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The Feasibility of Using UAV Structure from Motion Photogrammetry to Extract HBIM of the Great Ziggurat of UR

Hussein R Sarhan*, **Fanar M. Abed**

Department of Surveying, College of Engineering, University of Baghdad, Baghdad, Iraq

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Abstract

Culture heritage reflects nation's legacy and therefore should be protected from damage in order to pass it to future generations. Recently, such protection can be applied by 3D digitization techniques such as conservation, restoration, documentation, etc. The 3D digitalization of heritage assets has encountered numerous focus in the last two decades due to the development in data capturing techniques and technological advancement in 3D remote sensing (RS) approaches such as photogrammetry and laser scanning. However, the abundance of 3D information resources and spatial data modelling and analysis methods have urged stakeholders to adopt intelligent 3D data management system so called Building Information Modelling (BIM) to facilitate data approaching and management. Historic Building Information Model (HBIM) is a special case of the BIM system, however it reflects the possibility to apply the BIM technology to the historical and heritage buildings. In this research, Structure from motion (SfM) photogrammetric routine based on Unmanned Aerial Vehicles (UAVs) images was applied to build HBIM of the Great Ziggurat of Ur in the south of Iraq. Based on the 3D geometric and texturing information extracted through photogrammetry and the historical information provided, virtual reconstruction has been carried out using (HBIM) technology. This was achieved by applying realistic materials and texturing information in order to document the building, which is directed to investigate the feasibility of implementing image-based 3D modelling within HBIM environments. Restoring the missing parts of the Ziggurat temple was also a focus of this research by implementing reverse engineering methodologies based on available information considered within the extracted HBIM. This can successfully represent a complete virtual reality model and a management information system of the Ziggurat building to be passed to future generations. The work also includes data assessment and validation with the as-built model generated from reference measurements within Computer Aided Design (CAD) environment.

Keywords: UAV photogrammetry, SfM, HBIM, Heritage Buildings, virtual reconstruction, 3D modelling.

دراسة جدوى استخدام طائرات التصوير المسيرة لانتاج نموذج البناء الرقمي التاريخي لزقورة اور الاثرية

حسين رياض سرحان* ، فنار منصور عبد

قسم المساحة، كلية الهندسة، جامعة بغداد، العراق.

الخلاصة

يعكس التراث الثقافي تراث الأمم ، وبالتالي يجب حمايته من الضرر حتى ينتقل إلى الأجيال القادمة. يمكن

*Email: hussein.riyadh2012@gmail.com

تطبيق هذا مؤخرًا باتباع تقنيات الرقمنة ثلاثية الأبعاد مثل الحفظ والاستعادة والتوثيق وما إلى ذلك. واجهت الرقمنة ثلاثية الأبعاد للأصول التراثية تركيزًا كبيرًا في العقدين الماضيين بسبب التطور في تقنيات التقاط البيانات والتقدم التكنولوجي في مناهج الاستشعار عن بعد (RS) ثلاثية الأبعاد مثل المسح التصويري والمسح الليزري. ومع ذلك ، فإن وفرة موارد المعلومات ثلاثية الأبعاد ونمذجة البيانات المكانية وأساليب التحليل قد حث أصحاب المصلحة على اعتماد نظام ذكي لإدارة البيانات ثلاثية الأبعاد يسمى نمذجة معلومات البناء (BIM) لتسهيل التعامل مع البيانات وإدارتها. نموذج معلومات البناء التاريخي (HBIM) هو حالة خاصة لنظام BIM ، ولكنه يعكس إمكانية تطبيق تقنية BIM على المباني التاريخية والتراثية. في هذا البحث ، تم تطبيق روتين قياس البناء من الحركة (SfM) بناءً على صور الطائرات المسيرة غير المأهولة (UAVs) لبناء HBIM لزقورة أور الكبرى في جنوب العراق. استناداً إلى المعلومات الهندسية والتركيبية ثلاثية الأبعاد المستخرجة من خلال القياس التصويري والمعلومات التاريخية المقدمة، تم تنفيذ إعادة البناء الافتراضية باستخدام تقنية (HBIM). تم تحقيق ذلك من خلال تطبيق مواد واقعية ومعلومات التركيب من أجل توثيق المبنى ، والتي تم توجيهها للتحقيق في جدوى تنفيذ النمذجة ثلاثية الأبعاد القائمة على الصور في بيئات HBIM. كان استرجاع الأجزاء المفقودة من معبد الزقورة أيضًا محور هذا البحث باتباع منهجيات الهندسة العكسية بناءً على المعلومات المتاحة التي تم أخذها في الاعتبار داخل HBIM المنتج. يمكن أن يمثل هذا بنجاح نموذجًا ناجحاً للواقع الافتراضي ونظامًا لأدارة المعلومات لمبنى الزقورة ليتم تمريره إلى الأجيال القادمة. يتضمن العمل أيضًا تقييم البيانات والتحقق من صحتها باستخدام النموذج المبني الناتج من القياسات المرجعية داخل بيئة التصميم بمساعدة الكمبيوتر (CAD).

1. Introduction

The term BIM is describing a data management system to process, manage, and produce structured information electronically [1]. However, HBIM is a novel prototype data management system originally designed to electronically process, manage, and produce heritage structured information using parametric objects library [2]. The development of HBIM systems can be used to record features' geometry, materials, and texture, in addition to relationships between features within the historical monument or the entire landscape environment [1,2]. Thus, in case of damaging or disappearing, HBIM can help in the restoration of heritage monument and managing conservation during the maintenance and operation [3,4]. To reconstitute the geometry of cultural heritage elements utilizing HBIM (Scan-to-BIM), Different data acquisition techniques are being used such as Structure from Motion (SfM) photogrammetry or Terrestrial Laser Scanning (TLS).

Production of BIM using SfM photogrammetry and TLS is an issue addressed in the scientific literature. Reference [5] has applied the basis of UAV photogrammetric survey of a dilapidated cultural heritage building and the historical information gathered to produce virtual reconstruction using a HBIM system. In this respect, [6] defines reference standards for the reliability declaration of the As-Built HBIM models considering both the geometric and attribute information aspects. To deal with more effective projects of documentation, restoration, and maintenance of historical buildings, [7] has focused on these stages, beginning from a point cloud and leading to the well-structured final product (BIM). They presented an important analysis of the application of these stages in the field of cultural heritage and they analyse the survey of existing strategies on the topics of acquisition, segmentation and BIM creation.

In this study, a photogrammetric survey of a great ziggurat of Ur was applied to implement SfM photogrammetric solution based on UAV images. Based on this survey and the historical information gathered about the building, HBIM was produced through successive steps, which structured in this paper into five sections; section 1 is an introduction followed by a definitive description of the case study in section 2. Section 3 is devoted to discuss important details concerning data collection and processing steps. In section 4, we discuss through the methodology and results delivered of the 3D point cloud extracted and 3D modelling phases, HBIM modelling, and related deliverables. Later, results discussions and validations with as-built CAD model extracted from field work and traditional survey was presented in section 5. Eventually, conclusions were made and highlighted in section 6.

2. Case Study

The city of Ur (Figure 1) was one of the main Sumerian city-states in old Mesopotamia during the 3rd millenary BC. One of best saved and most astonishing survives from this antiquated city is the Great Ziggurat of Ur [8]. The Great Ziggurat is a huge stepped pyramid about 64 m in length, 46 m in width, which is situated today in the Thi Qar Province, in the south of Iraq. It consists of a series of successively junior platforms which rose to a height of about 30 m. This altitude, nevertheless, is only estimation, as only the foundations of this old landmark is endured today. The Great Ziggurat of Ur constructed with three different levels platforms that had a strong centre of mud-block, which was wrapped by thick cover of burnt brick.

This external layer shielded the centre from the environmental elements. The Ziggurat was the managerial heart of Ur, which was established around 2100 B.C.E by King Ur-Nammu who belonged to the Third Dynasty of Ur, and later was completed by his son, King Shulgi [9].

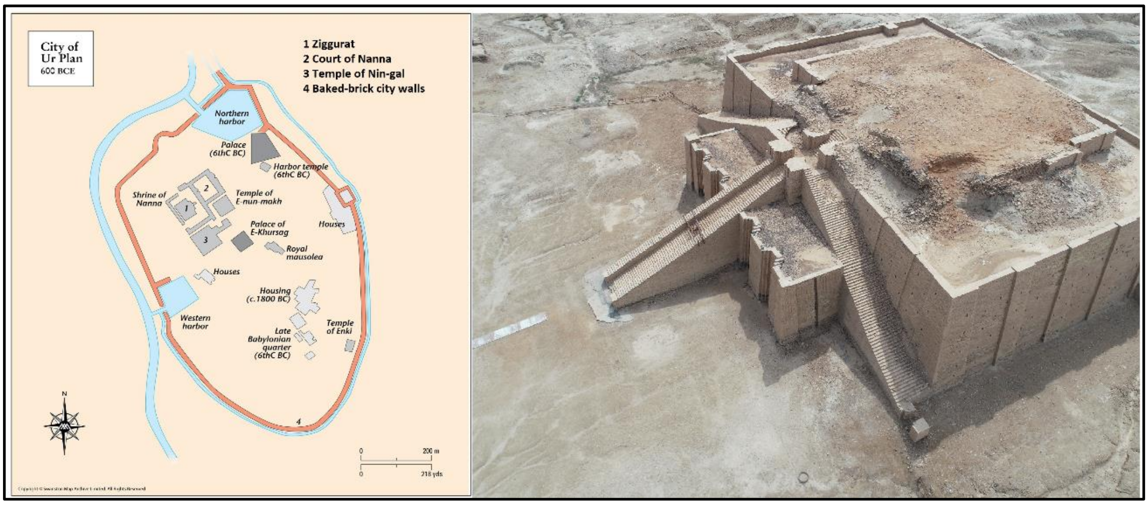

Figure 1-The Great Ziggurat of Ur case study; Left: Study site map represented historical location and importance of Ur city; Right: aerial image of the Ur Ziggurat nowadays.

The Great Ziggurat of Ur was devoted to Nanna, the moon god, who was the patron deity of the antiquated city. The ziggurat may have worked as an exemplification to the homes of Mesopotamian gods as they were generally connected toward the eastern mountains. A solitary little sanctum was set on the highest point of the ziggurat for the god because the people of Ur thought that the ziggurat was the spot on earth where Nanna decided to stay. A bedchamber was given to Nanna in the holy place on top of his ziggurat because the people of antiquated Mesopotamia thought that their divines had needs completely like their mortal subjects. This chamber was participatory with a maiden picked to be the god's companion. The ziggurat was surrounded by the temple's storage facility, a royal ceremonial palace and the places of priests [9]. The importance of Ur Ziggurat gives us the motivation in this research to create the virtual reality model of this monument and restore its missing parts by generating the HBIM using RS approaches, towards keep it save from intruders and export it to other nations and future generations as a sign of early civilizations in the world.

3. Vision and data collection

A wide domain of RS data can be of extraordinary advantage for the operation of documentation, modelling and visualisation of heritage legacy within HBIM systems. These data (regardless of whether tangible, for example, the geometry, structural systems and materials, or intangible, for example, the historical document of the structure, its performance and its cultural assets) can vary in domain, intent and the examination tools. These distinctive data can be sorted into four primary classifications, every domain require its own documentation and examination apparatuses (Figure 2):

- Archaeological and historical data; which include archaeological investigations, chronicled records and structure's morphological data over time.
- Geometry; which includes the survey and presentation of the heritage building in its present status to distinguish shape, size, identity and position the segments of the historic landmark.
- Pathology; which includes the degradation and expected harm of the texture of the heritage landmark, and the examination of the sub-surface characteristics of its materials and structural frame.
- Performance; which includes experimental data concerning the structure's performance and operability in different aspects.

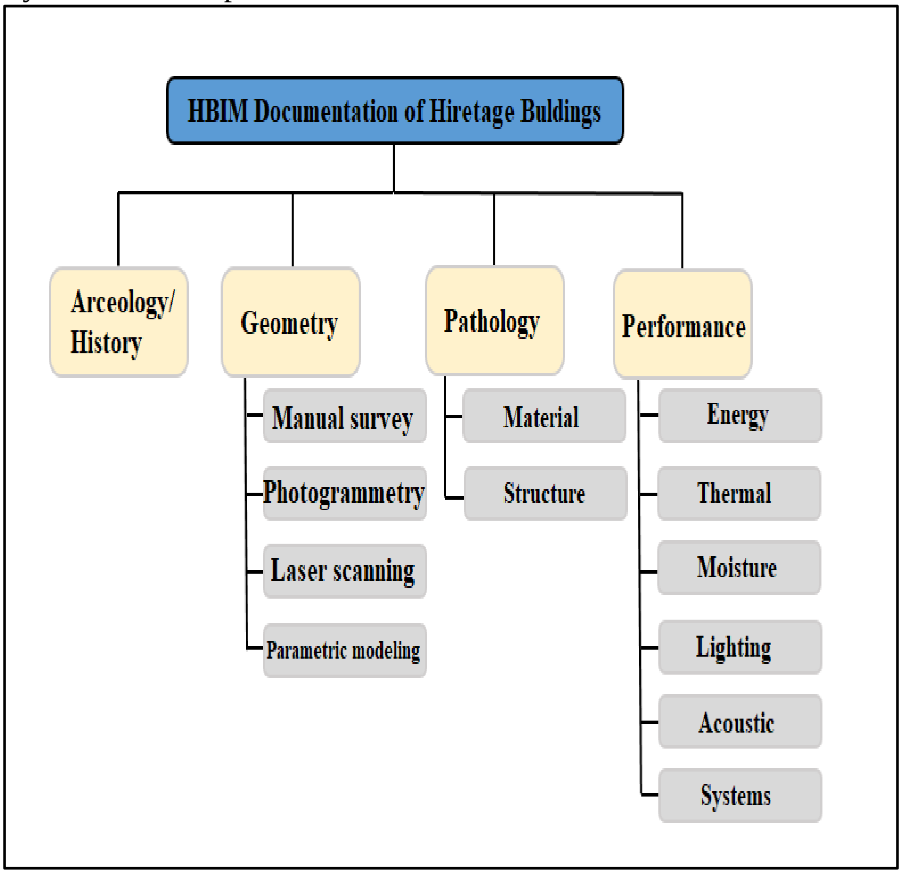

Figure 2-The categories of data domains incorporate in heritage documentation.

3.1 Archaeological and historical data

HBIM introduces different scenarios to digitally document all in-situ features that are included the heritage building over its life cycle, thereby manages intelligent approaches for information preservation [10]. Consequently, HBIM can integrate the tangible features with different intangible aspects/parts (e.g. historical drawings and sketches, archival texts and photos …etc.). The variety of data sources can be beneficial to understand the actual status of historic buildings and to demonstrate its historic morphology over time. Besides, HBIM products are of great help to disseminate heritage assets wider audience by implementing the different phases of building history into the modelling process. To this end, more sophisticated visualization methods are deployed using virtual and augmented reality techniques (i.e. VR and AR) [3]. In case of the lack of historic data, the missing information can be retrieved by using reverse and interpolation processes based on geometric surveys and archival documents, see [11] as an example carried on St. Maria church in Scaria d'Intelvi in Italy.

3.2 Geometric data

There are several geomatic techniques available for collecting data needed to create accurate as-built BIM, such as photogrammetry, laser scanning and other traditional survey instruments like total stations and GPS/GNSS devices. However, in this research UAV-photogrammetry was selected to collect geometric data for the case study. This is particularly because UAV is more affordable and low-cost than TLS to use for delivering high level of details (LOD) within minimum field works efforts for this relatively big building. Further, as we are looking for a reality capture model, photogrammetry can deliver better texture information than TLS and smoother 3D data for modelling process [12] and therefore photogrammetry was selected to build the geometric data of the HBIM.

3.2.1 UAV photogrammetric Survey

To implement the photogrammetric survey; at first, 4 ground targets were placed around the building (Figure 3). The targets are made of square paper with (600 × 600 mm) in dimensions, Global Navigation Satellite System (GNSS) receiver (Topcon GR-3) was used to observe the 3D coordinates of these targets. Horizontal coordinates are referred to as UTM Zone 38N (World Geodetic System 1984, WGS84) and the elevation is referred to the Mean Sea Level (MSL) using the EGM08 geoid model. After words, a 3D photogrammetric mission was launched using a quad-rotary UAV (DJI Phantom 4) as shown in (Figure 4). Two flight plans were set to assure a complete coverage for the facades and top details using the autopilot application Pix4Dcapture © Pix4D. The first flight (Double Grid) is dedicated to record the top and surrounding of the building with 40m height and (80%, 70%) overlap and side lap, respectively. The second flight plan (Circular) was established at 22m height to obtain oblique photographs for the four facades, see Figure 5, to demonstrate the alignment of the collected photographs in two flight plans. Therefore, the total number of recorded images was (359), those used to deliver a detailed 3D point cloud model, see Figure 6, using SfM photogrammetry.

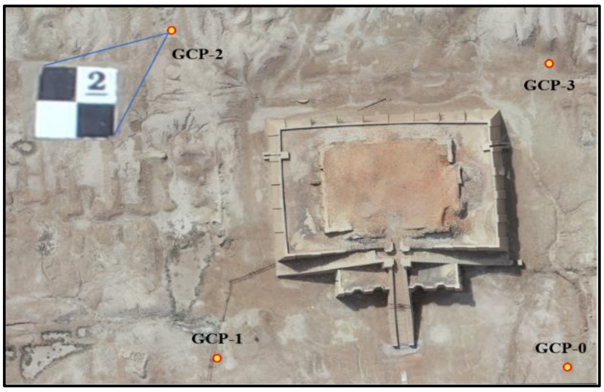

Figure 3-The distribution of GCPs within the study site.

Figure 4-UAV (DJI Phantom 4) used to collect the geometric data.

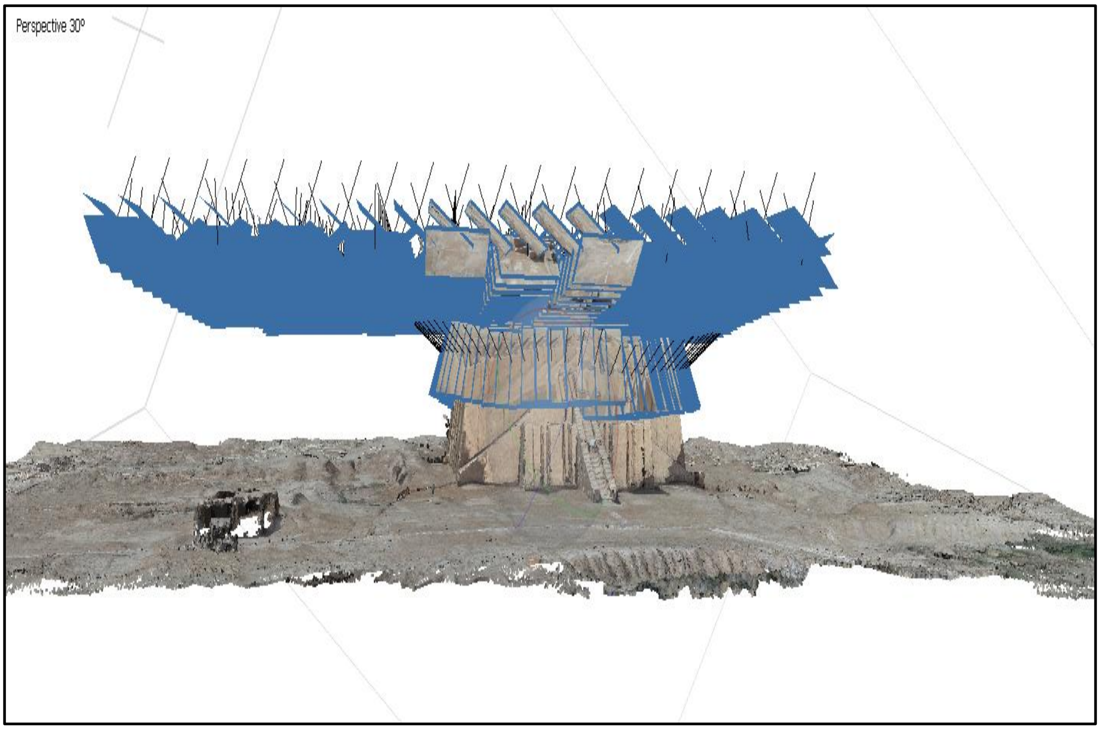

Figure 5- Alignments of the collected photographs in two flight plans.

3.2.2 Traditional survey

A complete ground survey was carried out using Total station (Topcon ES-105) device to record the 3D coordinates of the building facades. This traditional survey data is referenced to the ground control point network and directed to assess the final product of HBIM which will be discussed in section 5.

4. Data processing and modelling

4.1 3D Point cloud modelling

The modelling process was carried out using the software package Agisoft Metashape Professional © version 1.6.2. This photogrammetric software used the 3D vision reconstruction technology and the SfM algorithm to create high-quality 3D models from images [13, 14]. The photogrammetric point cloud generated from image datasets was georeferenced indirectly based on the ground targets measured in field. The resultant dense point clouds (Figure 6) are served to reconstruct the 3D surface/mesh of the object, and then realistic colours are extracted from the photo textures and applied to the derived 3D mesh. Table 1, representing alignment report of the UAV images provided by Agisoft Metashape. To deploy the generated 3D point cloud in HBIM modelling, the point clouds is exported as (*.las) format to ReCap software which in turn initiate the dataset into the HBIM environment.

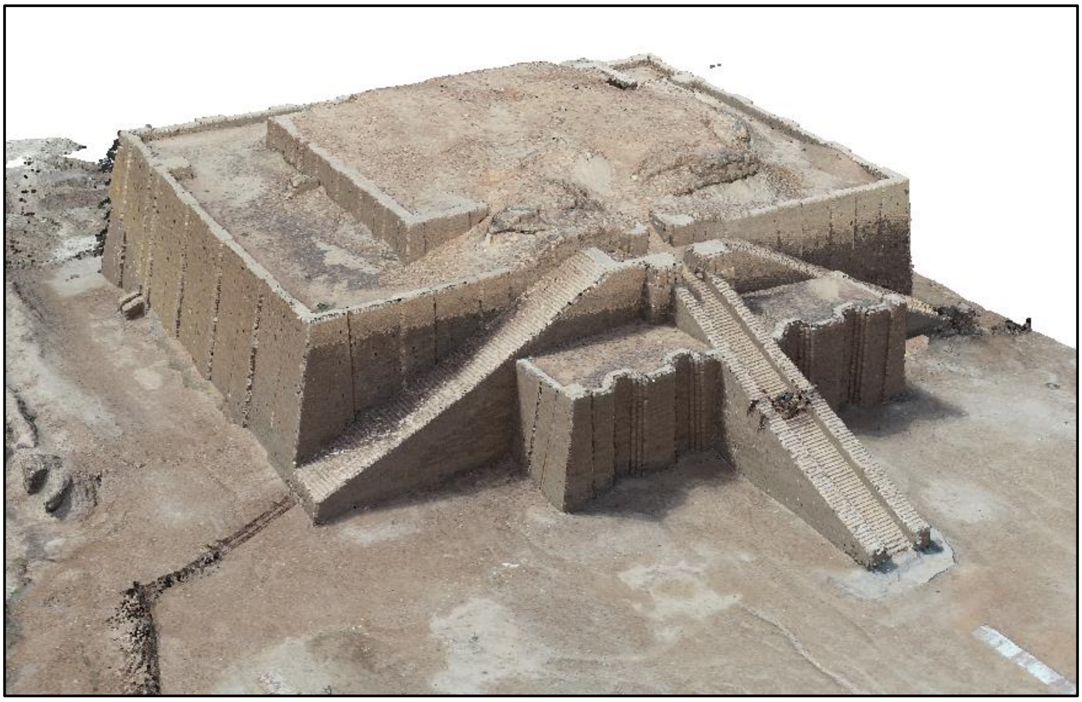

Figure 6-3D point c

Table 1- Alignment report of the case study provided by Agisoft Metashape.louds model obtained from UAV SfM photogrammetry.

Count of registered images	359
Automatic tie points (ATP)	3 566 797
Mean re-projection error [pixels]	0.064
Point cloud count	31 430 612
Alignment time	01h:10m:57s

4.2 Heritage Building Information Modeling (HBIM)

The generated point clouds can be served as a base for modelling the various components of the building in a BIM platform, using parametric objects of known geometry. Nonetheless, the fundamental issue in modelling historical buildings that making it difficult to track down specific libraries and materials in commercial BIM software is that its structures or styles are not as unified as current buildings. Therefore, the important step is to build several families of parametric elements that help in modelling the complicated and atypical shapes in historical buildings. This is time consuming, but it permits us to originate the libraries that will make up the HBIM and thus can be utilized in other future projects. In this regard, it is critical to mention that BIM is the work methodology, and the software is the extraction instrument.

After the PC modelling, the BIM modelling is done using Autodesk Revit 2021 commercial software. Utilizing the format (*.las) that stores the colour information obtained from the images, Revit software can incorporate the point clouds from its own interface or through the Autodesk ReCap software to allow their visualization. The strategy that has been achieved for Scan to BIM is illustrated in (Figure 7). The modelling started with the identification of the levels of different parts of the building starting from the ground floor level, first floor, and second-floor level. Those levels are limited horizontal planes that work as a reference for level-hosted elements, such as roofs, floors, and ceilings in building sections views cut through the model. Revit, as a BIM software, does not have an automatic geometry recognition option. For this reason, the modelling implemented manually for all the elements that make up the model. One of the most important steps for modelling non-conventional forms such as slanted walls, stairs, and towers, was to create different families that contained their metadata (Figure 8). The metadata (materials, geometric and structure information) are introduced and all created BIM component in the scene. Figure 9 demonstrates a typical example for the slanted walls where the metadata is introduced. The complete modelling operation was accomplished in around 36 hours of work.

To gain photorealistic images, it is important to add textures and materials to the 3D model in a process called rendering as shown in (Figure10). Rendering is usually done in a third-Party software (e.g.) Lumion which is made especially for architects and designers to produce realistic themes quickly. Lumion can help quickly bring the model to life and show it in a richly detailed in a captivating environment. In addition, the Revit model can be exported to Lumion to add textures and materials because each software has the ability to exchange formats.

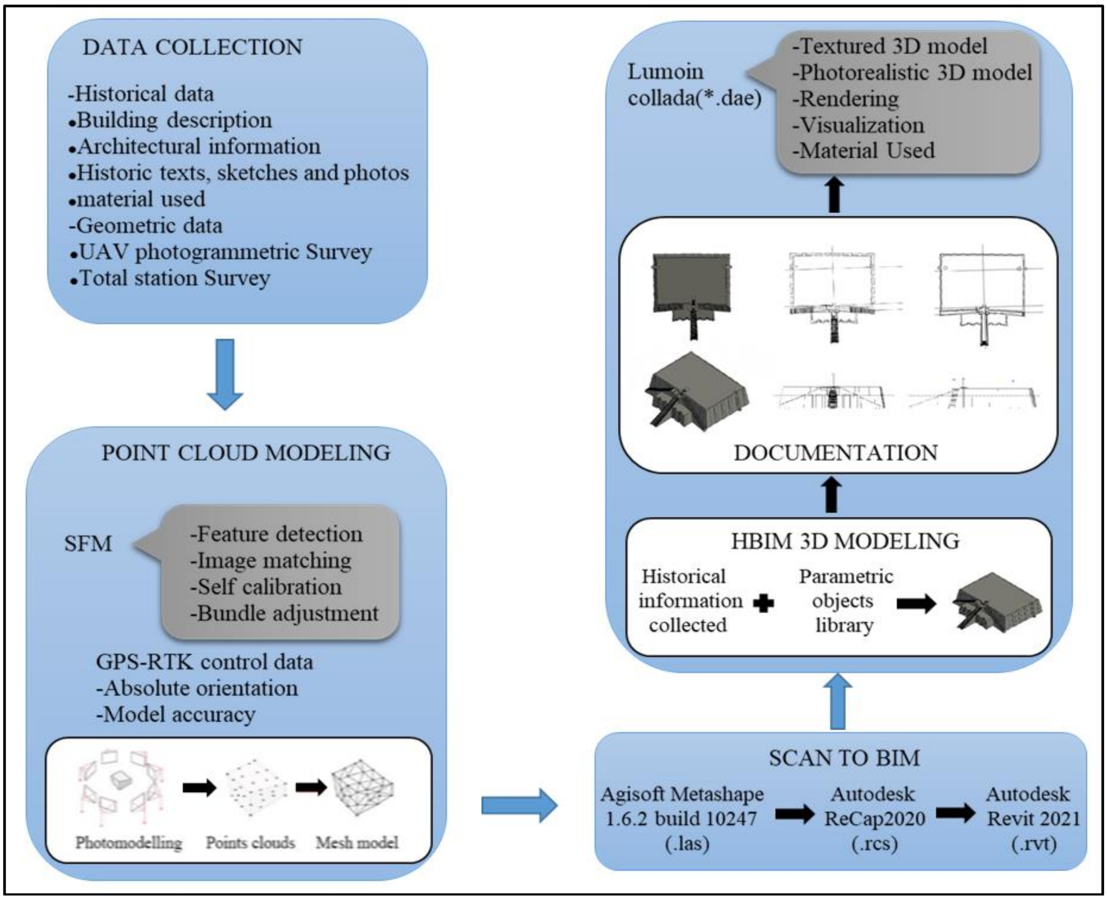

Figure 7-HBIM methodology workflow.

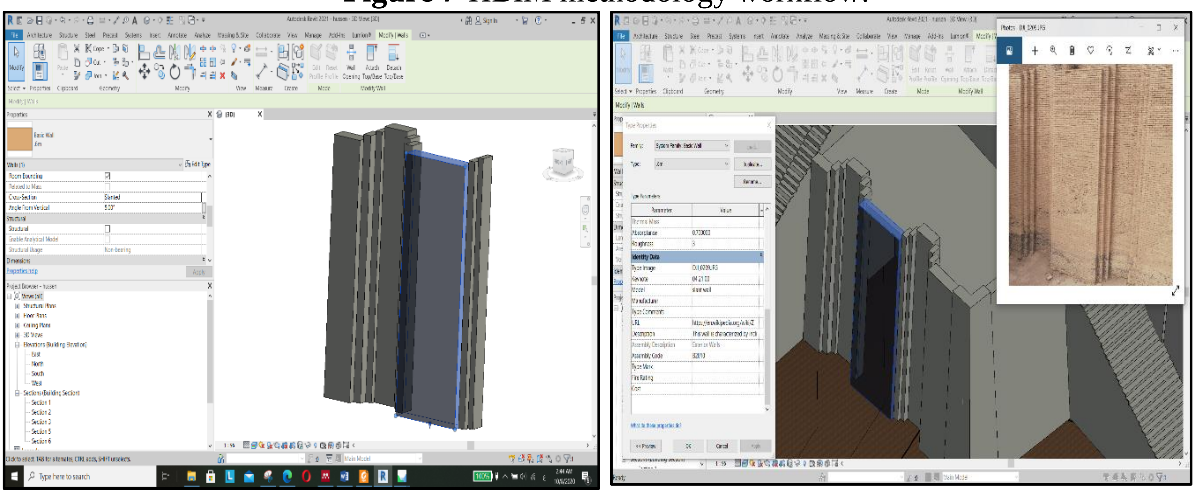

Figure 9 -Metadata; geometric data and characteristics of the materials of slanted wall.

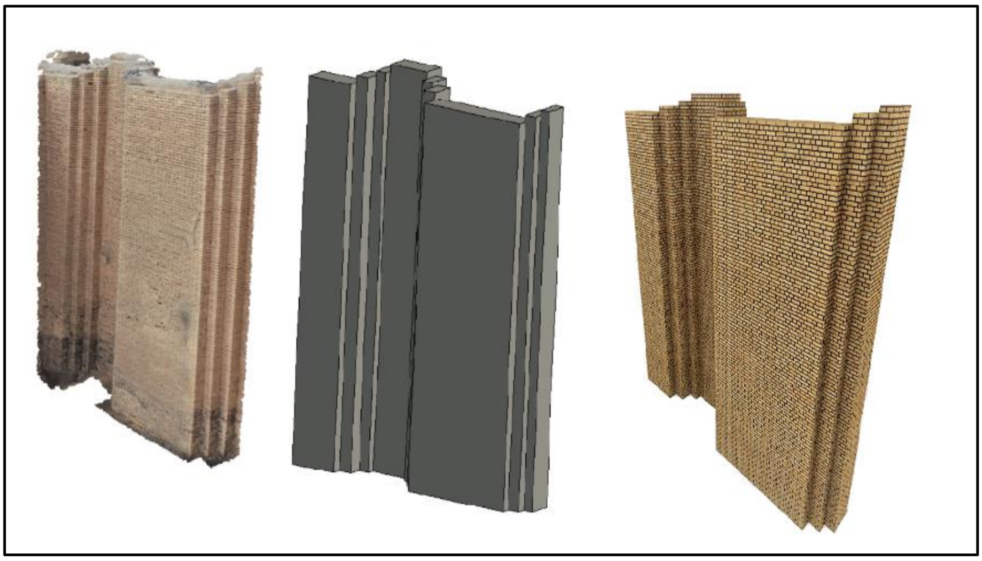

Figure 10-Renders obtained with Lumion 3D rendering software.

5. Validation and discussions

The most crucial matter of as-built BIM production is to ensure an accurate representation of the building true condition. In particular, when BIM is directed for documentation, restoration and/or building analysis purposes. As the workflow of BIM creation can include several manual steps, thus the final BIM product is likely to be prone to errors. Therefore, necessary quality assurance (QA) procedures should be undertaken to ensure the integrity of the produced models.

The proposed geometric deviation analysis followed in this research involves computing the deviations between a sample of data from HBIM and related ground true data by finding correspondences between true coordinates and the generated BIM, see (Figure 11). Then after, computing the distances of correspondences (Table 2) is implemented, and the deviations are plotted with a line chart as shown in Figure 12.

The geometric comparison outlined the feasibility of using structure from motion (SFM) photogrammetry to derive accurate, consistent and dense point clouds that turns to be the best possible base for the survey and modelling of legacy buildings in deteriorated conditions.

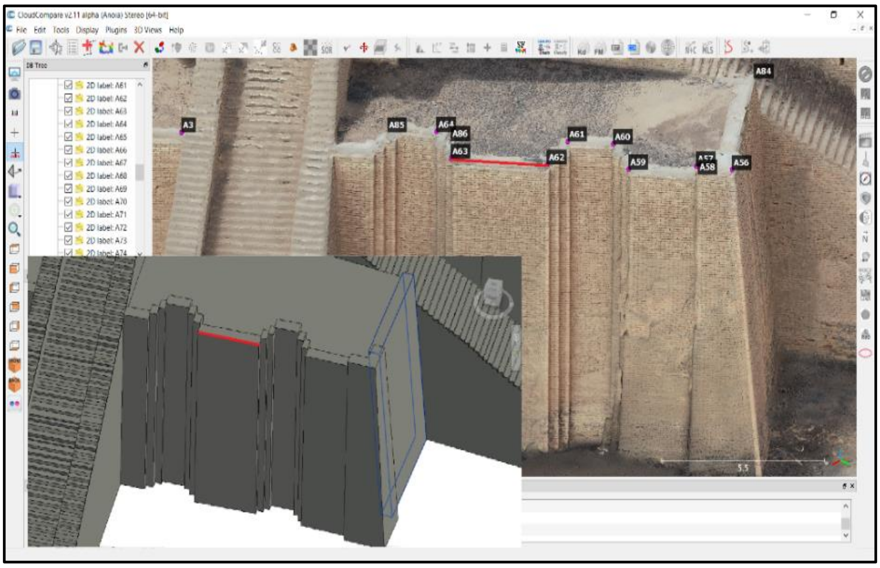

Figure 11-Example of correspondences between the ground truth CAD model and the extracted HBIM.

Table 2- The computing the sample distances of correspondences.

PT	TS	BIM
1	**2.752**	**2.802**
2	**2.516**	**2.6**
3	**2.216**	**2.202**
4	**1.299**	**1.283**
5	**1.355**	**1.386**
6	**3.253**	**3.27**

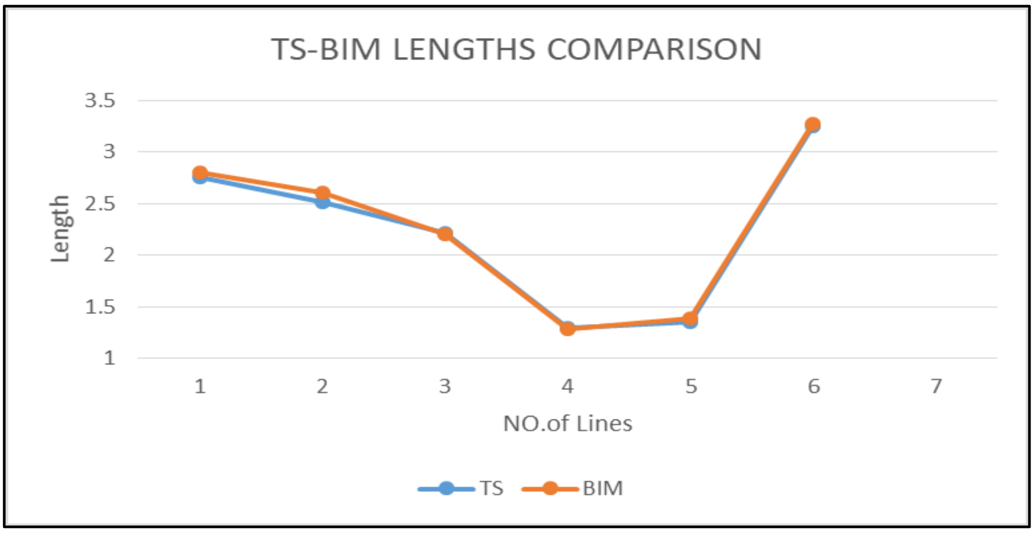

Figure 12-TS and BIM length deviations.

6. Conclusions

The aim of this research is to produce and represent a complete HBIM workflow of one of most important heritage sites in Iraq, which is the ziggurat of great Sumerian city of UR. The methodology relies on appropriate IT infrastructure in terms of software, hardware and networks, which is informed by heritage conservation project requirements. The workflow based on SfM photogrammetry by using Phantom DJI UAV platform to collect aerial and oblique images to the study monument. Later 3D point clouds were generated to extract the geometric model of the HBIM in addition to the texturing information those have been delivered from the generated orthmosaic. A prototype library was generated to define the parametric objects of the generated HBIM using Revit software. Validation process with a reference ground truth CAD model, which has generated based on total station field measurements was implemented to check the quality control of the extracted HBIM. Through this study, the feasibility of deploying photogrammetry in BIM environment has been highlighted which proven to successfully reconstruct intelligent HBIMs for future restoration and conservation projects.

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