An Interactive Cultural Experience Combining Ancient Roman Mosaic and AI-Generation

Abstract

With the artificial intelligence permeating into our daily art and design field, Generation intelligence is becoming a key motion that can remodel our culture. This research will discuss about GenAI can surpass the tool properties, to be the co-creator who can do storytelling and improve interaction design. From now on, it led the public culture service to make an innovative breakthrough.

Select the museums of Rome, which are a UNESCO World Heritage Site, as the research point. It shows that most historical architecture museums are limited by their space structure and Legislation on Cultural Heritage Protection. Because of that, it is divorced from the storytelling and high-tech interaction experience that youth need.

This research used a mixed methodology, combining questionnaire surveys, field investigations, typological analysis, and experimental verification. An analysis was conducted on the data of 22 museums, and a six-dimensional evaluation framework was established. Through research, it was found that mosaic art, as a medium, has the greatest potential for cultural presentation. Comparative experiments were carried out using ComfyUI (generation AI) and TouchDesigner (real-time system) to test and evaluate the differences between virtual reality and interaction experience.

The conclusion of the research announces the advantages of GenAI in digital cultural exhibitions: it can, in virtue of the higher precision and creativity, enhance content regeneration and visual expression capabilities. This study presents content generation and technical verification, providing new design ideas and technical frameworks for the digital transformation of cultural heritage and the organization of inclusive exhibitions.

KEYWORDS | ARTIFICIAL INTELLEGENCE, MUSEUM, INTERACTION DESIGN

1. Background

With the artificial intelligence expansively expanding in the field of art and design, generation AI has no longer ceased to be merely an assistant tool, but has gradually into a crucial driving force for the transformation of cultural dissemination methods, the shift of artistic creation paradigms, and the innovation of public experiences. It finally turns the generation process of cultural storytelling from human construction to human-computer co-creation. It is different from the material invocation and parametric modeling, which traditional digital design relies on.

Generation AI with the help of images, text, and semantic information, automatically generates original and contextually relevant new content. This feature demonstrates unprecedented potential in various fields such as digital representation of cultural heritage, promotion of art education, visualization of scientific knowledge, and immersive exhibition experiences. The AI generation process is not typical “copy” or “imitate”, but rather reinterprets the visual features and semantic relationships to construct a data-driven cultural re-creation model.

In museum or interaction exhibitions, such as the digital coding tool like TouchDesigner, it was still the core support of technology. This type of system of node logic could make the real-time rendering, dynamic data processing, audio-video synchronization, and interactive feedback widely applied in visual installations, immersive theaters, and multimedia displays in public spaces. TouchDesign is good at constructing the response experience; its advantage is able to base the audience's real-time action input to generate visual changes, to make the "humen-space-media" cooperation at the same time. But Generation AI shows another technological paradigm: it focuses on the context layer to output automatically, and is able to generate images, textures, and stories. This is the outcome from zero to one. So it shows clearly that TouchDesigner, by using special effects superimposition and spatial mapping, provides the sensory immersion experience of the audience. In essence, the two elements construct a relationship of "generation" and "reproduction", respectively corresponding to the two poles of "creative originality" and "dynamic experience" in cultural experiences.

Relying on these logical comparisons of technology, this research made the ancient Roman mosaic art the core relevant media. Mosaic art depends on its special geometric shape, color gradation, and symbolic image, and has a very high standing in art history because it is a symbol of visual culture. It also provides an ideal data semantic pattern for AI image generation. Research based on Roman mosaic images as the database support, and put the digital rebuild and generation experiment into effect. The experiment provides two parallel creative paths for GenAI and TouchDesigner: the front relies on the AI modeling to learn and infer new visual content, and the other relies on visual coding to make the dynamic interaction and display in the space.

A comparative analysis will be conducted on the visual presentation, semantic consistency, and audience engagement of the results generated by the two systems. In the end, the research tries to explore: if AI can break through from the property of a simple technological tool, to show in the future exhibitions as cooperation with humans.

1.1 Literature Review

The generation of artificial intelligence is swiftly becoming the core driving force for promoting innovation in public service design and upgrading social experiences. It not only changes the process of creative production but also redefines the barrier of human-machine collaboration. The application of GenAI has expanded from simple content generation to various fields such as visual design, semantic interaction, space planning, education dissemination, and public participation mechanism design. It has provided new solutions to complex social and cultural issues, making design no longer an exclusive skill of professionals but a creative initiative that can be participated in by the general public.

During the design practice, the application boundaries and depth of GenAI have continuously extended. As the image generation tools like Stable Diffusion, Midjourney and DALLE3, and so on. It could make the oral description transform into a visual design draft and service blueprint in a community interview, field research, or public studio. From this, it made the different participants, even without a design background, can participate in the design process and show their thinking and preferences. (Guridi et al., 2025) this generation path has highly reduced the Collaboration threshold, which goes from "meaning to visual", and promotes the formation of a diversified pattern for collaborative creation scenarios. Right now, Generative Adversarial Networks (GANs) have been employed to automatically generate museum exhibition layout and space flow optimization plans (Tang et al.,2024). This approach significantly reduces the iteration time for architectural and exhibition design, allowing designers to focus more on conceptual innovation and cultural narrative.

Large language models (LLMs) with image generation capabilities also showed great potential in service system design. When combined with visual generation tools, they can achieve a coherent process of

“semantic understanding-image generation-design iteration”, enabling users to obtain immediate feedback and rapid prototype creation when collaborating on projects such as designing dormitories and community spaces. This significantly enhances users’ enthusiasm for participation and the speed of interaction (Liu et al., 2025). GenAI is not only a tool for improving efficiency; it is also a ”cognitive connector” in the design co-creation model, helping participants from different backgrounds reach a common understanding in the visual dimension.

Although generative AI has achieved significant breakthroughs in public service design and cultural innovation, its development still needs to address multiple challenges and ethical dilemmas. AI still has limitations when processing human emotions and semantic details. Although its algorithms have the ability to simulate styles or emotions, in fact, they are difficult to truly grasp the subtle distinctions of emotions in cultural contexts and the complex situations of ethical reasoning. (Zhong, 2024,) In the specific scenarios of participatory design, researchers noticed that "incomplete AI outputs" are more valuable compared to highly accurate results, because they can trigger more critical thinking and multi-directional communication, enhancing the reflection and openness in human-machine co-creation.

Although the general public's attitude towards AI in the cultural field is beginning to shift towards a more positive direction (Guridi et al., 2023), many current AI application projects still lack a systematic ethical design framework. The pace of technological innovation often overshadows the construction of cultural depth (Vian et al., 2024), resulting in the design outcomes being highly praised in terms of form, but lacking depth in the social value category. Establishing a trust mechanism and transparent algorithm governance structure is the key to enabling AI to gain a legitimate position in social and cultural scenarios. Designers and researchers should assume the dual roles of ethical and technical mediators to ensure that the deployment of AI is adapted to the cultural context and social responsibilities; they are not just users, but also the guiding and regulating agents of the "socialization" of AI systems.

More and more scholars believe that AI should be regarded as a creative collaboration partner under artificial supervision, rather than just a simple production tool (Hirvonen & Breen, 2020). In this framework context, humans are no longer the ones controlling AI, but the meaning builders in the collaborative system. Through continuous communication with AI, they achieve a balance of cultural value and social innovation.

Generative AI has opened up unprecedented new paths for public spaces. It can organically integrate user diversity, spatial complexity, and technological intelligence, giving new innovative logics to urban cultural spaces, educational venues, community services, and other fields. This process must take localization strategies, long-term behavior verification, and interdisciplinary integrated design as prerequisites. Only when design, technology, and society collaborate mutually can generative AI truly become a sustainable force for achieving cultural inclusiveness and social co-creation.

1.2 Research Question & Aim

In the present era of parallel development of cultural heritage protection and digital innovation, the museums are facing a fundamental challenge. Such as how can we introduce emerging technologies like AI while respecting the reality of history and the entirety of physical objects, in order to improve public participation and the depth of cultural communication? Therefore, the core issue of this study can be summarized as:

How to make the GenAI combine into the exhibition design in the museum, to enhance the cultural inclusivity, improve the audience engagement, and make the content regeneration come true? Can GenAI be a passive digital tool to a co-creator that works with humans and makes efforts for public spatial experience? In other words, can AI be involved in the process of cultural narrative and emotional

expression, transcending its role as a tool and evolving into a “digital co-creator” with the ability to resonate culturally?

Aim to discuss the above question, this research made five research aims:

1. Analyze the interactive needs and behavioral patterns of museum visitors:
   Through questionnaire surveys, observations, and on-site interviews, this study investigates the psychological motivations and behavioral characteristics of museum visitors during their visits, with a particular focus on the application potential of two experience models: storytelling and gamification. The aim is to reveal the cultural participation paths and perception preferences of the audience, providing behavioral-based evidence for the subsequent design of AI interactive content.
2. Clarify the spatial and technical limitations of Roman museums:
   Most Roman museum buildings are based on historical heritage, and their spatial layout, lighting conditions, and building materials are subject to strict protection restrictions, making them difficult to modify. Therefore, this study will combine spatial mapping and technical feasibility analysis to define the areas suitable for digital display and the appropriate interactive forms, ensuring that the design scheme complies with protection regulations while being operable and innovative.
3. Construct and apply the "Six-Dimensional Exhibition Evaluation Framework":
   This study proposes a "Six-dimensional Evaluation Framework" based on academic literature and empirical research, including originality, functionality, influence, craftsmanship, display, and digitization. This framework is used to analyze the transformation potential of different exhibition types, thereby determining which exhibits are most suitable for digital reproduction or interactive reconstruction through AI technology. Through this model, this study discovered that Ancient Roman Mosaic has significant advantages in artistic value, educational potential, and cultural symbolism, making it an ideal subject for subsequent experiments.
4. Conduct a comparative experiment of generative artificial intelligence and real-time visualization systems:
   This study employed two representative technical approaches for conducting the experimental comparison. The first path is ComfyUI + LoRA (Low-Rank Adaptation): used for high-fidelity generation content reconstruction and semantic expansion; the second path is TouchDesigner: used for real-time visual response and interactive dynamic demonstrations. By analyzing the differences in visual fidelity, semantic coherence, and system performance between these two technologies, this research aims to reveal the new potential of artificial intelligence in art regeneration and cultural dissemination, and explore how different technical systems in museum environments can complement and collaborate with each other.
5. Propose and validate the "Cultural Service Design Framework":
   The ultimate goal is to establish a validated research framework (validated framework) that integrates user insights, spatial analysis, content generation, and technical validation into a systematic methodology, providing operational design references for future museums and public cultural spaces. This framework is not only applicable to the digital display of cultural heritage, but also provides a sustainable technological path and social model for inclusive service design.

Overall, the structure and goals of this research mutually reinforce each other, forming a four-layer progressive logic from "audience - space - content - technology". Through systematic experiments and design verification, this research not only addresses the application issues of generative artificial intelligence in cultural heritage scenarios, but also provides a methodological basis and practical paradigm for "AI-driven cultural innovation".

2. Research Methodology

This research adopts a mixed-method research design, effectively integrating quantitative surveys, qualitative observations, typological comparative analysis, and artificial intelligence experiments. It systematically explores the design strategies and technological transformation paths for inclusive and interactive exhibitions in the context of the Roman Museum.

By integrating multiple methods, this research not only focuses on audience behavior and their experience needs, but also pays attention to the coordination between technological applications and the spatial environment, in order to form a comprehensive research framework with scientific reliability. The entire research process is divided into four main stages: data collection, analysis and evaluation, experimental verification, and methodological integration. Each stage aims to ensure the rigor, reproducibility, and practicality of the research results, thereby providing systematic reference and inspiration for future public cultural space design.

2.1 Data Collection

In order to gain a deep understanding of the behavioral characteristics and experience demands of museum visitors, the researchers initially conducted a quantitative questionnaire survey to systematically collect information such as user preferences, exhibition motivations, and interaction expectations.

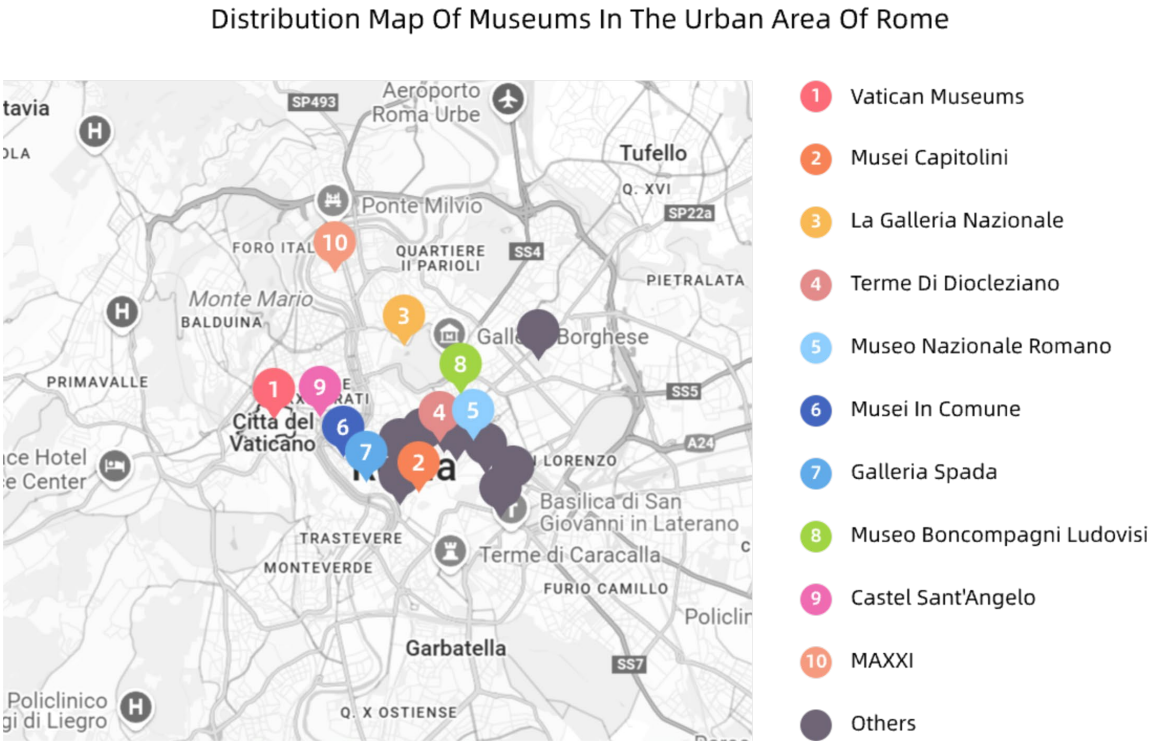

Figure 1. Distribution Map Of Museums In The Urban Area Of Rome.

The questionnaire results revealed that the main audience for museum visits consists of young adults, and the majority of them show a high preference for narrative story presentation or game-like interactive experiences. The main problems of traditional single display forms are attributed to "insufficient interactivity" and "monotonous content". Most respondents expect that technological interaction can enhance participation and also improve the understanding of cultural background and historical connotations. Based on these research findings, the researchers designed clear audience profiles, laying the foundation for the subsequent design direction in terms of behaviorology and psychology. These character models not only take into account age, educational background, and interest preferences but also

incorporate the spatial behavior patterns and information processing habits of visitors, providing quantitative and qualitative support for the experience design of interactive exhibitions.

After the questionnaire survey stage was completed, the researchers conducted further field investigations, covering 22 museums in Rome and its surrounding areas as well as in other countries. The field investigations mainly involved the collection and analysis of the following information:

Museum Interactive Equipment Survey Data Sheet

Nation	Name	Number Of Interactive Devices	Interactive Media	Content	Target Group	Language Support	Display Type
Italy Area							
Italy	Vatican Museums	NO					Traditional Static Display
Italy	Borghese Museum	NO					Traditional Static Display
Italy	Musei Capitolini	1	Projection	Cultural Relics History	Everybody	Italian	Some Dynamic Display
Italy	La Galleria Nazionale	2	Projection Display Screen	Short Film	Everybody	Italian	Some Dynamic Display
Italy	Terme Di Diocleziano	2	Projection Display Screen	Building Restoration Video	Everybody	Italian	Some Dynamic Display
Italy	Museo Nazionale Romano	NO					Traditional Static Display
Italy	Musei In Comune	2	Projection	Cultural Relics History	Everybody	No Words	Some Dynamic Display
Italy	MAXXI	22	Projection, VR Display Screen	Exhibition Video	Everybody	Italian, English	Diversified Display
Italy	Villa D'Este	1	Display Screen	Fashion Video	Everybody	No	Some Dynamic Display
Italy	Galleria Spada	NO					Traditional Static Display
Italy	Museo Boncompagni Ludovisi	NO					Traditional Static Display
Italy	Castel Sant'Angelo	NO					Traditional Static Display
Italy	Museo Pietro Canonica	NO					Traditional Static Display
Italy	Museo Civico Di Zoologia	17	Display Screen, AR, Projection	Animal Science	Children	Italian, English	Diversified Display
Italy	Museo Carlo Bilotti	4	Display Screen, Projection	Art Video	Everybody	No	Some Dynamic Display
Other Area							
France	Louvre Museum	NO					Traditional Static Display
France	Musée D'Orsay-Van Gogh	1	Display Screen	Historical Video	Everybody	No	Some Dynamic Display
France	Musée D'Orsay-L'Art Estdans La Rue	6	Projection, Touchscreen, Board For Blind	Printmaking Game, Historical Video	Everybody	France, English	Some Dynamic Display
France	Centre Pompidou-Picasso	1	Projection	Painting Process	Everybody	No	Some Dynamic Display
France	Palace Of Versailles	9	Projection, TV, Model	Historical Video, Building, Material	Everybody	No	Diversified Display
Netherlands	Rijksmuseum	NO					Traditional Static Display
Netherlands	Van Gogh Museum	2	Audio, Touch	Painting	Everybody	No	Some Dynamic Display

Figure 2. Museum interactive equipment survey data sheet. This sheet presents the status of interactive devices in 22 museums that were surveyed in the field.

These empirical records not only enrich our understanding of the typology of museum interactive installations, but also provide reliable support for the subsequent data analysis, technical comparison and design experiments. By meticulously documenting the quantity, spatial layout and user behaviors of various interactive installations, researchers are capable of further analyzing the interrelationships between technology and space, content and experience, thereby providing a data foundation for the application of generative AI and visualization systems in future museum exhibitions.

2.2 Data Analysis & Evaluation

During the data analysis stage, this study immediately conducted situational and spatial analysis from the very beginning, aiming to achieve a systematic understanding of the physical environment of the museum, its cultural background, and the constraints it imposes on the design of interactive exhibitions. The preliminary research found that the Roman museum was highly concentrated in the historical district, with most buildings being in the form of historical relics renovations. The layout of the space, the form of the structure, and the materials used were all strictly controlled by protective regulations. The cultural essence of such museums is "preserving history and protecting traditions", and their exhibition spaces bear the responsibility of carrying cultural memories. They also face constraints related to physical elements and policies. Given the limited space and the need to comply with cultural heritage protection requirements, large-scale immersive installations are often difficult to implement, which requires designers to explore interactive technical solutions that can balance innovation and protection.

In this context, this study learned that projection technology is the most appropriate interactive approach. This technology can achieve dynamic visual displays without interfering with the structure of historical buildings, and it can adapt to relatively small exhibition venues. Projection technology mainly uses video content for information display and interactive design, which can achieve content innovation while meeting the requirements of cultural heritage protection. Due to its low invasiveness, high adaptability, and strong content plasticity, this method appropriately alleviates the contradiction between innovative displays and architectural protection, providing a feasible approach for museum digital interaction.

The study combined literature review and field research data to conduct typological comparative analysis. The analysis results show that local museums play a core role in cultural dissemination and community education. Unlike large national museums that aim to attract tourists and increase their own popularity, local museums are generally located in traditional old buildings and use three-dimensional physical cultural relics to record the local residents and regional history. Their exhibition methods are more in line with community life. As scholars claim:

Local museums are generally located in buildings with historical value, using three-dimensional physical documents to display the cultural history of local residents. This model best reflects the core function of museums in serving local communities. Local museums can deeply and naturally present local environments and community characteristics, unlike large museums that mainly focus on attracting tourists and increasing the number of visitors. (Mohamed Gamal Rashed, 2024)

This study further focused on the analysis of the transformation path of local cultural institutions to explore interactive design strategies under the constraints of limited space, historical protection, and community participation.

In terms of the exhibition, this research was conducted based on the results of the questionnaire survey and academic literature, and a six-dimensional evaluation framework was constructed to measure the interactive presentation potential of different exhibits. This framework consists of six dimensions: originality, through which a systematic analysis of the exhibits was carried out. “Mosaic art” performed well in terms of artistic value, participation potential, and cultural representativeness, demonstrating significant advantages in interactive display.

Six-Dimensional Analysis Table Of Art Types

	Art Forms	A Originality	B Functionality	C Influence	D Craftsmanship	E Display	F Digitization	Total Score
Sculpture	Relief	4	5	4	3	3	3	22
	Bust	5	5	4	4	3	2	23
	Round Sculpture	3	4	4	4	4	2	21
	Religious Status	3	3	3	3	3	2	17
Painting	Mural	3	2	3	2	3	4	17
	Oil Painting	4	4	5	4	3	3	23
	Icon Painting	2	3	3	1	3	3	15
	Illustration	2	3	5	4	2	2	18
Decorative Art	Mosaic	4	3	4	4	4	4	24
	Painted Pottery	3	2	3	2	3	4	17
Architecture	Dome	4	5	5	3	3	2	22
	Capital And Base	3	3	5	3	4	2	20
	Lintels And Niches	3	3	3	4	2	2	17

Figure 3. Six-Dimensional Analysis Table of Art Types. This table presents the results of 13 types of artworks in the six-dimensional assessment for comparison purposes.

2.3 Experimentation & Validation

After clearly defining the research topic, the study enters the experimental research stage (Experimental Study), to verify the application potential of artificial intelligence in artistic reproduction and cultural visualization.

Firstly, the LoRA (Low-Rank Adaptation) technology is adopted to train the generation model, and a complete workflow is built on the ComfyUI platform to achieve the generation process from input images to output mosaic-style images. Through multiple parameter experiments to compare the output results, the optimal parameter scheme is selected, and tests are conducted using images of models of different skin colors and genders. The results show that the model can well capture the features of the original image and restore the mosaic style, but it still has limitations in male recognition and style stability.

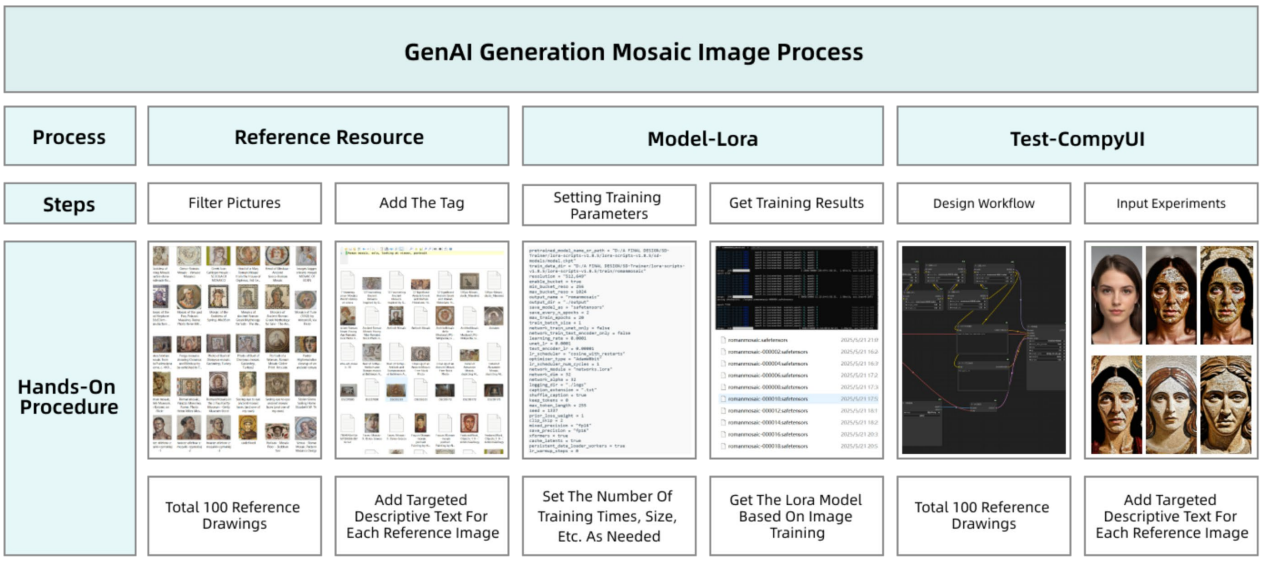

Figure 4. GenAI Generation Mosaic Image Process. This table presents from select pictures to test the final model.

Subsequently, the study develops a real-time mosaic visual system using the TouchDesigner platform to achieve real-time response and interactive display. In the future, through A/B testing (A/B Test), the visual stability and user experience differences between generated AI images and the real-time interactive version will be compared to provide empirical evidence for the combination of cultural content and generation technology.

Figure 5. The changes that occur in the image under different variables, as well as the best results of each parameter.

2.4 Integration & Scientific Validity

To ensure the reliability and logical consistency of the research results, this study employed the triangulation approach at all stages. Triangulation is a widely used method in social sciences and design research, which involves collecting data from multiple independent aspects and conducting cross-verifications to enhance the reliability and explanatory power of the research conclusions. In this study, the researchers conducted a comprehensive analysis of multi-source data, including questionnaire surveys, field observations, and generative AI experiments, to ensure the independence and reliability of each analysis result, and to make the different methods and data sources logically consistent. By adopting this

approach, the study can prevent biases caused by a single data source and enhance the scientificity and generalizability of the overall conclusion.

During the data analysis period, this study achieved a balance between quantitative statistics and qualitative insights. Quantitative statistics precisely measured user behavior patterns, preference distributions, and participation trends, while qualitative analysis thoroughly explored the subjective feelings of the audience in interactive experiences, spatial perception, and cultural understanding. By combining user data with spatial environment analysis, technical experiment results, the study not only explored the regular trends of audience experiences, but also provided scientific basis for exhibition design decisions. It analyzed the duration of audience stays, participation in activities, and completion of tasks in different interactive devices, and combined with the technical effectiveness of the mosaic digitalization experiment, the study could infer which interaction forms have the greatest effect on enhancing cultural understanding and participation.

This study utilized the triple verification of user preferences, site conditions, and cultural context to affirm the rationality of mosaic art as the core experimental theme. This method embodies the "data-driven + context-oriented" design research logic, that is, the research does not rely solely on objective data, but also fully considers the constraints and effects of space, culture, and historical background on interactive design. Through triple verification, the study ensures the multiple validity of design choices in theory, practical operation, and cultural significance, laying a solid foundation for subsequent experiments and applications.

The multi-level and progressive research method used in this study established a complete logical framework from user needs to spatial analysis, from content presentation to technical application. This approach not only revealed the challenges of museum interactive design in practical practice, such as space limitations, conflicts between historical building protection and technology adaptation, but also explored the regeneration methods of traditional art in a digital and inclusive environment through generative AI experiments. This methodological approach provides a new research model for the transformation of service design in public cultural spaces, not only emphasizing the integration of design and technology, but also demonstrating the collaborative effects of user participation, cultural context, and technological innovation.

Through this comprehensive approach, the study provided an operational theoretical practice framework for the digital transformation of museums and other public cultural institutions, demonstrating how to enhance public participation and cultural experience while maintaining historical cultural values through emerging technologies such as generative AI. This laid the methodological foundation for the next generation of AI-led cultural experience design.

3. Research Conclusion

This study comprehensively employed questionnaire surveys, on-site investigations, typological analysis, and generative artificial intelligence experiments to systematically investigate the digital transition and inclusive innovation of traditional cultural spaces within the context of the Roman Museum. The aim of this study is to explore how to enhance public participation and cultural experience levels by relying on digital technology and interactive design while respecting historical heritage. This study provides scientific basis and practical references for the future development of museums and public cultural spaces.

The findings show that younger audiences are increasingly favoring exhibition formats centered on story-telling and interactive experiences. These audiences not only expect to acquire knowledge through exhibitions but also hope to achieve a deeper cultural understanding and emotional resonance through interactive participation. Traditional exhibition methods, due to insufficient interactivity and monotonous content, are difficult to meet this demand, resulting in a significant reduction in audience experience and

participation. This phenomenon is particularly evident in several museums in the Roman historical district. Some museums, affected by historical building protection regulations and limited space, are unable to introduce large-scale new media equipment or immersive experiences, restricting the scope of exhibition innovation.

Given this background, the study learned that projection technology is the best solution. Projection technology not only achieves visual innovation without damaging the structure of historical buildings but can also flexibly adapt to limited spaces and present diverse interactive effects through video content. Compared with other high-occupancy space new media styles, projection technology balances the dual needs of exhibition innovation and cultural heritage protection, providing a digital path with both innovation and operational feasibility for museums.

From the perspective of exhibits, the study further confirmed that mosaic art is the most promising interactive medium. Mosaic not only presents a strong visual impact but also offers strong participation. Moreover, it has a deep symbolic connection with Roman culture, making it an ideal carrier for digital re-creation and interactive display. The layered structure of mosaics can achieve multi-level information transmission: from color recognition and shape identification at the perception level, to narrative explanation at the middle level, and to spatial symbolic meaning at the top level, completing the re-contextualization of traditional art in the digital environment. This multi-level information structure not only prompts audience understanding of the form and content of the art work but also provides a large amount of creative space for designers in digital interaction and educational modules.

The experimental results show that generative artificial intelligence demonstrates outstanding advantages in digital cultural exhibitions. By generating new content based on image and semantic input, generative AI can enhance the regeneration ability and visual expression strength of exhibition content. In the process of reproducing and reinterpreting cultural artworks, it shows higher accuracy, precision, and creativity. Real-time rendering systems like TouchDesigner perform well in terms of interactivity and user participation. However, in terms of aesthetic harmony, semantic coherence, and autonomous cultural creation ability, generative AI demonstrates stronger potential.

This study has established a multi-level research framework that closely links user insights, space analysis, content evaluation, and technical verification. This framework not only reveals the actual problems faced by museum interactive design, such as space limitations, conflicts between historical protection requirements and technological adaptation, but also uses generative AI experiments to explore the regeneration path of traditional art in a digital and inclusive environment. This methodology provides an operational research model for the transformation of public cultural space service design, emphasizing the collaborative efficacy of user participation, cultural context, and technological innovation, and providing a theoretical and practical foundation for the inclusive design of museums and public cultural spaces in the digital transformation stage. The research conclusion further elaborates that generative AI is not merely a tool; it has gradually become a partner in cultural innovation. Its capabilities go beyond simple content generation and can conduct multi-dimensional communication with users and cultural content during the design process, promoting the digital transformation and social inclusiveness of public cultural spaces.

This provides a methodological foundation for the next generation of cultural experience design relying on AI and also brings new ideas to the academic and practical fields: how to fully utilize generative AI technology to enhance public participation and the depth of cultural experiences while preserving historical and cultural values.

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