Integration of Laser Scanning and Photogrammetry in 3D/4D Cultural Heritage Preservation – A Review

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Abstract

Developments in photogrammetric systems together with terrestrial laser scanning workflows are creating increasingly comprehensive and accurate 3D colored point cloud data. Also, new methodologies in cartographic production have become possible. Point clouds are currently the most popular laser scanning approach. In contrast, photogrammetric Dense Image Matching (DIM) generates dense colored point clouds and concentrates on representative structures of the object. Both technologies provide dense 3D point clouds, neither represents a clearly superior result in terms of quality. The integration of both output datasets from the two techniques, photogrammetry and laser scanning, is a prerequisite to take advantage of the complementary characteristics. In addition, the challenges represented by four-dimensional (4D) modeling require additional adjustments and modifications, due to restoration procedures, excavation, weather conditions or natural phenomena factors. This paper presents a review of the present integration methods. A SWOT analysis of the sources of 3D information, from laser scanning and imagery, is conducted as a comparative analysis.

Keywords: Photogrammetry, Laser Scanning, Cultural Heritage, 3D & 4D Modeling, Structure-from-Motion, SWOT

1.Introduction

Cultural Heritage Preservation is a noble task and essential for all civilizations on Earth (Moussa et al., 2013). The inheritance of cultural heritage from generation to generation is a necessity to preserve the roots and developments of any civilization. Moreover, tourism, economy and ecology are the direct result of cultural heritage for today's societies. Therefore, a guarantee that historical locations and monuments are well preserved is obligatory for the politicians and authorities (Oliveira et al., 2014). The fast and frantic evolution in three-dimensional (3D) modeling research, fuelled by recent breakthroughs in key point detection and matching, the advances in computational power of desktop and mobile devices, the advent of digital photography and the subsequent availability of large datasets of public images gives optimism for new developments in the geospatial data domain, also in the cultural heritage area(Toldo et al., 2015). Today, the goal of bridging the gap between physical reality and the digital world, also called digital twin, seems within reach given the magnitude, breadth and scope of current 3D modeling systems. On the contrary, unforeseen causes such as war and uncontrolled developments, human-caused disasters, and neglecting and poor conservation, respectively, natural disasters, combined with slow documentation processes of architectural and archaeological cultural heritage sites, aremain reasons that cultural heritage is vanishing (Amans et al., 2013). The evolution in three-dimensional (3D) data collection and modeling allows for new research and development in sensor and data integration. Consequently, the combination of terrestrial laser scanners and photogrammetric multi-image procedures supports geometrical 3D recording of very complex objects (Kersten et al., 2014). In (Remondino et al., 2006)diverse approaches for acquisition, processing and visualization of 3D information are discussed, see Figure 1.

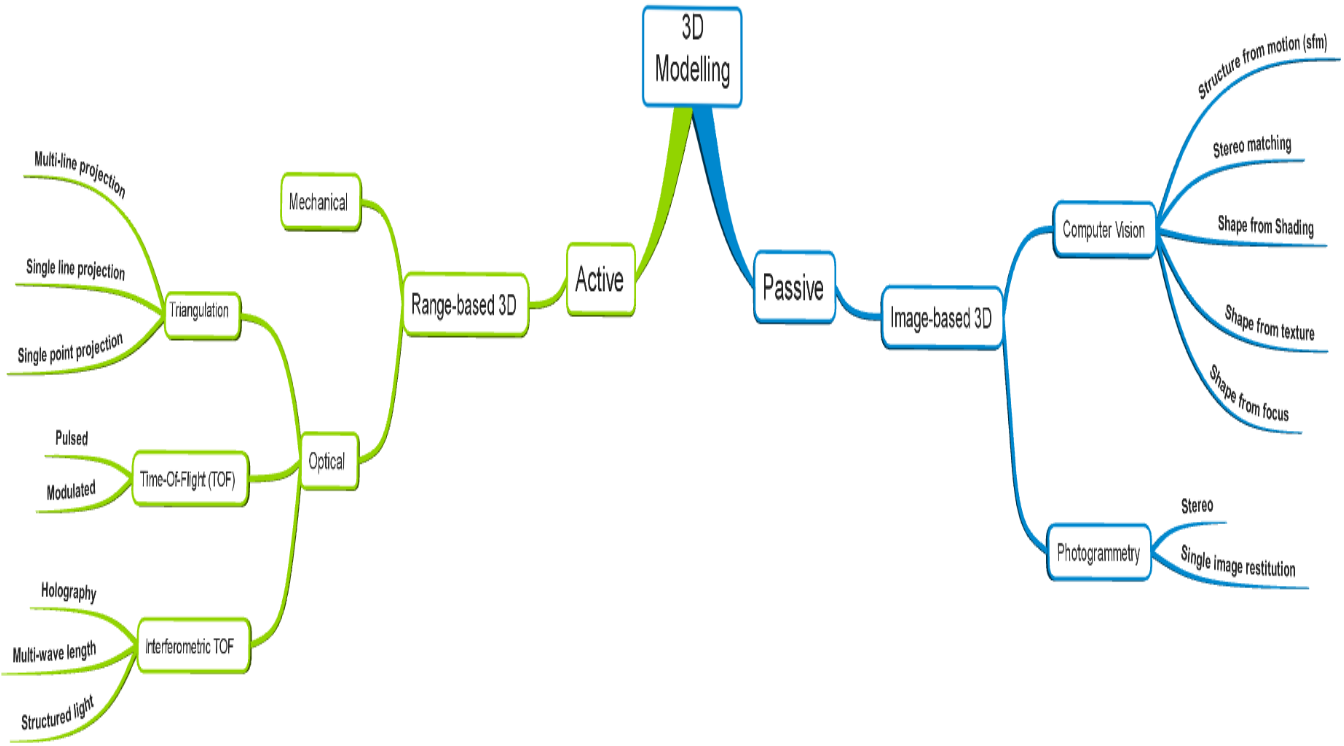


Figure 1: Taxonomy of 3D modeling techniques (Remondino et al., 2006; Moons et al., 2010)

Integration means delivering a new technique created from a fusion of two or more solutions/methods. It aims to maximize the strength and minimize the weakness of each individual technique (Rönnholm et al., 2007). Recent developments in photogrammetric systems together with terrestrial laser scanning hardware are creating increasingly comprehensive and accurate 3D colored point cloud data (Oliveira et al., 2014). The geometrical 3D recording of complex objects is often accomplished today by a combination of photogrammetric multi-image procedures and terrestrial laser scanners (Wenzel et al., 2012; Kersten et al., 2015) . 3D laser scanning can reconstruct disconnected sets, also called scan worlds, of three-dimensional sample points and dense point clouds of the surface geometry of objects, that is required to create high-resolution geometric models. On the other hand, digital photogrammetry can produce 3D models through reconstructing point clouds in addition to provide also high-resolution textures. Without doubt, the two technologies, laser scanning and digital photogrammetry, can complement each other in reconstructing, recordings and pre-settings of high-quality digital three-dimensional models (Kadobayashi et al., 2004; Amans et al., 2013; Balsa-Barreiro et al., 2015). Three approaches are used for data collection and surface point recovery of a scene regarding close-range and/or terrestrial applications. These methods are: image-based approach, range-based approach and a combined approach (Moussa et al., 2013; Wu et al., 2015). The relevant analysis and comparison for these approaches has been published in many papers of related literature. A general trend is of integration aiming towards the optimal solution (Altuntas et al., 2016).

The 4D photorealistic modeling of historical monuments through the fusion of time frames based on precise 3D models, provided by sophisticated photogrammetric data processing and reconstruction methods, allows for the exploitation of the cultural heritage objects associated with Web multimedia repositories, also called “Images from the wild”. This may enclose millions of pictures uploaded by users, including a significant number covering Cultural Heritage objects, monuments, and sites. The 4D modeling leverages Cultural Heritage e-documentation and allows users to get more knowledge of cultural heritage assets changing with time (Ioannides et al., 2013; Kersten et al., 2014; Balsa-Barreiro et al., 2015; Voulodimos et al., 2017). Within the literature, several surveys and reviewsof the approaches to integration of TLS and photogrammetry exist. The majority of publications covered by this review do not provide a comparative analysis to explore new solutions for problems, such as identifying barriers that will limit fusion objectives and decisions for the most effective integration techniques. Our review is a mixed note from a wide perspective to deep-dive in research issues and applications.

2. Terrestrial Image-based 3D Modeling

The image-based 3D modeling technique is ideally suited for precise, practical and versatile non-contact measurements, increasingly being adopted for industrial applications and cultural heritage preservation. Even if classical photogrammetry is a matured discipline, compared to modern geometric computer vision, shared goals as well as distinct approaches exist. (Hartley et al., 1993; Díez et al., 2008; Sturzenegger et al., 2009). The promising 3D acquisition and rebuilding shapes from several images by using a restitution model is one of the innovative methods for creating precise 3D models digitally, by obtaining geometric surfaces of objects from numerous 2D images. Also this technique of 3D modeling became favorite for many researchers as a result of the economical use and resolution of new digital cameras (Kadobayashi et al., 2004; Westoby et al., 2012; Bayram et al., 2015). Obtaining trustworthy 3D geometric models and its related measurements, by means of photographs, to recover 3D object surface information, can be seen from a photogrammetry and computer vision point of view as utilizing 2D image measurements integrated in a mathematical model. Although photogrammetric and geometric computer vision models are coherent and both disciplines are concerned primarily with the pinhole or perspective camera model and the mapping from points in the 3D world (object points)to 2D image points, the math notation is different. The collinearity equations are used in photogrammetry to express the 2D-3D correspondences (2.1, 2.2), while computer vision uses the projective equations (2.3) & (2.4) (Hartley et al., 1993; Rothermel et al., 2012). The collinearity equations of photogrammetry are as follows:

$$x - x_0 = -f \frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} \tag{2.1}$$

$$y - y_0 = -f \frac{r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} \tag{2.2}$$

with the following definitions: x,y are the image coordinates,X,Y,Z are the object space coordinates and$f$ is the focal length of the camera.$r_{11} \ldots r_{33}$are the elements of the rotation matrix R that relates the reference systems of the image and object space.

The projective equations of computer vision are described as:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & x_0 \\ 0 & f & y_0 \\ 0 & 0 & 1 \end{bmatrix} R^T \begin{bmatrix} 1 & 0 & 0 & -X_0 \\ 0 & 1 & 0 & -Y_0 \\ 0 & 0 & 1 & -Z_0 \end{bmatrix} \tag{2.3}$$

In homogenous notation (2.3) can be abbreviated as

$$\vec{x} = K.R^T.[I| - {}^{H}\vec{\mathbf{X}}], \qquad K = \begin{bmatrix} f & 0 & x_0 \\ 0 & f & y_0 \\ 0 & 0 & 1 \end{bmatrix}$$

(2.4)where$\boldsymbol{K}$ is the camera matrix, f is the calibrated focal length, and $\boldsymbol{x_0}$, $\boldsymbol{y_0}$ are the coordinates of the principal point. In (Reznicek et al., 2008; Moons et al., 2010; McCarthy, 2014; Gimenez et al., 2015) extraction methods to 3D models from plain images are discussed. They address the main problems and available solutions for the generation of 3D models from terrestrial images by reviewing 3D acquisition technologies and highlight their important advantages. There is a considerable number of references on 3D reconstruction methods depending on Structure-from-Motion (SfM) algorithms, which refer to the simultaneous estimation of camera orientations and three-dimensional point clouds from a set of image correspondences. Figure 2 represents a general SfM workflow.

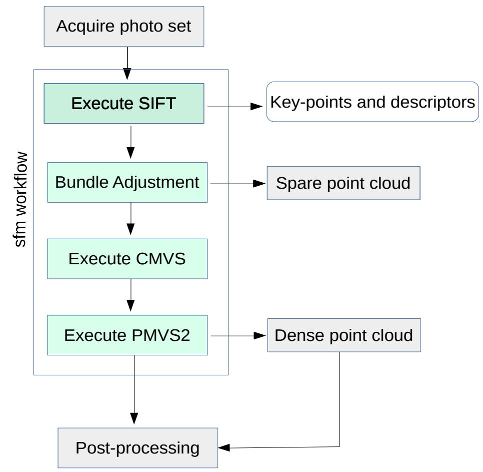


Figure 2: Structure-from-Motion workflow

In (Westoby et al., 2012)) authors highlight the SfM advantage of concurrently attaining 3D camera location and scene geometry by using related algorithms for camera pose estimation automatically. A new SfM pipeline proposed by (Toldo et al., 2015) named "dubbed Samantha", that uses a hierarchical approach, produces advantages in both computational complexity and overall error containment, instead of the sequential paradigm aiming at the problem of finding camera motion and 3D structure from point matches. On the other hand, an algorithm proposed by Lowe(1999) provides Scale Invariant Feature Transforms (SIFT) as a method for deriving distinctive and exclusive invariant features from images. (Zhang et al., 2008)) demonstrates experimental results and show the improved parallel SIFT implementation scales well on an 8-core system and are proposing two parallel algorithms and some optimization techniques for the SIFT implementation on multi-core systems. In the same context, the main part of SfM, that produces spare point clouds is the bundle block adjustment, the simultaneous generation of structure and camera parameters in visual reconstruction. Triggs et al. (1999) provide a survey of the theory and methods of bundle block adjustment, and Wu et al. (2011)present multi-core solutions to the problem of bundle adjustment that provide more space efficient algorithms and savings in runtime in the light of available CPUs and GPUs.

3. Terrestrial Laser Scanning and 3D Modeling

Range-based techniques are the method of directly capturing the 3D geometric information of an object, referred to as Light Detection And Ranging (LiDAR).It is a remote sensing technique based on laser beam radiation to be used for distance measurements, mapping of topography, as-built infrastructures, 3D reconstructions, vegetation, city modeling and some topical applications, such as forestry, hydrology, or in geophysics (Remondino et al., 2006). The process pipeline of creating a 3D model from terrestrial laser scanning data consists of main steps; data acquisition, scan registration, surface reconstruction and texturing, it is depicted in Figure 3.

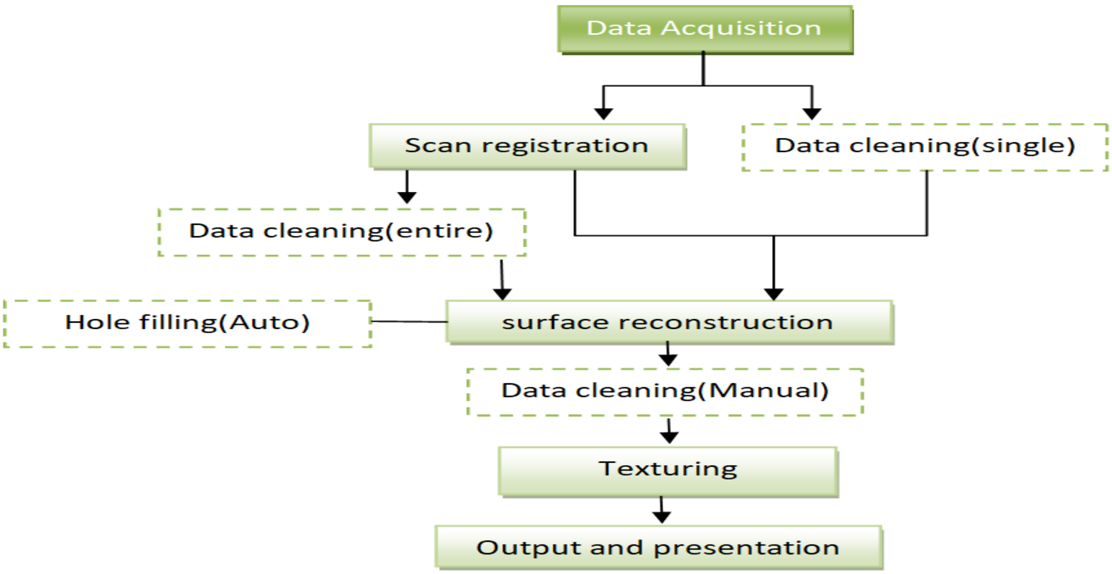
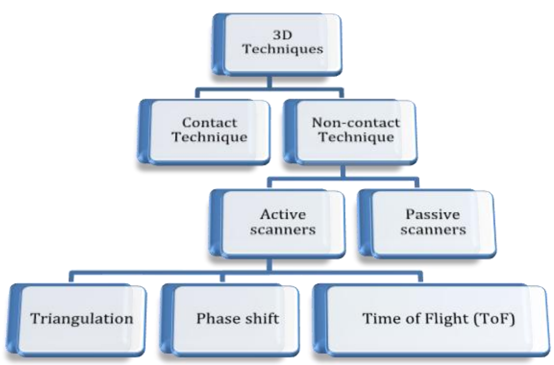


Figure 3:The Laser Scanning Pipeline (Rüther et al., 2012). Dotted lines means "optional"

This technique, also classified as active scanning with non-contact of the object (see Figure 4), is used to measure the distance for a large set of points in the target scene. The result is a point cloud with a vastly accurate and useful bunch of points to be used in engineering analysis, virtual assembly, reverse engineering, feature and surface inspection or rapid prototyping. Due to the 3D modeling capability, optical range sensors received great concentration in the last years (Hyyppä, 2011; Manferdini et al., 2012; Ebrahim, 2015). In addition, another classification can be considered for the current laser scanner technologies, which are static, with fixed position during the data acquisition, and kinematic systems, characterized by mobility, where additional positioning systems are required (Moussa et al., 2013; Oliveira et al., 2014).

Figure 4:3D Scanner Types



3.1 Time-of-flight Terrestrial Laser Scanners

The time-of-flight (TOF) 3D TLS are active scanners, that exploit laser pulse/light generated by the emitter unit to probe the target surface, and then register the reflected pulse received. The core of this scanner type is measuring a time frame between two events through using suitable electronics, measuring the roundtrip travel time of the returning signal and its intensity. Given the known speed of light c and t is the round-trip time, than then distance is to be calculated by (3.1) (Sansoni et al., 2009; Moussa, 2014; Ebrahim, 2015).

$$Z = \frac{1}{2} c\Delta t \tag{3.1}$$

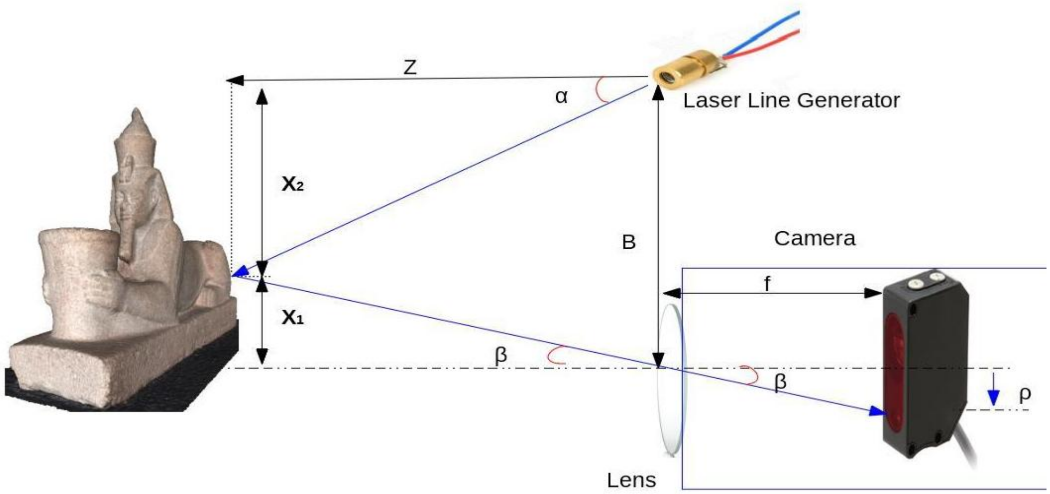


Figure 5: Triangulation Systems

3.2 Triangulation Systems

The triangulation-based laser scanner, categorized as active scanner, is also called triangulation scanner, because the laser projection/dot, a camera on board and the laser emitter form a triangle (see Figure 5) and describe therefore mathematically a triangle, according to (3.2).

$$\boldsymbol{B} = \boldsymbol{X_1} + \boldsymbol{X_2} = \boldsymbol{Z}\,\mathbf{tan}(\boldsymbol{\alpha}) + \boldsymbol{Z}\,\mathbf{tan}(\boldsymbol{\beta}) = \boldsymbol{Z}(\mathbf{tan}(\boldsymbol{\alpha}) + \mathbf{tan}(\boldsymbol{\beta})) \tag{3.2}$$

3.3 TLS Registration

Laser scanners generate point clouds through the collection of massive amounts of object points. Multiple scans are necessary to capture all object faces, seen from different positions, due to the limited field of view available to the Laser Scanner (LS). The resulting sets of point clouds need to be registered to complete the full coverage of a scene. The research groups that work in LS registration can be divided into two parts: firstly registration through support from third-party data such as imagery, and secondly registration without support from third-party (Forkuo et al., 2004; Seo et al., 2005; Yang et al., 2014).

4. Image-based and Range-based Case Studies in Sudan

Sudan is very rich in cultural heritage objects. Despite the political changes in the recent past it is the vision of all Sudanese citizens to attract visitors from all over the world to visit Sudan and to pay attention to Sudanese heritage. Therefore, using the latest technologies in image-based 3D reconstructions allows for the showcasing 3D cultural heritage objects on the Internet, in order to demonstrate the variety and arts of old Sudanese tradition.

4.1 Image-based Reconstruction of the Sphinx of Senkamanisken Kushite

One of the experimental goals of applying image-based 3D modeling is the generation of a 3D representation of the Sphinx of King Senkamanisken in the Sudan National Museum, Khartoum, which is depicted in Figure 6.

***F*igure 6: Sphinx of King Senkamanisken in Nubian style, Left: photographic archive (Bianchi, 2004), Right: at present in Sudan National Museum**

The sphinx granite statue of Senkamanisken Kushite depicts the Napatan Kushite King Senkamanisken of about 643 - 623 BC, in the ancient Egyptian form of a sphinx. A lion with human arms and hands (a variation known from ancient Egypt) holding an offering Jar inscribed with the king's names, bearded and wearing the nemes head-cloth and the double crown, or uraei, that identify the work as Kushite (Bianchi, 2004; Mohamed et al., 2013). The sphinx were entirely captured with a high number of overlapping digital images, collected by a calibrated DSLR camera Canon EOS 70D with a sensor having a resolution of 20.2Mpix and a lens with 18mm focal length, from a distance less than 2m. In total, 97 close range images were shot with resolution of 72pixels per inch of each image. Using SfM and the VisualSfM software (Wu, 2011) delivered the orientation parameters and the sparse surface geometry. The final 3D model consists of 1.2M vertices and is depicted in Figure 7.

(a) (b) (c) (d)

Figure 7:3D surveying and modeling of the Sphinx of Senkamanisken Kushite (a) photography,(b) sparse point cloud,(c) dense point cloud and(d) 3D textured model.

4.1.1. Photogrammetry advantages

In order to make a comparison between passive and active data collections, in particular to compare computer vision and photogrammetry with laser scanning, we can say, that for this example the first method is better suited. With this technique, we can also achieve very realistic models, especially if using photogrammetry in combination with manual post modeling (Radosevic et al., 2010). The advantages of geometric computer vision and digital close range photogrammetry are summarized as follows:

- Increasing accuracy.
- Reduced equipment cost.
- Increased throughput (automation).
- Less qualified operators (simple user interface, no or little stereo-viewing)
- Faster availability of results (on-line and real-time processing).

- Fast image transmission (use of digital images).
- Better quality and more flexible products (combined, hybrid data).
- Better data integration; joint platforms with CAD/GIS.
- New type of products (image based, visualization, animation).

4.1.2 Photogrammetric disadvantages

One main disadvantage of image-based techniques is the required time effort. It requires well-experienced operators in order to achieve post processing to get good results. It is not completely impossible to improve the accuracy of the model created by this technique, but it could acquire a lot of additional time to achieve high quality 3D models. This may require some user interaction, although there are a lot of research efforts for achieving higher level of automation in photogrammetry. Fully automated modeling using photogrammetry is still an continuing research area in this area of 3D modeling.

4.2. Range-based Case Study in Sudan

Naqa and Musawwarates-Sufra is considered as one of the Meiotic Kingdom (270 BC - 350 AD) historic sites, located about 150km north-east of Khartoum. This model is generated as part of the African Cultural Heritage Sites by the Zamani Project (University of Cape Town) and Landscapes Documentation Project. High-resolution laser scanners are used to scan the site with cm accuracy, see Figure8 (Bianchi, 2004; Rüther et al., 2011; Rüther et al., 2012).

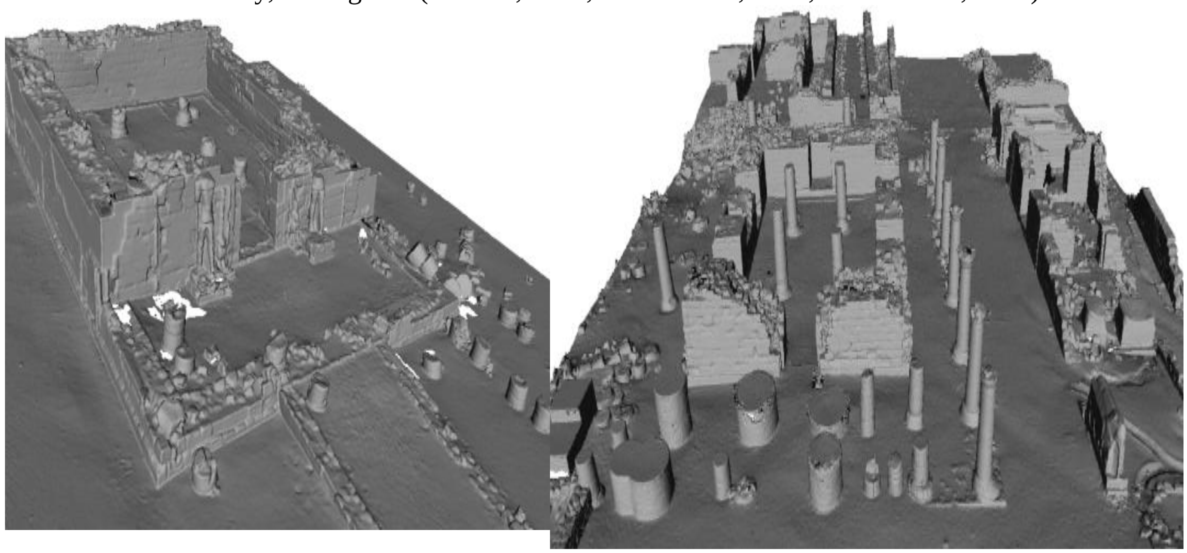


Figure 8:Naqa and Musawwarates-Sufra 3D Model

4.2.1. Laser scanning advantages

The most important advantage of using LS is its accuracy. LS provides 1-2 millimeter accuracy and this should be more than enough for most applications. LS can also be time saving. 3D models using LS are automatically generated and then optimized to get good results. With object textures we can create models with a high level of detail and of high accuracy – the models look very real.

4.2.2. Laser scanning drawbacks

LS is an expensive technology and the raw scanned models usually have a lot of small mistakes that must be manually removed in order to achieve the best level of detail. Scanning by night can be used to overcome laser scanner’s daylight sensitivity, but may cause another problem with textures, that results in the exclusion of the scanned textures from the project. The optimization of 3D modeling generated by LS can be problematic and very expensive. Also models created after the optimization process consist of a huge number of faces, and cannot be optimized without losing overall quality (Kadobayashi et al., 2004; Aguilera et al., 2006; Grussenmeyer et al., 2008; Radosevic et al., 2010; Mueller, 2014; Bayram et al., 2015).

5. SWOT Analysis

A general SWOT analysis given by a literature and web survey can be accomplished by identifying the key internal and external factors, seen as important from the views of users, developers and experts to achieve an objective classification.

The SWOT Matrix aims to identify how external opportunities and threats facing a particular organization can be matched with internal strengths and weaknesses, in order to result in possible alternatives in strategic planning (Groenendijk et al., 2003; Anh, 2007). In (O'Connell, 2015) a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis was applied for 3D laser scanning in conservation documentation (from the end-product point of view). A more recent study (Khosravani, 2016) represents a SWOT analysis of the Microsoft Kinect as a sensor system, to be used for point cloud collections. The main internal factors of Kinect technology in the current laser scanning practice are as follows:

- Price
- Accessibility
- Size and weight
- Data acquisition rate
- Available open-source drivers and software

The main external factors (opportunities/threats) of Kinect technology in the current laser scanning practice :

- Popular for many researchers working on different areas such as 3D reconstructions, indoor mapping, SLAM and robotics.
- Potential for use in crowd sourcing the 3D mapping of the building interiors.
- Developing RGB-D cameras with more functionality such as developing structure sensors that collect and align data in real-time.

One of the goals of this paper is to accomplish a SWOT analysis of image-based (geometric computer vision and photogrammetry) and range-based systems (laser scanning) for cultural object reconstructions. Our SWOT analysis gathers the external and internal factors from a variety of research outputs that focus on comparisons between photogrammetry and TLS (Baltsavias, 1999; Kadobayashi et al., 2004; Aguilera et al., 2006; Grussenmeyer et al., 2008; Radosevic et al., 2010; Mueller, 2014; Bayram et al., 2015). It finally groups key pieces of information into the two main categories "internal" and "external" and is displayed in Table 1 and Table 2.

Table 1. Photogrammetry SWOT Analysis

	Positive	**Negative**
Internal	**Strengths** **S1**: It takes less required field time. **S2**: Flexible in terms of range using lens. **S3**: A few control points are required and can be fixed in each survey. **S4**: Easy and inexpensive. **S5**: High accuracy on well-defined targets. **S6**: Size and weight **S7**: Available open-source drivers and software.	**Weaknesses** **W1**: Sparse data covering. **W2**: Difficulties in case of limited texture. **W3**: Large objects require more high resolution imagery. **W4**: Large objects lead to larger post processing efforts.
External	**Opportunities** **O1**: Does not require much skills **O2**: The dependency of point cloud precision/resolution on the image scale. **O3**: Development of efficient algorithms as well as computation hardware. **O4**: Information type: punctual, lineal or superficial. **O5**: Easy to interpret reconstructed models. **O6**:New type of products (e.g. animation) **O7**: The performance of the digital photogrammetric software.	**Threats** **T1**: Low data acquisition rate **T2**: Missing scale info requires more manual works. **T3**: End-user software problem: slow and manual process. **T4**: Not reliable if automated especially at large scales. **T5**: Flight constraints: daylight and clean atmosphere. **T6**: Sampling of full areas.

Table 2. Laser Scanning SWOT Analysis

	Positive	**Negative**

Internal	**Strengths** **S1**: Relatively simple. **S2**: Performance independent of ambient light. **S3**: High data acquisition rate. **S4**:For large objects creates 3D coordinates immediately. **S5**:Processing groups, they appear satisfactory as far as the number of points (density/sq meter) and precision.	**Weaknesses** **W1**: More time required in the field. **W2**:The maximum distances relation to reflectivity of the surface. **W3**:Limited range and measurement volume. **W4**:Missing data in correspondence with occlusions and shadows **W5**:Cost **W6**:Insufficient to reconstruct small features, clean edges or break lines **W7**: Complex objects needs many scanning positions and field efforts.
External	**Opportunities** **O1**:Production software: Depends on qualified commercial & technical people **O2**: Less flight constraints. **O3**: The performance of a laser scanner is determined at manufacturing. **O4**: The fusion of data from different sensors lead to possible new products.	**Threats** **T1**: More attention in setting up and operation of the scanner. **T2**:Safety constraint associated with the use of laser source. **T3**:The predetermined performance with no ability getting better.

From the SWOT analysis above the feasible alternative strategies, which is the integration of Photogrammetry and TLS, can be created by combining the strength and weaknesses with the opportunities and threats [SO, ST, WO, WT] to provide more accurate applications for modeling, interpretation and classification of objects. The results indicate a range of opportunities for the application of the fusion process in future 3D reconstruction practice and allow the weaknesses of each technique to be compensated for.

6. Integration of Laser Scanning and Photogrammetry

Many researchers hypothesized around the beginning of 2000 that photogrammetry would be totally replaced by Laser Scanning due to the fact that LS devices had been developed to a business level. It has become more apparent that integrating optical information with LS has many advantages. Some major advantages of using images is their similarity to the human vision system, their well-known internal geometry, good interpretability, ability to capture texture and multi-channel reflectance information, capability to model moving objects, re-measurability, and the use of frame-based acquisition methods(Forkuo et al., 2004; Lambers et al., 2007; Rönnholm et al., 2007; El-Omari et al., 2008; Bastonero et al., 2014; Moussa, 2014; Serna et al., 2015; Altuntas et al., 2016).The timeline of integrating both technologies is depicted in Figure 9.

Figure 9:Timeline of publications on the integration of photogrammetry and TLS

Integration is not limited to the integration of either airborne or terrestrial data. Actually, the most complete 3D virtual models may integrate information from ALS, TLS, aerial images, terrestrial images, and geodetic observations. Orientation to the common coordinate system is usually done separately for LS and images. However, if common features can be found, registration of interpreted 3D objects can also be used (Rönnholm et al., 2007). There are a large number of references devoted to the integration of laser scanning and photogrammetry available. (Forkuo et al., 2004), (Bastonero et al., 2014) and (Wu et al., 2015) represent a systematic review of the main three approaches for the laser scanning and photogrammetry integration, which are data fusion, image fusion and model-based image fusion. In the same context (Remondino, 2011) discusses the actual optical 3D measurements sensors and techniques and highlights the advantages of doing integration at the datalevel instead of the modellevelin order to overcome the weaknesses of each sensor.

Registration, which aligns the laser scanner data with the imagery, can be considered a main step for the integration process, and the quality of the registration process is an essential factor in accurate combined processing. Current registration approaches can be divided into four levels of integration, as proposed by (Rönnholm et al., 2007) which are:

- Object-level integration .
- Photogrammetry aided by laser scanning.
- Laser scanning aided by photogrammetry.
- Tightly integrated laser scanning and optical images.

(Brenner, 2005) reviews a number of automatic and semiautomatic methods for registration, (Serna et al., 2015) proposed a semi-automatic 2D-3D local registration pipeline capable of utilizing uncalibrated images for coloring LS 3D models. The automatic co-registration of terrestrial laser scanners (TLS) and amateur digital cameras is proposed by (González-Aguilera et al., 2009), (Weinmann et al., 2011)) and (Moussa et al., 2014). (Lambers et al., 2007), (Lerma et al., 2010), (Elaksher, 2016), (Armstrong et al., 2018) and (Oliveira et al., 2014) describe the potential of integrating TLS and close range photogrammetry for detailed recording and archival documentation of archaeological surveys.

6.1. Integration Case Study in Sudan

The case study for integrating Laser Scanning and photogrammetry is the pyramid for KandakeAmanitore Beg.N1, one of Meroë pyramids located in North cemetery. It contains the royal burial tombs of the Kings and Queens of Meroe from ca 300 BC to about 350 AD (Hinkel, 2000; Larson, 2006). The data which has been used for our experiment include 3D survey data (LS point cloud) and photos for Structure-from Motion of the pyramid Beg. N1, as documented for QMPS by the Zamani-project at Meroe/Begrawiya North.[1]The Beg. N1 pyramid was entirely covered with a high number of overlapping digital images by a calibrated DSLR camera Canon EOS. In total, 233 close range images were collected with a resolution of 72 pixels per inch. The orientation parameters and the sparse surface geometry from these images were derived using the SfM method in VisualSfM software. The final dense point cloud consists of 8.4 M vertices. On the other hand, a LS survey was done using Zoeller+Frohlich scanner 5010c - the point cloud generated consists of 47.8 M vertices which is depicted in Figure 10.

(A) (B) (C)

Figure 10:3D modeling for Beg. N1pyramid (A) photography,(B) dense point cloud and(C) LS point cloud. Figure 11 represents the result of applying Cloud-to-Cloud Distance tools in CloudCompare V2.1,which computes the distances between two point clouds - the dense point cloud in Figure 10(B) and the LS point cloud in Figure 10(C). (CloudCompare, 2017).

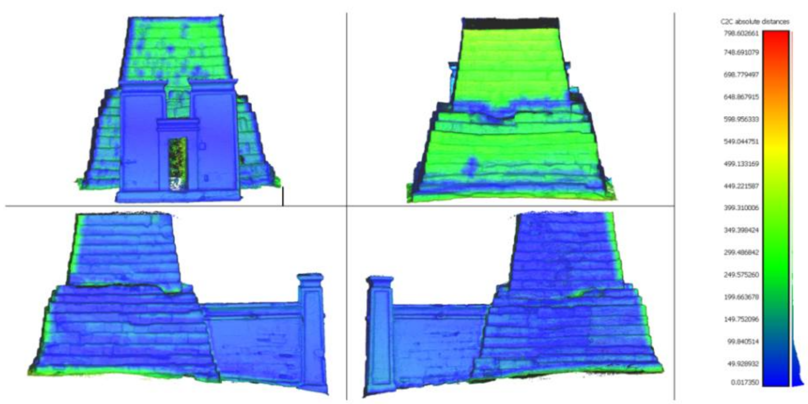


Figure 11: *Cloud-to-cloud distance scalar field*

7. Summary and Conclusion

Sudan is very rich in cultural heritage objects. However, unforeseen causes such as war and uncontrolled developments, human-caused disasters, neglect poor conservation, and natural disasters, combined with slow

[1] "Courtesy of the Qatari Mission for the Pyramids of Sudan (QMPS)"

documentation processes of architectural and archaeological cultural heritage sites, are main reasons that cultural heritage is vanishing.

This paper gives a review of results in the area of 3D cultural heritage preservation through representing the state-of-art in 3D model reconstruction using Laser scanning and photogrammetry. Point clouds are the core of attention for the laser scanning approach without taking special notice of corners and edges. In contrast, photogrammetric Dense Image Matching (DIM) generates dense colored point clouds and concentrates on representative structures of the object. Both technologies provide dense 3D point clouds, neither of them produces better-quality results than the other, but can complement each other very well. In this study a review of the present integration methods of both output datasets from the two acquisition techniques are discussed in order to optimize the visual quality and the geometric accuracy of 3D data collection for historical scenes. Identifying a number of Strengths, Weaknesses, Opportunities and Threats (SWOT) that photogrammetry and TLS faces, with the intent that items described here can be used to strengthen and guide the successful integration of approaches. Bearing in mind the rapid evolution of the technologies and practices, we believe that a review update is worthwhile and valuable. This might hopefully help Sudanese cultural heritage objects to get digitally preserved, either by professional surveyors or volunteers, to present the richness of past centuries, not only for Sudan but for Internet users and potential Sudanese visitors.

8. Acknowledgement

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