3D GIS Interactive Visualization of the Archaeological Sites in Qatar for Research and Learning

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Abstract—This work provides a proficient approach to coordinate archeological exercises, information administration, digital object representation, and spatial investigation. The proposed framework furnishes the client with the intuitive investigation of the 3D model artifacts along with detailed information on specific points of interest alongside their 3D geographic information system (3D GIS). A parallel result is the utilization of fully transparent and cost-effective open-source tools and free software. The work addressed the creation of a computerized system that aids classification, administration, and representation of archeological discoveries inside a 3D web-based repository; and the utilization of 3D digital models as a restoration of the artifacts to allow navigation through the data; besides enabling 3D GIS to spatially store, share, envision and examine complex archeological components; This work is one of the first of its type in Qatar to archive and record all of the archeological data from the Murwab site in Qatar.

Keywords—3D GIS, archaeology, cultural heritage preservation, web-based information system, 3D visualization

1 Introduction

The 3D GIS perception innovation can be connected to the world of cultural heritage as a means of safeguarding, recreating, documenting, researching, and advancing. Moreover, representation frameworks such as 3D models and 3D GIS attempt to delineate and allow the collection of additional data. These representations are of extraordinary significance to archeologists to study past landscapes and human societies [1]–[3]. The objective of this project is to create a tool to archive and record all of the archeological data from the Murwab site in Qatar to be available for archeologists to study the site and for students as a learning tool about the site and its history.

Murwab is exceptional among the most noteworthy historical sites in the Gulf Region. Its antiquarianism and urban enhancement as the earliest Islamic site contribute to the historical backdrop of Qatar. This project will improve the historical centers' educational resources with the rich essential assets of Murwab that contribute fundamentally to the documentation of Qatar’s modern history and an understanding of local connections among Qatar and the significant worldwide forces that were in the Gulf Region during this time.

This project is developed with interdisciplinary approaches and techniques as a unique collaboration between the 3D GIS team, Archeology expert, and Computer Science department. The primary goals are the following: (i) the creation of a computerized structure that aids characterization, administration, and perception of archeological discoveries inside a 3D web-based repository of reality-based data; (ii) the creation and use of 3D digital models as a restoration of the real object, allowing navigation through the in-depth detail; (iii) the 3D GIS representation enabling archeologists to spatially store, share, visualize and analyze the complex archeological components; (iv) the subsequent representation process to show the connections inside an archeological ‘reconstruction’ more clearly; and (v) the creation of a special research instrument for archeologists.

Innovative advances and the demonstrated abilities of personal computers have prompted the production of high-fidelity 3D models that are significantly less demanding than those in the recent past. With the use of handheld scanners, 3D computerized displays of the actual ancient rarities were created as a collection of organized items for archeological cognitive systems. By reconciling laser scanning technology and photogrammetry, a rare state of detail and exactness can be acquired [4]–[9]. These models are utilized to analyze the information and are regularly supplemented by additional metadata data and manufactured recreations of missing information. Finally, the project delivers an exceptional research instrument for fulfilling the general prerequisite of protection and additionally investigates the cultural heritage assets and the works of archeologists and scientists. These models overcome the "do not touch" obstacle by using 3D printers to create 3D models that are highly detailed replicas of original artifacts, opening the world of heritage exploration to students and researchers worldwide.

It is generally understood that 3D GIS could provide an effective approach to incorporate archaeological data with digital object representation and spatial analysis. Ideally, this integration could prompt the development of a computerized work process for archeological documentation. It likewise guarantees a periodic checking of landmarks that is valuable in archeological research and reclamation administration focused on protection and conservation [10].

Preservation of historical assets not only shields them from destruction but is also a method to dynamically integrate the heritage with a recording of the landscape. Visibility analysis can assist in the investigation of the dispersion of components in the landscape or aid in responding to inquiries such as the following: Why was a particular site in a specific area? What object is next to what? What surrounds it? What is above, beneath, or to the side? [1], [3], [11]. The essential objective is to produce a computerized system to view the 3D GIS of a vast archeological site alongside 3D models of the artifacts. With the rapid migration of desktop-based applications to the web, a pressing need has emerged to develop platform-independent web applications. The fifth version of HTML, HTML5, is an essential factor in this direction. HTML5 is an open standard configuration and provides a common platform for applications to be created and utilized on the web. Creating an intelligent representation of 3D models straightforwardly inside a standard website page has become a reality with the arrival of HTML5. Recognition for 3D GIS representation on the web must be given to Cesium, who provides a free, open-source, expandable, and web-based platform with the potential for the development and deployment of large-scale web-based 3D geospatial visualization and applications. The Cesium application uses the WebGL language based on JavaScript, which allows hardware acceleration for high-performance graphics and visualization. It is also cross-platform and cross-browser; therefore, has high portability.

Historic studies are an erudition discipline where the learning increases significantly and recording cultural heritage is a multidimensional procedure. There are many advantages of using 3D environments for education due to their potential in engaging learners in the exploration and manipulation of 3D objects [12], [13]. The 3D representation test and opportunity can be measured by the aggregate number of artifacts. Capturing the entire set would require many hours of effort by knowledgeable personnel. Another challenge is the difficulty of building a summary of specialized particulars, apparatuses, strategies, and agent systems to produce 3D reality-based models, as various ancient rarities are displayed by various administrators working in different places under various circumstances and frequently utilizing distinctive techniques or methods. When considering the third dimension, the amount of information increases drastically. This is particularly true if textures are utilized to accomplish realistic photo image quality. Issues are caused by the amount of information as well as the complex nature of the information (vector and raster data). The requirement for grounded, unambiguous technical specifications, tools, systems, and strategies with particular guidelines for securing, developing, perceiving, and coordinating the 3D models into the 3D GIS are required [14]. Providing a UI with quick 3D representation in a 3D GIS is successful if the user can move quickly and effortlessly through the model. A considerable amount of manual work is vital, which makes a UI the most costly element of an average 3D GIS application to maintain satisfactory quality.

This project aims to use a 3D-GIS application to document and record all archaeological data of the *Murwab* site. It provides a proficient approach to coordinate archeological exercises, information administration, digital object representation, and spatial investigation. The implemented framework enables the client to intuitively investigate the 3D model artifacts along with detailed information on specific points of interest alongside their 3D geographic information system. It allows archaeologists to spatially store, share, visualize and, analyze the complex archaeological features in a 3D environment. Furthermore, the 3D GIS allows the inclusion of 3D georeferenced historical images and 3D models in a scientifically transparent way. At the base of the 3D GIS lies a sophisticated cloud-based data infrastructure, providing various services to different clients with an interactive web viewer. As for the technical aspect, providing a cost-effective platform was among the principal objectives of this project, therefore open-source tools and free software were utilized to develop the platform. Consequently, the project provides functionalities and analysis tools that have never been available for archaeological sites in Qatar. Additionally, the developed 3D GIS offers, yet unexplored, state-of-the-art opportunities to present the research results to the archaeological research community, make it available for students, and the broader public.

2 Background

The needs of preserving a cultural heritage have recently increased established researchers' consideration of 3D digitizing techniques. The conventional techniques for archiving artifacts have several restrictions, as they include manual drawing and various photos of the artifacts from different angles. These are very tedious and time consuming and depend on each individual and the quality of the camera. Records containing astounding 3D models and 3D GIS information are strong and unalterable, and hence can be utilized as a reference for observing the decay and rebuilding of works. In any case, during the past ten years, an assortment of models that provide computerized documentation of excavations have been produced in various nations and based on specific fieldwork practices [15]–[18]. The utilization of 3D documentation has increased rapidly over the previous decade and has become more typical in archeological practice. Researchers and practitioners that teach have begun to present these new devices for the documentation of archeological sites; however, employing 3D innovations for routine work requires additional understanding of the real capability of the advances. Although these advances provide step-by-step enhancement, a more dynamic feature in these advanced methods in actual archeological translation is still sought. Digital datasets can provide reflexivity in excavation, as they empower simpler connection, re-evaluation, and re-assembly of fragmented data in the excavation archive [19], [20]. A complete digital workflow for archeological documentation is possible by the use of GIS, as it integrates excavation recording procedures, data management, digital object representation, and spatial analysis [21].

2.1 Historical background of the Murwab

The site is located 5 km to the east of the western coast of Qatar and 15 km north of the city of Dokkhan, between Al-Na'aman village and the ruins of the Umm Al Maa fort. The etymological meaning of Murwab follows: Almurwab is a vessel in which milk is shaken. This meaning concurs with the Murwab area being a pasture zone. It is located inside an alluvial depression that allows a cover of vegetation (various grasses and shrubs) to appear with the first light rain during the winter season and nearby the water wells are a source of life in the region. Al-Kholaifi proposed that there is a connection between the etymological meaning of Murwab and its economy related to the breeding of sheep, goats, camels, and cattle and the production of milk; thus, the area was popularized after homogenization of milk began (Murwab).

The site was discovered and excavated by a Danish mission in 1958 and 1959. Then, a French archaeological mission, under the direction of C. Hardy-Guilbert, excavated the site between 1979 and 1981, followed by a local Qatari mission from the Qatar Museums Authority under the direction of Mohammed Jassim Al- Kholaifi in 1983 and 1984 [22].

Excavations revealed a set of defense buildings including two forts that were established in the center of the city. The city comprises a group of 255 buildings and an industrial area, which was intended for the manufacture of pottery. The forts were surrounded by facilities such as residential buildings, markets, and two mosques. All previous inhabitants were supplied by several groundwater wells in the interior and the exterior. The entire site covers an area of 1.4 by 0.5 km. The site is of special importance as it is the earliest Islamic site in Qatar. The Danish mission in 1958 and 1959 dated the Murwab fortified palace to the Abbasid period based on an unclean copper coin found in one of the houses at Murwab. However, after the coin was cleaned, they compared it with a similar coin found at Al-Raqqah city situated in Syria; thus, dating it between the 7th and 9th century AD. Al- Kholaifi did not support this suggested dating because it was based on only one coin. However, the French archaeological mission that excavated the Murwab site between 1979 and 1981 dated it to the Abbasid period (749-1258 AD). They compared the palace (that they called a "citadel") with that at Khan al `Atshan in Iraq (778 AD), which was built during Calipha Abu Ja'far Abdallah ibn Muhammad al-Mansur (754-774 AD). Additionally, based on coins and ceramic material found at the site, they dated it to the 9th century AD (Abbasid period) [22]. The site is in urgent need of a restoration plan that includes the housing group, the two mosques, and the forts, linking the material found in the site to a deep understanding of the history of the site.

2.2 3D model visualization for archaeology

Visualization of archeological data is an outstanding example of how PC innovation can be used in archaeology. Visualization techniques are always being developed. The cost-effectiveness of PCs and quick development of their handling and memory limit has made the acquisition, recording, and remote availability of 3D digital images technically feasible [23]. In the early 1990s, visualization meant 3D modeling, and the vast majority of these 3D models were created for museum presentations. In 1992, P. Reilly provided an excellent overview of 3D modeling in archaeology [24]. Currently, numerous strategies for 3D scanning, using a few operation standards, are accessible [25], [26], from the utilization of stereoscopy for low-resolution models to techniques based on mechanical sensors providing hundredths of millimeters of precision [27]. Atypical levels of detail and precision can be acquired by combining laser scanning technology and photogrammetry [4]–[6], [9]. By applying these models to two contextual analyses, diverse digitizing advancements were attempted and assessed, demonstrating that 3D digitizing technologies could be adequately developed for broad application in the cultural heritage field [26].

Although many research works have exhibited how 3D modeling and visualization have been beneficial for historical/archaeological site analysis, documentation, preservation, and restoration, currently, most 3D models are exhibited in heritage centers and museums displays. Occasionally, some are accessible on the Internet. A mainstream publication of visualizations of critical locations worldwide was updated by [28]. An example of web-based visualization in VRML that allows discovering an archaeological landscape (large scale) has been provided in [29]. A framework with intuitive maps and 3D models that functioned as web interfaces to acquire perspectives of the database records depended on the research work of [30], [31] and was created in [32]. An online application for user access and interactive investigation of 3D models that use coordinated geometrical and non-geometrical data input via an instinctive interface to provide the user a new experience including a free interactive analysis of the relationships among the artifacts and perhaps providing more definite data on particular areas of interest was developed by [6].

The techniques for three-dimensional digitization of cultural heritage recordings were evaluated by [33]. Another study evaluated both the exactness and thickness dependability of 3D models, which demonstrated how the diverse 3D documentation procedures and strategies can be coordinated to record the excavation procedure of an archeological site and exhibited a precise information assessment [34]. As the quantity of 3D models accessible on the web increased, open archives of scientifically validated 3D models from traditional scholarly journals with standard components for protection, peer audit, production, refreshing, and dispersal of the 3D models were available. Unfortunately, conventional content-based search methods are not generally successful for 3D information. Other shape-based inquiry strategies were proposed by [35] in a web-based search engine system that poses questions to search and locate 3D sketches, 2D sketches, 3D models, and/or text catchphrases.

2.3 3D Geographic information systems for archaeology

As archaeological data is distributed both in space and time showing a dual nature, GIS capability to examine the visualization of spatial relationships and to produce thematic maps have made GIS an integral part of new archaeological research. Since the early 1980s, the application of GIS has grown immensely [36]–[38].

Currently, the increase in archeological research has led to the need for more digital documentation of archeological sites at different scales and resolutions for conservation, restoration, visualization, education, data sharing, and 3D GIS. 3D information generation begins with data acquisition, followed by geometric and radiometric data processing of the 3D surveying and modeling of scenes or objects. A characteristic common to all GIS software is the capacity of managing multi-layer and multi-scale geographic data, making GIS applications ideal for managing archaeological data for on-site data storage and management of surveyed data. The development of new scanners, sensors, data capturing techniques, and 3D representations have contributed greatly to the growth of research in the cultural heritage field. The use of 3D GIS facilitates significant information and knowledge transfer between researchers and archeologists, specifically in the reconstruction of a cultural heritage site. Although WebGIS and 3D GIS applications support stand-alone users as well as users on a network and the Internet, a common interoperable data format must still be defined by the international scientific community.

3 Methodology

This paper attempts to produce a unique research instrument for the archaeologists working in the study area. It provides functionalities and analysis tools that have not previously been available for archaeological sites in Qatar. Additionally, the developed 3D GIS offers yet unexplored, state-of-the-art opportunities to present the research results to the archaeological research community and the broader public. This project offers an implemented framework for a 3D geographic information system (3D GIS) to facilitate archaeological research.

3.1 Geographic Information Systems (GIS)

3D GIS is used for recording and documenting spatial data in the restoration management of the Murwab archaeological site. 3D GIS can capture, integrate, store, edit, analyze, and display geographically referenced information. Therefore, the utilization of GIS in archaeology is based on its capacity to relate different information in a spatial context and to reach a decision concerning the archeological relationships.

The information system intends to create a database containing all the information concerning materials, constructive technologies, and conservation levels of the monuments. Alphanumeric data will be supported by graphic data (i.e., pictures, drawings, and maps) to describe the conservation state of the monuments. The GIS will be connected to organize and maintain different aspects of the periodic system including artistic, historical, and material characters of the monuments, guaranteeing effective conservation and preservation of the site. The 3D GIS allows archaeologists to spatially store, share, visualize and analyze complex archaeological features in a virtual 3D environment. Furthermore, the 3D GIS allows the inclusion of 3D georeferenced historical images and virtual 3D reconstructions in a scientifically transparent manner. At the foundation of the 3D GIS is a sophisticated cloud-based data infrastructure, providing various services to different clients ranging from an interactive web viewer to a dedicated desktop viewer.

Developing a computerized system that will assist in the advanced recreation of the Murwab site, including characterization and representation of archeological finds within an advanced 3D web-based repository of reality-based information. The ultimate goal is to upgrade the information on the website inside the framework with its chronicled development and its institutional administration.

High-quality 3D models can be utilized to portray existing antiques and as representations for navigation inside different types of data. The subsequent perception process can uncover the connections inside an archeological 'reconstruction' clearly, as the procedure can demonstrate relative area (what is besides, what encompasses, what is above, beneath, to the side of, and so forth.).

Hence, 3D GIS is an effective tool for archaeology by joining specialized data and reasonable illustrations to create a framework that can oversee, address and reduce the unpredictability of archeological records in space and time. It will be instrumental in perceiving the significance of developing, executing, and assessing distinctive procedures that will improve viable archeological methodologies.

3.2 3D Model acquisition

Archeological information is very complex from a geometric perspective, and existing strategies for 3D modeling have led to extensive improvements. 3D model construction is an unpredictable portion of the improvement of an archeological 3D GIS. To institutionalize a truth-based 3D process, a development process with the following six distinct steps is followed to develop a shape: 3D model construction, color/texture, microstructure mapping, 3D models semantic organization, multi-resolution model generation, and visualization/positioning. We propose a 3D model development framework that allows a scanner to be placed approximately 15 inches from the object, which turns as the scanner remains fixed. The cleaning and enhancing tool supporting the 3D scanner will create excellent 3D models. The 3D scanner allows 3D models to be saved in a wide range of formats including, stl, employ, and obj document design. They can be effectively scaled to support different levels of visualization quality to be viewed via standalone or web-based systems.

3.3 3D GIS data acquisition

3D data collection techniques such as aerial and close-range photogrammetry, airborne or ground-based laser scanning, surveying, and GPS have recently improved. Sensors are faster and more accurate. In addition to new techniques and hardware developments, processors, memory, and disk storage devices have become more efficient in processing large data sets, especially with the use of graphics cards. Data populating an archaeological 3D GIS may be divided into a vector, raster, and spatial data along with a database management system, as shown in Figure 1.

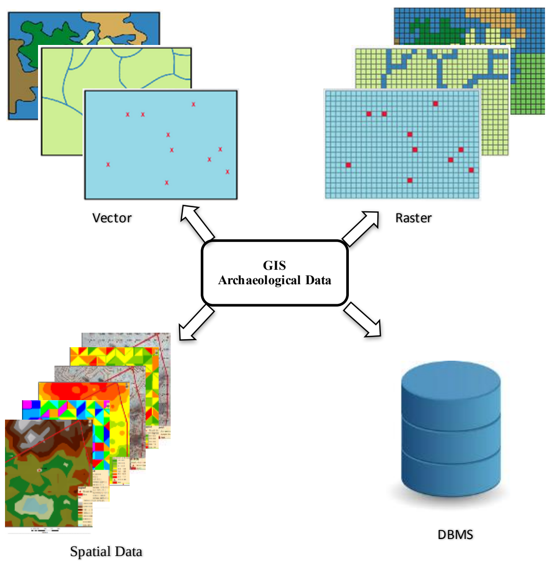


Fig. 1. Archaeological GIS data

Both raster and vector format data are integrated into GIS applications, and the 3D surface models are constructed, providing the fundamental potential of a GIS. A built-in relational DBMS or external software such as MySQL, PostgreSQL, Oracle, or SQL Server can be used. Spatial data are all those data to which it is possible to associate a reference system. Many systems and methods allow the acquisition of spatial data, which use typical geometric methods and instruments such as remote sensing techniques (digital images obtained through airborne and satellite sensors); topographic techniques (total stations and digital levels); photogrammetric techniques (analog and digital images produced by aerial and terrestrial cameras); GPS techniques; and aerial and terrestrial laser-scanning techniques. GIS software tools have also made a significant movement towards 3D GIS especially in the ArcGIS platform, where 3D has become not only a core capability but also a core competency within our user community. Remote sensing through satellite stereo images, aerial photography, LiDAR, DGPS, contour lines, and spot heights are various sources from which to obtain DEMs. We used KMZ files created using ArcGIS as the input to the Cesium WebGL software. This model attempts to indicate physical or logical values defined by a set of features and behavior rules expressing its state, both dynamic and static. Surface maps showing spot heights (see Figure 2), triangular irregular networks (see Figure 3), contours (see Figure 4), and elevation (see Figure 5) can be derived from these models in the archaeological domain. Additionally, aspect and slope surface maps can be derived, see Figure 6. It was possible to obtain flexible on-site management of various stratigraphic layers to support archaeological excavations.

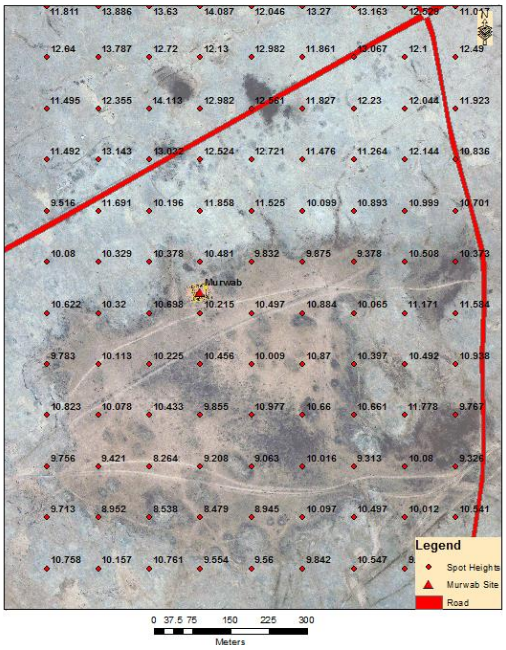


Fig. 2. Surface maps (Spot Heights)

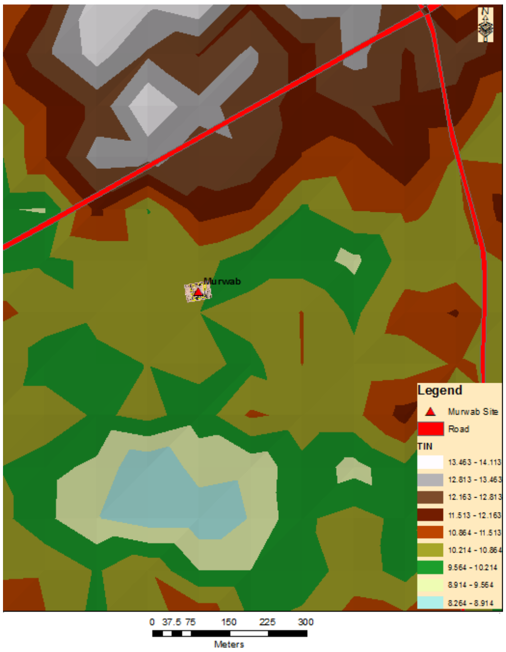


Fig. 3. Surface maps (TIN)

Fig. 4. Surface maps (contours)

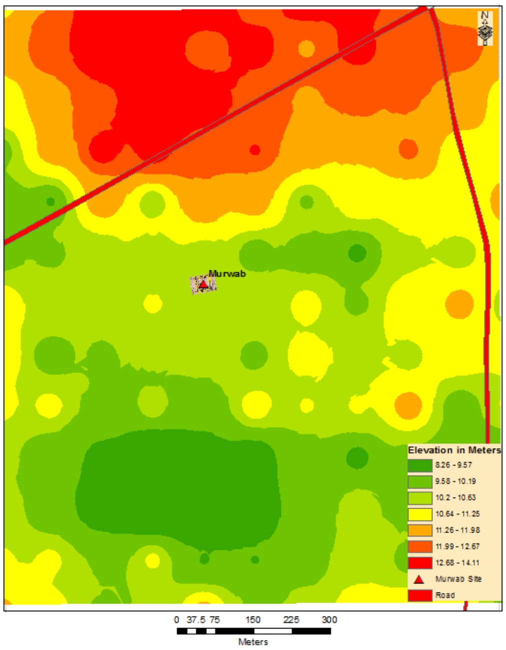
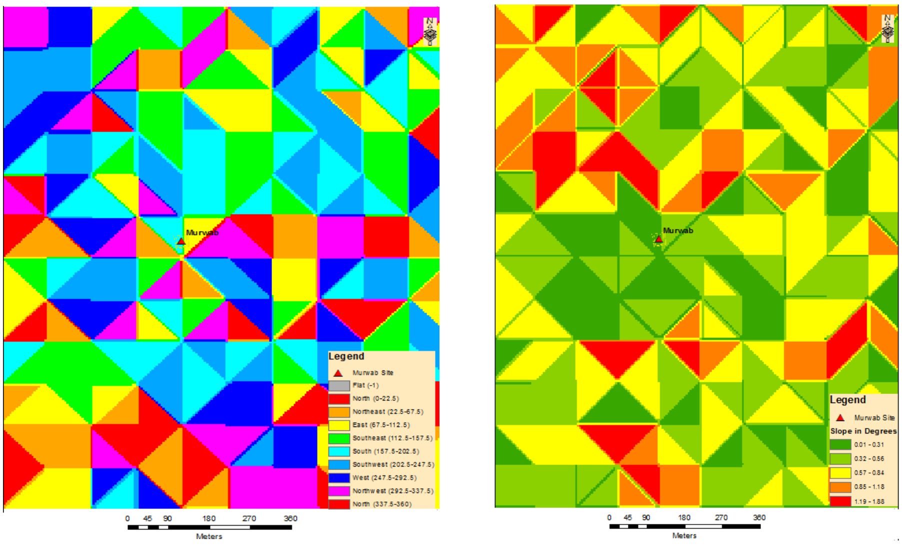


Fig. 5. Surface maps (elevation)



(a) (b)

Fig. 6. (a) Aspect of surface maps, (b) slope of surface maps

3.4 Creation of webpage with 3D GIS and 3D models

In the proposed framework, 3D interactivity depends on the blend of HTML5, WebGL, JavaScript, and Cesium. The artifact 3D models in any format (i.e., stl, employ, or obj) generated by the scanners can be displayed on the web page. The 3D models of the artifacts can be browsed as shown in Figure 7. The attributes and metadata associated with the artifacts and the HTML-like label which contains both the connection (URL) to the site page where information will be shown (Figure 8) and a reference ID are saved in the data repository on the server. The system provides a remote presentation of data in a web environment utilizing Cesium, an open-source GIS library for 3D visualization of geospatial data, as shown in Figure 9. It supports layer imagery from numerous sources, including WMS, TMS, WMTS, Bing Maps, Mapbox, Google Earth Enterprise, OpenStreetMap, ArcGIS MapServer, standard picture files, and custom tiling plans. Various stratigraphic layers to support archaeological excavations are displayed on the web page as shown in Figure 10. The framework works easily with low to high-resolution 3D models and can support a low data transfer capacity. There is no requirement for a specific server or server-side calculations; only space is required on a web server. There is no need for plug-ins or additional components.

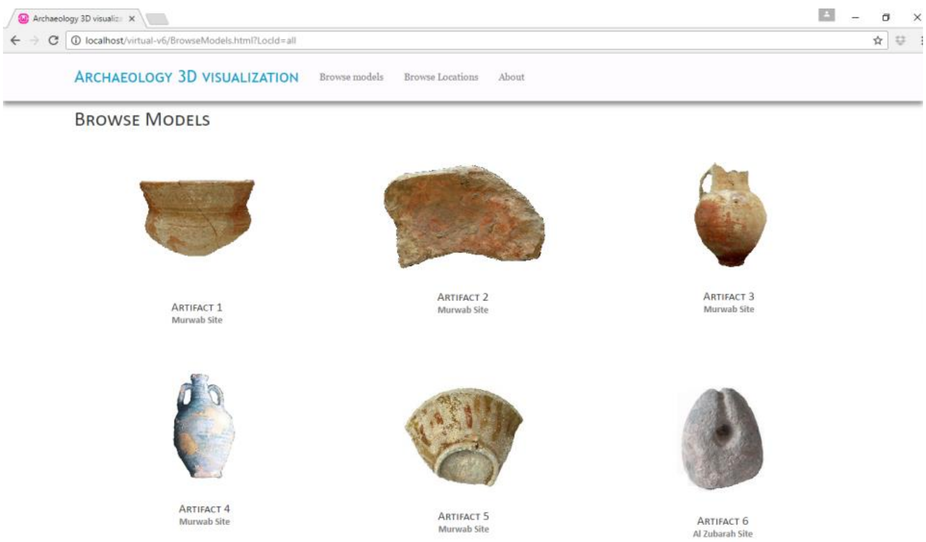


Fig. 7. Web page showing 3D models of the artifacts

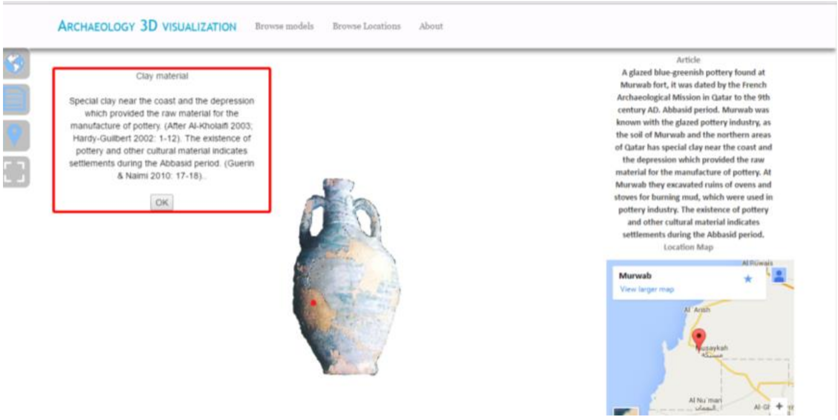


Fig. 8. Web page showing a 3D model of the artifact with article description, location, and point of interest details

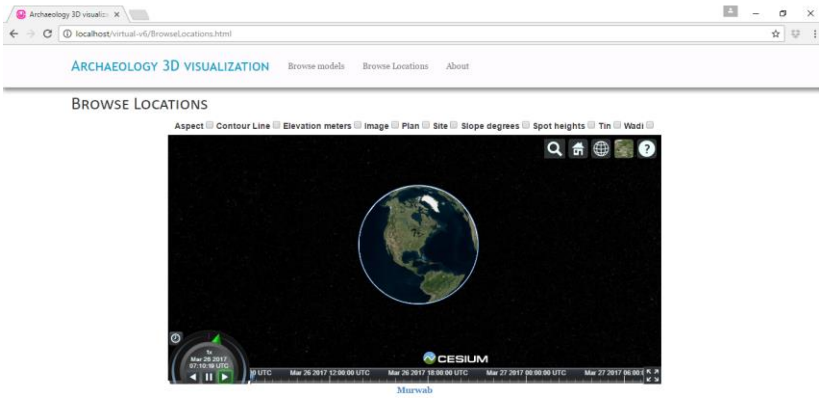


Fig. 9. Web page showing the 3D GIS location

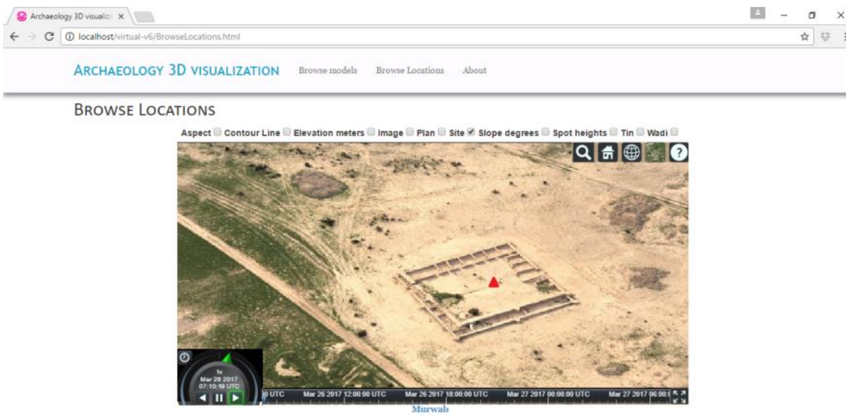


Fig. 10. Web page showing the 3D GIS of the Murwab site

4 Result

Ten experts from the archeology and history department have been asked to use the portal and explore the potential of using such a system for archeological exercises and digital object representation and spatial investigation. After finished with their expletory test, they were asked to answer a questionnaire to evaluate the framework in terms of achieving the objectives. The system proved to be intuitive to investigate the 3D model artifacts 92%, 94% found the information of their point of interest, 88% could work with the spatial visualization, and 92% could access the 3D georeferenced historical images and found it very useful, see Figure 11.

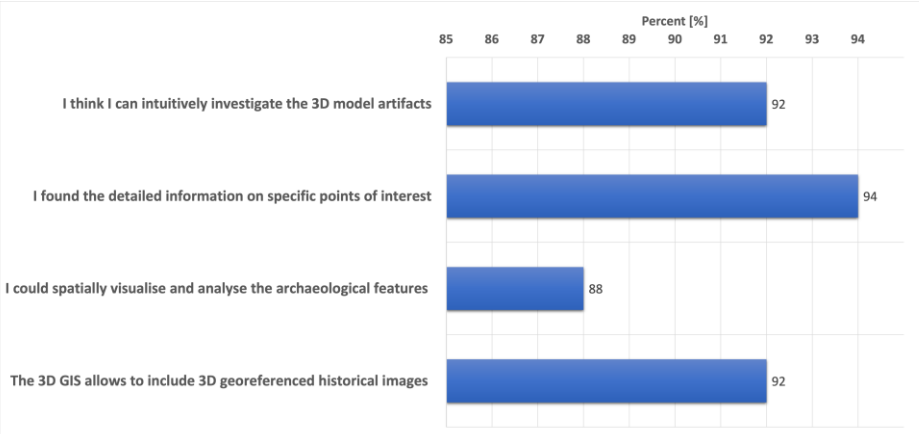


Fig. 11. The evaluation of the framework in terms of the achievements of the main objectives

Ten university students from history and computer science majors were asked to evaluate the system and answer the well-established SUS usability questionnaire [39], [40]. Participants liked the system and found it very useful and usable. High scores in the questions related likeness, well-integrated, easy to use, and confidence to use the system with scores over 90%. Low scores for the odd questions that related to complexity, inconsistency with scores less than 30% as can be seen in Figure 12. The overall final SUS score was 89.25, which is considered in the excellent usability score range.

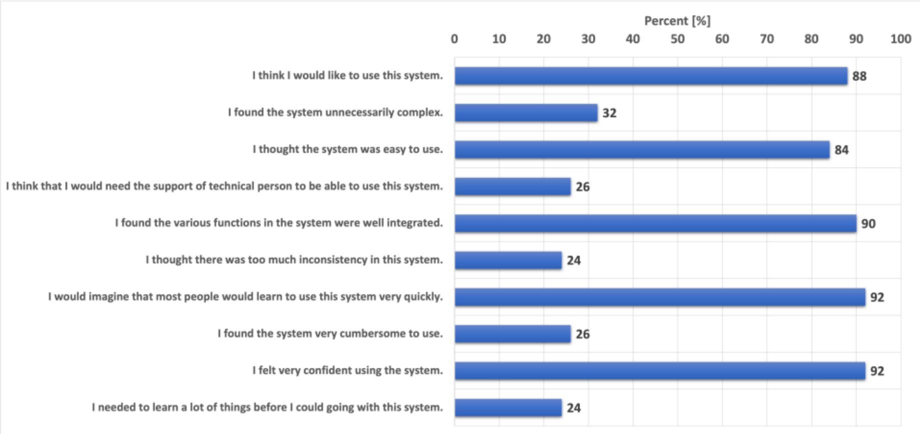


Fig. 12. SUS evaluation result for the system

5 Conclusion

Murwab is a significant archaeological site in Qatar because the excavations provide a depiction of how the social and monetary relations among various members of the community became physical realities. A 3D GIS model with archaeological attributes was built, providing documentation of all the advanced work processes for the site as an effective approach to coordinate archaeological activities, data management, digital object representation, and spatial analysis. Because this is achieved with HTML5, Cesium, and WebGL, which are free and open-source, the development and deployment of large-scale web-based 3D geospatial visualization were possible without requiring users to install a browser plug-in or application on their device. A user interface with fast 3D visualization of acceptable quality requires a significant amount of manual effort and expense. The concept could be used to attract tourists to museums by providing access to 3D archaeological data. 3D printing of artifacts to provide the touch and feel of the original can be appealing to academics. Connecting to other museums worldwide and creating a cloud-based map of the archaeological site along with a simulation of the surrounding environment can be achieved as an extension of this project.

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