بسم الله الرحمن الرحيم

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Preserving Sudanese Cultural Heritage by Means of Photogrammetric three-dimensional (3D) Reconstruction.

الحفاظ على التراث الثقافي السوداني بوسائل إعادة البناء التصويرية ثلاثية الأبعاد

A Thesis Submitted in Partial Fulfillment of the Requirements of Master Degree in Computer science (GIS Geographical Information Systems)

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Table of Contents

Contents

I

Table of Contents I

الآية III

Dedication IV

ABSTRACT V

المستخلص VI

1.1 Introduction 1

1.1.1 Geographic Information System (GIS) 2

1.1.2 Relating Information from Different Sources 3

1.1.3 Data Representation 3

1.1.4 History of 3D Modeling 4

1.1.5 Methods of creating 3D models 4

1.2 The Research problem 5

1.3 Research Objectives 5

1.4 Methodology and Project Planning 5

1.5 Research Layout 6

2.1 Theoretical Framework 7

2.1.1 Computer Graphics 7

2.1.2 Photogrammetry 11

2.1.3 Geographical information System (GIS) 13

2.1.3.1 What is GIS 14

2.3.1.2 The Power of GIS: 15

2.3.1.3 GIS in Action: 16

2.2.1 Literature Review 18

2.2.2 Own comments on previous studies 19

2.3 System Description 19

2.3.1 Current System 19

2.3.2 Current System Problems 20

2.3.3 Proposed System Description 20
2.3.4 Scope of the System 20
3.1 Research Community 21
3.2 Methodology and Project Planning 21
3.2.1 Data Modeling 21
3.2.2 Data Measurements, Processing and Preparation 22
3.2.3. Building 3D Models 22
3.2.4. Build a 3D GIS Model with all Relational Spatial Data Bases 23
3.2.5. Texture Mapping 24
3.3 Selected Methodology and Techniques 25
3.3.1 AgiSoft's PhotoScan 25
3.3.2 Trimble's SketchUp Pro (Version 2016) 25
3.3.3 Esri's ArcGIS 10.1 25
3.3.4 Sketchfab 26
4.1 System Requirements 27
4.1.1 Functional Requirements: 27
4.1.2 Technical Requirements: 27
4.1.3 Nonfunctional Requirements 28
4.2 Analysis and Design 28
4.2.1 Database Design 28
4.2.2 Database Transactions 29
5.1 Photogrammetry 30
5.3 3D Model Reconstructions 38
5.4 ArcGIS 43
6.1 Conclusions 45
6.2 Recommendations: 45
7.1 References 47

الآيـة

بسم الله الرحمن الرحيم

قال تعالى {قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ } [البقرة :32]

صدق الله العظيم

Dedication

This thesis is dedicated to my parents, brothers, sisters, work colleagues, classmates and my supervisor.

For their endless love and support.

ABSTRACT

The nations always pay a great attention to their cultural heritage, they are focusing on preserving it against gradual changes and damages caused accidently by humans or due to natural disasters.

The National Museum of Sudan is one of the largest legacies in the country and includes hundreds of artifacts, statues, temples and other historical objects that the nation has undergone since it is inception. So the preservation of this museum and it is priceless components is a priority of the whole nation.

This is the reason for the idea of designing three-dimensional models for the museum's objects and features that had a historical importance to be part of the heritage conservation project. In future they should be maintained in a 3D model to help in the restoration of these pieces, just in case of partial or total damage to the specific artifact. The virtual reality model which is built by utilizing the most modern 3D technologies and GIS, and to be used in the future will guide visitors to locate artifacts, temples, and statues smoothly by just using their smart phones. Beside all of these considerations the research goal is to share the nation's past with the future generations, so that they can be linked to their nation's development, and to know how their ancestors exerted their efforts to build that nation.

Moreover, the developed 3D models can be used to the promotion of the Sudanese national heritage by publishing them through the internet or mobile applications to stimulate tourism in Sudan and also to attract foreign tourists to visit the country to see these artifacts in reality. Hopefully, such measures will positively affect the Sudanese economy and feed the state treasury with some funds and money which will come from the tourism sector.

المستخلص

دائما ما تولي الامم اهتماما متعاظما بإرثها الثقافي، وتركز في الحفاظ على هذا الإرث من التغيرات التدريجية التى تطرأ على هذا التراث بسبب تدخل الانسان بصورة غير مقصودة او الأضرار التى تنجم عن الكوارث الطبيعية كالأمطار و الأعاصير و الزلازل.

يعتبر متحف السودان القومي واحدا من أهم الموروثات التاريخية للامة السودانية و يحتوي على مئات القطع الأثرية و التماثيل و المعابد و بعض المنعطفات و الأحداث التاريخية التي مرت بها الامة منذ نشأتها الاولى و حتى يومنا هذا، لهذا نجد ان المحافظة على هذا المتحف و مكوناته التي لاتقدر بثمن واحدة من اولويات الامة السودانية.

لهذا جاءت فكرة تصميم نماذج ثلاثية الأبعاد لمبنى المتحف ذات نفسه و بعض القطع الأثرية ذات الاهمية التاريخية للأمة للمحافظة عليها، وقد تم تصميم نموذج افتراضي ثلاثي الأبعاد لمحاكاة الواقع، وذلك بالإستفادة من التقنيات الحديثة و ربط هذا النموذج بواسطة نظم المعلومات الجغرافية للإستفادة منه مستقبلا في توجيه زوار المتحف عن طريق تطبيق ملحق بجهاز كمبيوتر او هاتف ذكي للقطع الاثرية و التماثيل و المعابد الموجودة بالمتحف.

عن طريق هذه النماذج ثلاثية الأبعاد يمكننا مشاركة ماضي الأمة مع الأجيال القادمة، ليتعرفوا على ثقافة أسلافهم، وتقدير التضحيات و المجهودات التى بذلوها لبناء هذه الحضارة الممتدة على مر الازمان.

كما يمكننا إستخدام هذه النماذج للترويج لتراث الأمة عالميا و ذلك بنشر هذه النماذج على الإنترنت او تصميم تطبيقات هواتف ذكية تستخدم لعرض هذه النماذج و ذلك بغرض تشجيع السياحة و جذب السياح الاجانب لمشاهدة هذه النماذج على الطبيعة، و سينعكس هذا الامر كمردود ايجابي على خزينة الدولة و انعاش اقتصادها.

Chapter one

Introduction

1.1 Introduction

1.2 The Research Problem

1.3 The Research Objectives

1.4 Methodology and Project Planning

1.5 Research layout

Chapter One - Introduction

1.1 Introduction

Nowadays, efforts to preserve resources of cultural heritage have gained new momentum throughout the world. Protecting cultural heritage is economical, as well as historical and also a cultural process. While cultural heritage preservation has not yet become firmly rooted in Sudan, a great number of people and organizations see cultural resources as critical to the nation's economic development through tourism. Cultural heritage is based on the aspects of nation's past, want to keep and pass on to future generations and the outside world. However, the economic benefits of preservation are secondary to the intrinsic value of that heritage which is been preserved.

Nation's heritage is needed like food, water, and shelter. That is something heard daily in the work environments. But in a world where warfare destabilizes states and environmental disasters upend communal order, heritage is often seen as dispensable.

That is the wrong approach. Heritage is not just a link to the past. It is a catalyst that can uplift communities economically, culturally, and spiritually now and for generations to come. This is what people call the world "beyond monuments."

Nation owe it is success to everyone from the ancestors. Preserving heritage is one way of giving back to ancestors and making sure the next generations have something to be proud of.

Libraries, archives, and museums hold disparate collections in a variety of media, presenting a vast body of knowledge accumulated over the institutions' history, and the mission of these institutions is to make their collections accessible to intended users. The research area of interest is heritage preservation by concentrating the efforts to the Sudan national museum. The research will apply three-dimensional (3D) visualization with texture mapping to make real simulations of objects of the Sudan museum. Furthermore, utilizing geographical information system (GIS) tools to create an interactive and flexible system providing an amazing visual interpretation of the museum. This interpretation can help in planning and decision making.

Besides that, precise digital documentation of cultural heritage assets is essential for its preservation and protection. This documentation increases the efficiency of scientific studies that are being carried out during the restoration and renovation processes. Precise digital documentation makes use of different geospatial technologies, such as using laser scanners and imaging.

3D imaging techniques, multimedia applications, virtual reality and augmented reality applications become increasingly used in museums and galleries around the world, covering a wide range of areas starting with museums dedicated to nature and natural history, human science, religious, etc.

Due to the wide availability of 3D scanners and other data acquisition systems, many 3D models are obtained through the scanning process of actual objects from the museum collections. The discrete point set obtained is then processed to a continuous surface representation such as using splines, volumetric or polygonal models.

The increasing availability of low-cost 3D acquisition devices has resulted in the widespread dissemination of 3D point clouds of sampled real-world objects. As a consequence, surface reconstruction from acquired 3D point clouds has become an important problem in computer graphics and computer vision.

1.1.1 Geographic Information System (GIS)

GIS is a system designed to capture, store, manipulate, analyze, manage, and present spatial or geographic data [1]. The acronym GIS is sometimes used for geographic information science (GIScience) to refer to the academic discipline that studies geographic information systems and is a large domain within the broader academic discipline of geoinformatics. What goes beyond a GIS is a spatial data infrastructure, a concept that has no such restrictive boundaries.

In general, the term describes any information system that integrates, stores, edits, analyzes, shares, and displays geographic information. GIS applications are tools that allow users to create interactive queries (user-created searches), analyze spatial information, edit data in maps, and present the results of all these operations. Geographic Information Science is the science underlying geographic concepts, applications, and systems.

GIS is a broad term that can refer to a number of different technologies, processes, and methods. It is attached to many operations and has many applications related to engineering, planning, management, transport/logistics, insurance, telecommunications, and business. For that reason, GIS and location intelligence applications can be the foundation for many location-enabled services that rely on analysis and visualization.

1.1.2 Relating Information from Different Sources

GIS uses spatio-temporal (space-time) location as the key index variable for all other information. Just as a relational database containing text or numbers different tables can be related using common key index variables, GIS can relate otherwise unrelated information by using location as the key index variable. The key is the location and/or extent in space-time.

Any variable that can be located spatially, and increasingly also temporally, can be referenced using a GIS. Locations or extents in Earth space–time may be recorded as dates/times of occurrence, and x, y, and z coordinates representing, longitude, latitude, and elevation, respectively. These GIS coordinates may represent other quantified systems of spatial-temporal reference (for example, film frame number, stream gage station, highway mile-marker, surveyor benchmark, building address, street intersection, entrance gate, water depth sounding, POS or CAD drawing origin/units). Units applied to recorded spatial-temporal data can vary widely (even when using exactly the same data, see map projections), but all Earth-based spatial–temporal location and extent references should, ideally, be relatable to one another and ultimately to a "real" physical location or extent in space–time.

Related by accurate spatial information, an incredible variety of real-world and projected past or future data can be analyzed, interpreted and represented. This key characteristic of GIS has begun to open new avenues of scientific inquiry into behaviors and patterns of real-world information that previously had not been systematically correlated [1].

1.1.3 Data Representation

GIS data represents real objects (such as roads, land use, elevation, trees, waterways, etc.) with digital data determining the mix. Real objects can be divided into two abstractions: discrete objects (e.g., a house) and continuous fields (such as rainfall amount, or elevations). Traditionally, there are two broad methods used to store data in a GIS for both kinds of abstractions mapping references: raster images and vector data. Points, lines, and polygons are the features of mapped location attribute references. A new hybrid method of storing data is that of identifying point clouds, which combine three-dimensional points with red green blue (RGB) information at each point, returning a "3D color image". GIS thematic maps are then becoming more and more realistically visually descriptive of what they set out to show or determine [1].

1.1.4 History of 3D Modeling

3D modeling is the process of creating a three-dimensional model of an object. Using 3D, it is possible to capture size, shape, and texture of a real or imaginary object.

The first 3D models were created in 1960s. Back then, only those professionals in the field of computer engineering and automation who worked with mathematical models and data analysis were involved in 3D modeling.

A pioneer of 3D graphics is Ivan Sutherland, the creator of Sketchpad. This revolutionary program helped to create the first 3D objects – 3D is what it is today thanks to Sketchpad. Sutherland, along with his colleague David Evans, has opened the first ever department of computer technologies at the University of Utah. They attracted numerous talented professionals from all over the country who helped contribute to the development of the industry. Edwin Catmull, a current head of Pixar Animation Studios and Walt Disney Animation Studios, was one of Sutherland’s students.

Sutherland and Evans opened the first 3D graphics company in 1969, calling it simply “Evans & Sutherland”. Initially, 3D modeling and animation was used mostly on television and in advertisement, but with time, its presence in other areas of life increased greatly [2].

1.1.5 Methods of creating 3D models

A model can be created automatically (with the help of a 3D scanner), or manually by a 3D modeler (using special computer programs). Quite often, 3D modeling refers to the process when a designer creates a 3D model using

software – in this case, the term is related to digital sculpting.
The modeling types are polygonal, spline, and non-uniform relational spline (NURBS) [2].

1.2 The Research problem

The lack of clear guidelines for visitors to the National Museum to help them reach any galleries, temples and small archeological villages in the museum. Beside that the maintenance and restoration of archaeological artifacts damaged due to natural conditions or human intervention is a major challenge to the management of the museum because of the lack of clear documentation of these pieces.

1.3 Research Objectives

The main purpose of this research is to understand the benefits of utilizing interactive, 3D visualization by designing a 3D model for Sudan's Museum to assist the visitors, the museum administration when they need to reach any place inside the museum, Restructuring, and provides information about all resources inside the museum.

1.4 Methodology and Project Planning

Data Modeling: data must be collected of all available geospatial databases and attribute, Images, point clouds, files generated from point clouds for model reconstruction, and attribute database and documentations.
Data Measurements, Processing and Preparation: includes high resolution images, stereo images, photos with good texture, derived point clouds, build 3D, edit photos and create database files.
Building of 3D models: Based on the required details and available spatial data and also according to the GIS data model design all the needed features are selected.
Build a 3D GIS model with all relational spatial databases: This step corresponds to the 3D model. There are several techniques to insert the built-up 3D models from step 3 within the 3D GIS environment.
Texture Mapping: Appending to all facets of the 3D features the true texture

is very essential to simulate reality and thus provide the user/planner with a true scene that can help in making better decisions.

1.5 Research Layout

Chapter one is an introduction to the research and headlines to the next chapters.

Chapter two contains theoretical framework, literature reviews, and the system description.

Chapter three contains three main headlines, the first about the community of research; the second is Methodology and Research Planning, and the third one is selected methodology and techniques.

Chapter four contains system requirements, subdivided in functional and non-functional requirements and system analysis with design.

Chapter five: this chapter will explain all the practical aspects of designing a three-dimensional model of the National Museum of Sudan, especially the main showroom and some statues and temples. Range of available techniques used to produce these designs in the best possible way.

Chapter six contains the conclusion and outlook, and the recommendations.

Chapter seven contains the references.

Chapter tow:

Related Work and Literature Review

2.1 Theoretical Framework

2.2 Literature Review

2.3 System Description

Chapter two - Related Works and Literature Review

2.1 Theoretical Framework

To achieve the goals of this project; computer graphics, Geographic Information Systems and photogrammetry were used to construct Virtual Reality 3D models and to convert them into GIS objects allowing for 2D spatial analysis, such as short path analysis, buffering and 3D spatial analysis. For these reasons, the strength of these three fields will be demonstrated first.

2.1.1 Computer Graphics

Computer Graphics are pictures and films created using usually computers. The term refers to computer-generated image data created with the support of specialized graphical hardware and software. It is a vast and recent area in computer science. The phrase was launched in 1960, by the computer graphics researchers Verne Hudson and William Vetter working with Boeing. It is often abbreviated as CG, though sometimes erroneously referred to as CGI.

Important topics in computer graphics include user interface design, sprite graphics, vector graphics, 3D modeling, shaders, GPU design, implicit surface visualization with ray tracing, and computer vision, among others. The overall methodology depends heavily on the underlying sciences of geometry, optics, and physics.

Computer graphics is responsible for displaying art and image data effectively and meaningfully to the user. It is also used for processing image data received from the physical world. Computer graphic development has had a significant impact on many types of media and has revolutionized animation, movies, advertising, video games, and graphic design generally, (see figure 2.1).

Typically, the term computer graphics refers to several different things such as the representation and manipulation of image data by a computer, the various technologies used to create and manipulate images, and the sub-field of computer science which studies methods for digitally synthesizing and manipulating visual content [3].

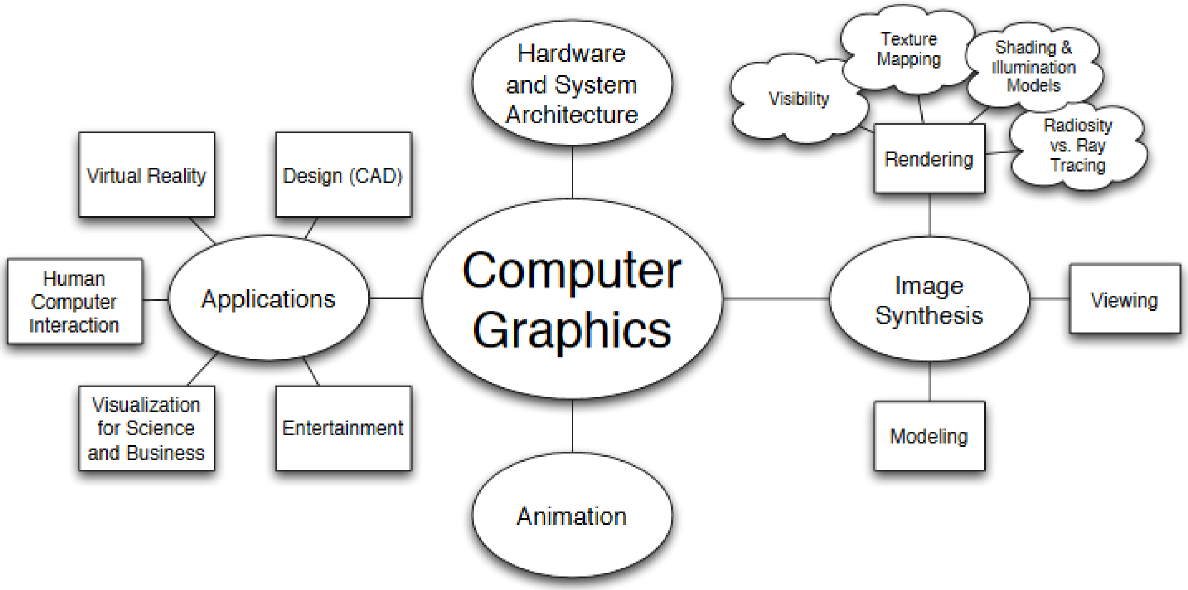

figure 2.1: computer graphics

An image that is presented on the computer screen is made up of pixels. The screen consists of a rectangular grid of pixels, arranged in rows and columns. The pixels are small enough that they are not easy to see individually. In fact, for many very high-resolution displays, they become essentially invisible.

Raster Graphics: The term "Raster Graphics" technically refers to the mechanism used on older vacuum tube computer monitors. An electron beam would move along the rows of pixels, making the glow. The beam was moved across the screen by powerful magnets that would deflect the path of electrons. The stronger the beam, the brighter the glow of the pixel. So the brightness of the pixels could be controlled by modulating the intensity of the electron beam. The color values stored in the frame buffer were used to determine the intensity of the electron beam. (For a color screen, each pixel had a red dot, a green dot, and a blue dot, which were separately illuminated by the beam.)

A modern flat-screen computer monitor is not a raster in the same sense. There is no moving electron beam. The mechanism that controls the colors of the pixels is different for different types of screen. But the screen is still made up of pixels, and the color values for all the pixels are still stored in a frame buffer. The idea of an image consisting of a grid of pixels, with numerical color values for each pixel, defines raster graphics (see figure 2.2).

Vector Graphics: Represent an image as a list of the geometric shapes that it contains. To make things more interesting, the shapes can have attributes, such as the thickness of a line or the color that fills a rectangle. Of course, not every image can be composed from simple geometric shapes. This approach certainly would not work for a picture of a beautiful sunset (or for most any other photographic image). However, it works well for many types of images, such as architectural blueprints and scientific illustrations.

Figure 2.2: low resolution digital image. Left: black and white. Right: color

Elements of 3D Graphics: When turn to 3D graphics, the fact is the most common approaches have more in common with vector graphics than with raster graphics. That is, the content of an image is specified as a list of geometric objects. The technique is referred to as geometric modeling, (see figure 2.3).

The starting point is to construct an "Artificial 3D World" as a collection of simple geometric shapes, arranged in three-dimensional space. The objects can have attributes that, combined with global properties of the world, determine the appearance of the objects. Often, the range of basic shapes is very limited, perhaps including only points, line segments, and triangles. A more complex shape such as a polygon or sphere can be built or approximated as a collection of more basic shapes, if it is not itself considered to be basic, to make a two-dimensional image of the scene. The scene is projected from three dimensions down to two dimensions. Projection is the equivalent of taking a photograph of the scene. Let us look at how it all works in a little more detail.

First, the geometry. Starting with an empty 3D space or "world". And then build a scene inside the world, made up of geometric objects. For example, a line segment in the scene can be specified by giving the coordinates of its two endpoints, and a tringle can be specified by giving the coordinates of its three vertices. Geometric primitives are the smallest building blocks that could be work with, such as line segments and triangles.

Note that once a geometric model has been designed, it can be used as a component in more complex models. This is referred to as hierarchical modeling. Suppose that you have constructed a model of a wheel out of geometric primitives. When the wheel is moved into position in the model of an automobile, the coordinates of all of its primitives will have to be adjusted. The type of adjustment that is used is called a geometric transform or geometric transformation. The geometric transform is used to adjust the size, orientation, and position of the geometric object. The three most basic kinds of geometric transform are called scaling, rotation, and translation. The scaling transform is used to set the size of the object, that is, to make it bigger or smaller by some specified factor. The scaling transform is used to set the size of an object, that is, to make it bigger or smaller by some specified factor. A rotation transform is used to set an object's orientation, by rotating it by some angle about some specific axis. The translation transform is used to set the position of an object, by displacing it by a given amount from its original position [4].

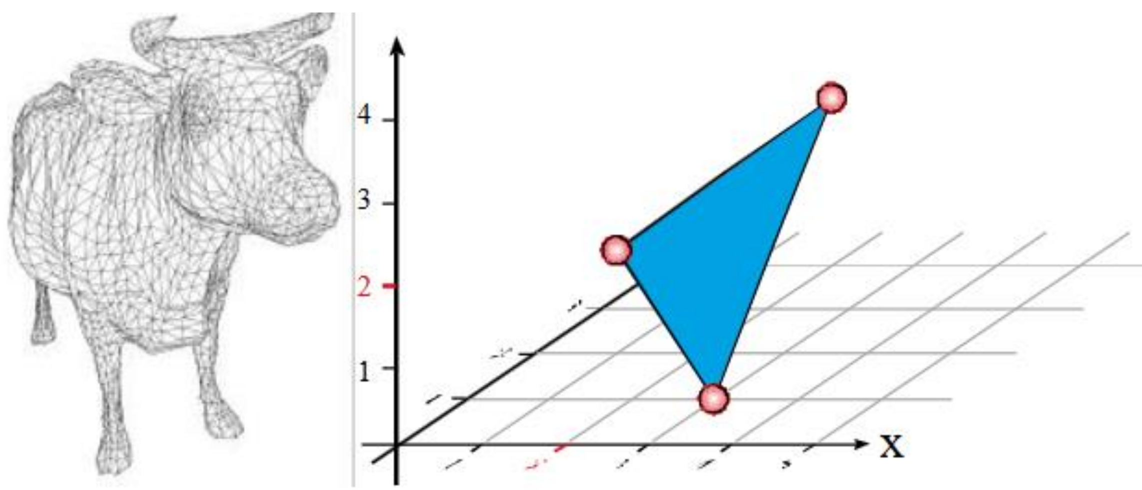

Figure 2.3: left: a cow modeled as a mesh of tringles. right tringle can be stored using [(2,4,2),(3,1,0),(1,1,2)]

2.1.2 Photogrammetry

Photogrammetry can be defined as the science and art of determining qualitative and quantitative characteristics of objects from the images recorded on photographic emulsions. Objects are identified and qualitatively described by observing photographic image characteristics such as shape, pattern, tone and texture. Identification of the deciduous versus coniferous trees, delineation of geologic landforms, and inventories of existing land use are examples of qualitative observations obtained from photography.

The quantitative characteristics of objects such as size, orientation, and position are determined from measured image positions in the image plane of the camera taking the photography. Tree heights, stockpile volumes, topographic maps, and horizontal and vertical coordinates of unknown points are examples of quantitative measurements obtained from photography [5].

Data acquisition in photogrammetry is concerned with obtaining reliable information about the properties of surfaces and objects. This is accomplished without physical contact with the objects which is, in essence, the most obvious difference to surveying, (see figure 2.4).

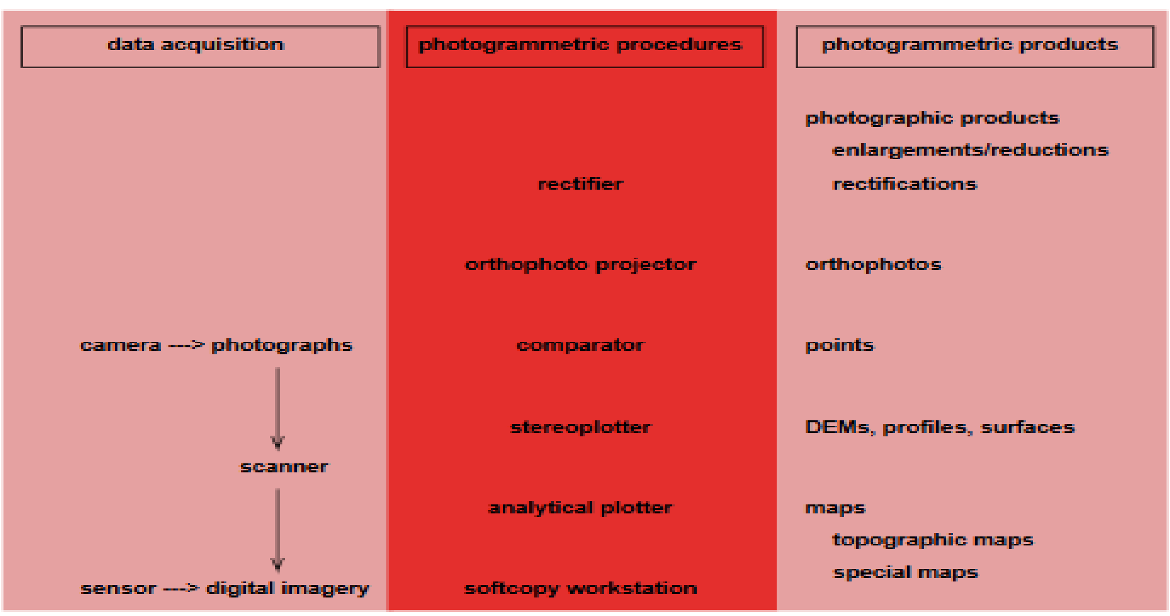

figure 2.4: photogrammetry portrayed as systems approach. the input is usually referred to as data acquisition, the “black box" involves photogrammetric procedures and instruments; the output comprises photogrammetric products [6].

The remotely received information can be grouped into four categories:

Geometric information: Involves the spatial position and the shape of objects. It is the most important information source in photogrammetry.
Physical information: Refers to properties of electromagnetic radiation, e.g. radiant energy, wavelength, and polarization.
Semantic information: Is related to the meaning of an image. It is usually obtained by interpreting the recorded data.
Temporal information: is related to the change of an object in time. Usually obtained by comparing several images which were recorded at different times.
Photogrammetric procedures and instruments: the task of photogrammetric procedures is to convert the input to the desired output. Let us take an aerial photograph as a typical input and the map as a typical output. Now, what are the main differences between the two, the following table lists three differences: Are examples of quantitative measurements obtained from

	photograph	*map*	*task*
projection	central	orthogonal	transformations
data	$\approx$ 0.5 GB	few KB	feature identification
information	explicit	implicit	and feature extraction

Photogrammetric products: Fall into three categories: photographic products, computational results, and maps.
Photogrammetry can be classified a number of ways but one standard method is to split the field based on camera location during photography. On this basis Aerial Photogrammetry, and Close-Range Photogrammetry are the choice.
In Aerial Photogrammetry the camera is mounted in an aircraft and is usually pointed vertically towards the ground. Multiple overlapping photos of the ground are taken as the aircraft flies along a flight path. These photos have been processed in a stereo-plotter (an instrument that lets an operator see two photos at once in a stereo view) in analog and analytical photogrammetry. Nowadays, all photogrammetric restitutions are done digitally. These photos are also used in automated processing for Digital Elevation Model (DEM) creation, e.g. using dense image matching.
In Close-range Photogrammetry the camera is close to the subject and is typically hand-held or on a tripod (but can be on a vehicle too). Usually this type of photogrammetry is non-topographic - that is, the output is not topographic products like terrain models or topographic maps, but instead

drawings, 3D models, measurements and point clouds. Everyday cameras are used to model and measure buildings, engineering structures, forensic and accident scenes, mines, earth-works, stock-piles, archaeological artifacts, film sets, etc. This type of photogrammetry (CRP for short) is also sometimes called Image-Based Modeling. It is closely related to geometric Computer Vision.

Digital photogrammetry is a well-established technique for acquiring dense 3D geometric information for real-world objects from stereoscopic image overlap and has been shown to have extensive applications in a variety of fields.

Aerial photogrammetry refers to the collection and processing of imagery captured from an aerial or orbital vehicle. Close-Range photogrammetry (CRP) refers to the collection of photography from the ground or some lesser distance than traditional aerial photogrammetry and is becoming increasing popular and accessible due to new, easy to use software and digital cameras. Non-metric, off-the-shelf digital cameras can be used along with relatively inexpensive, or in some cases free, open-source software, to extract and process highly accurate and detailed 3D models of real-world objects [7].

2.1.3 Geographical information System (GIS)

A transformation is taking place. Businesses and governments, schools and hospitals, nonprofit organizations, and others, are taking advantage of geospatial data and information. All around the world, people are working more efficiently because of it.

Information that was limited to spreadsheets and databases is being unleashed in a new, exciting way all using geography. But this is not your elementary school's geography. This approach uses geography to gain new insights and make better, more informed decisions. Consider an example. In Texas, a department store analyzing credit card receipts by ZIP Code finds that a large number of its customers drive along a particular section of the freeway to reach a mall. The store could then make smart choices about where to place its billboard ads. Linking location to information is a process that applies to many aspects of decision making in business and the community. Choosing a site, targeting a market segment, planning a distribution network, zoning a neighborhood, allocating resources, and responding to emergencies—all these problems involve questions of geography. Where are current and potential customers? In which areas do consumers with particular profiles live? Which areas of a city are most vulnerable to seasonal flooding or other natural disasters, where are power poles located, and when did they last receive maintenance [8].

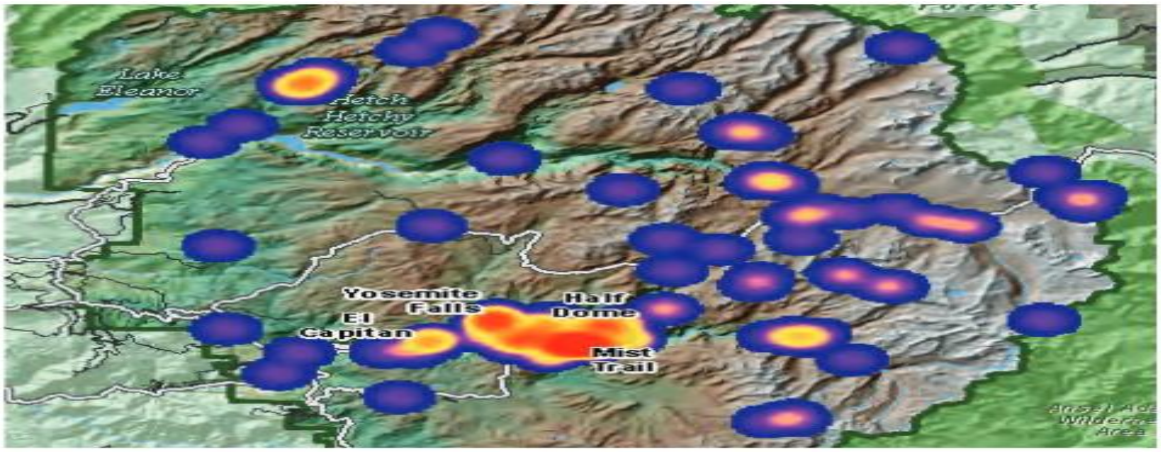

Figure 2.5: search and rescue teams use GIS to analyze incidents and help save lives [7]

2.1.3.1 What is GIS

How do organizations unlock geography from the data they use every day to make decisions? For anyone trying to evaluate information, the most intuitive way to view it is on a map.

Not just any map intelligent digital maps made possible by geographic information system (GIS) technology. Even people who have never used maps to analyze data are finding that maps make processing information much easier and more effective.

GIS represents features on the earth—buildings, cities, roads, rivers, and states—on a computer. People use GIS to visualize, question, analyze, and understand data about the world and human activity. Often, this data is viewed on a map, which provides an advantage over using spreadsheets or databases. Why? Because maps and spatial analysis can reveal patterns, point out problems, and show connections that may not be apparent in tables or text.

Figure 2.6: GIS links imagery and data to utility, landscape, and maintenance schedules for complete rights-of-way management

2.3.1.2 The Power of GIS:

GIS is computer software that links geographic information (where things are) with descriptive information (what things are). Unlike a flat paper map, where what you see is what you get, GIS can present many layers of different information.

To use a paper map, all you do is unfold it. Spread out before you is a representation of cities and roads, mountains and rivers, railroads, and political boundaries. The cities are represented by little dots or circles, the roads by black lines, the mountain peaks by tiny triangles, and the lakes by small blue areas similar to the real lakes.

A GIS-based map is not much more difficult to use than a paper map. As on the paper map, there are dots or points that represent features on the map such as cities, lines that represent features such as roads, and small areas that represent features such as lakes.

All this information where the point is located, how long the road is, and even how many square miles a lake occupies is stored as layers in digital format as a pattern of ones and zeros in a computer.

Figure 2.7: 3D analysis enables planners to model the impacts of proposed changes

2.3.1.3 GIS in Action:

Planners of all kinds of business analysts, city planners, environmental planners, and strategists from all organizations create new patterns or reshape existing ones every day. Their job is to lay out a framework so growth can occur in a managed way and benefit as many people as possible while respecting our natural resources.

Every day, businesses need to deliver goods and services to clients all around a city. Each truck driver needs a route of how to most efficiently visit each client. GIS provides tools to create efficient routes that save time and money and reduce pollution.

In the military, leaders need to understand terrain to make decisions about how and where to deploy their troops, equipment, and expertise. They need to know which areas to avoid and which are safe. GIS provides tools to help get personnel and materials to the place where they can best do their job.

During floods and hurricanes, emergency response teams save lives and property. GIS provides tools to help locate shelters, distribute food and medicine, and evacuate those in need.

In forestry, caring for existing and future trees ensures a steady supply of wood for the world's building needs. GIS provides tools to help determine where to cut today and where to seed tomorrow while minimizing negative impacts on our natural resources [9].

2.2.1 Literature Review

A lot of researches has been done on similar prior studies, which also focuses on the applications of 3D modeling and the techniques to achieve these projects. The following descriptions are showing some of these prior studies:

First study: 3D models are more powerful than 2D maps for indoor navigation in a complicate space like Hubei Provincial Museum because they can provide accurate descriptions of locations of indoor objects (e.g., doors, windows, tables) and context information of these objects. This research project has clearly demonstrated that the proposed 3D model is valuable for indoor navigation since it can describe the location in object-level, provide context information of spatial objects (e.g., the museum and exhibitions), and more importantly offer a very realistic navigation environment as well as a good overview of it[10].

Second study: The main purpose of the European Project "3DIcons" is to digitize masterpieces of Cultural Heritage and provide the related 3D models and metadata to Europeana, an Internet portal that acts as an interface to millions of books, paintings, films, museum objects and archival records that have been digitized throughout Europe. In this paper an optimized 3D modelling pipeline is shown, that takes into account all the potential problems occurring during the survey and the related data processing, This optimized process has been applied on a significant number of items, showing how this technique can allow large scale 3D digitization projects with relatively limited efforts.

The data processing was carried out with the Agisoft Photoscan package, a semi-automatic software in which both the camera orientation and the internal calibration are made, allowing little interaction to the user [11].

Third study: The presented paper refers to a project that aims to create 3D textured models of two lekythoi that are exhibited in the National Archaeological Museum of Athens in Greece; on the surfaces of these lekythoi scenes of the adventures of Odysseus are depicted. The creation of accurate developments of the paintings and of accurate 3D models is the basis for the visualization of the adventures of the mythical hero. The data collection was made by using a structured light scanner consisting of two machine vision cameras that are used for the determination of geometry of the object, a high resolution camera for the recording of the texture, and a DLP projector. For a better result a combination of commercial and in-house software made for the automation of various steps of the procedure was used. The results derived from the above procedure were especially satisfactory in terms of accuracy and quality of the model. However, the procedure was proved to be time consuming while the use of various software packages presumes the services of a specialist [12].

2.2.2 Own comments on previous studies

The previous studies contributed to an examination to use current off-the-shelf software technology to build 3D models using several techniques for various applications. This research aims to take advantage of the proposed recommendations, including the possibility of applying the regulations on the 3D mapping systems using photogrammetry and viewing real world models over PC's desktop environment, tablets and phones.

2.3 System Description

2.3.1 Current System

The National Museum of Sudan is one of the richest museums in the African continent. The museum contains all kinds of Sudanese heritage for all historical periods. The museum consists of exhibition halls, administrative offices, temples, ancient villages and some important statues. Thousands of Sudanese and other nationalities are visiting the museum to learn about Sudan's history and civilizations. To guide these visitors, the museum relies on the development of signs and guides leading to archeological and heritage sites in the museum's halls, with a simple guide. This is not enough to reach archaeological sites quickly and accurately, as some visitors suffer very much to reach the required place.
In some cases, parts of the museum's antiquities are damaged and lose a large part of their original form. The maintenance of these pieces requires a great effort. This restoration is often based on the imagination of the archeologist who follows the condition of this piece, this may result in loss of the original shape of the piece.

2.3.2 Current System Problems

Restoration of the artifacts requires a great effort to bring them back to their original state and the piece may lose its original shape, and the guidelines and information available are not enough to guide visitors to archaeological sites, and it is time consuming for the visitors to reach a specific archaeological site or artefact, and there is no clear navigation system in the museum.

2.3.3 Proposed System Description

The main objective of 3D modeling and texture mapping is to build suitable procedures for the National Museum of Sudan building and thus to serve as tools to make information accessible for administration and visitors, who can virtually visit and explore the Museum without going to the site. The importance of museum planning focuses on offering 3D real world visualization for the National Museum of Sudan's main building, focusing on exhibition halls with its semantic information. In addition, the proposed system will be accessible from desktops and smartphones to take advantage of the virtual visualization anytime.

Constructed 3D models can be used in the restoration operations that are carried out on some archaeological pieces parts, which have been lost due to natural disasters or other reasons.

2.3.4 Scope of the System

The proposed system offers a 3D model for the National Museum of Sudan and includes the main exhibition hall building and featured archeological artifacts and heritage exhibits. The system offers 3D visualization for the building as well as indoor artifacts and provides information using desktop and tablet computers

Chapter three:

Methodology and Research Planning

3.1 Research Community

3.2 Methodology and Research Planning

3.3 Selected Methodology and Techniques

Chapter Three - Methodology and Research Planning

3.1 Research Community

The most important class to the museum are the tourists who are looking for information related to cultural heritage, and also the students and researchers who are seeking knowledge, beside the administration of the museum to support them in decision making and future planning.

3.2 Methodology and Project Planning

The objective of this research is to support decisions for the development of virtual museum models by presenting a structured overview of 3D GIS analyses that are likely to be applied in 3D modelling.

The research methodology and project planning will be done using the following steps by using ArcGIS applications: data acquisition, generation of a 3D model, and visualization of the 3D model. In the following the implementation steps required to build a true reality 3D GIS model of National Museum of Sudan with texture mapping are given.

Starting from data modeling, data measurements, processing and preparation, Building of 3D models, build a 3D GIS model with all relational spatial databases, and finally the texture mapping.

3.2.1 Data Modeling

Data modeling is a process used to define and analyze data requirements needed to support the business processes within the scope of corresponding information systems in organizations [13].

Data modeling needs data collection of all available geospatial databases and attribute data it includes Images captured by scanning buildings for dense image matching, Point cloud files (Las data format), Files available from point clouds for the 3D model construction, and Attribute database and documentations related to the Museum information.

GIS Data Modeling: This is an important step to define all required geospatial databases including vector and raster layers and their relationships based on the defined objectives of the project. This will draft what is required and also missing to build the desired GIS data model.

3.2.2 Data Measurements, Processing and Preparation

To build the required 3D GIS Information System the following steps have to be accomplished:

Data measurements and capturing: For this process the following important data measurements are to be taken. Take high-resolution overlapping images of the area of interest using a high precision photo camera, then take as many stereo images as possible of objects to build 3D models afterwards, and finally Photos of with good textures to be used later on to build textured 3D models.

Data Processing and Preparations: In this process the following are some important processing steps:Derive point clouds for the area of interest (AgiSoft PhotoScan is used), Build 3D view of the point clouds (Autodesk 3ds MAX and Trimble SketchUp are used), then Edit captured photos and add texture (MS Paint is used), According to the GIS data-model, build 2D layers and also add their attribute data (Esri ArcMap is used), and Build relational databases within the GIS data model layers (Esri ArcMap and Esri ArcEditor are used).

3.2.3. Building 3D Models

Based on the required details and available spatial data and also according to the GIS data model design all the needed features are selected. In the following are the important implemented cases: [13]

Case I Simple 3D shape geometry: In this case the 2D layer is built and the height dimension is determined either by direct survey measurements or taken from CAD drawings. The 3D model can be built directly in the 3D GIS software environment. The shape appears like 3D block shapes (Esri ArcScene software is used).

Case II 3D CAD Model is available: In this case, the dimensions have to be verified by scaling it with the built 2D layer and also via survey measurements. The final 3D model is then verified and georeferenced to its exact position on a map (Autodesk AutoCAD and Trimble SketchUp software’s are used).

Case III Only 2D layer is available: In this case close range photogrammetry is used to build a 3D wire mesh of the required object(s) using the captured stereo imagery during the data capturing step (AgiSoft PhotoScan and Photomodeler software's are used).

Case IV some parts are available in 2D and others in 3D: Combination of case II and III is used, but it is very important to use a consistent reference system to merge all 3D objects into one object (Trimble SketchUp software works well in this case) [14].

3.2.4. Build a 3D GIS Model with all Relational Spatial Data Bases

This step corresponds to the 3D model. There are several techniques to insert the built-up 3D models from step 3 within the 3D GIS environment as follows: [14]

- The 3D GIS environment in our case is the ArcScene environment of the ArcGIS software. The datum for providing a reference base-height for any inserted point, 2D or 3D objects is chosen.

• Case I Simple 3D shape geometry: In this case ArcScene build the 3D model directly using the 2D vector layer with the added height information as part of the layer attribute for each feature in the layer, or added directly as a constant height for all features in the layer. A DTM is also specified as the base-height for all layers.

• Case II 3D CAD Model is available: In this case, if the CAD software has the capability to export the 3D model file into 3D shape file, it then can be inserted directly into the ArcScene environment. Quite often the file can be imported into SketchUp software, where it will be exported into the proper format for ArcScene. It is important to note that complex 3D models should be split as much as possible to smaller objects in order to be able to export it easily into the environment using the geodatabase format. Our practice found that the best scenario is to use SketchUp software. You can better control your splitted objects since the export formats are geodatabase standards. Also, it is important to georeference the model to its exact position in ArcScene before exporting it.

• Case III Only 2D layer is available: In this case close range photogrammetry such as PhotoModeler or other photogrammetry software such as SOCET SET or Z/I can export the 3D model to 3D CAD model or shape file. Our recommendation is to convert the models to CAD format and then exporting them to SketchUp software and repeat the same as described above.

• Case IV Some parts are available in 2D and others in 3D: A combination of case II and III is used, but it is very important to use a consistent reference system to merge all 3D parts into one object (SketchUp software works well in this case) [14].

3.2.5. Texture Mapping

Appending to all facets of the 3D features the true texture is very essential to simulate reality and thus provide the user/planner with a true scene that can help in making better decisions. The following are the options and scenarios one can follow: [14]

- Use the Orthophoto with added DTM as a base-height to provide true texture of the earth and ground surface for the area of interest.

- Append/stitch texture to build up 3D models using the following options:

• Orthophoto Accurate Texture Mapping**:** One needs to build Orthophotos of all the faces of the objects. Use these images as filters to append/stitch these to the 3D CAD model surfaces using SketchUp or 3ds MAX software's.

• Direct photo texture mapping: It is important when capturing the photos for the model surfaces to make the line of site of the camera axis as perpendicular as possible to the surface of interest. Then use these photos as filters to append/stitch these to the 3D CAD model surfaces using SketchUp or 3ds MAX software.

In both cases, the best way to export the 3D model with texture is through exporting all models to SketchUp software and then exporting it in a geodatabase format to ArcScene software.

- Export the built-up 3D model object with texture as point-symbols.

SketchUp software is designed to work perfectly in case of:

• The object is designed to provide general attributes of the whole building for example, if he object is very complex and cannot be exported as true 3D model with texture.

• The objects are standard and are very similar in shape such as villa compounds. To be built using other software's such as SketchUp or 3ds MAX [14].

The resultant 3D reality model offers a flexible and interactive visual decision support system for data management. The following sections are the direct implementation results of the above discussed methodology for various applications that are related to the conducted system.

3.3 Selected Methodology and Techniques

The suggested methodology is very flexible and can be utilized and implemented for various types of projects and applications, that are becoming essential in the near future. Photogrammetry and texture mapping is now becoming feasible with low cost and less time consuming using the new capabilities of the below mentioned software's. In this proposed system, several softwares will be employed and used in order to complete the required production, which are the following:

3.3.1 AgiSoft's PhotoScan

AgiSoft PhotoScan is an advanced image-based 3D modeling solution aimed at creating professional quality 3D content from still images. [15]

It will be used to align all photos taken and to extract the point clouds by dense image matching of the areas of interest.

3.3.2 Trimble's SketchUp Pro (Version 2016)

The platform enables users to create collections of models, including 3D buildings, and share them with fellow modelers around the world. SketchUp, which was a tiny startup when it was bought by Google in 2006, now boasts of millions of active users. [16]

It will be used to import point clouds in *.las format and exporting 3D models from and to ArcGIS depending to build/complete 3D building models. Finally, it is used for adding the true texture to these models.

The Undet extension package works well with SketchUp for importing point clouds and exporting 3D models in various file's formats.

3.3.3 Esri's ArcGIS 10.1

ArcGIS Desktop is comprised of a set of integrated applications, which are accessible from the Start Menu of your computer: ArcMap, Arcscene and ArcCatalog. ArcMap is the main mapping application which allows you to create maps, query attributes, analyze spatial relationships, and layout final projects. ArcCatalog organizes spatial data contained on your computer and various other locations and allows for searching, previewing, and adding data to ArcMap as well as manage metadata and set up address locator services (geocoding). ArcToolbox is the third application of ArcGIS Desktop. Although it is not accessible from the Start Menu, it is easily accessed and used within ArcMap and ArcCatalog. ArcToolbox contains tools for geoprocessing, data conversion, coordinate systems, projections, and more.

ArcMap will be used to build 2D GIS layers and data-model, in addition to ArcScene that provides suitable 3D environment [17].

3.3.4 Sketchfab

Is the leading Internet platform to publish and find 3D and VR content, anywhere online. Moreover, it is a good environment to upload files in almost any 3D format.

Sketchfap will be used to visualize the 3D model in VR mode by uploading the model to be accessible online.

Chapter Four

System Analysis and Design

4.1 System Requirements

4.2 Analysis and Design

Chapter four - System analysis and design

4.1 System Requirements

4.1.1 Functional Requirements:

1. The system provides a 3D design for the National Museum of Sudan.
2. The system aims to provide information about all parts of the Museum.
3. It also aims to represent all resources within the Museum in a hologram.
4. The system offers real world visualization, helps visitors and administrators viewing the resources inside the Museum and administration buildings.
5. It also supports virtual visualization over desktop platforms to be accessible anytime.
6. The system illustrates locations of the exhibition halls and buildings.
7. It also illustrates locations of landmarks, gates and textured buildings.
8. It illustrates locations of cafeterias.
9. At this point in time trees and further vegetation are not yet involved in the model.

4.1.2 Technical Requirements:

The building geometry (dense point cloud and mesh generation) usually has the largest memory footprint, especially if the model is constructed in medium or high quality. This fact should be carefully taken into account. The processing of the photographs and the 3D model construction comprises the following main system requirements:

Minimal configuration

- Windows XP or later (32 or 64 bit), Mac OS X Snow Leopard or later, Debian/Ubuntu (64 bit).
- Intel Core 2 Duo processor or equivalent.
- 2GB of RAM

Recommended configuration

- Windows XP or later (64 bit), Mac OS X Snow Leopard or later, Debian/Ubuntu (64 bit).
- Intel Core i7 processor.

- 12GB of RAM.

The number of photos that can be processed by Photo Scan depends on the available RAM and reconstruction parameters used. Assuming that a single photo resolution is of the order of 10 MPixel, 2GB RAM is sufficient to create a model based on 20 to 30 photos. However, 12GB RAM will allow to process up to 200-300 photographs.

In addition, capturing photos for objects must be taken panoramically and it is better to use a high precision camera as well as an Xcopter with a camera on board. The resulting 3D model should be made available over desktops and various smartphone platforms (Windows, Android, and iOS)

4.1.3 Nonfunctional Requirements

In order to obtain better model visualizations, the system has to achieve the following specified requirements:

1. Performance: The most important requirement is the performance of the system which includes the following:
   - Query and Reporting time: the response time between the mouse action and retrieving object information.
   - Response time: also the time of loading the model, which is subject to the screen refresh times or orientations.
2. Availability: the system needs to be available all the time, for every passenger/visitor over desktop and smartphone platforms.
3. Maintainability: the model also has to be updated due to the ongoing renewal of the museum buildings.

4.2 Analysis and Design

4.2.1 Database Design

As well known, GIS layers are groups of features organized object-wise – vectors are stored in a Shapefile format. In this Research, 2D and 3D layers have been created using Esri’s ArcGIS software. The model comprises 2D GIS layers, which contain the geospatial data of the objects. In particular these layers are the building layers.

4.2.2 Database Transactions

- Information retrieval is essentially required, when the users inquire about a particular object by getting a popup message. Thus the data must be well organized.
- The 3D model of the National Museum of Sudan will be visible for each visitor online for better view and access over desktops (Web browser) and smartphones allowing them to orient the model or retrieve geodata in response of a mouse click.

Chapter five

Simulations and Results

5.1 Photogrammetry

5.2 3D Model Reconstructions

Chapter Five - Simulations and results

5.1 Photogrammetry

A 3D model of the Sudan National Museum has been designed using modern photogrammetry techniques. Also illustrated the location of Sudan's national museum using google maps (see figure 5.1).

The first step of creating this 3D model is getting the images of the targeted place by using available cameras, and then set of overlapping images has been collected panoramically using a KODAK camera and Huawei Mate 7 phone camera (see figure 5.2). The photos taken are illustrated in figures 5.3 to 5.5. In order to start with creating the 3D model, first the point clouds of the building and statues are generated from the collection of the overlapping photos, that has taken earlier by the camera and mobile device using dense image matching algorithms.

Secondly, to build the required 2D and 3D GIS information system, some data measurements and processing have to be accomplished, using the point clouds as input.

Figure 5.1: An Aerial Photo excerpt illustrating the Geographical Location of Sudan's National Museum

Figure 5.2: Huawei Mate 7 and the KODAK camera

Figure 5.3: Outdoor photo scanning of the museum's exhibition hall.

Figure 5.4: Indoor photo scanning of the museum's exhibition hall.

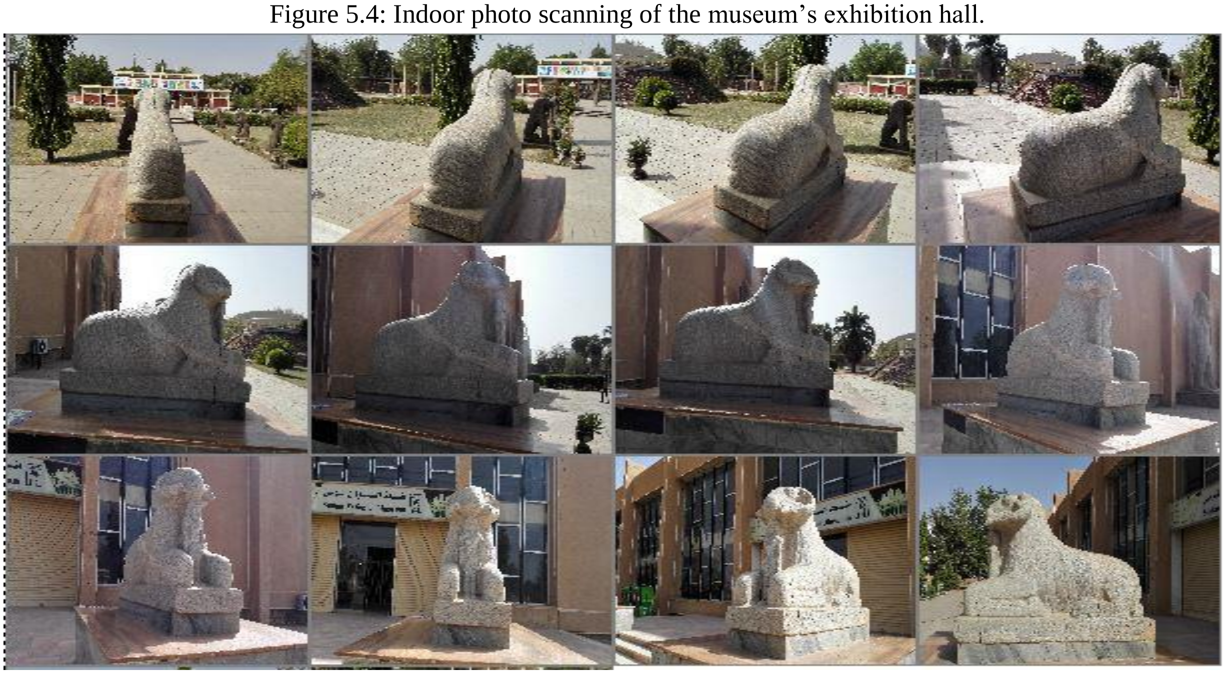

Figure 5.5.1: Photo scanning of some museum's statues.

Figure 5.5.2: Photo scanning of some museum's statues.

AgiSoft Photoscan:

Agisoft PhotoScan is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production. Moreover, it may serve as well for indirect measurements of objects of various scales. Figure 5.6 illustrates the opening screen of this application.

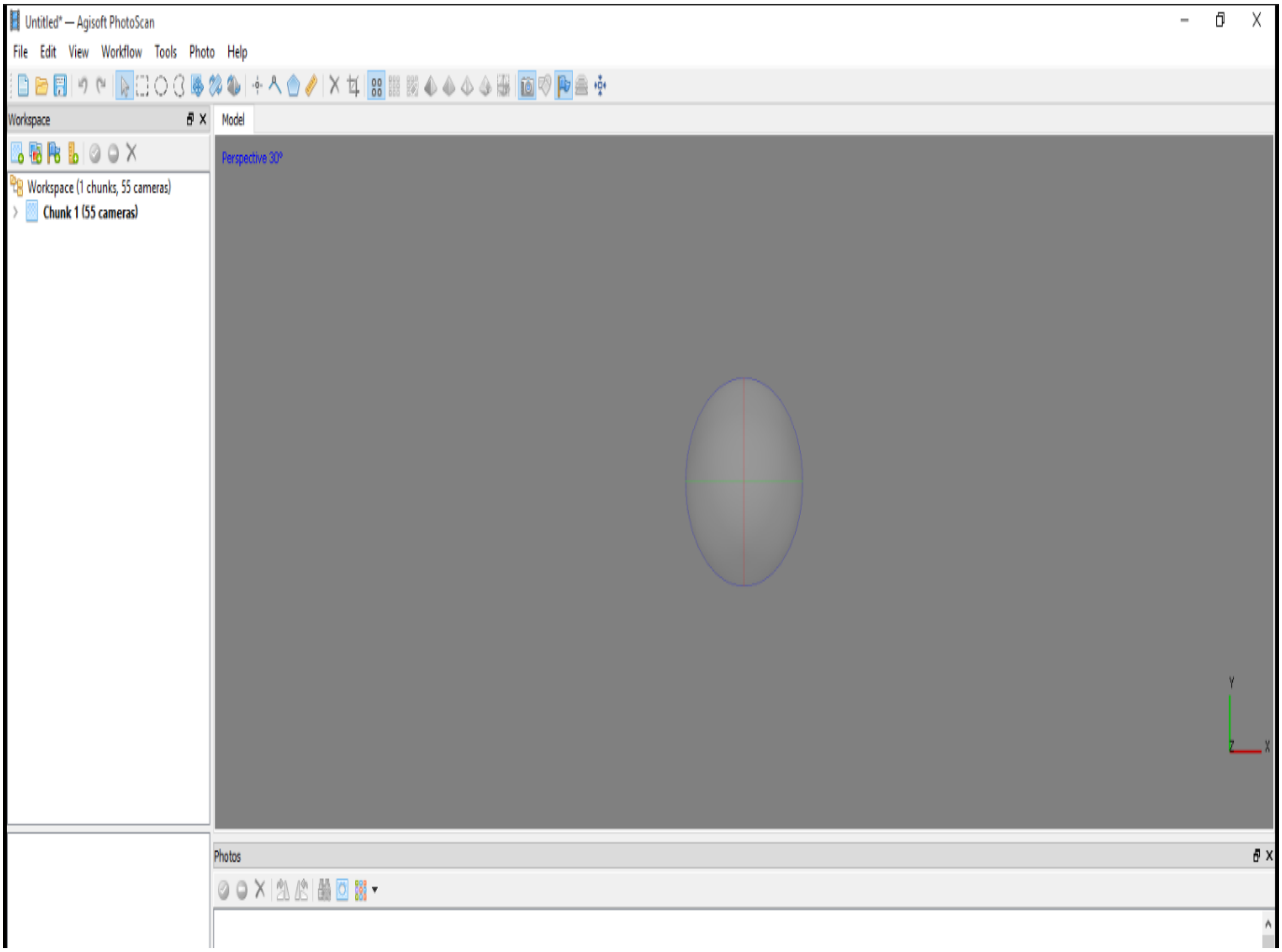

Figure 5.6: Agisoft Photoscan start page.

The steps of creating an initial 3D Model by Agisoft's PhotoScan are as follows:

- Add the scanned photos of the object.
- Align photos (see figure 5.7).
- Detecting the points (see figure 5.8).
- Build mesh (see figure 5.9).

- Build dense cloud (see figure 5.10).
- Build texture (see figure 5.11).

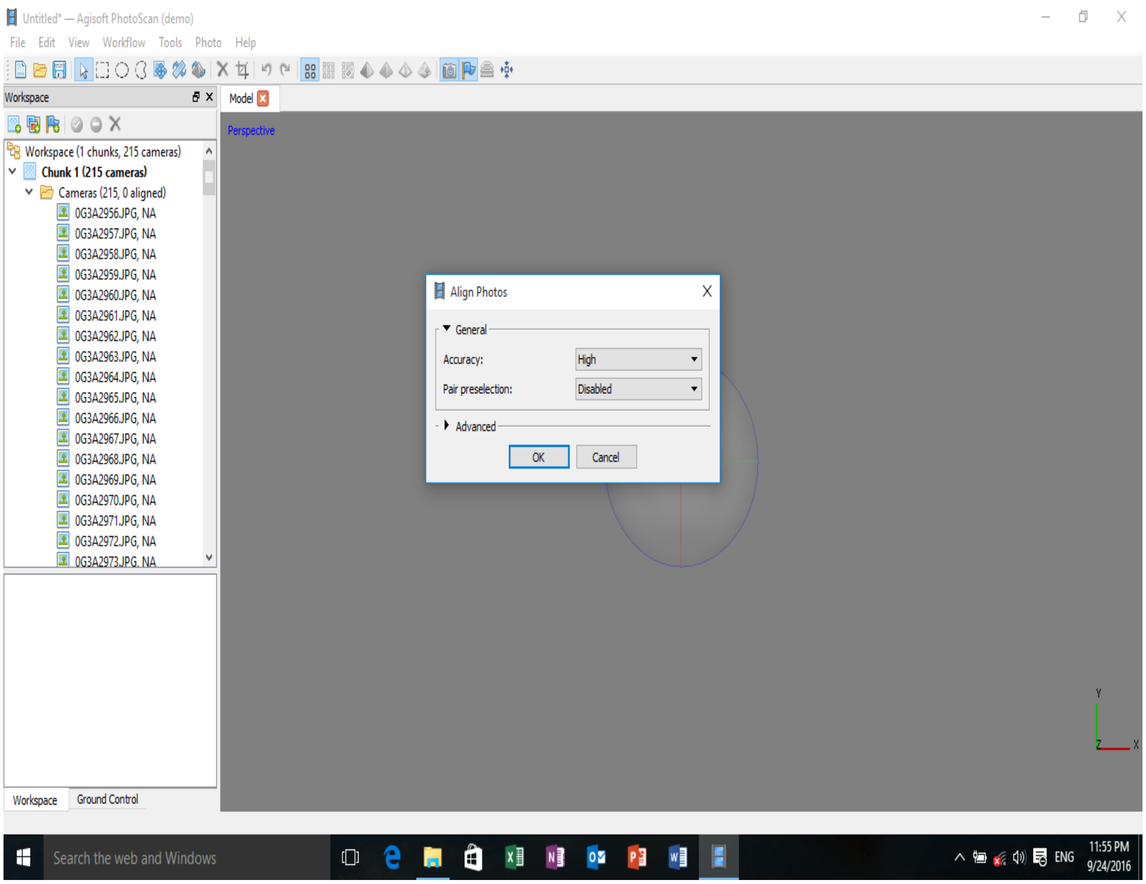

Figure 5.7: Align Photos

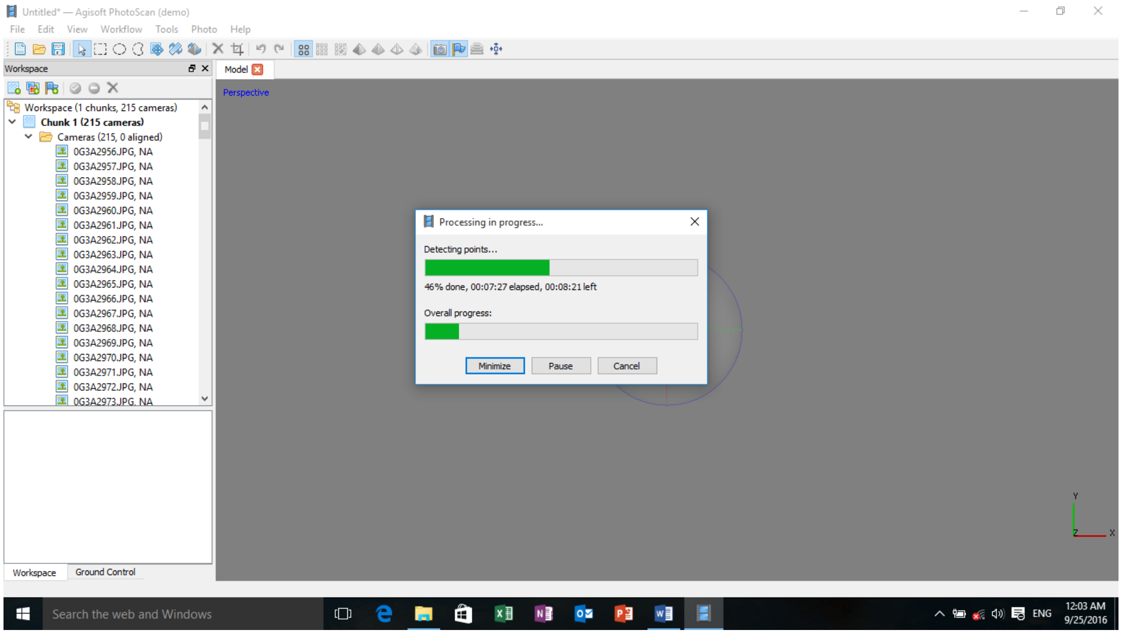

Figure 5.8.1 : Detecting Points

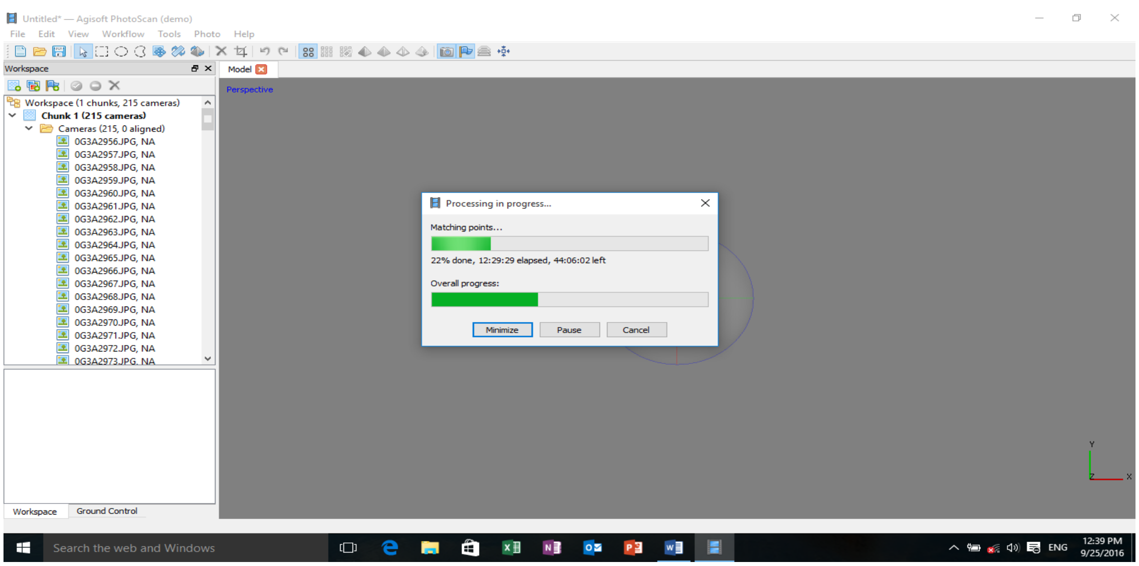

Figure 5.8.2: Detecting Points

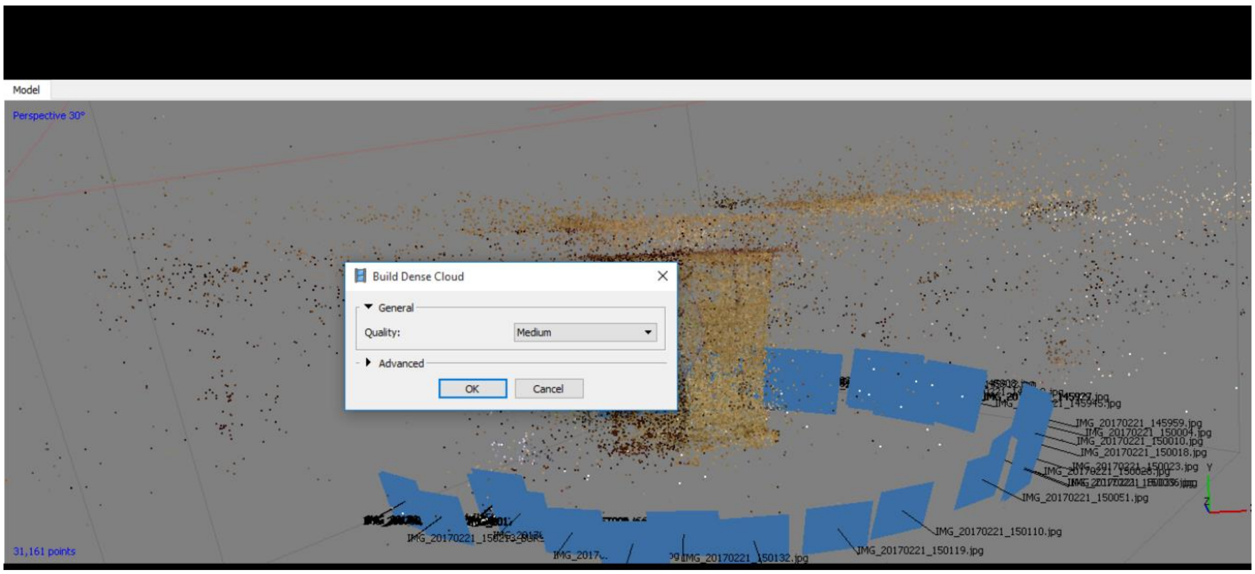

Figure 5.9 : Build dense point cloud

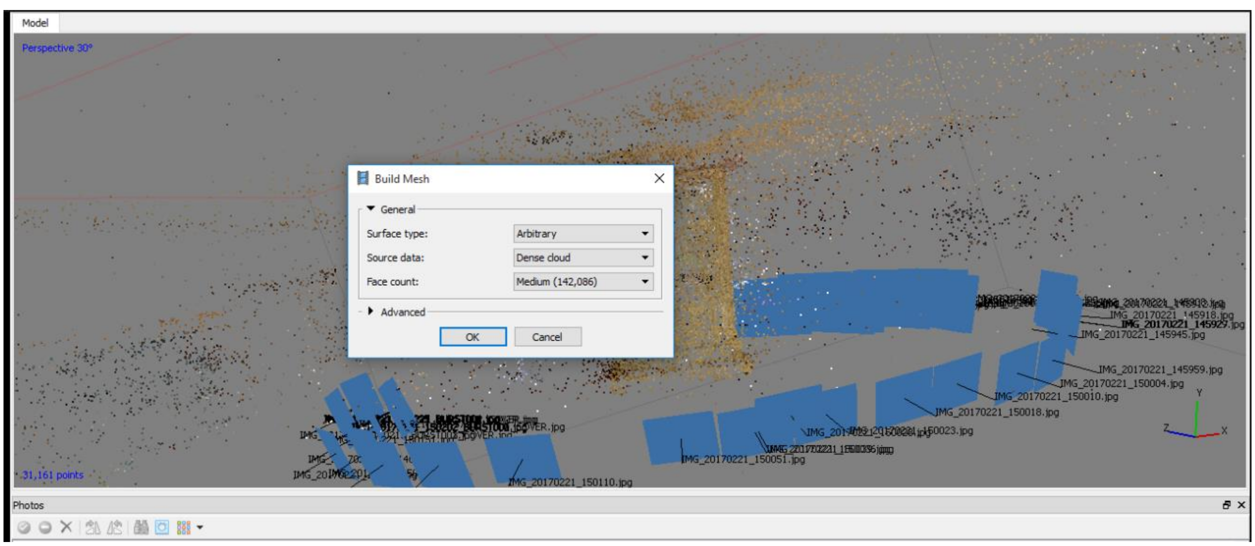

Figure 5.10: Build Mesh

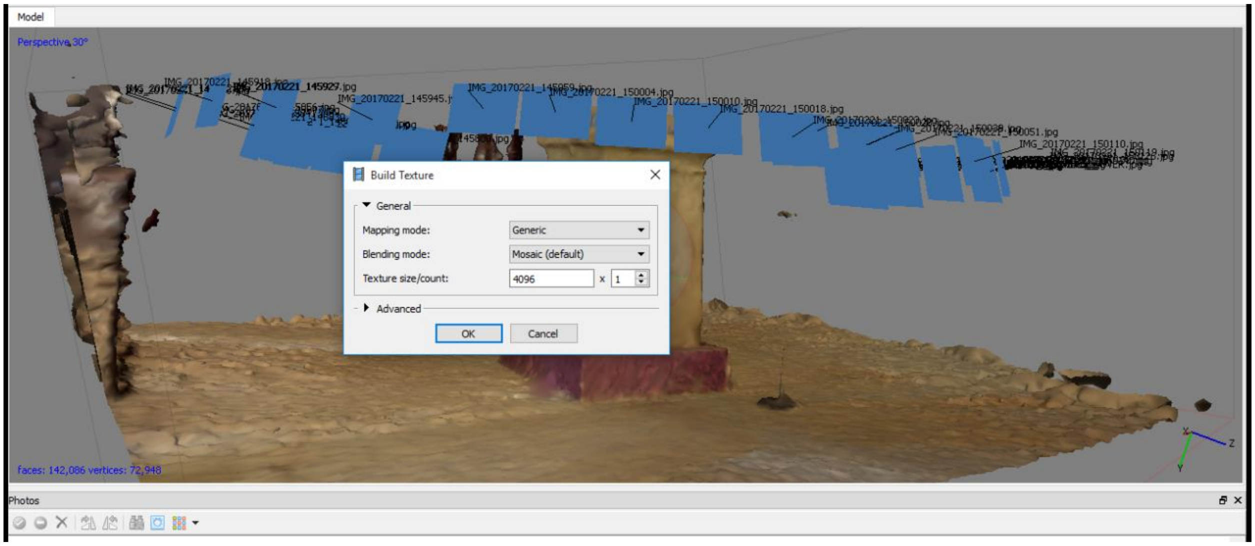

Figure 5.11: Build Textured Point Cloud

5.3 3D Model Reconstructions

After finishing the process of building the initial 3d model by Agisoft's PhotoScan, some improvements and restores must be made to fill the gabs of the lost points of the model.

3D and 2D vector and raster data were created for the Region of Interest (RoI) using Trimble's SketchUp Pro software and Esri's ArcGIS.

SketchUp software works well for texture mapping and allows to customize and duplicate any shape or repeated pattern. This procedure is useful for creating virtual reality models. The first step with SketchUp was importing the point cloud files and customizing the objects by filling gaps and clarifying building details. The Agisoft PhotoScan prepared 3d model must be exported to a file with (.3ds) extension and then the import of that file to SketchUp is carried out to complete the model entirely. Figure 5.12 illustrates the model after importing.

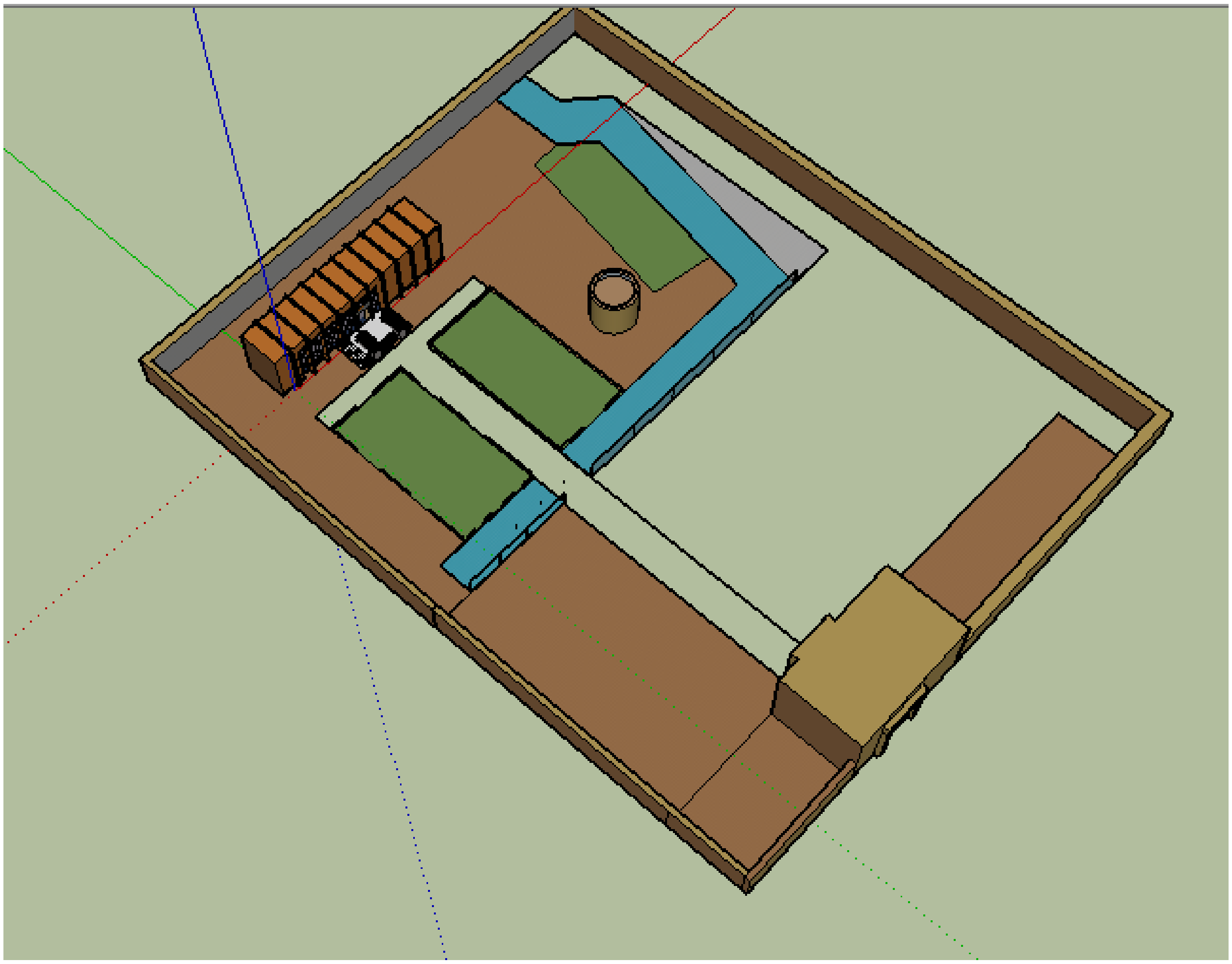

Figure 5.12.1 : Illustrates the imported Agisoft PhotoScan model after restoration and filling gaps by using SketchUp from different views

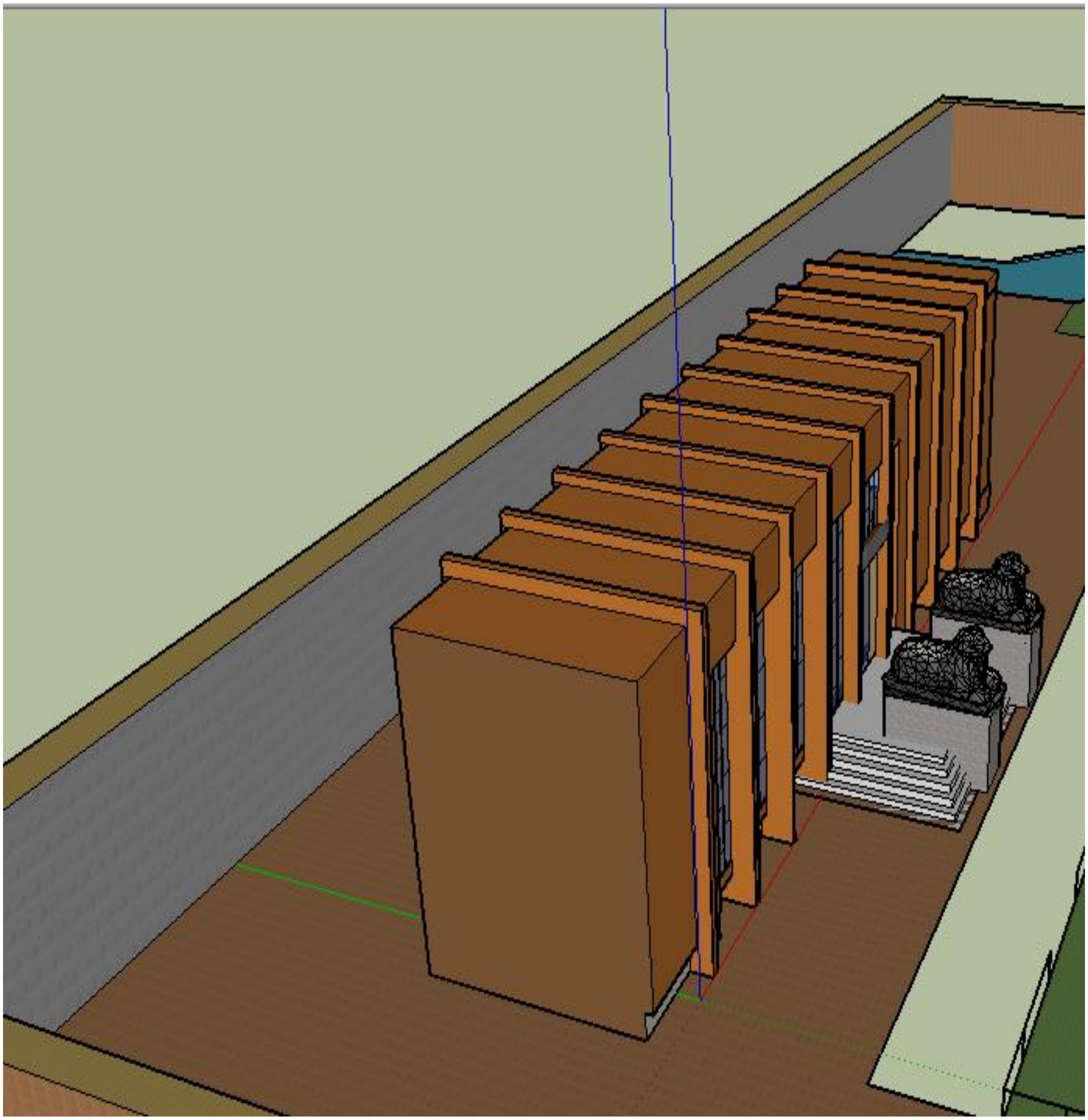

Figure 5.12.2 : Illustrates the imported Agisoft PhotoScan model after restoration and filling gaps by using SketchUp from different views

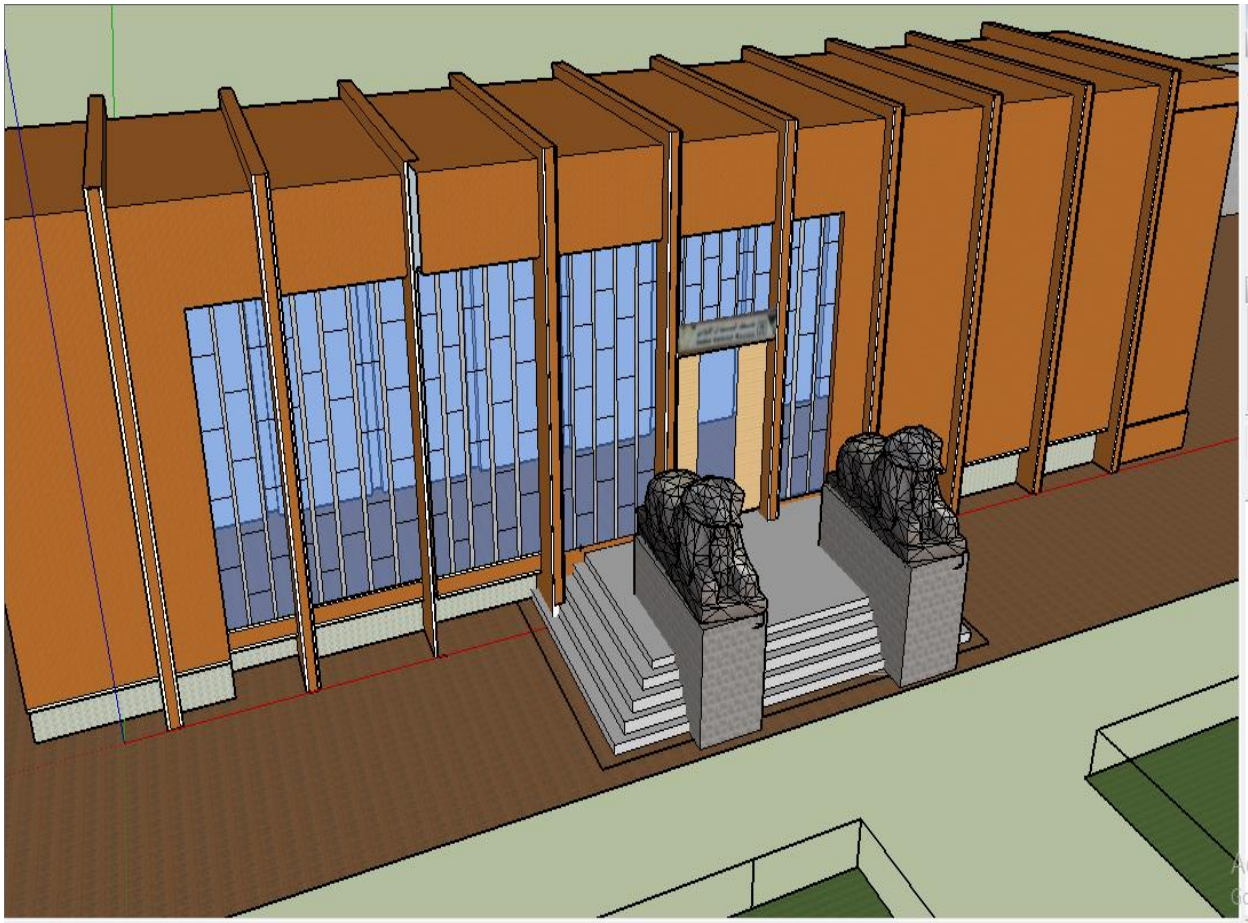

Figure 5.12.3: Illustrates the imported Agisoft PhotoScan model after restoration and filling gaps by using SketchUp from different views

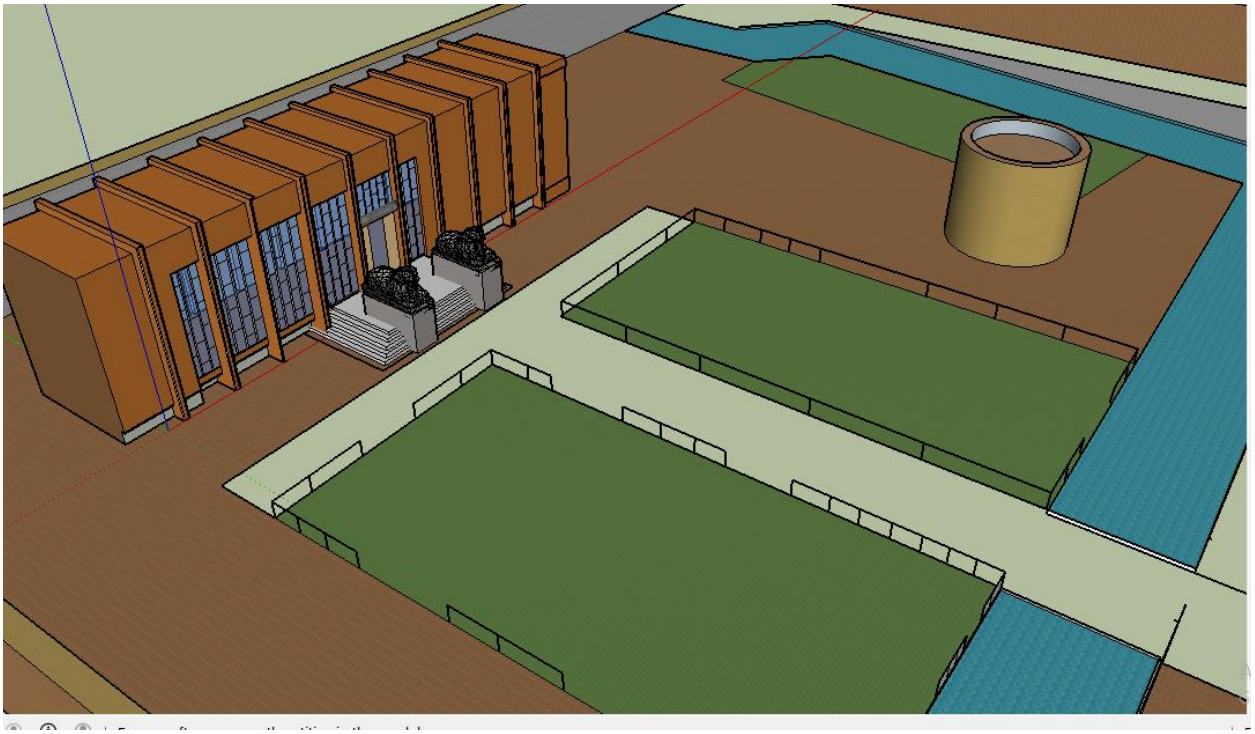

Figure 5.12.4: Illustrates the imported Agisoft PhotoScan model after restoration and filling gaps by using SketchUp from different views

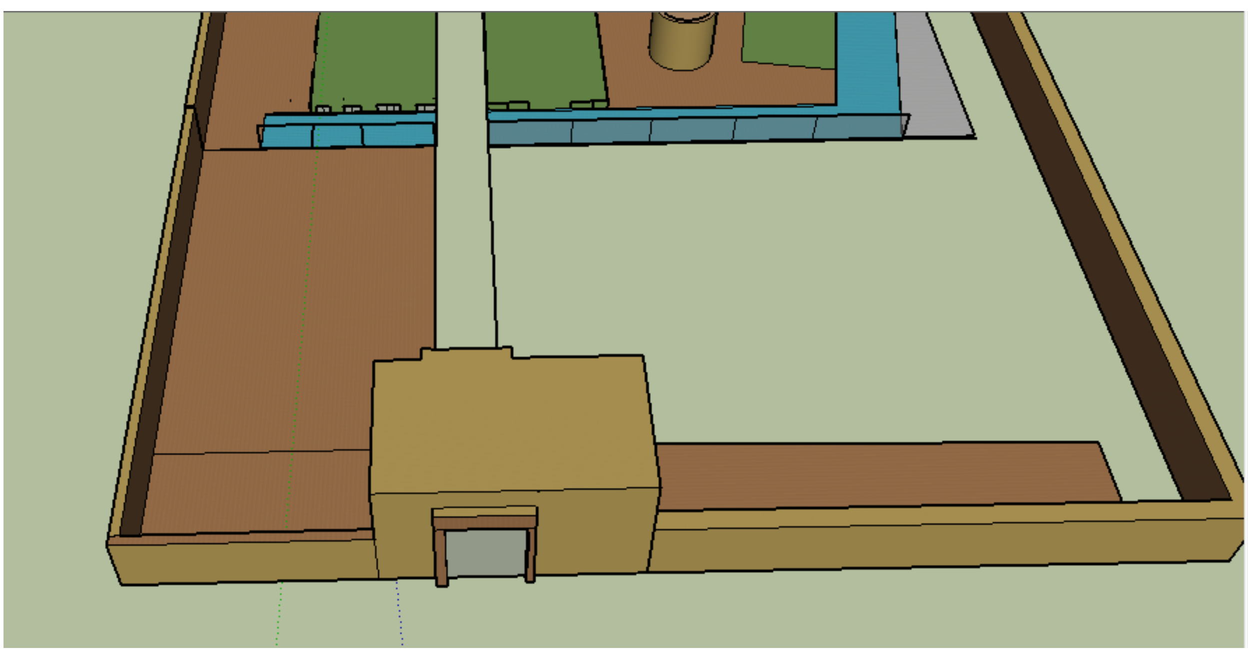

Figure 5.12.5: Illustrates the imported Agisoft PhotoScan model after restoration and filling gaps by using SketchUp from different views

The above screen shots illustrate the final model of the museum after filling the gaps and restore the missed points and corners by using SketchUp from different views. A 3D model has been extracted from this phase as a final textured model as shown above, the output from this step is a 3D file in *.dae format.
That *.dae file must be imported to ArcGIS to create the shape files and geodata bases of that model, supporting the analysis and searching through our model.

5.4 ArcGIS

ArcGIS is a Geographic Information System (GIS) for working with maps and geographic information. It is used for creating and using maps; compiling geographic data; analyzing mapped information; sharing and discovering geographic information; using maps and geographic information in a range of applications; and managing geographic information in a database.
To create shape files from the 3d model, the model must be to ArcGIS as illustrated by the following figures:

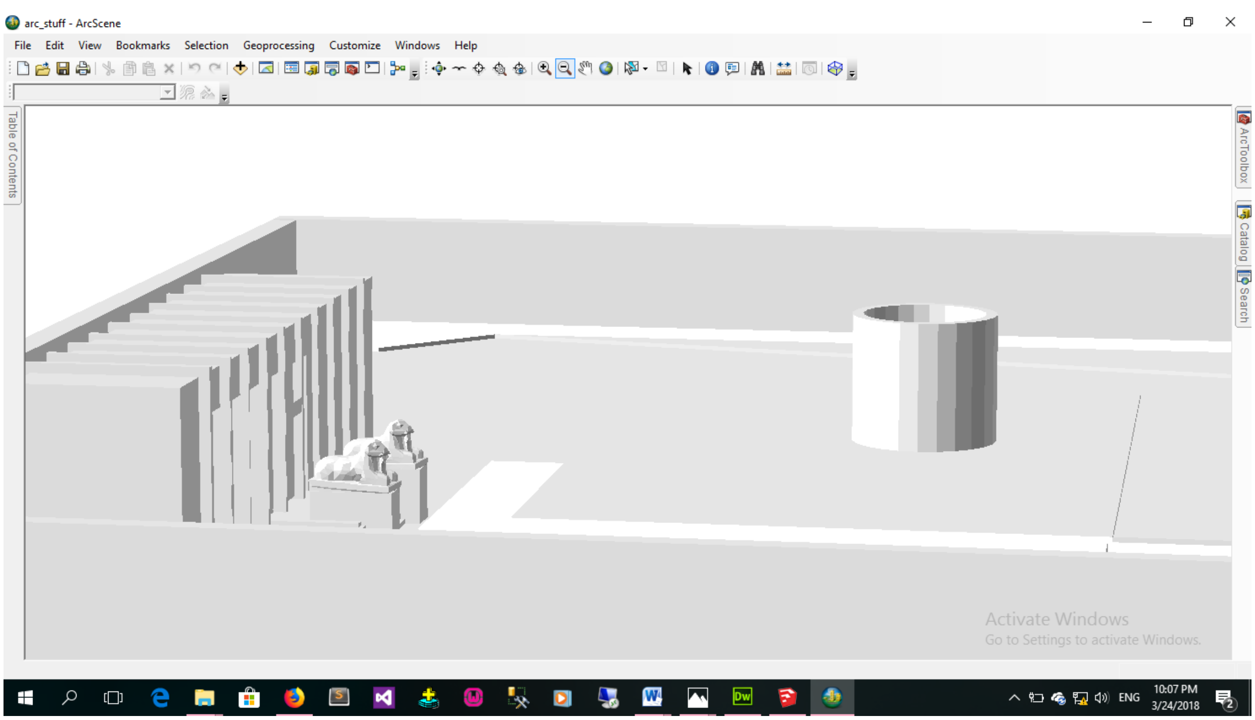

Figure 5.13.1: Illustrates the shape file of the exhibition hall.

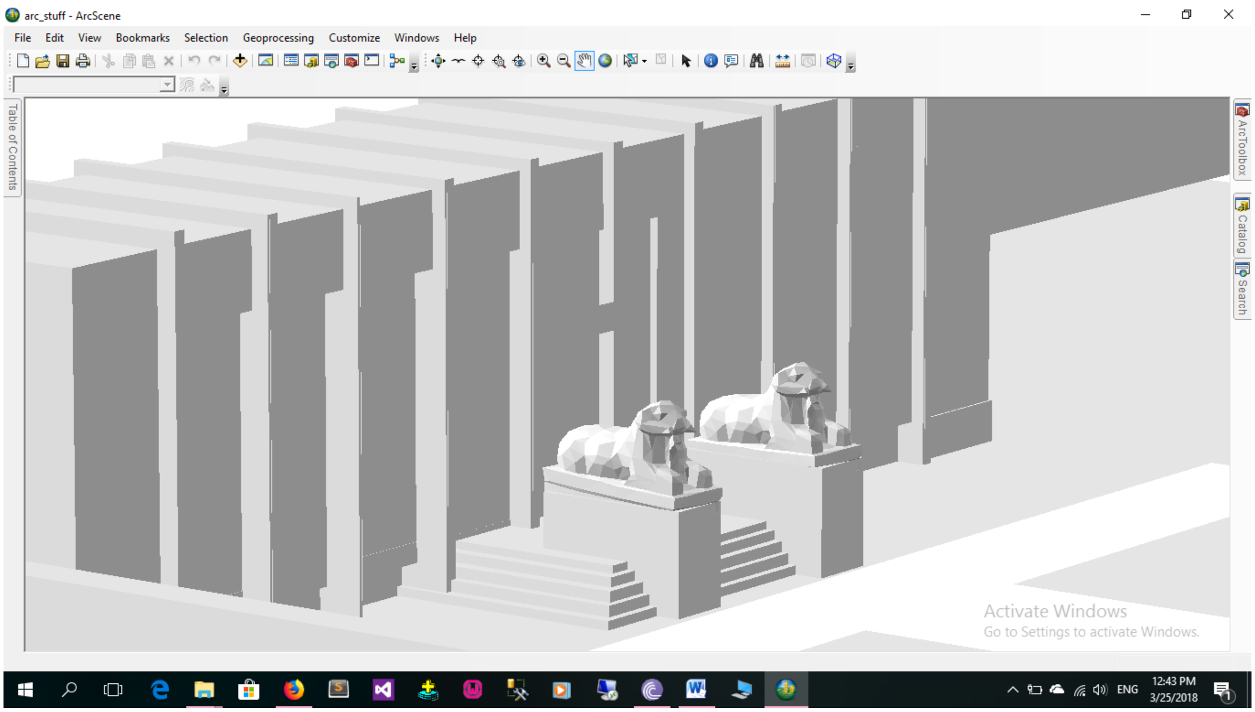

Figure 5.13.2: Illustrates the shape file of the exhibition hall from different sides

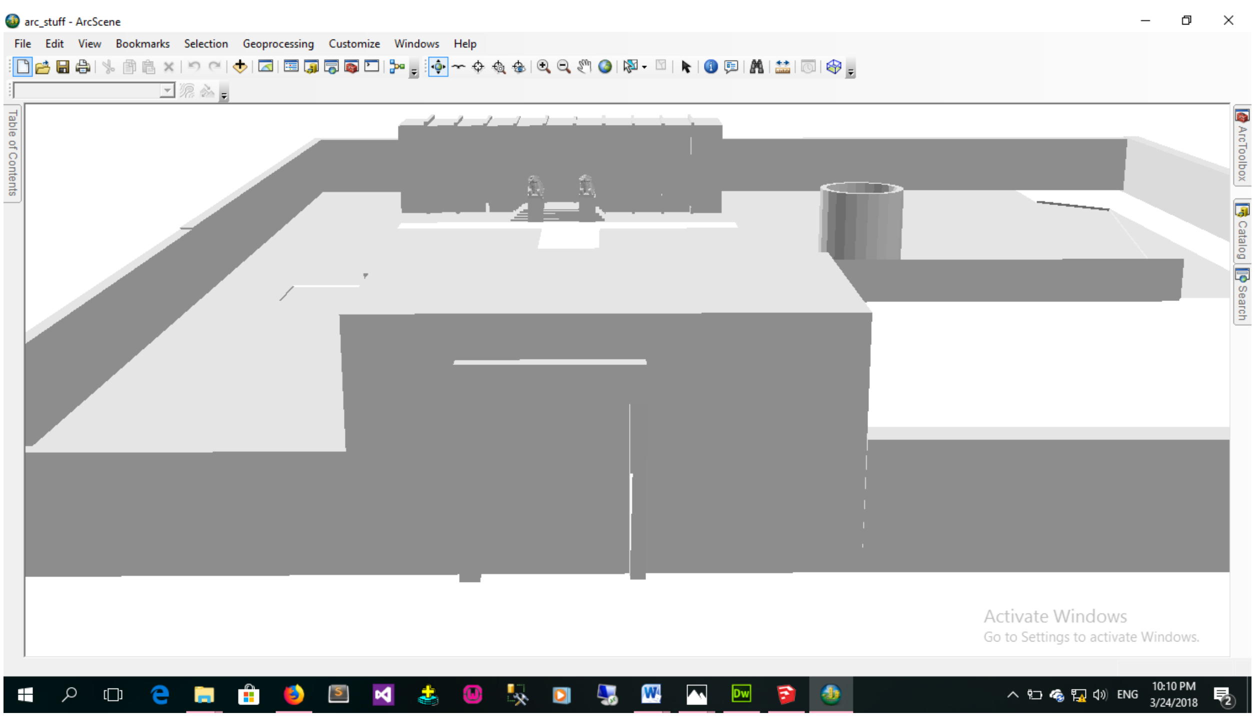

Figure 5.14: Illustrates the shape file of the entire building

Chapter six

Conclusions and Recommendations

6.2 Conclusions

6.2 Recommendations

Chapter six: Conclusions and Recommendations

6.1 Conclusions

This research reveals that the progresses in 3D geospatial modeling and information technologies have provided the project with building blocks, tools, and methodologies required to create very complex and rich 3D information systems that can be used to improve the information accessibility in museums, for planning and management.

It was clear that 3D models are increasing the ability to analyze and assess spatial phenomena and support us to make the right decisions based on solid information.

The fundamental technology related issues and problems, that hindered the efficient and regular use of virtual 3D museum models and their applications seem now be overcome. Indeed qualified 3D geodata has become available, system solutions are matured and it is generally possible to create and disseminate complex 3D models and 3D information systems.

To encourage the work on 3D models, it is highly recommended that governments and organizations and governmental bodies should support the adoption and integration of 3D models for planning and management.

By finishing this thesis a new path was started to researchers to care about the culture and heritage of the country by representing nation's history to interested people all over the world in a 3D model, which makes it available to a vast audience through desktops, browsers, and mobile devices.

Despite of some concerns about the complexity of the indoor objects of the museum, the project succeeded in documenting some indoor items and converted them to 3D models. This means, further individual objects need to be collected and organized inside the indoor 3D model which was already created by this thesis.

6.2 Recommendations:

Efforts exerted on outdoor objects of the museum, and less simple work is done on the indoor objects. It is clear that indoor features and objects need a lot of efforts to scan/collect all the objects inside the show rooms of the museum, convert them to 3D models and integrate them with the indoor system that was already created.

Indoor objects are complex and sensitive so it needs a fully trained and equipped team to achieve this job.

Improving the ability of navigation through that 3D model is highly recommended, so it needs to be accurate and reliable.

An ideal plan is to host that model in a server made available to vast users from anywhere. This will encourage them to visit Sudan to see the real heritage of the country, and hopefully this is going to support the economy by getting more income from the tourism sector.

Using Arc GIS server to host the model in order to make it available to users through the desktop and mobile devices.

Chapter seven

References

7.1 References

Chapter seven: References

7.1 References

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