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REVOLUTIONIZING ART EXHIBITIONS: PHOTOGRAMMETRY'S ROLE IN VIRTUAL REALITY EXPERIENCES

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ABSTRACT

The COVID-19 pandemic significantly impacted many aspects of human life, including the way we work, travel, and even our art-viewing habits. In the past, art exhibitions were the primary channel through which art lovers could view, experience, and purchase artwork. However, the pandemic brought the art industry to a sudden halt as people are unable to visit physical exhibitions. Even after the pandemic has passed, what will happen if a similar outbreak occurs? Recent advances in photogrammetry, 3D scanning, and virtual reality technology enable the creation of an immersive and realistic digital environment. The integration of the two technologies could be a revolutionary approach to art presentation. In this mixed-method study, the researchers used a photogrammetry scanning technique to scan sculptures of His Majesty King Bhumibol Adulyadej and turn them into a virtual reality exhibition. We invited three experts in art, design, and technology to share their perspectives on the exhibition. We asked forty-five participants to evaluate the exhibition's ease of use, level of immersion, and satisfaction. The study reveals expert and participant feedback on a virtual reality exhibition. The visual art expert praised the virtual reality experience for offering new opportunities and remarkable immersion, though it lacked tactile elements compared to physical galleries. The design expert lauded the intuitive navigation and impressive spatial design, which enhanced immersion. The technology expert noted that while a photogrammetry-based virtual reality experience offers unprecedented immersion, the quality varies based on hardware and technical factors. Participants found the virtual reality exhibition largely positive, with 86.7% rating it as easy or very easy to use. More than 91% felt the exhibition was immersive, and 100% were satisfied, with 62.2% expressing extreme satisfaction. These results highlight the strong potential of virtual reality exhibitions.

Keywords: Virtual reality; art exhibition; photogrammetry; 3D scanning

1. INTRODUCTION

The transmission of the Coronavirus primarily occurs through close proximity between individuals, typically within a distance of one meter. People can become infected with the virus by inhaling or coming into direct contact with aerosols and droplets that contain the virus. These can enter the body through the nose, eyes, or mouth (World Health Organization, 2021). Prior to the emergence of the pandemic, art venues had the capacity to accommodate a substantial number of attendees concurrently. This is especially true for popular art museums where there might be too many visitors at a time. However, because of the pandemic, many art museums, galleries, and exhibitions were forced to shut down as a preventive measure against virus contraction in public. The advent of the virus impacted the museum and art galleries. According to the United Nations (2020), over 85,000 art institutions, or approximately 90% of the art viewing venues were shut down during the pandemic.

Nevertheless, in order to tackle this difficult situation in the field of art, a potentially effective solution for art exhibitions could reside in the application of virtual reality technology. Lever (2021) reported that virtual reality (VR) is experiencing growth despite the pandemic. According to Lever (2021) "VR Will Be a Part of the Post-Pandemic Built World," virtual reality has become a fundamental element of modern popular culture. The global pandemic has caused a rise in remote work, which has resulted in individuals having more independence in terms of their geographical location. This was confirmed by a comprehensive investigation into this technology and its developing uses (Ludlow, 2015). Virtual reality has the potential to bridge the existing divide by providing an alternative method of experiencing art.

The researchers have curated a compilation of nine bronze sculptures that portray the diverse regal duties executed by the deceased King Bhumibol Adulyadej throughout his tenure. The sculptures were the primary subject of investigation in this study. The researchers employed photogrammetry to accurately capture the physical bronze sculptures into their virtual models.

German architect Albrecht Meydenbauer initially coined the term "photogrammetry." Photogrammetry uses techniques from multiple fields, such as optics and projective geometry (Grimm, 2007). The process of creating digital models of a physical object comprises two steps: digital picture-taking and photogrammetric processing. The first step produces two-dimensional (2D) images as raw materials for the second step, which combines the 2D images to create three-dimensional (3D) models (Suziedelyte-Visockiene et al., 2015). The method is frequently used to restore cultural artifacts (Kyriakaki et al., 2014).

Despite its pros, the technology has not been widely adopted in the world of art viewings. Thus, the researchers used photogrammetry to create highly accurate digital replicas of bronze statues and placed them in a virtual gallery setting, simulating the replica of their physical counterparts.

2. RESEARCH OBJECTIVES

This research has two main objectives:

1. Study photogrammetry as a technique to digitally create statues of King Rama IX and a virtual twin art exhibition.

2. Assess the level of audience satisfaction with the virtual art exhibition created using the photogrammetry technique.

3. RESEARCH METHODOLOGY

The section describes the research methodology used to investigate the potential of photogrammetry to create virtual digital statues from real-world statues.

3.1 Research samples

The researcher used two sample groups for this study. The first was the experts in the related fields of study and the second was the audience of the virtual exhibition.

Experts: Three experts in the fields of art, design, and technology were selected for a formal interview session. Each expert provided invaluable insights and diverse perspectives from their fields of expertise.

Audience participants: Forty-five participants experienced the virtual exhibition. The criteria of this sample group were 1. Express interest in learning about King Bhumibol Adulyadej's royal duties and 2. Willing to try a new way to view art exhibitions.

3.2 Research tools

The study used the following tools to create a virtual reality exhibition and gather data.

The virtual reality exhibition: This research utilized a photogrammetry technique that generates an accurate three-dimensional representation of a physical object from multiple photographs (CINE Communities, n.d.). Despite the availability of numerous photogrammetry software programs, we selected Capturing Reality due to its widespread adoption, industry standard status, and robust 3D model generation algorithm. We used Maxon ZBrush to refine models from the photogrammetry stage, specifically for correcting imperfections that occurred during the photogrammetry scanning process. We used AutoDesk Maya as a UV editing tool. For texture editing, we utilized Adobe Photoshop. Finally, we utilized Unreal Engine 5.1 to create an immersive virtual experience for the virtual exhibition, due to its advanced rendering capabilities and real-time display. For the display output, we chose the Meta Rift-S virtual reality headset to ensure a high-quality, interactive VR experience for this research. This allowed the participants to fully experience the virtual exhibition and thus be able to evaluate its impact.

Expert interview: We held a formal interview session with three experts to gather their opinions and perspectives on the potential applications of photogrammetry. The selection criteria for the experts were based on their experience in visual arts, design, and technology, with a minimum of seven years of active practice. We set the inclusion criteria to ensure that each expert possessed a significant depth of knowledge, skills, and critical understanding within their respective fields. Additionally, their diverse backgrounds provided a balanced view, making the research well thought out.

Audience participant evaluation form: This form assessed the audience's feedback, collecting three aspects of the virtual reality art exhibition viewing experience: “Ease of viewing," “Level of viewing immersion," and “Level of satisfaction.”

3.3 Data collection

The two sample sets had the following data collection procedures.

Expert data collection: The researcher conducted a structured interview aiming to gain the experts' opinions and perspectives on the use of photogrammetry to create virtual reality exhibitions.

Audience participant data collection: After the exhibition, we asked participants to complete a questionnaire form to assess their experiences with the virtual reality art exhibition.

3.4 Data analysis

The expert interview sessions were analyzed to determine the most suitable photogrammetry technology for creating digital models from bronze statues. Three experts evaluated the innovation's validity; its inter-rater agreement coefficient (IOC) was 0.90. The construction of a suitable innovation involved meticulous consideration of the experts' input. Three experts evaluated the user satisfaction form's validity, demonstrating an inter-rater reliability coefficient of 0.85.

3.5 Ethical considerations of human research

This article presents a research study titled “Virtual Reality as an Emerging Art Exhibition Platform in the Age of Pandemic.” The study has obtained ethical clearance from the Ethics Review Board of Rangsit University and has been assigned the approval number RSUERB2021-053.

4. RESULTS AND DISCUSSIONS

This section presents research findings based on the established objectives. By analyzing the existing literature comprehensively and interviewing experts, the researchers determined a clear path for developing the prototype.

4.1 Tools and methods for creating a virtual reality exhibition

Creating 3D models from photographs of real-world items is known as photogrammetry. Computer processing is based on a two-dimensional image taken at an angle around the photograph's subject. A point cloud is a group of three-dimensional points that hold the value of the object's position in the X, Y, and Z axis coordinates for processing. The following equipment was employed to obtain the digital data of a real-world object.

The photogrammetry camera

Although any camera can capture images, a superior-quality camera can produce higher-resolution photographs. The researchers utilized the Canon EOS 5D Mark III (Figure 1) for this purpose. The camera model is equipped with a full-frame sensor that has a resolution of 22.3 megapixels. This camera model has an ISO sensitivity range of 100 to 25,600, which can expand up to 102,400. The wide range of ISO sensitivity makes it appropriate for the required research activities. The primary optical device utilized in this study was the EF Mount L-Series Lens/Full-Frame Format, as illustrated in Figure 2.

Figure 1: Canon EOS 5D Mark III

Figure 2: Canon EF 35mm f1.4L II USM

The photogrammetry software

RealityCapture by Epic Games is a standout photogrammetry program in the market, known for its extensive array of essential features. The software provides a variety of features, such as image registration for aligning purposes, automatic calibration, calculation of polygon meshes, coloring and texturing capabilities, parallel projections, georeferencing, DSM generation, coordinate system conversion, simplification, scaling, filtration, smoothing, measurement, inspection, and support for multiple import and export formats (Epic Games, Inc., 2024). Therefore, the researchers chose the software for this study. The researcher employed AutoDesk Maya as a tool for UV editing. The software application Maxon ZBrush was utilized to alter the shapes of models. The software application Adobe Lightroom was used to modify photographs. The software application Adobe Photoshop was employed to modify textures.

The virtual reality exhibition development

To develop a virtual exhibition experience the researchers opted for Unreal Engine 5.1, a widely adopted software platform capable of exporting content suitable for immersive viewing through virtual reality headsets.

The research was conducted on a computer operating a 64-bit edition of Windows 10, with 16 GB of RAM and an nVidia GeForce GTX 1080 graphics card. The personal computer is outfitted with the requisite specifications to facilitate virtual reality applications, enabling users to partake in immersive experiences via a head-mounted display. The Oculus Rift-S was the virtual reality headset employed in this study.

4.2 The photogrammetry process

Subsequent procedures were implemented to achieve optimal photogrammetry outcomes. Two key factors influenced the photogrammetry planning: the complexity of each sculpture and its placement.

Sculpture complexity

The sculptures possess diverse levels of complexity, which can be classified into three categories: low, medium, and high-complexity sculptures.

Low-complexity sculptures were characterized by a limited number of objects or figures, usually fewer than two. There were four sculptures within this particular category. The artwork titled "The White Elephant and the King" (Figure 3) depicts King Rama IX as he engaged in the act of caressing the young royal white elephant. The artwork titled "Mother's Teachings" (Figure 4) depicts Somdet Phra Srinagarindra Boromarajajonani, the mother of King Rama IX, as she is engaging in the act of cutting the king's hair.

Figure 3: "The White Elephant and the King" sculpture

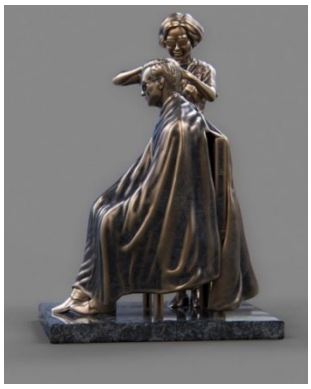

Figure 4: "Mother's Teachings" sculpture

The artwork "Two Dharma Kings" (Figure 5) depicts a statue of King Rama IX alongside the 19th Supreme Patriarch of Thailand. The artwork "Bodhi of the Land" (Figure 6) depicts King Rama IX sitting and planting a Bodhi sapling on the ground. The sapling is arranged to resemble the geographical outline of Thailand.

Figure 5: "Two Dharma Kings" sculpture

Figure 6: "Bodhi of the Land" sculpture

Two sculptures in this category were medium complexity, composed of three objects or figures. The artwork "Gifts from the Sky" (Figure 7) depicts the moment when King Rama IX graciously offered a notebook to a young female student. She is accompanied by a teacher who holds a bag containing a special gift from the royal family. The set of three bust statues of King Rama IX, titled "The Great King" (Figure 8), is accompanied by wooden bases.

Figure 7: "Gifts from the Sky" sculpture

Figure 8: "The Great King" sculptures

High-complexity sculptures are sculptures with more than three objects or figures. Three sculptures were found within this specific category. The artwork titled "The King's Happiness" (Figure 9) depicts the members of the royal family, including King Rama IX, Queen Sirikit, Princess Ubolratana Rajakanya, and Prince Vajiralongkorn, positioned within a Disney-themed ride. The artwork "Protector of the Land" (Figure 10) depicts King Bhumibol Adulyadej seated on a mule, with a hill tribe leader walking ahead. There are courtiers positioned on both the left and right sides.

Figure 9: "The King's Happiness" sculpture

Figure 10: "Protector of the Land" sculpture

The artwork titled "Regalis Vehiculum" (Figures 11 and 12) portrays His Majesty King Bhumibol Adulyadej the Great Borommanatbophit in a squatting position, leaning towards the left side of the Royal Land Rover Series III, also referred to as the "Series Three" Long Wheel Base model. Alongside the King, a villager has taken up residence and offers valuable insights. Two courtiers sit in the presence of the royal carriage, with a royal guard positioned on the right side of the conveyance.

Figure 11: "Regalis Vehiculum" Sculpture (Left View)

Figure 12: "Regalis Vehiculum" Sculpture (Right View)

Sculpture placement

The sculptures were carefully arranged and appropriately lit to enhance their visibility. It was essential to ensure that the resulting images accurately captured the intended light and shadow effects when the models were scanned using photogrammetry.

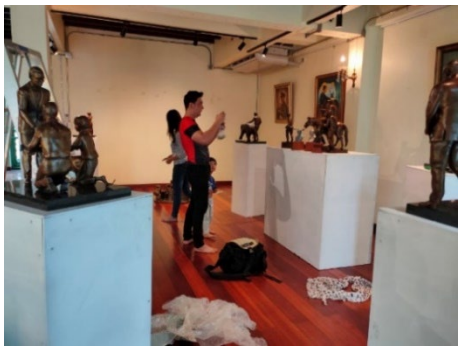

Figure 13: The researchers placing the bronze statues

Figure 14: The researchers placing the camera for photogrammetry

Figures 13–14 depict three different shooting angles capturing a single object. Due to the subject's complexity, it was recommended that the photographer take a complete set of images from different perspectives. This allows the software to calculate the object's surface area efficiently. To address environmental factors, researchers thoroughly photographed each sculpture. Table 1 displays the number of photographs linked to each sculpture required for the photogrammetry.

Table 1: Number of photos for the photogrammetry process and complexity of each sculpture

Sculpture title	Complexity	Above	Parallel	Below	Close-up	Total
The White Elephant and the King	Low	16	20	13	36	85
Mother's Teachings	Low	15	20	23	28	86
Two Dharma Kings	Medium	23	35	17	26	101
Bodhi of the Land	Medium	34	25	15	29	103
Gifts from the Sky	Medium	22	35	42	27	126
The Great King	Medium	46	47	56	28	177
The King's Happiness	High	24	37	42	39	142
Regalis Vehiculum	High	40	36	53	69	198
Protector of the Land	High	44	42	45	71	202
Total						**1,220**

4.3 The virtual reality exhibition

The photogrammetry process required 1,220 photos. From these raw photos, digital, realistic models were recreated. The initial result is depicted in Figure 15.

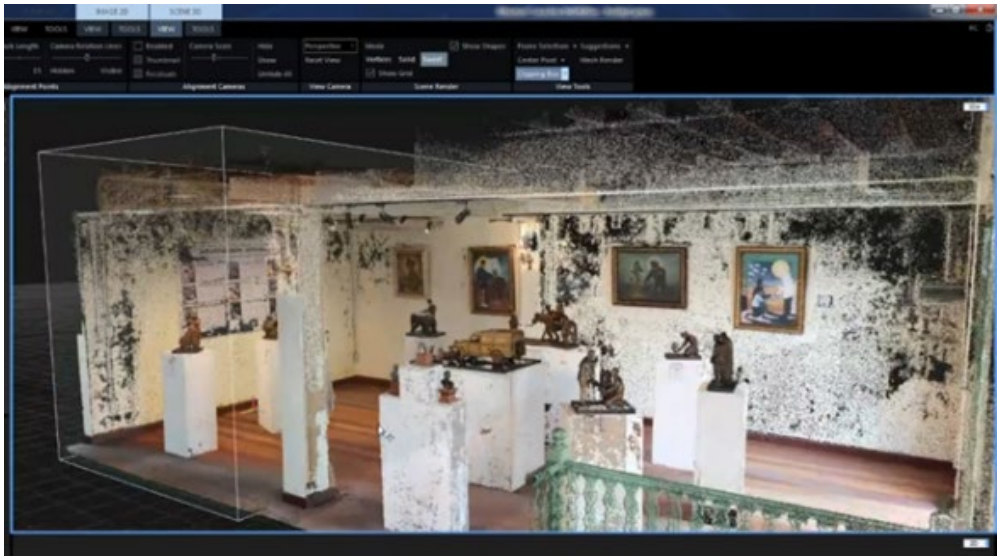

Figure 15: The initial photogrammetry result from 1,220 photographs of the sculptures

The researchers exported the 3D data and improved its quality to achieve optimal results. Finally, the models were reconstructed in Unreal Engine to create a virtual twin exhibition. Because the experience needs to run and display in real-time, we optimized the models for this virtual reality exhibition to have lower polygon counts. High-polygon models, while offering more detailed and realistic representations, demand substantial computational power, which can strain the performance of both the hardware and the VR platform. This can lead to undesirable outcomes such as reduced frame rates, latency issues, and even overheating of the device, all of which compromise the immersive quality of the experience. As depicted in Figures 16–20, the exhibition's final appearance exhibits photorealistic qualities essential for creating an immersive viewing experience.

Figure 16: The overall view of the virtual exhibition

Figure 17: The virtual exhibition showing the sculpture “Mother’s Teachings”

Figure 18: The virtual exhibition showing the sculpture “Two Dharma Kings”

Figure 19: The virtual exhibition showing the sculpture “Protector of the Land”

Figure 20: The virtual exhibition showing “Regalis Vehiculum” in the Foreground and "Protector of the Land” in the Background

4.4 Results from the exhibition

The exhibition was on November 5, 2022, on the upper level of the Erabica Art Gallery. It consisted of two rooms: one displaying physical sculptures and the other showcasing the virtual twin exhibition created using photogrammetry. The two rooms had the same spatial layout and displayed identical contents.

The opening ceremony was presided over by the Governor of Nan Province. Figure 21 shows the audience interacting with the virtual exhibition using a virtual reality head-mounted display connected to a notebook.

Figure 21: The researchers assisting the audience viewing the virtual exhibition

We interviewed the experts to get their perspectives on their engagement with the virtual reality exhibition. We also administered a questionnaire to the participants to collect their feedback.

Expert opinions

Three art, design, and technology experts participated in a structured interview session to share their perspectives on the virtual exhibition. The structured interview consists of three questions: 1. How do you feel about using virtual reality in this virtual exhibition? 2. How easy was it to experience the virtual exhibition? 3. How would you describe the level of immersion that the virtual exhibition offers? Table 2 displays the results.

Table 2: Expert suggestions

Question	Visual art expert	Design expert	Technology expert
1. How do you feel about using virtual reality in this virtual exhibition?	I see using virtual reality to create virtual exhibitions as a significant and exciting development in the art world. Virtual reality offers artists, curators, and audiences new ways to engage with art that transcend traditional physical limitations.	In VR exhibitions, the user experience becomes a central aspect of the design process. However, this study mimics the traditional galleries, where the physical layout guides movement intuitively, making the experience simple to use and enjoyable.	VR allows for an unprecedented level of immersion in virtual exhibitions. This study's ability to replicate digital environments enables viewers to interact with art without physical constraints, potentially serving as a remote exhibition viewing experience.
2. How easy was it to experience the virtual exhibition?	I thought wearing a VR headset to view a virtual reality exhibition would be a challenging experience. However, this exhibition was surprisingly simple to navigate because the entire exhibition space is on an accurate scale, and I can move around freely in the virtual space.	Experiencing the virtual reality art exhibition was relatively straightforward. The entire experience was well-designed, with good visuals.	The virtual reality exhibition, once inside, was immersive, but the quality of the experience depended on factors such as frame rates, latency, and the visual resolution of the artwork.
3. How would you describe the level of immersion that the virtual exhibition offers?	The level of immersion in the virtual reality art exhibition was remarkable, offering an engaging way to experience art. The level of immersion in the virtual reality art exhibition was remarkable, offering an engaging way to experience art. Overall, the virtual exhibition provided a highly immersive visual and spatial engagement with art, but it still lacked some physicality inherent to real-world galleries, such as touch.	The level of immersion in the virtual reality art exhibition was impressive from a design standpoint, leveraging spatial design, interaction, and environment to create a truly engaging experience. The VR platform allowed the viewer to move freely within a virtual gallery, offering a strong sense of presence that closely mimicked walking through a physical exhibition space. The ability to explore the art from multiple angles, zoom in for details, and experience works at different scales enhanced the sense of immersion.	I believe that technology has now advanced to a point where it can provide an immersive experience. However, the quality of the experience may depend greatly on the technical parts, especially the hardware that runs the virtual exhibition. I noticed that the researcher used a gaming notebook for this study, so I assume the virtual experience requires a high-performance computer to operate.

The visual art expert affirmed that the virtual reality exhibition is both an exciting and significant advancement in the art world. It not only offers new opportunities for artists, curators, and audiences but also can provide interactive features beyond traditional art exhibition viewing methods. Despite initial concerns about the hassle of using a VR headset, the expert found the exhibition was surprisingly simple to use due to its life-scale display allowing free movement within the assigned space. Additionally, the expert pointed out that the level of immersion was remarkable. The virtual exhibition was very engaging. However, it may fall short of the tactile experience of real-world art viewing.

The design expert commented that the strength of the virtual exhibition lies in the experience of viewing the artworks. He stated that the exhibition effectively mimicked the traditional gallery viewing experience, making it very fun and intuitive with little or no learning curve. He further affirmed that, despite the simplicity of the experience, it was well-designed with meticulously beautiful visuals. Furthermore, the level of immersion while experiencing the virtual exhibition was impressive; the audience can almost feel the spatial layout of the virtual gallery, making it an engaging experience. He concluded that the exhibition's use of virtual reality characteristics allows the audience to experience a strong sense of presence, akin to walking through a physical space.

The technology expert provided insights regarding the unprecedented level of immersion that virtual reality offers. He stated that because of virtual reality, viewers can then interact with art objects without physical limitations. He suggested that this can be a potential solution for remote art exhibition viewing. However, he mentioned that technical factors such as frame rates, internet connection latency, and the artwork's quality may ultimately determine the quality of the experience. He also noted that a high-performance computer is a crucial component in running the exhibition smoothly.

The demographic information of the participants

The demographic profile of the participants is presented in Table 3. Among the 45 individuals who attended the exhibition, 52.2% were male and 47.8% were female. The age distribution of attendees was as follows: 15 to 20 years old (31.1%), 41 to 50 years old (26.7%), 21 to 30 years old (15.6%), 31 to 40 years old (13.3%), 51 to 60 years old (8.9%), and 61 to 70 years old and older than 70 years old were equally represented (2.2%).

Table 3: Demographic information of the participants

	Frequency (*n* = 45)	Percentage (%)
Gender		
Male	24	52.2
Female	22	47.8
Age range		
15–20	14	31.1
21–30	7	15.6
31–40	6	13.3
41–50	12	26.7
51–60	4	8.9
61–70	1	2.2
> 70	1	2.2

We designed the questionnaire to be as minimally intrusive as possible, explicitly asking only three questions: 1. How easy was it to experience the virtual exhibition? 2. How would you describe the level of immersion that the virtual exhibition offers? 3. How satisfied were you with the virtual exhibition? The results of the questionnaire are as follows:

Ease of viewing the virtual reality exhibition

The researchers used a 5-level Likert scale to assess the opinions of the samples regarding the simplicity of viewing the virtual display. Twenty-one participants (46.7%) voted "easy to use," 18 participants (40%) voted "very easy to use," and 6 participants (13.3%) voted "neutral," as shown in Table 4.

Table 4: Ease of viewing the virtual reality exhibition

Likert scale	Frequency (*n* = 45)	Percentage (%)
Extremely difficult to use	0	0
Difficult to use	0	0
Neutral	6	13.3
Easy to use	21	46.7
Extremely easy to use	18	40

Level of viewing immersion in the virtual exhibition

The researchers employed a 5-level Likert scale to evaluate the participants' viewpoints on the level of immersion provided by the virtual exhibition compared to the physical exhibition. Table 5 shows that 23 participants, representing 51.1% of the total, rated the virtual exhibition as "highly immersive." Additionally, 18 participants, representing 40% of the total, voted "immersive." Lastly, 4 participants, equivalent to 8.9% of the total, voted "neutral."

Table 5: Level of viewing immersion of the virtual reality exhibition

Likert scale	Frequency (*n* = 45)	Percentage (%)
Extremely not immersive	0	0
Not immersive	0	0
Neutral	4	8.9
Immersive	18	40
Highly immersive	23	51.1

Level of satisfaction toward the virtual exhibition

The researchers employed a Likert scale to evaluate the participants' viewpoints on their level of satisfaction with the virtual exhibition. Table 6 shows that 28 participants, representing 62.2% of the total, expressed "extreme satisfaction," while 17 participants, representing 37.8%, chose "satisfied."

Table 6: Level of satisfaction with the virtual reality exhibition

Likert scale	Frequency (n = 45)	Percentage (%)
Extremely Dissatisfied	0	0
Dissatisfied	0	0
Neutral	0	0
Satisfied	17	37.8
Extremely Satisfied	28	62.2

4.5 Study limitations

The study was conducted in an enclosed space with relatively low light levels, necessitating suboptimal camera settings such as a slower shutter speed and a larger aperture. As a result, many photographs were blurry. The application may classify images with blurriness as defective. Therefore, it is critical to use appropriate lighting to ensure that photographs are fully illuminated. Future studies should prioritize adequate lighting, ensuring a well-lit environment to produce sharp, detailed photographs. Alternatively, image stabilization technology or advanced camera equipment with better low-light performance can mitigate this issue. Additionally, experimenting with HDR (High Dynamic Range) photography could help capture more detail in poorly lit environments, enhancing the overall quality of virtual reproductions.

Time constraints limited the research team's ability to take photographs at the exhibition, which was held in a commercial setting. If given enough time, the researchers would have been able to conduct a thorough analysis of the results from previous photography sessions and collect additional images.

Creating a device that captures photographs from an elevated perspective is critical, mainly when dealing with sculptures and other objects at significant heights. Adding a high-resolution camera to an uncrewed aerial vehicle (UAV) may help improve the photogrammetric process.

Due to space constraints, the artworks were arranged in close proximity. This presents a significant challenge in obtaining comprehensive photographs of the object of work from multiple perspectives. A greater degree of spatial separation between the sculptures may increase the likelihood of achieving better results.

4.6 The future of art exhibition

As this and other studies have found, the future of art exhibitions is poised to undergo significant transformations with the integration of technology, particularly with photogrammetry and virtual reality. This research showcased the potential of these technologies to overcome traditional barriers, especially in global crises like the recent COVID-19 pandemic. Using photogrammetry, a technique that captures detailed 3D models from photographs, this study created a virtual twin of a physical exhibition showcasing sculptures of King Bhumibol Adulyadej. The research demonstrated how the display of photogrammetric art objects through virtual reality technology can provide immersive and realistic viewing experiences. Therefore, it has the potential to serve as a substitute for physical exhibitions when necessary.

Developers can use virtual reality software like Unreal Engine and virtual reality head-mounted displays to create virtual exhibitions that replicate real-world locations, enabling audiences to experience them from any location. The remarks from the three experts from the art, design, and technology fields reassure that the innovation not only preserves the authenticity of the exhibition experiences but also opens up new topics to discuss. As the demand for virtual experiences grows, the use of both physical and virtual exhibitions will likely redefine the future of art exhibitions, signaling an intriguing direction for the future of art exhibitions.

5. CONCLUSION

In conclusion, this research highlights the transformative potential of virtual reality technology when combined with the power of photogrammetry in reshaping art exhibitions. The study's innovative use of photogrammetry to create highly accurate 3D virtual replicas of bronze sculptures depicting King Bhumibol Adulyadej's royal duties demonstrates how virtual exhibitions can bridge the gap between the physical and digital realms. This technique opens up new possibilities to create an art viewing platform for audiences to engage with artworks without the constraint of distance.

The virtual exhibition's evaluation by experts further reassures the effectiveness of this approach. Art, design, and technology experts all agreed the virtual exhibition's ability to mimic the traditional gallery experience offers near-physical immersion. Virtual reality is a viable platform for art exhibitions, particularly in cases where physical attendance is either limited or impossible.

The audience feedback further confirmed the potential of this virtual reality exhibition. Most participants rated the ease of viewing, immersion level, and overall satisfaction with the virtual exhibition as

highly satisfactory. The participants enjoyed the ability to explore the art from various angles while enjoying a sense of presence as if they were in a traditional gallery space. This result demonstrates the feasibility of virtual reality as a tool for art exhibitions and underscores its potential for broader application.

This virtual exhibition marks a significant advancement in the intersection of art, technology, and user experience for art viewing in the digital age.

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