ENHANCING CULTURAL HERITAGE DIGITALIZATION AND VISITOR ENGAGEMENT THROUGH LIDAR SCANNING AND GAMIFICATION

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Abstract. Cultural heritage assets are valuable, providing important information about humanity's past and conveying it to the future. Unfortunately, conventional documentation is insufficient to preserve them for the next generations. Furthermore, increasing visitor interaction with these assets and raising awareness has been one of the challenges in this field. In this paper, we will examine how mobile LiDAR (Laser Detection and Ranging) technology can be used to precisely scan and document historical sites and how it can be combined with gamification elements to provide visitors with better experiences. It is also important that the texture taken in mobile laser scanning can be used to better visualize 3D mesh models of the scanned objects, so the fastest application that produces 3D models is selected. The study area is Syedra Ancient City in Alanya / Turkey, where the research and excavation process has continued since 2015 and the restoration projects started in 2023. Future work includes the creation of experiences to provide a basis for gamification and revitalizing the story of the heritage for the visitors through digital storytelling and AR (Augmented Reality). Preserving historical sites while providing visitors with a more in-depth, vivid and enjoyable experience are important facts for enhancing cultural heritage and passing it on to future generations.

Keywords. Cultural Heritage, Digitalization, LiDAR, Mobile Laser Scanning, Digital Storytelling, Augmented Reality, Gamification.

1. Introduction

This paper explores how gamification elements can be used to enhance visitor engagement by documenting historical sites using mobile 3D LiDAR (Laser Detection and Ranging) technology. This approach goes beyond traditional preservation and presentation methods, combining the precision of LiDAR with the portability of mobile devices. It also explores the potential of gamification elements to make the site more engaging for visitors. The future work will include presenting the chosen

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archaeological artifacts by analogue and digital presentation materials to different experimental groups and evaluating the effects of different techniques on their memorability. It is aimed to develop a different approach to the presentation of artifacts in archaeological sites, encouraging people who have not yet had the opportunity to visit the archaeological site to experience the artifacts in situ and contribute to cultural tourism by triggering their interest in cultural heritage.

2. Background Research

2.1. LIDAR SCANNING TECHNOLOGIES WITHIN THE SCOPE OF DIGITALIZATION

This section will concentrate on research methodologies and scanning technologies employed for the digitalization of cultural heritage. It will specifically focus on the utilization of LiDAR scanning technology, highlighting its features, advantages, and limitations while exploring its role in cultural heritage documentation research and investigating the possibilities of using this technology in preparing data for gamification. While traditional documentation in the field of cultural heritage may involve recording details with hand drawings, today, digital documentation research has become more extensive and rapid with modern technological methods. Among these, scanning technologies are crucial elements in transforming the heritage documentation process. Techniques such as laser scanning, photogrammetry, fixed-point LiDAR and aerial LiDAR are used to digitize heritage assets with high precision and speed. LiDAR technology utilizes beams of electromagnetic radiation to gather information about objects (Łabędź et al., 2022). The capability to offer precise measurements and create detailed 3D models positions LiDAR as a valuable tool. The potential of research on scanning technologies includes its integration with fields such as AI (artificial intelligence), big data and AR that can provide greater interaction. This study will discuss potential strategies for more effective documentation of cultural heritage and identify notable areas for future work.

2.1.1. 3D Mobile LiDAR Scanning in Archaeology

LiDAR sensor is found to be a promising instrument compared to photogrammetric techniques, where there are inappropriate lighting conditions, such as harsh shadows or backlighting, that negatively affect the quality of the end results (Bruno et al., 2021). 3D mobile LiDAR technology is a powerful tool for documenting historical sites. An article on the survey of cultural heritage with Apple LiDAR sensor mentions that the instruments in this field have been developed primarily with the aim of optimizing costs and time (Vacca, 2023). It investigates the potential of a 3D mobile LiDAR sensor implemented in Apple devices since 2020 for the production of 3D models of cultural heritage objects in terms of applicability and accuracy. While comparing different apps, they showed different performances in terms of accuracy according to the sizes of the objects. The absence of information regarding its resolution raises questions about whether fine details are accurately captured for larger areas.

2.2. DIGITAL TECHNOLOGIES SUPPORTING VISITOR ENGAGEMENT THROUGH STORYTELLING AND GAMIFICATION STRATEGIES

Emerging digital technologies make powerful contributions to strengthening the perception of heritage and transforming how we experience it (Economou, 2016). It is observed that studies on experiencing cultural heritage artifacts in museums and archaeological sites with techniques such as AR, VR and gamification are effective in increasing cultural heritage awareness. In cases where archaeological sites cannot be visited in-situ, it becomes valuable to promote them through digital media. This can also positively affect people's interest and sensitivity to all world values and cultures.

In order to feed future stages of this paper, studies in which cultural heritage was introduced specifically through storytelling, AR and gamification elements as well as the effects of these techniques on cultural heritage awareness were examined. Analogue or digital completion on 2D images and 3D models, animation and gamification, together with AR technology, emerge as powerful tools. Studies where AR is applied to 3D models to help better perception of archaeological sites constitute practical and effective examples for the presentation and promotion of cultural heritage (Ozer et al. 2016).

One of the pioneering studies in which archaeological cultural heritage is experienced interactively in the museum by visitors with different social qualities through digital storytelling and AR is the project called "CHESS" (Cultural Heritage Experiences through Sociopersonel Interactions and Storytelling) (Pujol et al., 2012). Based on the idea of producing personalized interactive stories, it was stated that the possibility of experiencing a different story during each experience in the virtual environment may trigger a revisit. The study in which digital storytelling is considered as an investible tool for visitor engagement was developed by incorporating mobile AR experiences into personalized storytelling in the museum (Keil et al., 2013). Various techniques, such as voice-over, are used to increase the impact of storytelling. In another study that produced animated graphic narratives on a wooden statue of an important author at the Svevo Literature Museum using audio-visual materials through the Apple ARKit mobile app, the focus was primarily on content, and technology was used to enhance the story (Fenu et al., 2018). It was observed that it attracted the attention of older and various categories of users. In the scope of "The CHATS Project", works using digital storytelling and other tools in the last 10 years were compared in terms of method and content, and the 'personalized' digital story approach stood out in cultural heritage areas (Trichopoulos et al., 2022).

In a recent article investigating the impact of guided storytelling on museum visitors' emotional engagement, imagination and retention, it is emphasized that studies on heritage experiences integrating storytelling with digital technology and multimedia applications should be developed (Campos et al., 2023). Considering the gap in developing the impact of storytelling in heritage experiences, this paper aims to enhance an alternative method that can be applicable for tourists to establish an emotional connection with the heritage site before they even visit the place in-situ. In a similar study that presents the storytelling of a historical settlement in a museum through video projection mapping on a 3D printed model and by AR on large visuals, intangible values such as the history, lifestyle and folkloric music of the region are conveyed through audio elements (Nikolakopoulou et al., 2022).

A recent study in which a historical orphanage building is experienced with gamification and VR tools based on photogrammetric 3D modelling focuses on empathizing with the sociological context of the building through the use of intangible heritage elements such as children's and workers' memories and creating interactive environments that enhance a sense of place (Kalak et al., 2023). Combining practical documentation techniques such as photogrammetry and mobile scanning effectively with technologies that create interactive experiences for gamification is an area open to exploration. In a recent paper that maps out the publications in the field of gamified cultural heritage, it is figured out that gamification is generally used for engagement and creativity enhancement (Marques et al., 2023). In another study on the digitalization of architectural heritage, a fortress was modelled using a high-poly point cloud and a high-poly mesh by aerial photogrammetry. Then, the high-poly 3D model was transferred into a low-poly 3D model to optimize it for the game engines (Sancak et al., 2023). In gamified cultural heritage, mobile applications, AR and VR are found to be particularly prevalent. It is interpreted that future work on heritage will not only focus on transferring pre-existing knowledge but can align gamification with heritage as an ever-changing practice in aspects of identity, narrativity and belonging.

3. Material and Method

Especially in such studies for inheritance areas, it is even more important to accelerate the documentation process as much as possible for the in-situ conservation of artifacts like mosaics which are more sensitive in terms of material against external factors. In this direction, mobile scanning was preferred to be used in the first phase of the study.

3.1. DATA COLLECTION

The theoretical contribution of this study was to propose a method for comparing surface models based on the coordinate system. Firstly, the performance of the Apple iPad Pro LiDAR sensor is analysed in an outdoor scene with a building of significant size. The Frigidarium (Cold Room) chamber of the Great Roman Bath complex, including the large floor mosaic at the Syedra Ancient City, was scanned using a mobile LiDAR app and simultaneous 3D modelling with the aim of creating the most up-to-date model (Figure 1 left). The resulting model and texture data were exported in .fbx format and examined in the Blender 3D program. After conducting initial tests on various 3D scanning applications utilizing LiDAR sensors, four options were considered: 3D Scanner App, Polycam, Scaniverse, and SiteScape. These are some of the widely used apps that take place in similar studies (Łabędź et al., 2022). Following extensive evaluation, the Scaniverse app emerged as the preferred choice for further research due to its capability to generate highly accurate 3D models in the form of point clouds or meshes. Scaniverse allows users to visualize scanned models in both 3D and AR. The app facilitates exporting high-resolution models in a wide variety of formats. Notably, it offers flexibility in setting the scanning range, allowing users to skip unnecessary areas. The app can save the model in three resolutions: small object, medium object, and large object/area. There are three processing modes: speed, area, and detail. For the Frigidarium chamber, the "large object area" mode was used for scanning, and the "area" mode was used for processing. Despite user-friendly, timeefficient, and high-quality 3D results, some deficiencies that need to be improved were also identified, such as the scanning range being limited to 5 meters and failures in the model due to insufficient lighting.

Numerous scanning attempts failed during execution, especially when dealing with fine details. There were instances where the scanning process had to be repeated multiple times for verification. Additionally, users can edit the scanned model within the application, enhancing its appearance or making necessary trims. The 3D model data obtained by LiDAR scanning coincides with the conventional measurements with minimal deviation (Figure 1 right). Another crucial feature includes the ability to measure the actual size of the scanned model. The scans were performed in September 2023 at the Syedra Ancient City. During this time of the year, there is a lot of sun causing high contrasts and brightness, creating non-demanding conditions for image acquisition and photogrammetric reconstruction.

Figure 1. (left) 3D laser scanning process with the LiDAR and (right) high-quality 3D model

For smaller models, the maximum scanning range of 5 m may be excessive, making it convenient to focus solely on specific objects. As an example, we examined a small sized statue, known for its intricate details and surface irregularities (Figure 2). For this figure, "medium object" mode was used for scanning and "detail" mode was used for processing in the Scaniverse app.

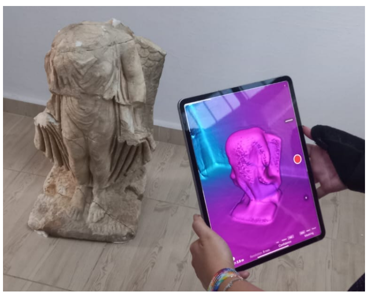

Figure 2. 3D scanning processes of a statue found in Syedra Ancient City

The iPad-derived point cloud displays noticeable regularity features and the resulting grid is marked by significant data simplification, resulting in a notable loss of detail. Upon a detailed analysis of the distribution of the point cloud derived by, it became evident that the model's depressions yielded the least favourable results, while relatively satisfactory outcomes were achieved in convex areas. It is crucial to emphasize that the model showcased represents the optimal result obtained through the utilization of the Apple iPad Pro.

At the same time, scanning was done using the photogrammetric method in the Scaniverse application with an old version of iPad Pro that does not contain a LiDAR sensor. The application obtains point cloud data with photo captures on these old-version devices. The point cloud generated through photogrammetric methods exhibited a significantly lower sharpness than in the previous case. Specifically for the iPad data, the focus was on points situated on the statue's surface. Furthermore, the device that used the photogrammetric method during processing took much time compared to the iPad LiDAR. The photogrammetric method produces grids with high density and rough surfaces, while iPad LiDAR generates meshes with smoothness and a higher level of generalization. The LiDAR sensor integrates the points it measures with information captured by the RGB camera within the device. The utilization of the Apple LiDAR sensor is restricted to dedicated applications available for download exclusively from the App Store.

A detailed 2D orthophoto of the large floor mosaic was also obtained using the Agisoft Metashape application for photogrammetric processing of the high-resolution digital photographs taken by a drone on site (Figure 3). In order to properly compare the properties of the technologies under study, the scanning procedure with both the iPad device and photogrammetry was performed under the same lighting conditions, during similar times of the day. These conditions also varied depending on the object.

Figure 3. Orthophoto of the large floor mosaic obtained by photogrammetry (Ergürer, 2023)

For the production of the basic 2D and 3D visualizations, the data obtained both by 3D LiDAR scanning application and the digital photogrammetry application was used. The above-mentioned floor mosaic covering the floor of the Frigidarium chamber is a large unique mosaic including a mythological narrative depicting the "Twelve Labours of Heracles”. The fact that each scene is placed in a continuous manner without interruption and that the hero is placed in different positions and in motion gives depth to the mosaic (Ergürer, 2023). Unfortunately, the mosaics depicting some scenes have been largely destroyed. It is planned that the digital completion of the mosaic will contribute to the perception of the work as a whole. If sufficient data is provided, digital completion of the completely destroyed roof and missing parts of the walls can be a future study that will strengthen the perception through AR.

3.2. A PRELIMINARY STUDY FOR GAMIFICATION: "MOSAIC PUZZLE"

In order to develop a preliminary study example for gamification, the high-resolution 2D orthophoto of the floor mosaic obtained by photogrammetry was converted into a puzzle game designed in UNITY. The interface of the puzzle game is seen in Figure 4. It is envisaged that the user will be able to establish a different relationship with the mosaic in a web-based platform. During this envisaged puzzle game, as each mythological scene is solved by the user, information and stories about that scene can be transferred to the user. In this case, when compared with photogrammetric processing, LiDAR is also an alternative technology that can be used to speed up the documentation process and create faster images for the gamification process.

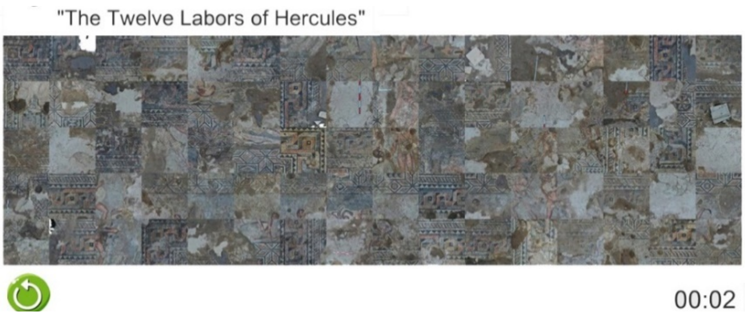

Figure 4. A preliminary study of the envisaged puzzle game "Mosaic Puzzle"

3.3. FUTURE WORK

The future work aims to enhance the perception of the above-mentioned archaeological heritage assets by adding storytelling and gamification elements through AR during the presentation of the artifacts to people away from the archaeological site. An audio narrative will be prepared about the artifacts in order to support intuitive interaction during the analogue and digital experiences. For this purpose, historical, archaeological and mythological data about the artifacts will be researched. If there is a lack of data, similar artifacts will be examined specifically for the digital completion phase (Figure 5). After creating a memorable text, the audio data will be created by vocalizing the story. An application supported by AI can be used for vocalization.

Figure 5. (left) The first scenes of the mosaic completed in 2D on the Procreate app after comparison with (right) a similar scene on a sarcophagus tomb presented in Konya Archaeological Museum (Dany, 2008)

For the analogue experience of the future work, a brochure is to be designed consisting of 2D visuals, including real rectified photographs of the mosaic derived by photogrammetry and also isometric photographs of the area derived by mobile laser scanning. For the digital experience, 2D and 3D digital completions will be produced by illustration and presented through AR to enhance the artifacts. Some areas of the floor mosaic reached during the 2019 excavations (Ergürer et al., 2023) have collapses and destructions due to the fall of the superstructure in the past, so the completion phase can help the visitors visualize the mosaic with ease. The first experimental phase includes the presentation of the designed brochure with 2D visuals to the control group (CG). To the first experimental group (EG1), the 2D brochure will be presented supported by an analogue puzzle game and to the second experimental group (EG2), the productions in which the visuals are digitally completed in 2D and 3D with AR will be presented. In the third experimental group (EG3), a digital gamification experience will be included in order to increase the interaction with the user. The steps explaining the planned experimental phase are also summarized in Table 1.

CONTROL GROUP-(CG) 30 people	FIRST EXPERIMENTAL GROUP-(EG1) 30 people	SECOND EXPERIMENTAL GROUP-(EG2) 30 people	THIRD EXPERIMENTAL GROUP-(EG3) 30 people
A brochure with 2D visuals (real photo of the mosaic, drawings and isometric photos of the area, etc.) + auditory narrative	Converting the brochure of 2D images into a 2D analogue game experience (ex: a puzzle to be completed by hand) + auditory narrative	On the brochure consisting of 2D images, completion of 2D mosaic (digital illustration / animation) and 3D model of the place through AR technology + auditory narrative	On the brochure consisting of 2D images, completion of 2D mosaic (digital illustration / animation) and 3D model of the place through AR technology + auditory narrative + a digital gamification experience (ex: interacting with 3D model appearing on the table)

Table 1. Experiences to be presented in an empty room to the control and experimental groups

Every experience will take place in an empty room, accompanied by the same auditory narrative that is about the history and mythological story of the artifacts. 2D and 3D digital illustrations will be developed by the Procreate application on Apple iPad Pro and animations will be produced by a compatible application such as Procreate Dreams or Adobe After Effects. For practical use, an experience with mobile tools such as smartphones or tablets is planned through an open-source AR application such as Artivive or Adobe Aero. Although the user will be able to experience the presentations with his/her own mobile device, it is planned to install the application on a tablet determined for this project in order to avoid disruptions during the experience.

4. Evaluation and Conclusion

This paper explores the potential of integrating gamification elements to make the archaeological site more engaging for visitors by documenting it using mobile 3D LiDAR technology and combining the precision of LiDAR with the portability of mobile devices. The preliminary results of this study show that the iPad Pro LiDAR sensor shows better performance when used for medium-sized objects/areas and can be an important alternative to high-cost professional scanners due to its low cost, portability, speed and ease of use. In the future, depending on the innovations in sensor technology, the technical features of LiDAR sensors used in mobile devices are expected to improve and measure longer distances. The 3D models created by these recent technologies also become the basis for new heritage documentation, improving the traditional way of representing, studying and displaying the relics of the past.

Speaking of future work, the characters in the mosaic can be animated through AR depending on the story and the reality will be increased by the 2D and 3D completions that will appear on it without detaching the person from the original work. By adding gamification experience, its effect on the perception of the story will be investigated. Following the user experiences, surveys can help to find out the level of interaction of the users with the site. The advantages and disadvantages of the tools used to produce 2D and 3D presentations will be investigated, as well as AR and gamification elements supporting the storytelling. The people's interest and curiosity in the archaeological field will be compared by measuring what they have learned during the experiences. In light of the data obtained, the applicability of the developed technique to different areas can be discussed.

Following the surveys to be conducted after the user experiences, a comparative evaluation will be made by examining the effects of the different methods. One of the expected results is a better perception of the stories of archaeological artifacts by the presentation of digital completions produced on 2D visuals through AR and the integration of gamification elements. In addition, future innovative studies on mobile 3D LiDAR scanning and AR will enable their more widespread use in enhancing visitor interaction and making it more enjoyable. By demonstrating the positive impact of these technologies on archaeological sites, this paper aims to lay the foundation to facilitate the transition to gamification in future studies and provide inspiration for shaping ways to experience cultural heritage.

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