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Artificial Intelligence–Empowered Cultural Heritage Experience Design: A Case Study of Pompeii

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Abstract. This study looks at how artificial intelligence works with cultural heritage experience design. It takes the ancient city of Pompeii as a study example. The results show that AI technologies are very important for rebuilding old scenes and giving personal guided tours. But AI can work well only when heritage information is digitized fully and correctly. It also needs to follow basic design rules. These rules include putting protection first, keeping the experience real, and using proper technology. The main new point of this study is building a complete framework. This framework includes "heritage information–AI technology–user experience". The study also makes smart experience plans based on real situations. These plans link the past and the present in a lively way. There are still some problems now. For example, technology costs a lot, data is not complete enough, and privacy is hard to protect. But future studies can make immersive experiences better by using multimodal interaction. These methods can also be used in more cultural heritage places. This will help cultural heritage become active again with smart technology and be passed on well for a long time.

Keywords: cultural heritage, artificial intelligence, digital experience, Pompeii

1. Introduction

The digital work of global cultural heritage keeps developing all the time. Frontier technologies like artificial intelligence take part in heritage conservation, academic research and public participation at an unprecedented level. As one of the most typical archaeological sites of ancient Roman civilization, the ancient city of Pompeii has very high historical and cultural value. But it still faces some basic challenges. For instance, its historical context is broken, its spatiotemporal continuity is interrupted, and it is hard to meet the growing needs of modern audiences for immersive and personalized story experiences. Existing studies have discussed the use of artificial intelligence in cultural heritage from many aspects, such as digital reconstruction and intelligent guided tours. But these studies still have obvious limitations. On one hand, the use of technologies does not match the real situation of heritage sites and the actual experience needs of users. On the other hand, there is no complete design framework that can combine heritage itself, technology application ways and user experience goals in a systematic way. To solve these problems, this study builds a systematic design framework. This framework centers on three core elements, which are "heritage information, AI technology and user experience". It also takes Pompeii as a practical case. Through a deep

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analysis of the heritage features and experience needs of this site, the study puts forward smart experience solutions. These solutions use technologies like computer vision, natural language processing and augmented reality. The purpose of these solutions is to build effective cognitive and emotional links between historical sites and modern audiences. It can change the heritage experience from static viewing to dynamic interaction. It can also change one-way information transmission to multidimensional perception of history.

2. Current state of digital inheritance and development of cultural heritage

The digitalization of cultural heritage is a result that comes from the combination of digital technologies and cultural resources. In recent years, the digital inheritance and development of cultural heritage have entered a stage of rapid development. This stage is marked by technology-driven innovation and experience-oriented design. Although this field has broad development prospects and increasingly mature technical tools, it still faces some key challenges. These challenges include the disconnection between theoretical research and practical application [1]. Another challenge is that the application of technologies cannot match the needs of user experience well. We must solve these problems so that we can realize a deep change from simple "technological digitalization" to "intelligent experientialization".

From the view of global research, interdisciplinary studies that combine cultural heritage and artificial intelligence get more and more attention. The number of related academic papers grows very fast, as we can see in Figure 1. According to a report from Grand View Research, the number of academic papers in this field was about 10 in 2010, and this number rose to about 150 by 2025. This trend shows that in recent years, the research that combines cultural heritage and artificial intelligence develops very quickly. It has become a new focus in the academic world [2].

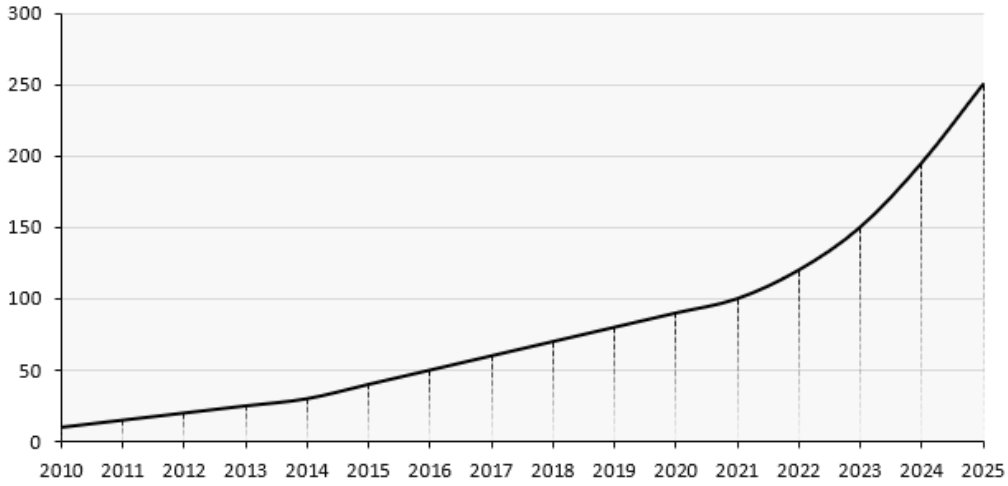

Figure 1. Global publication trends in interdisciplinary research on cultural heritage and artificial intelligence (2010–2025)

From the view of our country, digital cultural heritage projects increase at an explosive speed. These projects cover all steps from the conservation and restoration of cultural relics to cultural exhibition and communication, as we can see in Table 1. These projects not only help protect and pass on traditional cultural heritage, but also keep exploring new ways to combine with artificial intelligence technologies.

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Table 1. Selected domestic digital cultural heritage projects

Project Name	Project Overview	Technological Applications	Outcomes and Impact
Digital Palace Museum Project (The Palace Museum)	Comprehensive advancement of digital construction to create a "Digital Palace Museum," including digital artifact databases, digital exhibitions, and virtual tourism	3D scanning, modeling, augmented reality, virtual reality	Enriched modes of cultural resource presentation, enhanced visitor experience, and expanded the cultural influence of the Palace Museum
Digital Protection and Exhibition Project of the Liangzhu Ancient City Site	Digital protection and presentation of the ancient city site, reconstructing the social landscape and cultural characteristics of the Liangzhu civilization through digital technologies	Multispectral scanning, UAV surveying, 3D reconstruction	Provided new methods and perspectives for site conservation and research, and strengthened public awareness and identification with Liangzhu culture
Digital Mogao Grottoes Project (Dunhuang)	Digital acquisition, storage, restoration, and exhibition of murals, polychrome sculptures, and other precious artifacts, establishing a digital Dunhuang resource repository	Digital acquisition, image processing, virtual roaming	Effectively protected Dunhuang's cultural heritage, promoted its transmission and dissemination, and advanced in-depth research in Dunhuang studies

3. The intervention of artificial intelligence technologies

3.1. Advantages brought by artificial intelligence

Artificial intelligence is a major part of computer science. It includes many fields, such as machine learning, speech recognition, image recognition, natural language processing and expert systems. In the field of cultural heritage digitalization, AI technologies have the following advantages:

• High efficiency in information processing: AI can analyze and organize a large number of heritage data in a fast way. It helps integrate multimodal data sets and build spatiotemporal models. It also can find deeper information and inner connections in cultural heritage.

• Ability of personalized recommendation: AI can adapt to the different needs and preferences of users. It can provide accurate personalized services for people. For example, it can recommend materials with higher academic value to researchers. It can also design customized tour routes and cultural stories for ordinary visitors according to their interests.

• Context-aware interactive response: Through technologies like natural language processing and computer vision, AI can interact with users in real contexts. It can answer visitors' questions through voice dialogue. It also can use augmented reality to improve the immersive experience on site. It helps users understand cultural heritage in a more vivid and direct way.

Using AI brings many good effects to Pompeii's digital protection and display. We can see this clearly in Figure 2. Computer vision tools mark old murals carefully. They also find building parts in the ancient city. They fix these old relics step by step. These ways get important points fast and right. They give big help for the study and protection of old sites [3]. At the same time, AI makes many-language Q&A systems. These systems give easy culture information to visitors. Visitors come from different countries and areas. These systems make visitors' whole visit feeling much better. Most visitors feel happy with these useful systems.

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Figure 2. The RePAIR project team's use of artificial intelligence in the restoration of Pompeian murals

3.2. Forms of intelligent experience design

Smart cultural experiences use AI as the main part. They change the visiting ways of Pompeii with smart experience plans. These ways show in the following forms.

Smart marks and recognition for old relics: People use computer vision tools. These tools can mark and find relics in Pompeii in right ways. They give visitors much detailed information and background. For example, visitors can use a mobile phone to scan a mural. The system can know its content by itself. It will send many materials to visitors. These materials include texts, pictures and audios. This helps people learn the old stories well. It also helps people know the culture ideas of the art in a deep way [2].

Multilingual smart question-and-answer systems: These systems use natural language processing tools. They help visitors talk with Pompeii in smart ways. Visitors can ask questions by speaking or typing. The system gives fast and right answers. It tells the history of the site, how buildings look and the value of special relics. This function helps visitors from different language backgrounds very well.

Personalized visit plans: AI rules are used to make special visit routes and content for each visitor. These are made according to users' interests, visiting time and cultural backgrounds. For example, for professional scholars who are interested in ancient Roman architecture, the system gives priority to building remains in Pompeii. It also provides deep analysis of structural features and historical changes. For ordinary visitors, it recommends representative sites and experience activities. These activities include market scenes or simulations of ancient Roman daily life. Studies have proved that guide systems combining collaborative filtering and deep learning algorithms can push customized routes and explanations within two seconds according to user interest tags. On-site tests also show that 76% of architecture enthusiasts clicked on professional analysis pages. This number is much higher than that of general content recommendations [4].

Immersive interaction with historical scenes: VR/AR technologies and artificial intelligence are combined deeply. Visitors can "go back" to the daily life of Pompeii 2,000 years ago. When visitors wear VR headsets, they can immediately enter AI-made ancient Roman markets. They can bargain with virtual merchants. They can also enter noble houses to experience banquet etiquette. When they use AR glasses, broken colonnades and murals are rebuilt at once. Virtual residents walk by, and falling volcanic ash is added exactly to real archaeological remains. This kind of "virtual–real

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symbiosis" changes history from silent ruins into vivid scenes that people can see, experience and talk with [5].

Interactive disaster simulation: AI algorithms are used to make parametric simulation models. This method learns from the ways that Li Qingquan and his team use to build scenario databases for Mount Vesuvius. Visitors can adjust variables by themselves, such as eruption intensity and warning time. The system will give real-time feedback on affected areas and structural damage chains. This lets people feel the impact of the disaster on Pompeii directly. It also deepens people's awareness of cultural heritage protection [6].

Digital twin roaming and online interaction: An intelligent digital twin model of Pompeii is built online. It supports remote roaming and interaction for users all over the world. For example, Pompeii Archaeological Park and the EU-funded "Virtual Pompeii" project have released 64 hectares of laser point cloud data with 0.5 cm precision. They also publish Web Scenes on ArcGIS Online. Global users can roam through browsers. Official data show that monthly active users are more than 120,000. Through online access, users can visit the digital twin of Pompeii at any time and place. They can interact with AI-made virtual residents. They can also understand the city's history, culture and social life deeply. In addition, 3D printing technologies are used to turn digital twin models into offline cultural and creative products. These products include souvenirs and building models. This promotes the spread of cultural heritage and the development of related economy.

Different forms of experience in Pompeii's intelligent experience design have different popularity and user feedback, as we can see in Table 2. Immersive historical scene interaction is widely loved by visitors. It has a strong sense of immersion and entertainment value. It effectively improves people's perception and understanding of Pompeii's history and culture. Interactive disaster simulation has a unique experience way. It inspires people to think and explore ancient Roman history. It has great educational value.

Table 2. User feedback on intelligent experience design forms at Pompeii

Experience Form	Popularity (%)	Key User Feedback
Intelligent annotation and recognition of cultural relics	85	Rich information and convenient operation, though the accuracy of some annotations requires improvement
Multilingual intelligent Q&A	78	Accurate responses and user-friendly language, but insufficient depth in addressing complex questions
Personalized recommended tours	82	Well-designed routes and content aligned with interests, though greater diversity in recommendations is needed
Immersive historical scene interaction	90	Strong immersion and high entertainment value, but device comfort needs enhancement
Interactive disaster simulation	80	Unique experience with strong educational value, though operational complexity should be reduced
Digital twin roaming and online interaction	75	High accessibility and interactivity, but the realism of virtual models requires further improvement

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4. Analysis of the current state of digital applications at Pompeii

4.1. Case background

The ancient city of Pompeii is located at the foot of Mount Vesuvius in the Bay of Naples, Italy. Mount Vesuvius erupted suddenly in 79 CE. The city was buried under volcanic ash. So it becomes a "time capsule" of ancient Roman civilization. Pompeii keeps a large number of well-preserved buildings, murals and daily objects. It freezes the lifestyle and social landscape of ancient Romans. It provides invaluable material evidence for later studies of Roman society. Today, Pompeii is a World Cultural Heritage site. It attracts hundreds of thousands of visitors every year. These visitors come to explore the mystery and splendor of ancient Rome. However, the site has special geological conditions and a buried state. Traditional tourism and research ways have great limitations in showing its rich historical and cultural meaning. To overcome these limitations, Pompeii uses artificial intelligence technologies to carry out digital reconstruction. Terrestrial laser scanning equipment such as FARO Focus S70 is used to collect building structures and fine details. Drone swarms carry out comprehensive aerial surveys. They combine with structure-from-motion photogrammetry to cover large areas quickly. They make orthophotos and dense point clouds to build 3D models [2]. These data are combined with VR/AR technologies to restore historical appearances. AI-driven data analysis also supports site conservation work. These technologies provide brand-new visiting ways for both visitors and researchers. The digital rebirth of Pompeii has achieved good results in technology application.

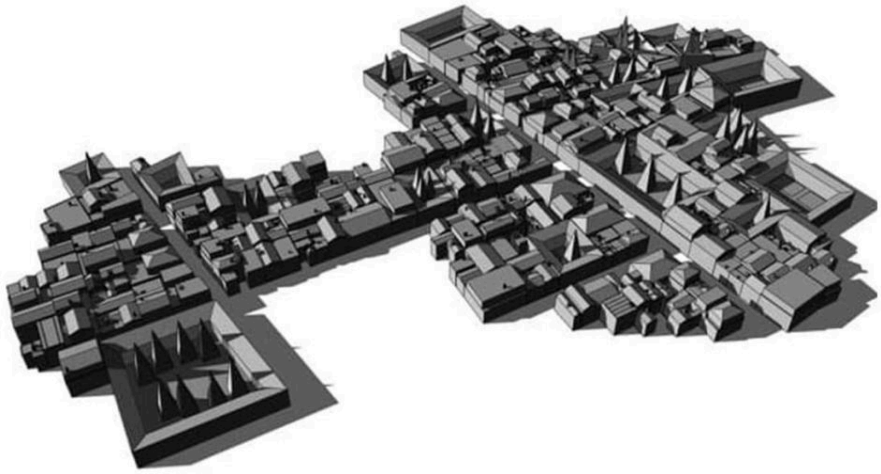

Figure 3. Schematic illustration of three-dimensional model construction for Pompeii

4.2. Exploration of existing challenges in the heritage of Pompeii

Cultural heritage is a special cultural phenomenon. It has deep connections with specific communities and regions. The presentation of Pompeii's cultural heritage mainly depends on building spaces and the intangible meanings related to historical events. But, today's visit ways have many problems in passing information. Studies tell us that old explanation ways only use one show mode and have clear limits. They cannot help people know the full value of old heritage in a complete way. They also cannot fit different needs of all kinds of visitors. This makes the visit experience not deep enough. It is hard for people to understand the history and culture of Pompeii fully [7]. Also, most interactions are passive. Visitors do not take part in these activities very much.

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This makes people less willing to explore on their own. It also weakens the emotional link between people and cultural heritage. For building visit scenes, today's ways cannot rebuild old history situations well. They cannot cross time and space to build emotional links between the past and the present. So, visitors cannot really feel the historical changes of Pompeii. They cannot feel its long-lasting charm either. Besides, today's ways cannot make special experiences for different groups. These groups include researchers, common tourists and students. The content shown to everyone is almost the same. This stops people from knowing cultural heritage more deeply. It also limits the wide spread of Pompeii's old culture.

Pompeii preserves ancient Roman society in an all-round way. It has exceptional value. But current experience ways are limited by broken information and spatiotemporal discontinuity. So we need more comprehensive and inheritance-oriented research urgently. These research fields include tourism experience design, cultural heritage conservation and innovative museum exhibitions. This can help us fully realize the cultural heritage value of the site and support its sustainable development.

5. Intelligent digital development of Pompeii and the exploration of new directions

5.1. Directions for intelligent digital development

Driven by the progress of artificial intelligence, the intelligent digital development of Pompeii is moving forward along several new paths:

Multimodal interaction integration: Multiple interaction ways such as voice, image and gesture are combined with AI technologies. This can create more natural and smooth user experiences. Practical cases of multimodal interaction show that in Pompeii, the combination of voice, image and gesture recognition brings a dual-channel experience. This experience is "natural language dialogue plus gesture-controlled scenes". After wearing AR glasses, visitors can ask about the symbolic meaning of murals by voice. At the same time, they can use hand gestures to rotate and zoom virtual models in real time. This helps them explore cultural heritage in a more immersive and personalized way [8].

Deep learning–driven optimization of personalized experiences: With the support of deep learning algorithms, the system can mine user interaction data in real time. These data include clicks, stay time and Q&A records in Pompeii's digital twin environment. The system keeps improving recommendation weights continuously. Take the House of the Vettii as an example. It is one of the best-preserved residential buildings in Pompeii. If a user zooms in mural details many times during a VR tour and asks about "architectural structure", the algorithm will push two special explanation contents to the next node automatically. These contents are "analysis of mural pigment composition" and "the evolution of Roman load-bearing walls". If the user is a family with children, the system will switch to interesting content instead. This content includes "stories of ancient Roman kitchens and interactive puzzles". This achieves accurate matching of "one site, two tailored experiences". As the interaction between users and the system increases, the system can capture user needs more accurately. It can provide experiences that fit personal interests better. This improves visitors' satisfaction and cultural identity with Pompeii.

Cultural heritage big data analysis and knowledge graph construction: First, we need to digitize all data related to Pompeii in a comprehensive way. These data include high-precision 3D scans of building parts such as forums and villas. They also include high-resolution images and material data of relics such as murals and ceramics. In addition, they include unstructured text materials such as historical documents and archaeological reports. On this basis, computer vision and natural language

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processing are used together. They carry out 3D scans and feature extraction of broken objects such as murals, mosaics and amphorae. They also automatically build semantic links of "fragment → original location → production technique → time period". This tech gives good study tools to people who research Pompeii. For example, scholars can look for spread ways of certain building styles in the city with graph reasoning. They can also study different points of home relics in different social groups. Best of all, people can turn these uses into digital fun experiences for common visitors directly. When people go to the site, they can use phones to scan old building parts or relic signs. They can get easy smart explanations from the knowledge graph. For example, if they scan the remains of a bread oven, they can know its use clearly. They can also see pictures of old bread found at the site. They can get small study cards about old Roman food share systems. They can even watch a short video that shows the working scene again. This way to show knowledge connects old stories and has many parts. It makes visit experiences more fun and richer. It helps Pompeii's history and culture get shared and kept well. It finishes the change from information to knowledge, and then to good stories.

AI helps protect and fix cultural heritage: AI gives new and good ways to protect and fix Pompeii. It makes all steps from watching big parts to fixing small parts righter and smarter. In conservation monitoring, image analysis based on deep learning can process high-resolution aerial images, multispectral scans of building facades and high-definition digital images of murals quickly. These images are collected continuously. In damage detection, computer vision methods based on deep learning can process a large number of multi-source image data from the site. Pompeii's murals have common problems such as salt efflorescence, cracking and biological erosion. Researchers use convolutional neural networks to segment and classify high-resolution digital images automatically. They conduct quantitative assessment of damage types, spatial distribution and severity. The accuracy and efficiency of these methods are much higher than traditional manual visual inspections. They provide strong data support for making different preventive conservation strategies [9]. In virtual restoration, we can use conditional generative adversarial networks. These networks can learn style features from well-preserved surrounding mosaic fragments. They can make multiple virtual restoration plans. These plans fit ancient Roman art features in pattern, color and composition logic. These results not only provide important decision support for physical restoration, but also inspire scholars to discuss the ethics and credibility of digital restoration [10]. On-site visitors or online museum users can use augmented reality devices. They can watch the dynamic process of damaged murals or building parts being "restored" in virtual space. They can also interactively learn the theoretical reasons and visual differences of different restoration hypotheses. This deep interaction gives new artistic life to Pompeii's broken remains. It also shows the scientific decision-making process and ethical thinking of heritage protection vividly. In this way, artificial intelligence is not just a technical tool. It becomes a key bridge linking Pompeii's fragile material remains, the professional knowledge of conservation experts and the global public. It guides cultural heritage protection to a more sustainable, open and socially participatory future.

5.2. Specific scenario design

5.2.1. Targeted, categorized intelligent guided tour system

We put forward a targeted and classified intelligent guided tour system for Pompeii. This system is built on the identification of user goals and preference profiles. It overcomes the technical limitations of traditional standard tours with single content output. It can realize dynamic and accurate content delivery and hierarchical adaptation. For professional groups such as researchers

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and scholars, the system is deeply integrated with the latest Pompeii archaeological databases. This new design focuses on key topics of ancient Roman Pompeii. It talks about city planning and building structure shaped by volcanic geology. It provides professional reports about architecture. It also puts first-hand history materials together. These materials include Pliny's letters and modern archaeological findings. People can search and export professional data sets in interactive ways. This supports high-level research work well. For common visitors, people use generative AI to change history materials. These materials are about daily life and old customs. They become scene audio stories and moving history animations. These contents cover market trades, bathhouse activities and gladiator training. This brings real immersive experiences to every visitor. This design has three new good points. First, it uses a two-way user positioning model. This model uses study goals and personal preference tags together. It is better than old single-tag ways. It can match right guide content for visitors in real time. Second, the professional tour part links with the newest Pompeii archaeological databases. This makes sure guide content follows latest study results. It fixes old guide problems like shallow depth and poor timeliness. Third, generative AI shows history materials in clear pictures. It also combines them with real site scenes. It breaks the limit of static talks in traditional visitor guidance.

5.2.2. Online intelligent digital twin and offline cultural and creative integration

We make a new system for Pompeii. It connects online smart digital twin with offline cultural and creative products. This system mixes digital world and real world in a deep way. It is not like traditional static digital twin shows. It is also not like old cultural products. Those products have no link with digital heritage. This way ties online interactive experiences and offline real products closely. Online, LiDAR works with AI semantic segmentation. It builds a smart digital twin of Pompeii. The precision of this twin is at millimeter level. Global users can roam Pompeii remotely. They can look at the site from many different views. The model can also rebuild historical scenes before the volcano erupted. Users can explore building remains by interactive ways. They can check mural details carefully too. This makes online immersive experiences much stronger. Offline, we use digital assets to make cultural and creative products. These assets come from the digital twin. They are correct in archaeology and follow standard rules. They include monument shapes, relic patterns and building textures. We use 3D printing technologies to make these products. The products have small Pompeii city models, cultural toys and art derivatives. All offline products can find their digital sources easily. This design has three key new points. First, it breaks the static show limits of traditional digital twins. AI helps make dynamic interaction and virtual rebuild of old scenes. This improves the experience value of digital heritage. Second, it builds a digital source trace system for offline cultural products. It makes sure all products are archaeologically correct. It solves long-term problems. The problems are same-style products and no link with real heritage. Third, it creates a closed-loop model. The model is "online remote interactive experience – offline physical cultural product making". This helps Pompeii spread all over the world. It also develops its economic value. It fixes the old problem of separating heritage protection and economic development.

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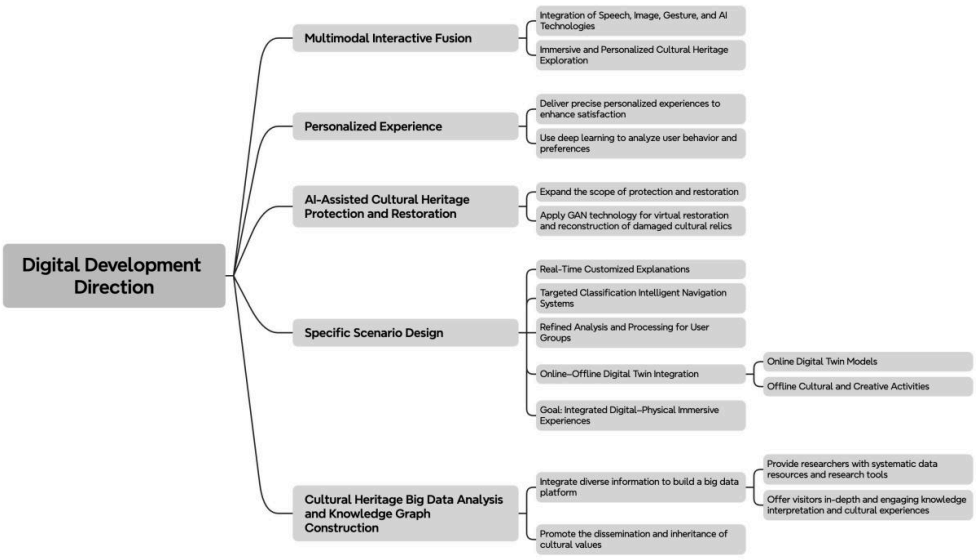

Figure 4. Directions for the intelligent digital development of Pompeii

6. Conclusion

This study builds a collaborative framework that integrates "heritage, technology and users". Its two core goals are heritage conservation and the improvement of user experience. Driven by artificial intelligence technologies, this framework realizes the practical application of scenario-based experiences in Pompeii. It builds a deep link between history and the present. It also clearly defines the boundaries and guiding principles for technological empowerment of cultural heritage. Although future development will still face practical constraints, such as high technological costs, problems of data integrity and worries about privacy and security, the integration of multimodal interaction and the expansion to more application scenarios are still the main directions. These directions will keep promoting the development of intelligent cultural heritage experiences.

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