknown
Required Time: Fast time was required due to the endangered wooden palace
Geometric Features: A wooden palace with complex geometrical masses and a sloped roof. It is a four-story building.
Accuracy level: High accuracy level of 2mm at 25m

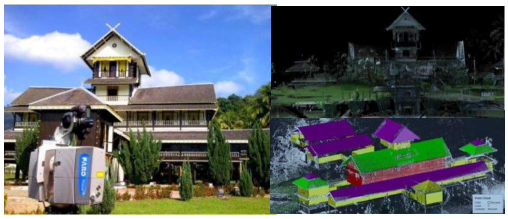

Figure 27: The palace's general geometry (left) and the 3D model in the processing phase and the outcome (right) [27].

Complexity (details): The building has the details of woodcarvings and is combined with multiple masses.
Size of object: Medium palace with wooden details
Accessibility: The palace has some vegetation around it. but generally was easy to access.
The objective of the surveying project: A Documentation project for this wooden palace which is considered one of Malaysia's significant cultural heritage. By producing a 3D model for the building with a high level of detail (LOD 3).
3D Scanning system used: Laser Scanning phase shift/comparison. There were 23 Scanning positions surrounding the building[27].

The shown Table No. IV contains several studied examples and indicates the different properties of those examples according to the deduced factors that affect choosing the surveying method. Generally, the highest level of accuracy exists in example number 6, and the lowest level of accuracy is found in example number 8. According to the table, the level of accuracy is directly proportional – in most of the examples- to the complexity level. Moreover, the sort of Geometric features for each example plays an important role in choosing the surveying method. For instance, in Example number 8 which has a regular shape a photogrammetry stereo-pair method was used to survey the building. In example number 3 which has an irregular shape a TOF laser scanner was used to survey the building. Accessibility, also, represents an important element in the process of choosing the used surveying method. Based on that, a TOF and a Phase shift laser scanners were used in examples number 3 and 7 respectively because the accessibility was easy and between the object and the scanners, there was a clear line of sight. Whereas a photogrammetry stereo-pair method was used in example number 5 to scan several parts of the walls that were hard to reach and had difficulty in locating a direct line of sight. Additionally, a close-range Triangulation laser scanner was used in example number 6 because the narrow width of the tomb provides no space for any other surveying method while maintaining the same required accuracy level. That narrow width expressed another side of the accessibility issues. Concerning the cost, laser scanning is considered, generally, more expensive than photogrammetry. However, this cannot be proved through the studied examples because there is not

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enough information or details about the cost of surveying projects for each example. Example number 6 which used a Triangulation laser scanner took the longest scanning time among other examples. While examples number 2 and 3 which used a TOF laser scanner took the shortest time respectively. The scanning time was relatively high in examples number 1,4,7 and 8. Significantly, the objective of the surveying project or the requested product out of surveying affects what surveying method should be used. Referring to that, when it is necessary to make decisions relating to conservation process details or future plans like in example number 6, or when it is required to document a complex building with a large number of details like in example number 3, an extremely accurate method should be used. Therefore, a phase shift laser scanner and a TOF laser scanner were used in example numbers 6 and 3 respectively. Besides, when it comes to documenting exterior or interior facades that have a small number of details or roofs like in examples number 4 and 8, there is no method better than photogrammetry on all levels. Eventually, the size of the object takes part in determining the most suitable surveying method to use. In example number 6 the Triangulation laser scanning method was used because it suits the tiny small details and has a close-range capturing ability. Furthermore, in example number 5 the surveying system combined phase shift laser scanning and photogrammetry due to the size and scale of the walls, as well as the materials and details that must be recorded. In example number 7 which is a building of a medium scale a phase shift laser was used. The reason is that the operating range or distance of a phase shift laser is limited and this is suitable for a medium building scale. Because the medium building scale does not require a long distance apart from it to be able to cover all the buildings during scanning, unlike a large-scale building. In conclusion, the displayed table includes several examined cases and highlights their various characteristics in accordance with the elements that have been determined to have an impact on the survey technique select.

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TABLE IV
ANALYSIS OF CASE STUDIES

No.	Project	Factors influencing the project's nature								3D Scanning system used
		Estimated cost	Required Time	Geometric Features	Accuracy level	Complexity (details)	Size of object	Accessibility	The objective of surveying project	
1	**The Fish Garden and Grotto, Cairo, Egypt**	--	Fast	Regular & Irregular	Medium	High	Very large	Moderate	Documentation	**laser TOF**
2	**House building in Aksaray, Turkey**	--	Very Fast	Regular	High	Moderate	Medium	Moderate	Documentation	**laser TOF**
3	**Baron Empain Palace, Cairo, Egypt**	--	very Fast	Irregular	Very High	Very high	Large	Easy	Using the model as an educational tool and managing the conservation process	**laser TOF**
4	**Basilica di Collemaggio in L'Aquila, Italy**	14 million Euro	Fast	Regular & Irregular	High	High	Large	Easy	Conservation and management	**laser phase-shift & photogrammetry stereo-pair**
5	**Historical Walls of Lagos, Portugal.**	--	Moderate	Regular & Irregular	High	Moderate	Large	Hard	Documentation & Conservation	**laser phase-shift & photogrammetry stereo-pair**
6	**Tout Ankh Amon Tomb, Valley of the Kings, Luxor, Egypt**	Reduce costs as possible	Slow	Irregular	Very High	Very high	Small	Hard	Documentation & construction of a facsimile	**laser triangulation**
7	**The Old Palace Seri Menanti, Malaysia**	--	Fast	Regular	Very High	High	Medium	Easy	Documentation	**laser phase-shift**
8	**Sille Aya-i Eleni Church, kKonya Turkey**	-	Fast	Regular	Low	Low	Medium	Easy	Façade Documentation	**photogrammetry stereo-pair**

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VI. RESULTS

Briefly, the photogrammetry techniques and the Triangulation laser scanning technique are cheaper than the other laser techniques "TOF and Phase-shift". With respect to geometric features, when the surface is flat and plain (has no details), the photogrammetry rectified image technique is used. When the surface is flat but has some details and has regular geometric shape or sharp edges, the choice should be the photogrammetry stereo-pair technique. The complex irregular geometric shapes and the large amount of details require the use of laser scanning techniques the TOF or the phase-shift. Significantly, the accuracy level grading from the lowest to the highest from photogrammetry to laser scanning. In general, the photogrammetry techniques are less accurate than the laser scanning techniques. The rectified image is less accurate than the stereo-pair technique. Also, the size of object is an influential element. All buildings or object sizes can use any technique except for the tiny elements which can also use the laser triangulation technique. Laser scanning with its three techniques can't be used when the accessibility is hard or if there are any obstacles between the scanner and the scanned object unless the photogrammetry techniques. Which can be used whether there are obstacles or not. Eventually, the scanning range differs from one technique to another. Overall, the photogrammetry techniques and the Laser phase-shift technique have the same scanning range. and the laser triangulation system has the shortest scanning range among all techniques. Therefore, according to the previous analysis of case studies and the literature review, The Given Methodology showed in Table No. V was suggested for choosing the most suitable surveying method in compliance with the project nature. the illustrated table is the proposed methodology that enables the stakeholders in surveying projects to make decisions about choosing the most suitable surveying method to be used. The methodology is based on determining the project nature through its affecting factors like: Estimated cost, Required time, Geometric features, Accuracy level, complexity, size of object, and Accessibility. After determining those factors, it will be easy to choose the most convenient method to survey any historical building or site.

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TABLE V
THE PROPOSED METHODOLOGY FOR CHOOSING THE MOST APPROPRIATE SURVEYING METHOD

		Estimated cost		Required Time				Geometric Features				Accuracy level			Complexity (details)		Size of object		Accessibility		Scanning Range		
		high	low	Scanning time		Processing time		Flat	edges	regular	Irregular	Low	Medium	High	high	Low	Large	Small	Direct	Indirect (have obstacles)	0.1-20 m	0.5-3500 m	1-300 m
				long	short	Long	Short																
Photogrammetry	Rectified photography (single image)		■		■	■		■				■				■	■		■	■			■
	stereo- pair and multiple-image photogrammetry		■		■	■		■	■	■			■			■	■		■	■			■
Laser Scanning	Triangulation scanners		■	■			■			■	■			■	■			■	■		■		
	Time-of-Flight (TOF) / pulse scanners	■			■	■				■	■			■	■		■		■			■	
	Phase-comparison / shift scanners	■			■	■				■	■			■	■		■		■				■

Notes:

- Phase comparison/shift **scanning time is faster** than time of flight TOF, but time of flight **processing time is faster** than phase comparison/shift.
- Rectified photography **scanning time is faster** than stereo and multiple image photogrammetry.

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VII. Recommendations

- Widely study the effectiveness of cost in choosing the appropriate digital surveying method
- Develop this methodology to reach another more detailed one to become a guide for heritage conservation organizations.
- Raise awareness about the popularity and effectiveness of modern 3D digital surveying methods through competent authorities.
- Generalize the use of laser scanning and photogrammetry in surveying heritage buildings instead of conventional methods.

VIII. Conclusion

Laser scanning and photogrammetry have become the most significant 3D digital surveying methods that have been used to survey and document heritage buildings recently. The paper is concerned with studying them and extracting the distinctive characteristics of both methods. Also, it is concerned with deducing a number of factors influencing each method and determining each surveying project's nature. As previously said, every surveying project is distinct from the others due to many aspects like the objective of the surveying project, the available budget or the size of object…etc. Therefore, the paper suggested the mentioned proposed methodology for choosing the most appropriate surveying method according to the surveying project's nature to save time, and money and reach the best surveying outcome of heritage buildings. The methodology explains the relation between the type of surveying method and the factors affecting the project's nature and consequently determines the best method for best practice.

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Conflicts of Interest: The authors should explicitly declare if there is a conflict of interest.

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