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Article

Virtual Reality for the Visualised-Guided Tours of the Notre Dame Museum in Paris

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Abstract: This study aims to explore the application of virtual reality technology for visualization in museums, using Notre Dame de Paris, France, as an example. It is more rich in scenes, more interactive graphics, and other visualizations, which enables viewers to enjoy the reconstructed Notre Dame online with the best audio-visual effects. We used the Likert scale research method for a survey. The questionnaire was administered to 15 students and 15 experts for basic information collection and experience feedback. Using data statistics and qualitative analysis, the effectiveness of the guided tours was validated. The result showed that VR museum tours were supported with great potential. Its more interactive guided tour experience enhanced the audience's experience and improved their understanding and interest in history and culture. Virtual reality technology was successfully applied to guide NDDP by providing a richer and more interactive guided experience and promote the cultural heritage and development of the cathedral. The research result provides a reference and inspiration for the future development of guided tours of museums.

Keywords: Virtual Reality, Museums, Digitization, Notre Dame de Paris

1. Introduction

The exhibitions of museums demand the physical attendance of visitors. Visitors can use illustrations, audiovisuals, and collections to understand the exhibits (Yang, 2021). However, on-site visits have limitations that are not favorable to the dissemination of culture. Consequently, new technologies are used for the communication of the contents of museums. The virtual museum with VR (VR) is an example of the application of technology. In virtual museums, VR technology is used to reproduce museum exhibits and culture through video and graphics. VR technology can increase audience as it overcomes time and space limitations and allows for enjoying the exhibits remotely and learning museum contents. Thus, VR technology helps disseminate culture (Shi, 2013) and cultural heritage (Liu & Qiao, 2008). VR technology can enhance the museum experience for visitors, which enables them to appreciate and experience artworks, which is an innovation trend in museums around the world (Zhang, 2020).

2. Literature Review

VR technology is not popular enough to use for museums with problems. In the virtual museum of architecture in the ancient town of Sanhe (Yao, Chen & Chen, 2023), the digital conservation of ancient architectural sites (Liu, 2022), and the virtual museum of the Jing ethnic group in Guangxi (Bai, 2021), VR technology is used but is lacking interactive experience, textual and graphic analysis, and equipment support, which restrict the participation and understanding of the audience. In the virtual museum of the West Road Army, VR device terminals are used (Tian & Wang, 2022), and Yuanmingyuan Park provides panoramic viewing through mobile-based software. However, textual and verbal interaction is lacking, and there are insufficient five-sense interactions. The Digital Olympic Museum still suffers from challenges in interactivity, completeness, and innovation despite technical progress (Pan, Chen, Zhang, Liu & Wu, 2009). Virtual Aerospace Museum has better interactivity but still lacks aesthetics (Mu, Liu & Tan, 2018). The VR tour of Notre Dame De Paris (NDDP) limits the player to have fixed-point viewing and does not allow the player to move freely. X-Reality Museums are cumbersome to use complex tools that are not available to the general audience (Margetis, Apostolakis, Ntoa, Papagiannakis & Stephanidis, 2021). Chinese Museum's VR design lacks interactivity (Liu & Qiao,2008).

While there are technological advances in virtual museums, the lack of interactivity, integrity, and innovation still exists. The designs still have limitations and need to be improved. Therefore, we designed the virtual NDDP museum using VR to be smarter, more involved, and free from time and space constraints. The design enables the audience to appreciate freely from multiple angles

without the limitation of time and space. The VR NDDP is a unique way of showing the place before the fire. This provides a precious opportunity to appreciate the beauty of this NDDP. The virtual presentation also allows those who cannot visit there to see the undamaged NDDP as it shows the grandeur and beauty using VR. The VR museum with real-life scenarios has several benefits. Firstly, virtual museums present better artistic effects and expressiveness, which eliminate the influence of uncontrollable factors such as weather. Secondly, virtual museums offer personalized visualization that is carefully designed. Finally, virtual museums interact with audiences to provide unique experiences. The VR NDDP provides exceptional artistry that transforms the way visitors enjoy the museum. It offers a new opportunity to interact and realize incredible experiences.

3. Materials and Methods

We reviewed the previous literature to construct a research framework, as shown in Fig. 1. A questionnaire was also created based on the literature review. Through statistical analysis and expert interviews, indicators obtained from the questionnaire survey were screened and optimized to evaluate the VR museum. In creating the VR NDDP, we used 3D Studio Max and Maya for realistic 3D modeling and showing complex structures and subtleties. Lumion allows for high-quality rendering and switching between daytime and nighttime scenes and presents realistic scenes. 720yun is a VR panorama-viewing application that provides interactive displays for viewers to browse freely for enhanced interactive introduction and immersion. These tools were used for museum production and creating an engaging and academic virtual experience.

Data on the structure of NDDP were collected and processed using 3Dmax and Maya for modeling. Lumion was used for modeling the surrounding buildings and obtaining the panoramic view of NDDP. According to the needs of the museum guide, the interactive interface was designed to build the virtual scenes to increase the route scene guide interaction, history and architectural significance of the voice-overs, graphics and text introductions. User experience was emphasized to ensure that the guided tour using smooth graphics and excellent navigation performance. Testing and debugging were carried out, and user feedback was collected to optimize and improve the VR tour system, virtual NDDP. The system was created for an immersive and educational VR tour and it provides a new way to visit NDDP .

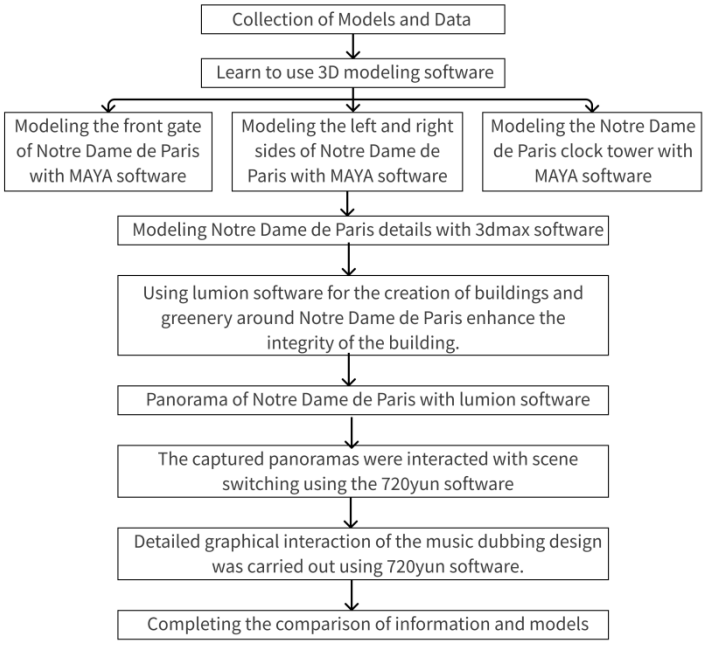


Fig. 1. Design of VR tour system of NDDP.

We designed virtual NDDP to present history and culture and provide an immersive experience. As shown in Table. 1, two weeks were spendt for planning and theme selection, three weeks for software training, and nine weeks for production and design. The questionnaire survey results revealed that the virtual NDDP was favored by students and experts for its interactive guided tour and increasing in understanding and interest in history and culture.

Table 1. Details of virtual NDDP.

Step	Detailed process of design and production	Design time
Plan learning tasks	Carrying out an in-depth and extensive VR project, which identifies the objectives of the project task and develops a learning plan accordingly.	1 week
Determine the design theme	(1) To define the objectives of the project including the scope, thematic core concepts and goals. (2) To research the background relevant to the theme containing works and design trends, conceptualise ideas and consider visual, audio, textual and interactive elements to ensure that the theme is interactive.	1 week
Designing a Software Learning Program	(1)To learn the basic operation of Maya, 3ds Max, Lumion and other software, and learn modelling skills. (2)To obtain skills in modelling, including basic models, complex characters, scenic design, UV mapping and texture addition.	3 weeks
Model design production	(1)To gather information such as photographs and drawings of NDDP. (2) Modelling includes basic structure, overall outline, material texture import, step-by-step addition of windows, arches and spires.	3 weeks
Model Refinement	(1) Optimisation of the details, including adjusting lighting, rendering parameters, and material textures that achieve the best possible visual results (2) Optimisation of the scenarios, including adjusting lighting, rendering parameters, materials and textures towards the best possible visual results	3 weeks
Interaction design	(1) To collect information on the history, architecture and artefacts of NDDP for determining the content of the display. (2) Interactive experienced design, including guided tours, trigger points, user-friendly interfaces, and integration of audio and graphic content.	3 weeks
Questionnaire	(1) Clarifying the objectives of the questionnaire including content of the VR museum, and the survey of satisfaction. (2) Choosing the methodology of the online questionnaire, including the questions, structure, testing and posting of the questionnaire.	2 weeks
Questionnaire analysis	(1) Comparing the responses of students and experts using statistically analyses that looked for differences and correlations in the data. (2) Writing a report of findings, including findings, issues and feedback.	1 week
Reflection and evaluation	To improve the content, user interface, and interactive experience of the virtual museum based on feedback from users.	2 weeks

4. Results and Discussion

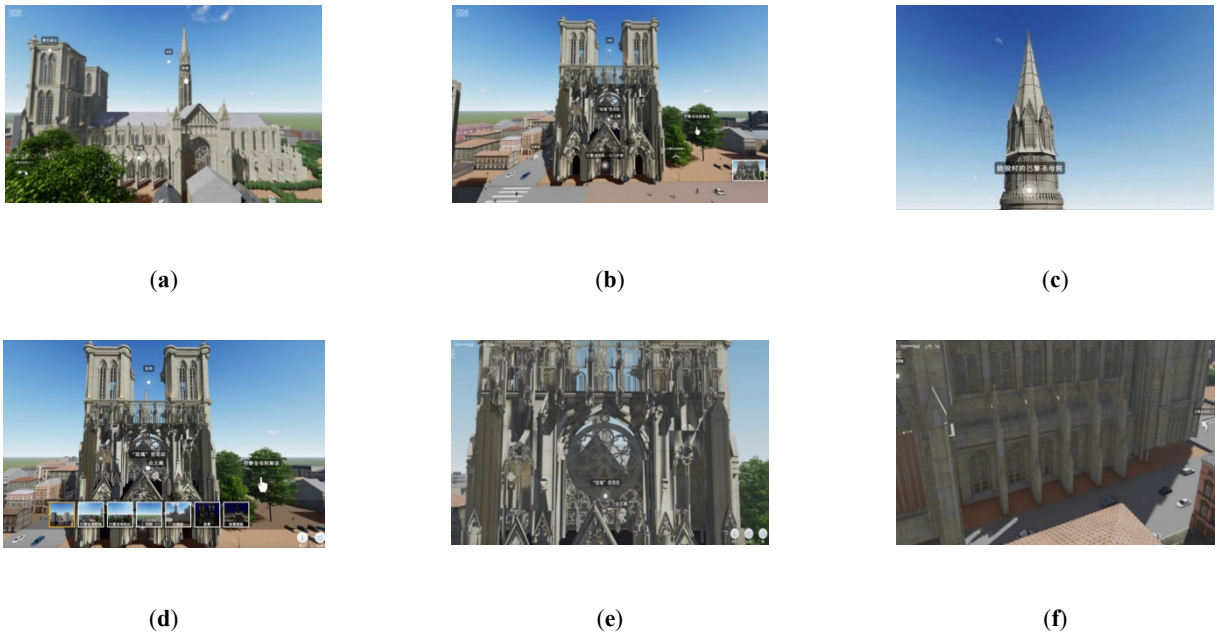
4.1. Design

The result of the design is shown in Fig. 2. Figure 2(a) shows the full view of the right side and contains design details such as the rose window, the fly-rail, and other design details. The viewer learns about the history of the fly-rail and the photographs of the fly-rail through the interaction points. Figure 2(b) shows the main gate made by the author, which is the iconic gate of NDDP, containing three peach-shaped doorways and the Gallery of Kings, the left door is called the "Gate of Purity", depicting the story of the Virgin Mary. The center door is called the "Gate of Justice", showing the resurrected Jesus presiding over the Last Judgement, and the right door is the "Gate of St. Anne", showing the consecration of the Virgin Mary. The Gallery of Kings is located on the upper part of the archway, displaying 28 kings, which allows the viewer to learn about their histories and their significance through the interactive points in a rich and graphic manner. Figure 2(c) shows the bell tower at the top of NDDP before it was burned down to give a better view of NDDP in its entirety. We set up an interactive point next to the bell tower to show graphically the reason and process of the fire.

We used 720yun with scene selection, graphics, voice-over, network connection sharing and other interactive settings, and the production results are shown in Fig. 2(d). A part of the VR NDDP is shown such as the main entrance, the left side, the backyard, the right side, and the top of the bell tower of NDDP and the side of NDDP in the night. By clicking on the options, scenes are changed to see the NDDP in different perspectives in the daytime and nighttime. Through precise digital reconstruction, the VR NDDP simulates the appearance and structure of NDDP, allowing visitors to roam freely in a virtual environment. All corners of the cathedral can be explored, including the main main entrance, the Rose Window, the bell tower and the backyard, etc. In the VR

environment, visitors hear audible explanations of detailed history and culture guides to understand the background of NDDP's construction, historical events, and cultural significance, etc., in background music. The VR NDDP interactively displays artifacts such as the Hall of Kings, the Rosary Window, and paintings (e.g., Figs. 2(e) and (f)). The rose window was shown on the click of the interactive text with pictures and texts from Baidu encyclopedia. Viewers can understand the historical significance of the rose window and the production process. Figure 2(f) shows the Fei Fu Bi created and the interactive texts to learn more about the historical significance of the Fei Fu Bi. Detailed information is displayed close.

Visitors can travel back in time and witness the historical moment when NDDP was burned by fire. This allows visitors to understand the building's rich history. Compared to the Three Rivers Ancient Town Architecture Virtual Museum (Yao, Chen & Chen, 2023), the digital ancient architectural sites (Liu,2022), the virtual museum of Guangxi Jing (Bai,2021), the VR NDDP shows enhanced interactivity so that the viewer can interact and fuse the real and the virtual world (Margetis, Apostolakis, Ntoa, Papagiannakis & Stephanidis, 2021). The VR NDDP provides an immersive experience for visitors to explore NDDP and learn about its history and cultural. The VR NDDP provides opportunities for learning and entertainment as well as for cultural and historical education. Its design provides an immersive, interactive, surreal display of artworks, compared to the West Road Army Virtual Museum (Tian & Wang, 2022), Mobile devices can be used for scanning, operating, experiencing and watching for more vivid and interesting experience of the art.



(**a**) (**b**) (**c**)

(**d**) (**e**) (**f**)

Fig. 2. VR NDDP Design Set (**a**) NDDP Right Side Face, (**b**) NDDP Main Gate, (**c**) NDDP Top Clock Tower, (**d**) NDDP Interactive Scene Selection, (**e**) NDDP Rosette Window, (**f**) NDDP Flying Rotary Wall.

4.2. Questionnaire Survey.

The questionnaire survey was conducted to evaluate the satisfaction of the VR NDDP for students and experts and its competencies and achievability. Panel discussions and expert interviews were accompanied by the survey. A five-point Likert scale was used for the survey. "1" represented "very unimportant" or "strongly disagree", "2" represented "unimportant" or "disagree", "3" represented "important" or "generally disagree", "4" represented "very important" or "Agree", and "5" represented "extremely important" or "Strongly Agree" according to questions. There were 16 questions in a single-choice format.

The results in Table 2 represent the significance of the test with $p < 0.05$. Usually, an absolute t-value greater than 2.0 is considered to be moderately significant, while an absolute t-value greater than 3.0 is considered to be highly significant. Items 1, 2, 5 and 11 showed ($t = -2.449$, $p < 0.005$), ($t = -4.516$, $p < 0.05$), ($t = -2.955$, $p < 0.05$), ($t = -3.850$, $p < 0.05$), and ($t = -3.055$, $p < 0.05$). TSSUch results showed significant differences between students and experts. Students' scores on items 2, 3, and 5 were lower than the experts' scores due to the different professional backgrounds and levels of study of the students.

Items 1, 2, and 3 were asked for the importance of the knowledge related to VR and the process and the scenario of the VR NDDP. The average score of the experts was higher than that of the student as the expert's level of knowledge was richer. Item 5

was asked to know the ability to understand the design process. The average score of the expert was significantly higher than that of the student. Item 11 was asked for the inclusion of the VR NDDP in digital media art. The score of the expert was also higher than that of the student. Such results implied that the experts had professional knowledge and rich experience in understanding the design and were familiar with VR technology. They had experience in the design of VR and the technical skills to create unique and high-quality experiences. They also had an understanding of the history and trends of digital media art and the application of VR technology. At the same time, they understood the potential and application of VR technology, and they are more familiar with VR authoring tools for optimizing the user experience. These made them more confident and interested in incorporating VR museums into digital media art than the students. The design of the VR NDDP involved the creation of digital media art and the use of VR technology. The mean scores of item 2 ($t = -4.516$, $p < 0.05$), item 3 ($t = -2.955$, $p < 0.05$), and item 5 ($t = -3.850$, $p < 0.05$) of the students were significantly lower than those of the experts. The students had a relatively low level of knowledge in general and lacked an understanding of VR technology. The scores of items 8 and 14 showed that the students recognized that the VR NDDP assisted their learning. Both groups were interested in learning about NDDP using VR technology. The mean scores for both groups were 4.67 and 4.87, showing a high level of satisfaction. The students were "very satisfied" and "satisfied" with the use of VR technology in museums. The alpha coefficient of the survey showed that the satisfaction degree of the experts and the students were 0.876 and 0.906.

Table 2. t-test result for experts and students in questionnaire survey.

No.	Items	Students (n = 15) α = 0.876		Experts (n = 15) α = 0.906		t-test	Significance (two-tailed)
		M	SD	M	SD		
1.	The importance of having knowledge about VR.（Peng, 2023)	4.40	0.828	4.80	0.414	-2.449	0.028
2.	Importance of having knowledge related to the process of doing VR museums.	4.07	0.704	4.93	0.258	-4.516	0.000
3.	Importance of having relevant knowledge of other scenarios to which VR museums are applied. (Guo,2008)	4.07	0.884	4.80	0.414	-2.955	0.010
4.	The purpose expressed by the author's VR museum is clear.	4.60	0.632	4.73	0.458	-0.619	0.546
5.	By viewing the VR NDDP designed by the author, you can understand the author's design process.	3.53	1.060	4.73	0.594	-3.850	0.002
6.	Being able to learn about actual museums from VR museums made by authors.	4.60	0.507	4.60	0.507	0.000	1.000
7.	Do you think the functional modules in the VR NDDP are presented clearly.	4.60	0.632	4.87	0.352	-1.740	0.104
8.	VR used in museums can help art students.	4.67	0.617	4.67	0.488	0.000	10.000
9.	VR Museums Can Help Teach Art Teachers. (Guo,2020)	4.40	0.737	4.60	0.632	-0.899	0.384
10.	Learning with VR is more interesting than traditional book learning.（Yun,2006)	4.67	0.617	4.87	0.352	-1.146	0.271
11.	More interest in adding VR museums to digital media art. (Shan,2017)	4.53	0.640	4.93	0.258	-3.055	0.009
12.	Author makes a VR museum that can help others design virtual museums.	4.27	0.961	4.60	0.507	-1.435	0.173
13.	A VR museum made by the author to help you in your academic life.	4.27	0.704	4.20	0.862	0.292	0.774
14.	VR museums can help art students in some way.	4.67	0.488	4.73	0.458	-0.564	0.582
15.	Your satisfaction with the VR NDDP.（Dai,2023)	4.47	0.743	4.67	0.617	-0.899	0.384
16.	VR museums have advantages over traditional museums. (Tang, 2023)	4.53	0.743	4.80	0.414	-1.468	0.164
	P < 0.05						

5. Conclusion

We examined the feasibility of the VR NDDP in teaching or hands-on excursions and its acceptance by students and experts. The results showed that the online VR tour had great potential and was supported by students and experts. The VR NDDP provided a vivid and interactive guided tour experience, attracting audiences who are interested in history and culture. The high alpha coefficients of the questionnaire results for the VR NDDP (0.876 and 0.906) indicated the reliability and internal consistency of the

survey. Feedback from visitors showed that live-action technology enhanced their experience and provided additional contextualized information and multimedia content for a richer experience. The VR NDDP promotes the development of cultural heritage and provides a reference for the future development of the museum industry, although further research and improvements are needed to meet the requirements of different visitors.

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