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Immersive Development and Value Transformation Mechanism of Major Archaeological Sites Empowered by Digital Technology

Xinyue Zhang[1,a], Guangwei Wang[2,b,*], Huiyan Yang[2,c]

[1]College of Social Sciences, University of Birmingham, Birmingham, UK
[2]College of Aviation Service and Tourism Management, Guilin University of Aerospace Technology, Guilin, Guangxi, China
[a]zhangxlnyue0823@outlook.com, [b]wangguangwei198809@guat.edu.cn, [c]18923763953@163.com
[*]Corresponding author

Abstract: *Exhibitions in archaeological sites tend to be based on physical presentation and written accounts, which leads to lack of interactivity, poor immersion effects, and lack of efficiency in cultural and economic transformation. To solve these problems, this paper proposes the use of 3D laser scanning, virtual reality (VR), 3D modeling, and multi-sensory interactive technology in order to create a simulated exhibition area. Using precise point cloud data capture, texture mapping and dynamic scene reconstruction, the original look of the archeological site is recreated digitally. The paper also clarifies the interactive processes and audience experience optimization that digital technology has introduced in immersive displays, and suggests the economic value change and improvement of local tourism industry associated with the large-scale display of archaeological sites with the use of digital technology. The experimental findings reveal that on average the experimental group scored 4.47 on immersion scale whereas control group scored 2.97 showing that the digital technology enabled immersive displays were indeed effective in enhancing the subjective immersive experience of the audience. As to the attention span, the audience of the experiment group averagely remained 25 minutes. The information indicates that interactive and immersive factors are capable of increasing the emotional involvement of the audience and their level of experience.*

Keywords: *Immersive Digital Archaeological Site Display; 3D Laser Scanning; Virtual Reality (VR); 3D Modeling; Cultural Value Transformation*

1. Introduction

As the digital technology is growing at a startling pace, the paradigms of cultural heritage protection and presentation are shifting radically. Conventional large-scale archaeological site exhibitions are largely passive with visitors receiving information passively and are not able to engage with the historical connotation and aesthetic worth of cultural heritage fully. Simultaneously, visitor engagement, enrichment, and retention level are low, which determines the restricted dissemination performance and social worth of cultural heritage exhibitions. It is against this background that digital capabilities, including 3D laser scanning, virtual reality (VR), 3D modeling, and interactive technologies, can provide new avenues of cultural heritage presentation, allowing a visitor to gain immersive experience on both virtual and augmented reality platforms, which will contribute to increased engagement, awareness, and cultural belonging.

It is on this basis that the use of digital technology in presentation of cultural heritage at large archaeological sites is considered the research object in this paper. It is a systemic study of the combined use of 3D laser scanning and point data processing, virtual reality immersive experience, 3D modeling, and interactive design. It develops assessment criteria of audience immersion and participation, and suggests a mechanism of the joint transformation of the cultural heritage economic and cultural value along with the development of cultural and creative products and the promotion of tourism. It determines the changes in the audience immersion, knowledge acquisition, cultural identity, and economic participation intentions through the empirical experiments with the aim to deliver scientific methods, technical means, and practical references to exhibit cultural heritage at the major archaeological sites and meet the numerous objectives of cultural protection, education spread, and increasing of the economic values.

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2. Related Work

In recent years, scholars have conducted extensive research on the protection and revitalization of cultural heritage and its sustainable role in tourism and community development. They have proposed theoretical frameworks and practical cases from multiple dimensions, including institutional governance, digital empowerment and economic value realization, providing rich evidence for further exploring the value transformation of cultural heritage in modern society.

Mzembe et al. had shown that sustainable cultural heritage tourism is multidimensional because it spans institutional and sectoral fields. They have identified gaps in institutional premises and research on sustainable cultural heritage tourism, and based on this, identified and proposed future research directions [1]. Madandola and Boussaa used a case study approach to introduce the revitalization of ancient historical cities in Fez, Morocco and Kano, Nigeria. The results show that culture-led urban revitalization is a viable place-making and sustainable development strategy. It has the potential to promote the heritage development needed in Oyo ancient town while promoting its environmental, economic and social sustainable development [2]. Aureli and Del Baldo used Urbino, a World Heritage city in Italy, as an example to explore the participatory governance model of local government in cultural heritage protection and sustainable development. The results show that the participation mechanism of local government can effectively promote citizens to jointly design and implement cultural heritage revitalization projects, and achieve a balance between heritage protection and socio-economic development [3]. Li et al. took 62 ancient villages as research objects, used linear concepts, defined the spatial influence of each village's culture from three dimensions: macro, meso and micro, used ArcGIS spatial analysis software to construct the corridor pattern of ancient villages in Mentougou District, and based on this, combined with the actual situation, meticulously depicted the spatial hierarchy, functional nature and characteristics of the corridor [4]. Muangasame and Tan took the Sapphaya community in Chaina Province, Thailand as an example to explore its practice of promoting the recovery of rural cultural heritage tourism through the "phygital" strategy in the context of the COVID-19 pandemic. They used participatory action research and network ethnography methods to analyze the community's online and offline integrated marketing practices. The results showed that the phygital strategy can enhance the experiential value and significance of cultural heritage tourism, and successful implementation requires broad participation from the grassroots in all stages of planning, development and management [5]. Magliacani pointed out that Italy chose Pavia as a smart city and implemented sustainable policies because of its valuable cultural heritage. He also constructed a conceptual model of knowledge antecedents of sustainable accounting and accountability [6]. Ramaano assessed the potential role of cultural heritage resources in tourism and community development in Musina, Limpopo Province, South Africa. Data was collected through questionnaires, focus group discussions and field observations. The results showed that the local area has rich cultural and heritage resources, but the impact of tourism on improving the lives of residents is limited. There is an urgent need to develop an effective cultural heritage tourism strategy to enhance community empowerment and sustainable development [7]. Del Soldato and Massari explored the challenges and opportunities of rural areas in sustainable development, emphasizing the reconstruction of community connections, strengthening of sense of belonging and protection of cultural heritage through digital and creative tools. Taking the Mediterranean region as an example, three case studies were combined to show the role of digital strategies in education, food production, tourism and cultural heritage. The results showed that digital innovation helps to promote rural economy, enhance climate adaptability and community resilience, and provide policymakers with a reference for promoting rural revitalization and migration governance [8]. Vlase and Lähdesmäki provided a new perspective for analyzing cultural heritage research and linked it to the rise of international heritage governance, which includes new institutional participants, professional networks and international agreements, all of which are components of scientific outcomes [9]. Souropetsis and Kyza introduced the design and validation of CompARe, a gamified augmented reality learning environment (LE) designed to support students in learning while visiting cultural sites. Based on an inquiry-based scenario, students work in groups to role-play as art historians and determine the date of an important mural by visiting four digital hotspots within the site.[10] Kostakis and Lolos provided empirical evidence on the role of cultural heritage assets in promoting economic growth. By constructing a neoclassical growth model and incorporating a dynamic cultural heritage index, they explored the relationship between economic growth and cultural heritage. The empirical results showed that cultural heritage resources have a positive impact on economic growth.[11] Although existing research has yielded rich results in cultural heritage protection, revitalization and tourism development, there are still bottlenecks in the research on the systematic immersive development of large-scale sites, the quantitative assessment of audience experience, and the mechanism of synergistic transformation of cultural and economic value.

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3. Methods

3.1 Related Technologies

3.1.1 Terrestrial 3D Laser Scanning Technology

Ground-based 3D laser scanning technology, comprising a high-precision 3D laser scanner, a high-resolution digital camera, professional data processing software, and a stable power supply system, enables precise measurement of archaeological sites. This technology can rapidly acquire and generate a large amount of 3D spatial coordinate information, thus creating a comprehensive and three-dimensional "digital portrait" of the site. During the scanning process, an integrated digital camera captures real-time images of the object being measured, providing rich texture information for the digital reconstruction of ancient architecture.

The collection and meticulous processing of cloud data from major archaeological sites are crucial for achieving digital reconstruction. Based on this, specialized software is used for preprocessing to ensure data continuity and consistency, and 3D modeling technology is employed to convert the data into accurate models, thereby restoring the original appearance of the archaeological sites.

3.1.2 Data Fusion

By fusing 3D laser scanning point clouds with densely matched point clouds generated from oblique images, and converting the point cloud data into a unified. las format, the consistency of the two types of point cloud data formats is ensured. Using the 3D laser scanning point cloud as a reference, iterative nearest neighbor (ICP) and manual registration techniques are employed to process the original and fine registration stages separately to obtain a high-precision point cloud.

After material fabrication and the creation of the virtual 3D scene model, to truly recreate the original appearance of the garden, it is necessary to create texture mapping materials and apply textures to the model. While images of the buildings can be obtained through on-site photography, the results may be unsatisfactory due to factors such as angle, distance, and lighting intensity. Therefore, Photoshop software is needed to appropriately crop and transform the images, and then 3DS Max is used to apply texture mapping to the processed materials to achieve a realistic 3D effect. During the rendering process, texture baking technology can be used to improve rendering speed and save CPU resources.

3.1.3 3D Modeling

Once all data is prepared, modeling can begin on the ground. A modular modeling approach can be used, integrating the model into a larger scene to reduce modeling difficulty and improve efficiency. The main steps of scene modeling include: determining the floor plan and location of each building; drawing CAD 2D floor plans based on measured building dimensions; using elevation data from 3DS Max for building modeling and mapping; correcting model format, dimensions, normals, and object coordinates; removing invisible parts; reducing the number of materials; and compressing textures to simplify the model and reduce its size, ultimately achieving a complete 3D virtual scene.

3.2 Optimization of Interactive Mechanisms and Audience Experience in Immersive Displays

The main idea of immersive exhibitions is based on the application of technological resources along with the interactive mechanisms to spatial design which helps to direct the visitors on the experience of high level of concentration and immersion within the scenario and also on elevating their sense of autonomy in the scenario. This model does not allow visitors to be passive receivers of information any longer, but participants and co-producers of the experience. The engagement with exhibits is multi-layered, that is, the visitors may engage with exhibits, the exhibition setting, digital media and even with one another, and all of this encourages profound cognitive, emotional and behavioral engagements.

Indicatively, the Museum of Qin Terracotta Warriors and Horses in Shaanxi Province has employed digital projection and augmented reality (AR) technology to enable the visitor to recreate the layout and battle formations of the exhibits in a virtual setting. Now, visitors are allowed to interact and control the images that are projected on the screen via gestures and touch and this has changed the experience to being a passive viewer to an interactive person. The project of the digital Palace Museum in the Palace Museum in Beijing is characterized by the presence of panoramic digital guides and virtual exhibition halls which enable the visitors without the opportunity to visit the palace to interact with the space on a

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one-to-one basis and get acquainted with the background of the architectural structure as well as the cultural relics.

In archaeological site exhibitions, conventional, non-interactive displays only reveal the original context of the unearthed objects, and, as such, are rather inert. Nevertheless, with the help of interactive installations, situational tasks, and cultural experiences, including virtual guided tours and exploration missions in Dali Ancient City, Yunnan, visitors will be able to explore the remains of the site, perform virtual archaeology-based activities, and get immediate responses and instructions. This design fulfills two functions, namely, to prolong the duration of the time spent at the site by the visitors, and to increase the immersion of the visitors in the cultural content, their understanding of it, and memorization, which in turn has an educational effect on the exhibition and raises the degree of cultural dissemination.

3.3 Economic Transformation and Cultural Heritage Strategies of Cultural Relics

The essence of cultural heritage site presentation is the transfer of economic value and the handing over of cultural value. When it comes to the economic transformation, the attention must be paid to the creation of cultural and creative products according to the unique patterns of the site, the creation of the unique brand, and the industrial park. At the same time, tourism and industry integration should also be encouraged, and a route of tourism based on the revitalization of the rural areas should be designed. Speaking about cultural inheritance, it must be incorporated into the school programs strictly, developing interest of young people with the help of books, practice, and lectures. Meanwhile, active cultural exchange with other countries is to be sought, increasing its impact at the international level through exhibitions, discussions, and online media, which would allow it to renew in the new era and gain sustainable growth.

Conversely, the digitization and abstraction of the uncommon patterns of the archaeological sites can also be used to come up with innovative designs that would satisfy the modern aesthetic requirements without losing the original colors and patterns. Traditional patterns on clothing, home furnishing, and digital art may be used to expand the market use and add value to the products in terms of the cultural aspects. At the same time, to encourage the considerable evolvement of the cultural industry, it is possible to create cultural and creative industrial parks that will combine design, production, and sales to create a whole chain of the industrial industry. Moreover, culture and products promoted online will attract more youth, which will add to the brand effect and market share. When applying data technology to enable the cultural exhibition of large archeological sites, complete capitalization of the local resources, including agritourism and handicraft experiences, can improve the income of farmers and cultural dissemination. Moreover, collaboration with travel agencies and online travel platforms may contribute to greater cultural tourism promotion, a higher level of tourism brand awareness, the attraction of domestic and international tourists, and the local economic growth.

4. Results and Discussion

4.1 Experimental Subjects

The target audience is individuals aged 18–60, with a balanced gender ratio. This includes primary, secondary, and university students. They are also museum staff, culture enthusiasts, and potential tourists.

Physical exhibition spaces are site protection areas, archaeological museums, or simulated exhibition spaces. Virtual exhibition spaces are VR headsets or immersive projection scenes.

4.2 Experimental Design

A control group-experimental group design was used for comparative analysis. The settings for the two groups are as follows:

Control group: Traditional static display (only physical objects and text descriptions are displayed).

Experimental group: Immersive display (digital modeling, VR interaction, multi-sensory experience, dynamic display, interactive tasks).

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4.3 Experimental Procedure

All participants entered the exhibition space (or wore VR devices) and were randomly assigned to groups. The experimental group was guided to participate in interactive tasks, such as manipulating virtual objects, completing exploration tasks, and experiencing dynamic displays and multi-sensory feedback including touch, vision, and hearing.

The control group only visited the static displays, and the observation time was recorded. Data from the entire experience (behavioral records, dwell time, and interaction frequency) was also recorded. Data was collected through interviews after the experiment.

4.4 Data Analysis

Table 1 Audience Immersion Experience Rating Table (1–5 points)

Subject ID	Display Type	Immersion Score	Attention Duration (min)	Emotional Engagement
S01	Control Group	2.8	12	2.5
S02	Control Group	3	14	2.8
S03	Experimental Group	4.5	25	4.6
S04	Experimental Group	4.2	twenty two	4.3
S05	Control Group	3.1	15	3
S06	Experimental Group	4.7	28	4.8

The mean score on immersion of the experimental group amounted to 4.47 and the mean score of the control group was only 2.97, which strongly suggests that immersive displays based on digital technology greatly increased the subjective level of immersion of the audience. In terms of attention span, the audience of the experimental group remained an average of 25 minutes, which is almost twice as long as that of the control group 13.7 minutes, and thus it is evident that immersive environments are effective in increasing the time of focus on the part of the audience. The same applied to emotional engagement with the experimental group reporting 4.57 on average and the control group reporting 2.77, which means that the elements of interaction and immersion can contribute to the emotional involvement of the audience and the depth of feelings, which is reflected in Table 1.

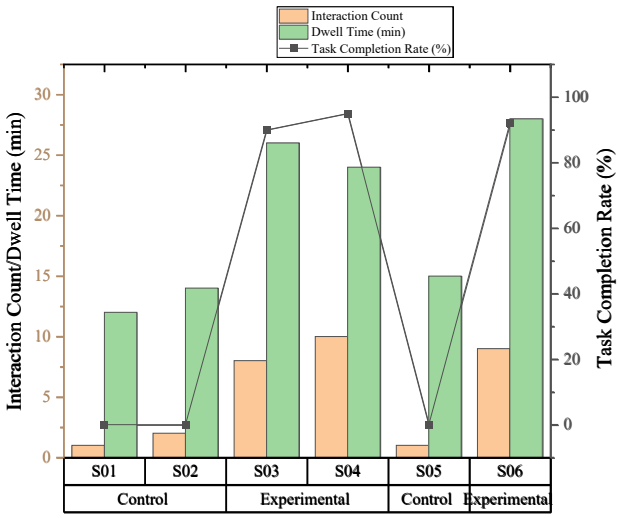

Figure 1 Audience Interaction and Participation Record

The average number of interactions in the experimental group was 9 and in the control group was only 1.3 and the fact remains that immersive environments have a significant effect in increasing the level of interaction with the audience. In terms of task completion rates, the experimental group had an average of 92.3 and the control a zero showing that the constructed interactive activities are very effective in motivating and motivating the audience to complete the advertised tasks in an immersive setting. The average time of stay of the experimental group was 26 minutes, which is only 13.7 minutes in the control group; this indicates that viewers in immersive settings have no hesitation about spending more time to explore the content (as show in figure 1).

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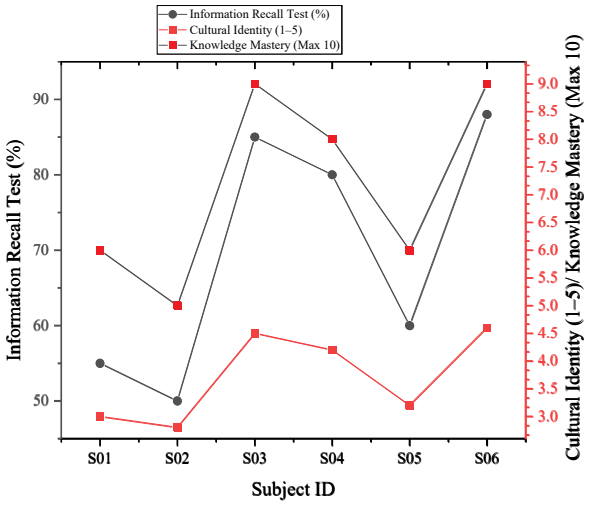

Figure 2 Knowledge Acquisition and Cultural Identity Scores

As shown in Figure 2, the experimental group significantly outperformed the control group in all three indicators: knowledge mastery, cultural identity, and information retention. The experimental group's average knowledge mastery score was 8.7 out of 10, while the control group averaged only 5.7, indicating that immersive displays effectively enhance audience understanding and mastery of cultural heritage knowledge. Regarding cultural identity, the experimental group averaged 4.43 out of 1–5, while the control group averaged 3.0, demonstrating that digital and interactive displays strengthen audience identification with and emotional engagement with the heritage site. The information retention test results showed that the experimental group achieved an average accuracy rate of 84.3%, compared to only 55% in the control group, further proving that immersive displays improve information absorption and retention. Overall, these results demonstrate that heritage displays empowered by digital technology and interactive design not only enhance audience participation but also achieve significant results in knowledge transfer and cultural identity building.

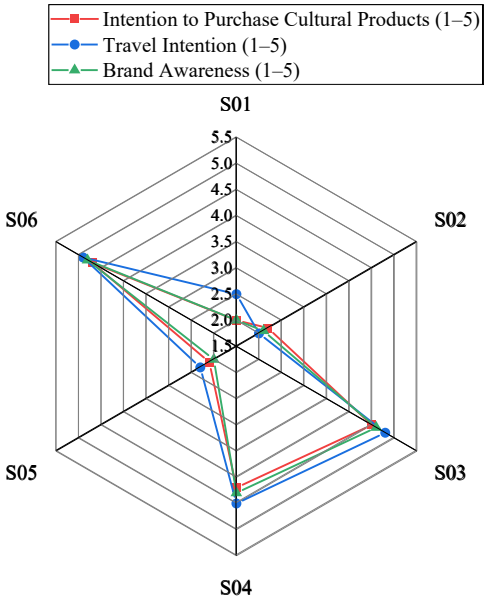

Figure 3 Economic Value and Cultural Participation Intention

4.47 (1–5) for cultural and creative products, while the control group only scored 2.1, indicating that immersive displays significantly enhance audience interest and willingness to consume cultural heritage derivative products. Regarding tourism intention, the experimental group averaged 4.73, while the control group averaged 2.27, showing that audiences in an immersive environment are more inclined to participate in related cultural tourism activities. In terms of brand awareness, the experimental group averaged 4.57, while the control group averaged only 2.03, indicating that digitally-enabled displays not only strengthen cultural identity but also increase audience awareness and understanding of cultural heritage sites and related brands. Figure 3 shows that overall, immersive

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displays have a significant effect on promoting the transformation of cultural heritage's economic value and increasing cultural participation willingness, providing empirical evidence for the development of cultural and creative products and tourism promotion.

5. Conclusion

This paper focuses on the display of large-scale archaeological heritage sites empowered by digital technology. It systematically explores the specific applications of technologies such as 3D laser scanning, point cloud data processing, virtual reality immersive experience, 3D modeling, and interactive design in site displays. Simultaneously, the study introduces experimental verification of the positive role of digital technology in enhancing audience experience and realizing the transformation of cultural heritage value. Furthermore, the study proposes strategies such as the practical significance of virtual reality immersive experience, audience perception, and the economic value transformation of large-scale archaeological heritage displays. The construction of cultural and creative industrial parks, the design of digital cultural and creative products, and tourism promotion provide feasible paths for the economic value transformation and cultural inheritance of archaeological culture. However, this study still has certain limitations. The experimental sample size is relatively limited and mainly focuses on a single site type, which may affect the broad applicability of the results. At the same time, the cost of technical equipment and interactive design is high, and resource and funding constraints may be encountered in the actual promotion process. Future research can conduct immersive display experiments across sites and regions on a larger scale, and combine advanced technologies such as artificial intelligence, big data analysis, and personalized recommendations to further optimize the audience experience, improve the efficiency of cultural dissemination, and achieve a deep integration of digital technology with cultural heritage protection, education, and economic value.

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