Recording, Preservation, and Exhibition of *Objects* and *Events*: An Approach to Digital Museums of Cultural Heritage

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Abstract:
The preservation and management of cultural heritage, while making it available for everyone to appreciate and passing it on to future generations is a formidable challenge. *Digital museums*, which use digital technologies to measure, record, preserve, and exhibit tangible and intangible cultural assets, have attracted increasing attention in the last two decades. By applying digital information technologies such as laser-scanning, computer graphics, geographic information systems, high-realistic sound filed recording, and virtual reality, digital museums enable the general public to appreciate the cultural heritage of both *objects* and *events* without the restraints of time and space. This paper briefly introduces the basic concepts, development status, technical requirements, and future prospects of digital museums. We also introduce our approach to the next-generation digital museum with two of our studies: the transparent visualization of laser-scanned 3D cultural heritages in Japan, and a virtual reproduction of the Yamahoko Parade of the Gion Festival.

Keywords: *digital museums, cultural heritage, transparent visualization*

1. Introduction

The process of properly managing and preserving tangible and intangible cultural heritage, and passing it on to future generations for its free appreciation is a far-reaching subject. The management, preservation, and display of the physical resources of cultural heritage are, of course, important, but as time goes by, public exhibitions may cause irreversible damage to the cultural objects themselves. Therefore, with the rapid development of digital information technology in recent years, the process of digitally archiving tangible and intangible cultural heritage and making it available to the general

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public through the Internet and other media has received more and more attention. Since the 1990s, Japan has carried out the construction of *digital archives* and promoted the digitization and display of cultural heritage. Cultural objects are no longer just stored in the warehouses of museums and archives, or in the showcases of exhibitions. Digitized cultural heritage is able to break through the limitations of time and space and reach a wider audience. Together with relevant documents, descriptive information, sound data, maps, pictures, videos, and other multimedia materials, both researchers and the general public can appreciate cultural resources from a new perspective and explore the relationship between them. In the twenty-first century, *digital humanities*, which uses electronic data and Internet technology for humanities research, has been widely spread around the world. Digital museums that combine digital archives with traditional museums using digital technology have become important (Hachimura, 2012: 1-343). The construction of digital museums depends not only on a substantial database but also on an environment that allows us to experience historical and cultural resources. For this reason, it is important to use visual information as the main factor, supplemented by the integration and presentation of auditory and tactile information. Multi-sensory interaction can provide users with a spectacular immersive feeling.

2. Technologies and Requirements of Digital Museums

Digital museums are one of the application fields of virtual reality (VR) technology. From small cultural relics suitable for indoor display to large cultural heritages such as buildings, digital museums can be used to present them in the virtual space. Its users can appreciate the exhibits in the virtual space anytime, anywhere through display terminals such as computers, tablets, head-mounted displays, immersive large screens, and naked-eye stereoscopic displays. In addition, through cooperation among multiple digital museums on the Internet, the construction of composite digital museums can be realized. As an extension of VR technology, the augmented reality (AR) technology has also been widely used in digital museums (Hirose, 2011: 492-497). For example, there is no need to place physical exhibits in museum booths in the real world, as users only need to wear special glasses to see the high-precision three-dimensional (3D) computer graphics (CG) of the exhibits. Moreover, for the ruined historical sites, the restored virtual 3D images can be integrated with the original sites for restoration and display. Even for murals that have faded, the vibrant original colors present during their completion can be projected on the surface using projection mapping technology.

In addition, compared with traditional museums, digital museums have incomparable advantages in the reproduction of intangible cultural heritage. The exhibits in traditional museums are mainly based on tangible cultural heritage such as the display of *objects*. The display of intangible cultural heritage is often limited to limited text, sound, and video materials. In addition to objects, digital museums also make possible the display of intangible cultural heritage such as dance performances, historical and traditional activities such as festivals: that is, *events* (Hachimura, 2016: 287-294). Representative works including the reproduction of the ancient ceremony of Namazu Pray (Papagiannakis, 2003: 235-240), the dynamic animation of audiences at the Roman Odeon (Ciechomski, 2005: 601-610), the simulated restoration of the people's daily lives in ancient Pompeii (Papagiannakis, 2007: 396-415), the performance simulation of Vaudeville (Saltz, 2003: 28-31), and the animated reproduction of Chinese life in the Song Dynasty in the painting Qingming Festival by the Riverside (Chen, 2010: 84-88), etc.

Digital museums have various technical requirements. First of all, the development of advanced basic technologies is necessary. The basic technology of media information, represented by the high-precision display technology of images, plays a pivotal role in the realization of digital museums. From HD to 4K, the resolution of displays has continued to increase. However, for the digital reproduction of fine textiles, only microscopy-level accuracy can reproduce its detailed features such as horizontal and vertical weaving. In addition to the high-quality reproduction of images, the process required to fully present the atmosphere of intangible cultural heritage such as historical events places higher demands on VR technology. To ensure that users can experience a stronger sense of immersion and presence, 3D display technology and high immersion audio technology are essential. This audio technology can adjust the corresponding sound or music output according to the user's position or posture in 3D space. In addition, the presentation of touch, smell, and taste also plays an important role in the existence of objects and the reality of events.

Second, the development of digital archives and related technologies is required. With the abovementioned ultra-high-definition imaging technology, it is necessary to produce display content that is most suitable for presentation. The raw data obtained using basic technology cannot always be presented in its original form but needs to be appropriately visualized. For example, point cloud data obtained from the 3D measurement of large-scale cultural heritage requires proper visualization or CG modeling to accurately display its colors and shapes. However, it is still a big challenge to record and reproduce intangible cultural heritage related to the performance of body movements such as dance, drama, and so on. If it is a simple body motion recording, it can be achieved by using existing motion capture technology. However, from the perspective of the protection of intangible cultural heritage, recording only the body movements of the performers is not equivalent to the recording of *events*. Its associated records of clothing, expressions, sights, as well as the stage, background, audience response, etc., are also crucial. Such complete recording, preservation, and reproduction of the entire cultural activity requires further development of related technologies. In addition, the development of network technology is also very important. From single digital museums to collaborations between multiple digital museums, this technology integrates digital archives provided by museums, art galleries, archives, universities, and other research institutions around the world to build an environment that can be uniformly retrieved and utilized. This is the latest trend in the development of digital museums. To achieve this goal, the improvement of accurate and high-speed multimedia information retrieval technology and the development of information integration technology for databases and archives scattered all over the world are imperative.

Finally, the development of supporting technologies for exhibition and viewing is essential. For the operation of digital museums, it is necessary to consider how to integrate and utilize the existing human resources of traditional museums. No matter how developed a digital museum is, it is still the curators who are responsible for planning and operating the exhibition content. Such business support is called exhibition support technology. On the other hand, providing a description of the exhibition content to the visitor or providing a tour route suggestion based on the interest of the visitor is called viewing support technology. Recording the visitors' route and other information and feeding it back to the exhibition planners can be of great help to the dynamic updating of the display content or the planning of new exhibitions in the future.

3. Our Works on Digital Museums

The authors and related teams of Ritsumeikan University, with the support of the Art Research Center of Ritsumeikan University, have committed to advancing the cooperation of arts and sciences, including the research and development of digital museums, for many years. Making full use of the geographical advantages of Ritsumeikan University, which is in the ancient capital Kyoto, we have constructed a comprehensive digital museum of the *objects*, *events*, and *people* of Kyoto's cultural heritage. These include the construction of the Virtual Kyoto geographic information system by Professor Keiji Yano's team (Yano, 2007: 1-161), the 3D measurement and visualization of cultural heritage by Professor Satoshi Tanaka's team (Tanaka, 2016: 73-80), the force and tactile reproduction of tangible cultural heritage by Professor Hiromi T. Tanaka's team (Wakita, 2014: 236-247), the high-fidelity recording and reproduction of the 3D sound field by Professor Takanobu Nishiura's team (Fukumori, 2012: 549-554), and the development of the virtual experience system of intangible cultural heritage by Professor Kozaburo Hachimura's team (Li, 2014: 248-255). In this paper, we introduce several representative works of the authors' teams.

(1) Transparent Visualization of Cultural Heritage

Computer simulation can often achieve special effects that cannot be achieved in the real world, and transparent visualization is one of them. Through transparent visualization of a cultural heritage, we can better observe and comprehend its complex internal 3D structures. The rapid development of 3D measurement technology in recent years has made it possible to accurately record and preserve cultural heritage. Laser scanning and photogrammetry scanning are two representative 3D measurement techniques. Both have developed rapidly in the past ten years, and their measurement accuracy has reached the millimeter level. In particular, the popularity of unmanned aerial vehicles in recent years has made it possible to measure large-scale monuments that are difficult for human beings to measure directly. Projects for permanently storing cultural properties such as historical buildings as digital data are being pursued in many countries around the world. In addition, with the help of computers, we do not have to worry about digital content being damaged due to browsing, which allows us to make better use of them. For example, if the interior of a world heritage site is reproduced with VR created based on digitally stored data, we can take a tour inside the site while staying at home in a virtual space. The data obtained from 3D measurement is a collection of a large number of points in 3D space, which is called a point cloud. The amount of data in a point cloud is often considerable. The data for measuring large-scale cultural heritage often reach tens of millions or even hundreds of millions of points. These point clouds are characterized not only by their huge amount of data but also by the complexity of their 3D structure. For example, today's 3D measurement technology measures the interior and exterior of a building separately and then combines the two to form a complete 3D point cloud. Such point cloud data not only records the appearance information of the building but also records details such as the internal structure and attached items of each room. When studying historical or architectural structures, or appreciating cultural heritage, transparent visualization can help us see the internal structure like computed tomography. In the realization of transparent visualization, different from the traditional depth sorting algorithm, we proposed Stochastic Point-Based Rendering (SPBR). This algorithm greatly saves the rendering time of large-scale point cloud data and solves the interface order problem that may be caused by depth sorting. We have recently conducted several case studies on high-precision transparent visualization of 3D cultural heritage based on measured data that are mentioned below.

1) Case Study 1: The Former Nakajima Residence

High-precision transparent visualization enables us to better grasp and understand the overall structure of 3D cultural heritage. For historical sites, because of the long history, the design or structural drawings are often not preserved to this day. Therefore, it takes a lot of manpower to make transparent 3D computer graphics that can reflect its internal structure. However, if 3D measurement data can be used to perform precise transparent visualization, the above problems can be solved easily. In addition, using the transparent visualization result as a reference, the design or structural drawings can be deduced and applied to 3D CAD software for structural analysis or 3D printers to make 3D models. We made laser scans of the former Nakajima Residence, which is a traditional-style Southeast Asian folk house with a half-hipped roof. This residential building was built in the nineteenth century and is preserved by the Ritto History Museum in Shiga Prefecture of Japan. We laser scanned the structures from six directions around the building as well as from inside each room. The acquired point cloud data has more than 2 million points after integration. Figure 1 shows the transparent visualization result of the laser-scanned point cloud using our method. The inner structures and details such as the partition of rooms and furniture locations can be clearly distinguished.

The transparent visualization method is expected to be utilized in immersive VR environments in the future. These visualization results not only allow us to understand the internal structure of the building, but also help us understand the characteristics of the building more easily through feature extraction and other methods. In this way, it provides architectural historians with more intuitive information about the characteristics of different buildings in various periods and regions.

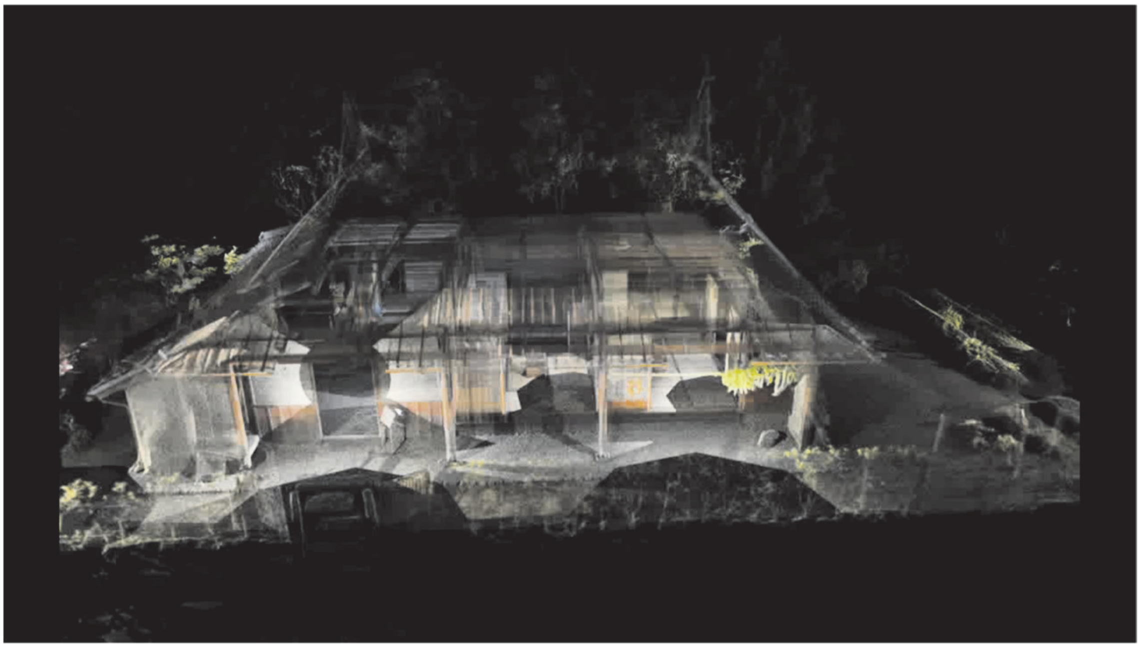

Figure 1. Transparent visualization of the former Nakajima Residence

2) Case Study 2: Yamahoko Floats in the Gion Festival

It is far from enough if the digital preservation of 3D cultural heritage is limited to shape, color, and other information about *objects*. The knowledge of how these cultural heritages were built, how they were used, and various other information such as the history, society, religion, etc. can only be truly inherited if they can also be preserved. This type of relevant information, which is not directly related to the record of physical existence, can be called *events*. In the preservation of cultural heritage, objects and events are equally important. As a related attempt, the authors focused on the Gion Festival in Kyoto and carried out research on its digital recording and virtual reproduction.

The Gion Festival is neither a mere sightseeing event nor a festival celebration organized by individual shrines. Instead, it is a large-scale traditional event that condenses the history and culture of the ancient city of Kyoto and has a history of thousands of years. The scale of the festival is rare, and it involves society, history, customs, religion, art, and other aspects. The most noticeable event in the Gion Festival is the Yamahoko Parade. Thirty-three floats of *yama* (mountain) and *hoko* (halberd), known as *moving museums*, decorated with various fine arts and crafts, parade the streets of Kyoto.

We carried out laser scanning of a boat-shaped float named Fune-hoko, and used its point cloud for reproduction and visualization. The transparent visualization result using our method is shown in Figure 2. In addition to the *objects* inside the float's internal structure, we also tried to reproduce the *events,* such as its assembly process. Yama and hoko are reassembled from parts during the Gion Festival each year and will be disassembled into parts and stored in the warehouse after the day of the parade. The work of assembling the hoko is called *hokotate* and takes 3 to 4 days. We carried out laser scanning of the float every morning during its hokotate. The acquired point cloud contains 170 million points. The process of hokotate is from the bottom to the top and from the inside to the outside. Therefore, if the measurement is carried out after hokotate is completed, the float's internal structure will be occluded by the external structure, and the laser beam will not be able to reach it. However, if the data are scanned separately in time sequence, and integrated using transparent visualization, we can better grasp and understand the process of hokotate. This process can be illustrated with snapshots or animations (Figure 3).

In addition to Fune-hoko, we have also carried out a visualization of Hachiman-yama. The visualization results of more than 25 million points of Hachiman-yama acquired by laser scanning are shown in Figure 4. Fune-hoko has a structure that is unique among all the yama and hoko floats, whereas Hachiman-yama has a typical yama structure. Therefore, Figure 4 is not only a visualization of Hachiman-yama, but also a visualization of the internal structure of all floats with standardized yama structures.

The meaning of visualization in this study includes not only realistic CG rendering of the floats, but also the presentation of additional information in visual form. For example, by feature extraction and edge highlighting of the 3D structure and the complex combinations of elements, we can provide more information, such as structural features, structural mechanics, and assembly process, than a traditional realistic CG representation.

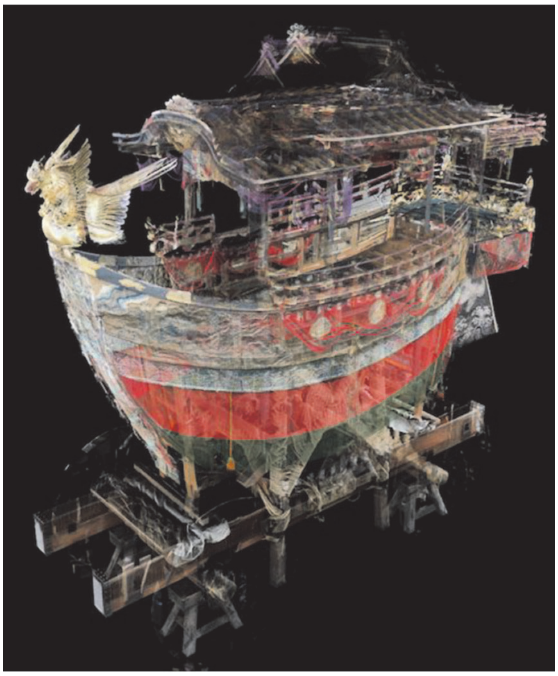

Figure 2. Transparent visualization of Fune-hoko

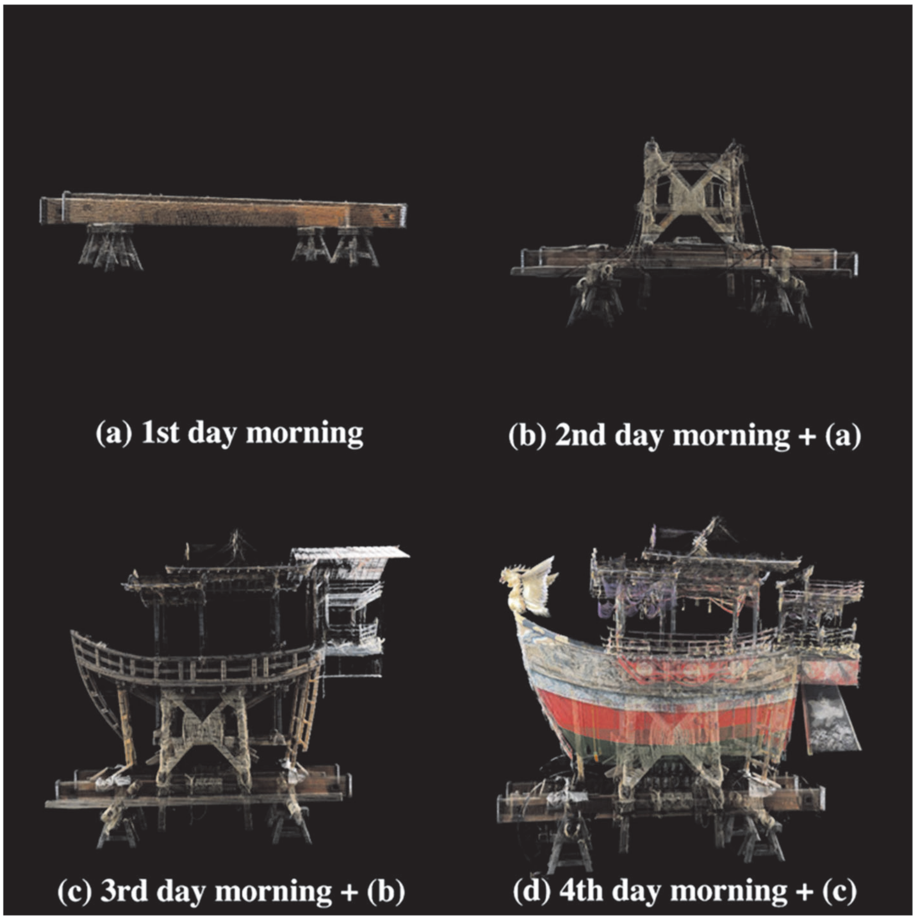

Figure 3. Visualization of Fune-hoko hokotate process

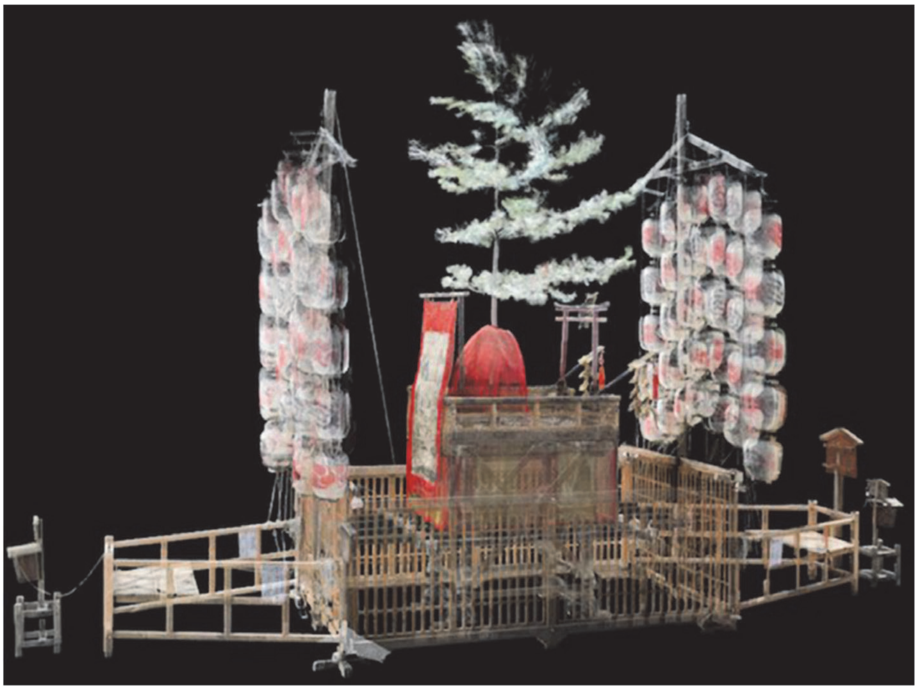

Figure 4. Transparent visualization of Hachiman-yama

3) Case Study 3: Caves of Zuiganji Temple

An important role of visualization is to reproduce things that cannot be observed in the real world by computer. In this work, we transparently visualized the caves of Zuiganji Temple in Matsushima-cho, Japan (Figure 5). The laser-scanned point cloud consists of 340 million points. We can clearly observe the distribution of the caves as well as the status inside the caves. With the development of surveying technology, the measurement of ancient underground relics has gradually become more accurate. Visualization of things that cannot be observed directly will play an increasingly important role in the future.

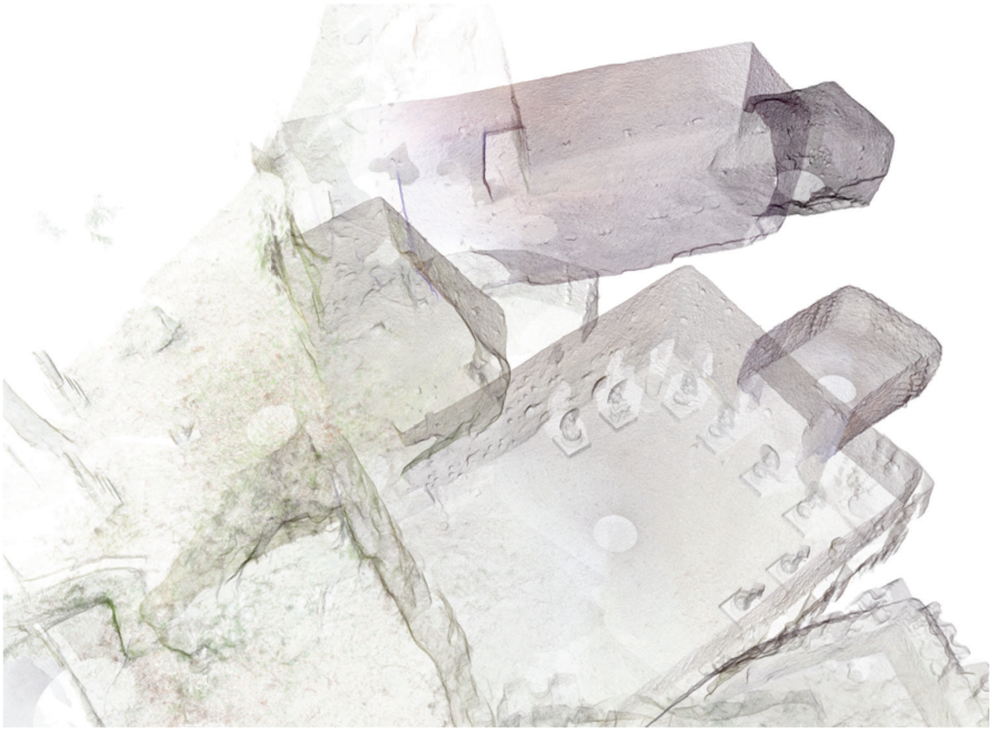

Figure 5. Transparent visualization of the caves of Zuiganji Temple

In the traditional 3D measurement of tangible cultural properties, the primary purpose was to measure the physical objects, make blueprints and structural drawings, and make 3D models. However, even if the latest measurement technology is used for a sufficient amount of time, measurement errors of several millimeters remain. At some local parts, the errors are even more significant. For this reason, manual adjustment of the data is essential to produce blueprints and structural drawings. However, with large-scale 3D measurement data, such manual work is practically difficult. Our research purpose was not to prepare a 3D model for museums in the real world. Instead, we aimed to realize a new exhibition form that uses information and communications technology (ICT), which cannot be represented by a 3D model. Transparent visualization is one of the good examples of this approach. Besides, various visualizations are possible, such as visualization of secular changes using time-series data, emphasis visualization of key parts, and high visibility visualization of the 3D structure by overlaying line drawings. In this way, the 3D model display and the ICT virtual display should complement each other and continue to develop.

(2) Virtual Yamahoko Parade of the Gion Festival

As another attempt to reproduce the *events*, we developed a virtual experience system of the

Yamahoko Parade of the Kyoto Gion Festival. We combined the CG models of the streets, Yamahoko floats, and characters, as well as the music played during the parade and used virtual reality technology to completely reproduce the atmosphere of the parade. Users can even have the experience of taking part in the parade on the deck of a float. To improve the immersive feeling of the users, in addition to the faithful presentation of visual and auditory information, it is also important to ensure the synchronization and real-time interaction of sensory information. For example, not only will the scene change as the user's point of view changes but also the volume and direction of the music, sounds, and noises during the parade will change according to the shift in the user's position and posture. In addition, for the reproduction of a large-scale intangible cultural heritage, the simulation of people and the crowd also plays a vital role in reproducing the overall atmosphere of the parade. Therefore, in the development of the virtual Yamahoko Parade system, we created not only the character models of the float crews but also the models and animations of roadside spectators and tourists.

Figure 6. Motion capture of (a) Hikikata, (b) Ondotori, (c) Kurumakata, and (d) Hayashikata

The Yamahoko Parade attracts more than 100,000 spectators on the day. It is still a challenging task to reproduce and interact with such a large-scale crowd in real-time. Therefore, we have currently made about 1,000 character models for crowd simulation. These character models cover a total of twenty-four different forms of men, women, and children. On this basis, we added clothing, body shape, and face changes to the models to increase the variety of characters. We also created different character actions such as standing, whispering, yelling, clapping, looking around, etc., and randomly assigned them to the character models. The float crews participating in the Yamahoko Parade have unique costumes and movements. Therefore, we specially made the CG models of four different crew characters of Fune-hoko float, namely Hayashikata, Kurumakata, Ondotori, and Hikikata. For the actual actions corresponding to each character, we collected them using motion capture technology (Figure 6).

Figure 7. Virtual Yamahoko parade experience system

Based on the Virtual Kyoto platform developed by Professor Yano, we imported six Yamahoko floats, including Fune-hoko float, into the virtual environment. We also used the high-fidelity music and ambient sounds recorded by Professor Nishiura to create a high-realistic sound field for the virtual parade. In the virtual environment, users can change the viewpoint in real-time through input devices such as a mouse, a gamepad, and gestures. The CG scene and 3D sound field experienced by users will also change in real-time with their interactions. During the actual parade, we installed acceleration sensors on Fune-hoko float, collected real vibration information, and used this to drive a vibration platform with six degrees of freedom. Users can experience the vibration and rolling of the float as if they are sitting on it and actually participating in the parade. Moreover, one of the biggest highlights of the parade, tsujimawashi which refers to the series of movements of turning a float at a crossroads cannot be directly reproduced using real acceleration data. Therefore, we used the rotation of the 3D scene and sound field and the tilt of the vibration platform to create a multi-sensory illusion, which gave the user a more realistic experience. The virtual Yamahoko Parade experience system is shown in Figure 7.

It is one of the missions of the digital museum to pass cultural heritages such as the Gion Festival, a festival that embodies the historical and cultural essence of not only Kyoto but Japan, to future generations. With the changes in lifestyles and information environments, information technology will play a bigger role in disseminating traditional culture. By representing such a large-scale festival in various forms, we can disseminate information about Japanese culture, customs, and religious ideas to the world. It is also possible to provide information from various perspectives such as the connection between Japan and overseas, which was not well known.

4. Conclusion

In this paper, we systematically introduced our approach to digital museums of tangible and intangible cultural heritage over the past ten years since the acceptance of the 21st Century COE Program. Case studies showed how the proposed technologies could be used in the recording, preservation, and exhibition of cultural objects and events. Recent research results and prospects were also discussed.

In the past decade, the technological development of 3D measurement has been significant, and the data obtained has been of extremely high definition. As a result, 3D measurement has come into full use in the field of cultural heritage preservation, which requires high accuracy. For humans to understand and utilize large-scale and complex 3D measurement point clouds, methods for presentation and visualization are essential. We are currently working on the development of noise-robust and precise visualization technology for large-scale point clouds. Figure 8 shows an example of the result of high-precision "fused" transparent visualization of two point clouds with different opacities using our latest noise-robust visualization method. Both outlier noise and random noise in

Figure 8. An example of transparent fused visualization of two different point clouds.

the laser-scanned point clouds are significantly reduced using the proposed visualization method. We want to further develop this technology and realize a new generation of VR with ultra-high quality and ultra-high definition that makes full use of the 3D measurement data of cultural properties.

One of the major roles of the modern museums is to connect the local cultures around the world. The case studies in this paper demonstrated how digital museum technology could better present the tangible and intangible regional culture of Kyoto to the world through information technology. What we hope for the digital museum is to fully utilize digital technologies as its infrastructure and connect digital archives from different communities.

In addition, digital museums are not only tools that utilize advanced information technology to preserve and display resources in traditional museums but also a new form of existence for the museums. Digital museums are expected to break through the barriers of traditional museums by not only providing digital archives but also functioning as research, educational, and community information institutes, which will potentially evoke a revolution of resource sharing. By connecting various forms of digital data, we can construct structured and meaningful contents, which can be retrieved and appreciated from digital museums all over the world without the geographical and social constraints.

In the future, with the continuous development of information technology, digital museums will receive more attention. Their ability to present *objects* and *events* can reproduce a variety of human activities in different regions and times, and vividly simulate a variety of natural phenomena as well as the activities of the earth and the universe. The application of visualization and VR technologies introduced in this paper is not limited to the cultural heritages in Kyoto, but also applicable to other cultural heritages in the world. For example, we are currently working on the 3D reconstruction and visualization of Borobudur Temple, the largest Buddhist temple in the world and a UNESCO World Heritage Site in Indonesia. We expect the digital contents created with our technologies will significantly contribute to the analysis of Borobudur Temple for researchers as well as providing regional culture promotion for the general public.

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