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Design and development of digital humans in virtual exhibition space

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Abstract
In the last three decades, the creation of virtual exhibitions is drawing much attention due to the game engines. The Web's growing technologies have reached a point of maturity where they may significantly impact the long-celebrated merging of education and culture with gaming. With current technologies, a virtual exhibition is more than just an online display of items or a virtual tour of an exhibition which are developed with panoramic images. In contemporary days, virtual exhibitions provide a more informative, entertaining, and enjoyable experience to the visitors through realism and user engagement in the virtual space. This paper will discuss the framework for developing Indian Freedom fighters of the old historical Era as digital humans. These digital humans can interact with visitors and share their stories by themselves through virtual reality using a head-mounted display. The analysis of advantages and disadvantages in current techniques, and unresolved challenges, to propose a set of guidelines as well as best practices for creating VR-based cultural heritage applications, such as Digital humans.

Keywords Virtual exhibition · Virtual reality · Freedom fighters · Head-mounted display · Virtual humans · 3D modeling

1 Introduction

The virtual exhibition can be considered as a collection of digital replicas in an environment where visitors can interact with them. Since virtual exhibition are not new and encompass a wide range of cultural heritage, their definitions vary with the technological advancements [1]. To augment the experience of traditional museums, exhibitions in virtual space is being widely adopted recently by enabling active interaction with culture without posing

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any physical constraints[2]. To exhibit in the virtual exhibition space, physical artefacts need to be converted in digital models. This can be achieved by multiple means. One such technique is the photo scan of images, which is used to convert artifacts into digital meshes with textures via image orientation and dense cloud mapping [3], [4], [5]. Another way to achieve digital replica is by photogrammetry and laser scanning method [6], [7], which were deployed for the development of the old segeberg townhouse. This was done with 3d modeling polylines through colored points from images to capture the texture of different surfaces. In addition to these methods, these artifacts can be enhanced with the help of haptic devices. This incorporates a sense of touch using sensors at the tip of a finger [4]. Even giant sculptures can be scanned in the virtual museum with the help of laser scanning to create 3d models of giant sculptures [7]. In contemporary times a virtual museum can be developed with the help of pre-programmed systems like DynaMus. This provides a whole composition interface that can quickly construct personalized entertaining virtual exhibits using the latest game engine technologies. Virtual curators can install pre-existing digital artifacts sourced from online platforms [8]. SYNTHESIS is an open-source alternative to DynaMus. It is a game engine-based program where creators can create a virtual museum of paintings. SYNTHESIS allows users without particular programming skills to have a high degree of open link data utilization. This imparts considerable application usability to the virtual museum created [9]. Further study on open link data has proposed a virtual exhibition authoring tool that guides users from knowledge graphs querying to the automatic generation of virtual experiences. The study provides a natural language interface to the users for retrieving data of interest without demanding for technical skills; hence, augmenting the users' engagement in the virtual exhibition space [2].

The virtual environment is constructing a whole scenario in a 3D space with an increased sense of presence to the visitors rather than showing a restricted virtual area. For instance, the digital reconstruction of the 18th-century merchant ships Le Boullongne [10] strives to comprehend on-board living circumstances through a realistic interactive marine simulation. This includes interaction with ship parts, spatialized noises, dynamic weather conditions, and realistic movements. The reconstruction of the virtual town of Otranto in Italy [11] takes this forward through historical virtual environments. These are feasible for the representation of medieval times for educative purposes.

Damaged or incomplete artifact can be revived through 3D modeling in virtual reality. Using 3D modeling, equipment of Germanic warriors from the second-fourth century AD [12]was revived for digital preservation. In a similar case study, 3D modeling was used to reconstruct mail armour since scanning technology was not adequate to do so accurately [13]. In addition, virtual reality also can revive ancient lost architecture, as can be seen in the case study of the reconstruction of Augustus in Rome [14]. Marine archaeology can also be benefitted from reconstruction through 3D modeling, by enhancing the underwater cultural heritage. For example, the Mercurio shipwreck was developed using 3D modeling and scanning [15]. Since the procedure of preservation of any archaeological site prevents it from being visible to the public, therefore the application of 3D modeling in virtual reality creates a paradigm for user interaction with the historic time. Through the application of 3D modeling in virtual reality, architectural space can be created where digital artifacts can be stored for exhibition [16]. Along with the architectural space, 3D modeling also helps to develop digital humans that leads to the preservation of cultural heritage, as can be seen in the case study of giving life to John Calvin [17]. In this study, with the help of 3D modeling, John Calvin as a digital human was developed. The focus of this study was on portraying the lifestyle of John Calvin rather than capturing his likeness in a realistic manner.

In cultural heritage applications, the employed digital humans serve a variety of functions [18]. This ranges from being a spatial decorative element to a full-fledged knowledge-imparting entity. The use of digital humans as virtual guides in virtual cultural heritage environments has proven to improve the interaction and amusement factor of the built scenario [19]. This can aid in attracting visitors and contributing to their learning process through individualized feedback like replying and related storytelling aspects [20]. For example, Digital humans can be installed as virtual guides in a museum to enhance engagement with museum visitors [11], [21]. These virtual guides can be incorporated with the feature of taking responsive decisions to a wide range of potential occurrences in the virtual environment [22]. For example, Visitors of the St Andrews Cathedral Recreation [23] have the facility to indulge in medieval situations through narrating tales of Bishop William de Lamberton, King Robert I, and visualizing the Cathedral Cannons, and other historical figures. Each of these virtual guides has been assigned a backstory and a fixed narrative and rules to abide by. Their verbal or textual conversation was scripted with keyword-based as input cues. Likewise, the virtual heritage Virtual Agora [24] aims to recreate daily life in the ancient Greek city of Agora employing digital humans. The designed digital humans were attributed with a set of characteristics that signify their biological nature and personality. Every digital human in the Virtual city of Agora has a limited set of actions based on their social status in Greek society. Users can witness the characters' daily routines and engage with them by asking questions. Similarly, the AMICA [25], [26] provides a way to conserve and showcase the process of engraving and printmaking through virtual reality. It replaces the conventional 3D models with 3D videos of real creators. Although, the use of virtual humans as guides in the virtual museum is useful for circulating information, however, these characters do not have any personality as an individual. Since the personalities of digital humans effect the user experience [27] therefore, the users cannot interact with the digital humans as guides in the same way as they would have with real ones.

Digital humans can be developed using commodity scanning hardware. This is done by scanning humans from multiple angles and providing a mesh with textures. This mesh and texture are further processed with rigging to permit movement control in 3D space [28]. One such device is the depth camera Microsoft Kinect, which can scan the human body. By using different depth cameras for different body parts, one can achieve virtual humans with high-quality mesh and textures [29]. The development of Digital humans through 3D cameras to capture a 3D form of humans and the capacity to incorporate the movement of digital humans is an important research challenge [30]. This method of development of digital humans provides the resemblance of a specific individual, but it incorporates real humans, to develop the mesh and textures. As a result, this method is restricted to be used for developing digital humans who are alive.

Numerous digital humans are used to simulate the scene in virtual reality. In the case of Virtual Romans, D. Arnold et al. [31] have developed a crowd to depict their life in 79 A.D through simulations of their daily work. M. Mudge et al. [32] have proposed a grid-based behavior mechanism, through which large crowds of digital humans with the scripted animation can be generated. These can further be designed to exist in synchronized harmony with each other. Virtual Romans achieves this by preventing spatial clashes between virtual humans. For the development of multiple digital humans, the Customization of a digital human plays an important role. In human body modeling and simulation, a study had proposed to generate different types of anthropometrical humans using skinned templates [33]. This creates new body size models over the original skeleton allowing its skinning information to be used in animation as well. In a similar fashion, morphable models can be applied in the realization of digital humans. In

this method, scans are matched against morphable models by their skeleton position and skinning attributes. These attributes are copied, yielded in skinning, and rigged to be identical to the hand-rigged model. This can help in modifying the model to be shorter, skinnier, fatter, or taller as desired [34]. The findings from of the earlier researchers on digital humans have been summarised in Table1.

From the Table 1 it can be seen that digital humans can be used in multiple ways but their applications are limited to virtual guides or development of anonymous human figurines. The existing methods employ procedural software to create a variety of digital humans, however, it takes only body proportions into account since the realistic facial features cannot be developed procedurally. For identification of any specific individual, their facial likeness should be more prominent over the body likeness. The current procedures fall short to incorporate facial likeness in the development phase. Moreover, the current methods of development of digital humans are inadequate in creating realistic replicas of deceased personalities. Therefore, a framework needs to be created for development of full-fledged realistic digital humans that resemble the physical appearance of historical personalities.

In India, the only virtual museum developed relies on panoramic images of real museums and no prior work had been done in the context of Indian freedom fighters. Hence, this study aims to create a framework for the development of full-fledged realistic digital humans that resemble the physical appearance of historical personalities involved in the Indian Freedom Struggle. The Indian independence movement stands as a monumental event in Indian history, representing a crucial chapter that led to the liberation of India from foreign dominance and inspiring similar quests for freedom in other nations. Indian independence activists played a pivotal role in this movement. Their unwavering commitment and sacrifices serve as powerful symbols of resilience, courage, and determination. By presenting these activists as digital humans in a virtual exhibition, their stories are brought to life, enabling visitors to connect with their experiences and draw inspiration from their struggles. Furthermore, specific context of Indian History was chosen based on the survey, conducted on 170 people to take their insights. Out of 170 people, 120 were male and 50 were female. Among all the participants, 78% were students pursuing an undergraduate or a post-graduate degree in design and information technology, while 18% were high school students. A questionnaire was constructed to understand the user's expectations and requirements of virtual exhibition. A set of 5 questions were included in the dichotomous questionnaire where the user had to select between the yes and no options. The key factors asked in the questionnaire were about awareness of the virtual museum and freedom fighters, the resemblance of freedom fighters, the requirement to revive freedom fighters as digital humans and their preference regarding better experience in virtual reality. The percentage analysis of responses to the survey can be seen in Fig. 1.

It can be seen from Fig. 1 that, out of 170 participants, more than 65% were still not aware of virtual reality. As the concept of virtual reality museum space was new to them, therefore, they found it very interesting. 68.50% of the participants were aware of the old images of freedom fighters, from which 94% wish to see freedom fighters as digital humans. 86.80% of participants would like to have an audio description of the digital humans in the virtual space. Thus, the findings from the survey, reveal the requirement to resurrect Indian freedom fighters as Digital humans. In this backdrop, the following research questions have been framed.

- RQ1: How the digital human model of the deceased personalities (such as, Indian freedom fighters) could be developed realistically considering viewers' perception?

Table 1 List of research paper related to digital humans

S.no	Research	Key implementation
1	Giving Life to John Calvin the Reformer [17]	portraying the lifestyle of John Calvin through virtual reality
2	Digital characters in cultural heritage applications [18]	digital character design, implementation approaches, usage in cultural heritage
3	Vision for Virtual Humans [19]	Digital humans as virtual guides to increase the amusement factor in the scenario
4	Relational Agents Improve Engagement and Learning in Science Museum Visitors [20]	Virtual guide for museum space with conversations to enhance social bonding
5	Ada and Grace: Toward realistic and engaging virtual museum guides [21]	Virtual guides to Enhance the engagement and interest in the virtual museum
6	Virtual agora: Representation of an ancient Greek agora in virtual worlds using biologically-inspired motivational agents [24]	Demonstrating the life style of ancient Greece people with custom appearance and dynamic behaviour of digital characters
7	An immersive VR experience to learn the craft of printmaking [26]	Detailed understanding and Learning craft of printmaking through digital avatars
8	Assessment of Virtual Guides' Credibility in Virtual Museum Environments [27]	Analysing the impact of virtual avatars on real humans emotion
9	Rapid avatar capture and simulation [28]	3D Avatar development through commodity depth sensor scanning hardware
10	Scanning 3D full human bodies using kinects [29]	Developing 3D bodies with Microsoft Kinect through scanning
11	Virtual humans in cultural heritage ICT applications [30]	User engagement, immersion, and learning effectiveness of avatar interaction
12	Populating ancient pompeii with crowds of virtual romans [31]	Simulating the life of ancient Pompeii people, with trigger-based behaviour
13	A Framework for Real-Time Virtual Crowds in Cultural Heritage Environments [32]	Creating illusion of avatars crowd to enrich the real time experience
14	Sizing Avatars from Skin Weights [33]	Developing variety of avatars using algorithm for sizing avatars body form anthropometrically
15	Avatar Reshaping and Automatic Rigging Using a Deformable Model [34]	Automatically rigging the avatar through morphable model which has rigging

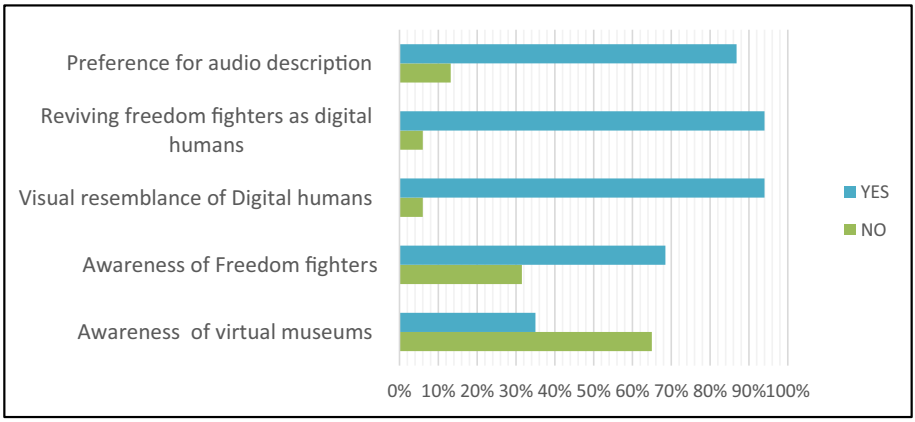

Fig. 1 Dichotomous scaled responses of the survey questionnaire

- RQ2: How the developed digital model of deceased personalities could be displayed in virtual exhibition space to evoke interest in history?

To address these issues, a virtual exhibition of freedom fighters, utilizing head-mounted displays (HMDs) has been designed in this study. It is expected that the outcome of the study will assist the younger generation in learning and interacting with freedom fighters in a modern setting.

2 Method

In the contemporary day and age, most Virtual exhibitions tend to rely on scanning artifacts to bring them into the virtual world. As per the survey results, majority of the users are aware of the freedom fighters and wish to have a rich and interactive exhibition experience of Indian freedom fighters as Digital humans. An attempt is made in this paper to create digital human representations of the Indian Freedom Fighters. This was achieved by taking their iconographic testimonies, paintings, and Death masks as a reference. To obtain authentic visual references for creating 3D digital representations of Indian freedom fighters, various reliable sources were explored. These sources include historical archives, and documents related to the freedom fighters available in real museums. The attires and appearance of the freedom fighters were developed with reference to these available sources. In addition, paintings, portraits, and artistic representations of the freedom fighters, as well as documentaries, films, and other format of visual media featuring the freedom fighters helped to develop the depiction of their visual appearances. Indian freedom fighters models were then gathered in the virtual exhibition where people could interact with them. The interactions were achieved through the movements of digital Humans, their facial expressions, and listening to their narratives in their voices. Started with the development of the whole virtual experience with Freedom fighters as digital humans, then modeled the exhibition space and compiled it all in the Game engine UNREAL Engine. Developing constraints of interaction, cameras, lights, audio profiles through the UNREAL engine. This was done to enable a space

for an immersive experience of Indian freedom fighters for visitors. Figure 2 shows the

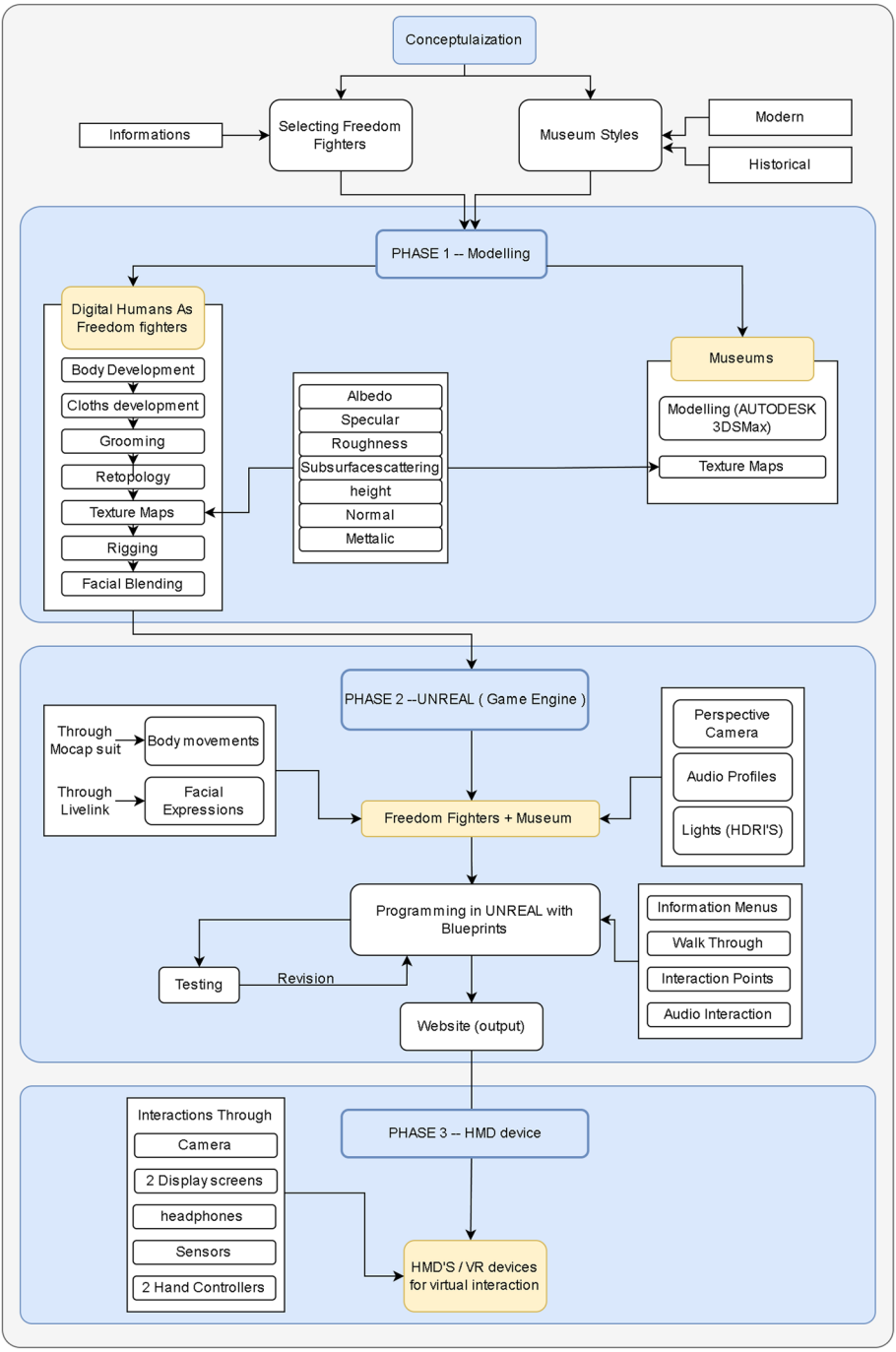

Fig. 2 Sequence diagram of the Development of virtual exhibition space and digital humans

complete framework of the development. Programs utilized for the development of freedom fighters as digital humans and virtual exhibition space are listed in Table 2.

2.1 Phase 1- Modeling

In the Development process of digital humans of freedom fighters, focusing on the accuracy of depiction is given. This involved getting high levels of the likeness of personalities, facial features, dressing styles, and related factors of realism to aid in visual recognition of the freedom fighters for visitors.

2.1.1 Face

For the likeness of faces, starting it with sculpting them in digital software for sculpting. ZBrush is one of the industry-standard sculpting software in which organic, and hard surface modeling, can be done by creators. The likeness of the personalities can be achieved by images or painting references from different angles. The process of this step produces the model of freedom fighters in a similar manner to that of producing a 3D model by scanning or photogrammetry. However, these are developed with better topology as the model is built by human interaction not completely by an algorithm. The facial details which were created on ZBrush can be seen in Fig. 3(f).

As the model has very fine skin details, its polygon count is in millions which are quite high and cannot be used further. Due to high polygon count movement, their body parts and facial features become difficult to control manually and render in real-time. The polygon count is then reduced by retopology, which is a manual way to create the same mesh but with a lower polygon count. This process can be done in 3D modeling software. For this study, Autodesk 3DSMax was opted due to its simplicity and easy interface. After retopology was done in Autodesk 3DSMax, the model had a reduced polygon count at around 15–17 thousand. This was a reduction by a thousandfold. As illustrated in Fig. 3(e), this can be used for further processes. The finer details for the model were unaffected. These were retrieved by using a Normal texture map of 8 K (8192×8192) resolution, as seen in Fig. 3(f).

Table 2 List of programs utilized for the development

S.No	Programs	Functionality
1	Zbrush	Digital sculpting
2	Substance painter	Digital 3D painting & texturing
3	Autodesk Maya	3D modeling and retopology
4	Marvelous designer	3D cloth creation
5	X Gen	Hair creation addon in Autodesk Maya
6	3DSMax	3D modeling of virtual environment
7	Unreal engine	Game engine-Development of virtual exhibition space
8	HTC vive	Heat mounted device for visualization

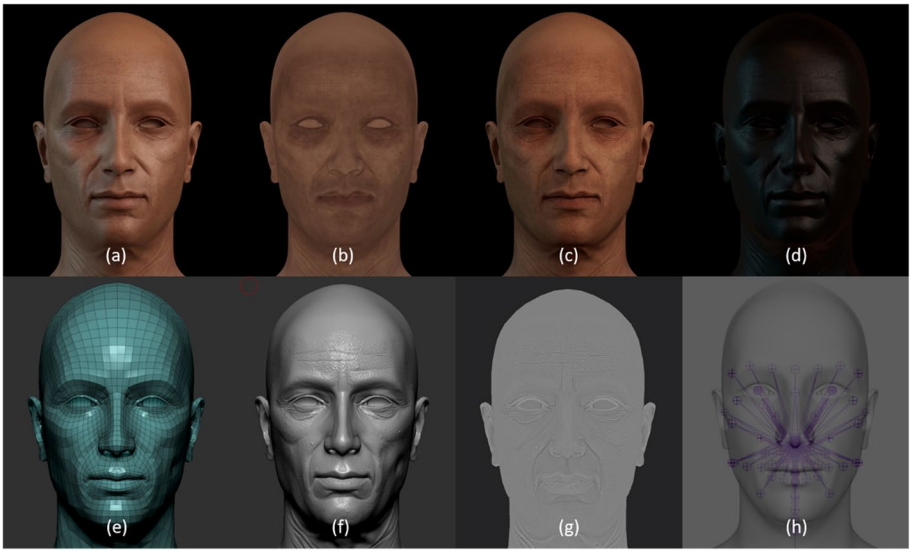

Fig. 3 Comparison between different texture maps and rigging reference

2.1.2 Texture maps

Different texture maps are applied to give the freedom fighters a realistic feel. For the body, these texture maps are created in adobe substance painter. It is a digital software in which users can paint on a 3D surface according to the requirements with multiple layers. Types of texture maps used can be seen in Tables 3.

The compilation of texture maps on the face can be seen in Fig. 3(a). Except for the Albedo map, all other maps are grayscale maps with information ranging from white to black color. In addition, all maps used for the development have 8 K (8192×8192) resolution to provide finer details to the model.

Table 3 Types of texture maps used in face development

s. no	Texture map	Implementation	Reference image
1	Albedo	This provides color information to the model	Figure 3(b)
2	Normal	It is a high-resolution map that contributes to the rich facial structure	Figure 3(f)
3	Specular	Used for shininess and roughness. For example, on lips, the skin has more shine	Figure 3(d)
4	Curvature	Helps to construct color details on the skin surface	Figure 3(g)
5	Subsurface	With the help of this map, the skin comes to life. As light travels inside human skin and refracts, creating the effect of layers on skin. Without this map, the model looks like plastic	Figure 3(c)

2.1.3 Clothes

To develop Realistic clothes, digital software called Marvelous Designer was used. Marvelous designer provides the base mesh for the cloth. Secondary details on the cloth are added in ZBrush manually. Then different texture maps are used for a realistic feel of clothes. The cloth mesh provided by Marvelous designer can also be used for real-time rendering, so there is no need to reduce their polygon count by retopology. Texture maps used on clothes are available for free on open source websites, like substance3D.com.

2.1.4 Grooming

To model the scalp hair, eyebrows, eyelashes, and peach fuzz XGEN was used. XGEN is an add-on in Autodesk Maya, with the help of guides, clumps, masks, layers, modifiers, and technical sliders, realistic human hairs of all types can be built.

All the models, Texture maps, grooms, clothes, and HDRI lights are then compiled in Autodesk Maya to render it with Arnold. Arnold is a render engine that provides realistic renders of the model that can help check its likeness (Fig. 4). Arnold provides natural shades of light and proper algorithms for the camera, like focal length, real size scale to meshes, so that users can see them in their actual size in virtual reality. This step can help identify any error in the rendered models, which can be revised in their particular software.

Fig. 4 Likeness comparison of freedom fighters in AutoDesk Maya

Figures 4(a), (b), (c) shows the reference images of Indian freedom fighters Bhagat Singh, Jawaharlal Nehru, Subhash Chandra Bose respectively. These images were used as the starting point as references. Figures 4(d), (e), (f) respectively show the digital humans that were developed using the reference images.

2.1.5 Movements of digital humans

To make the digital humans move in virtual space, the rigging method was used in Autodesk Maya, which works on the principles of the human skeletal structure. Facial rigging can be seen in Fig. 3(h). Further, to move them in 3D space, a sensor overlaid Mocap suit worn by an actual person to help the digital humans replicate these movements in 3D space. After this, facial blending on the faces of digital humans was applied, which worked as their underneath facial muscles and fat pads. Upon application of the facial blend, digital figures could replicate the characters' facial expressions with the help of the Live-link feature in UNREAL (game engine).

2.1.6 Development of exhibitions

A virtual exhibition was created for the users to interact better with the freedom fighters using Autodesk 3DSMax. This software creates virtual 3D spaces in full (life) scale for an appropriate representation of the virtual exhibition. Two types of virtual spaces were designed, the modern outlook for the exhibition's ambiance was implemented as seen in Fig. 5(a). Secondly, the historic ambiance of the independence era as seen in Fig. 5(b), so that the characters could be more relatable. 2 K (2048×2048) resolution texture maps of specular, albedo, and normal were used to enhance the exhibition's experience. Both types of exhibitions can be seen in Fig. 5.

2.2 Phase 2- Development in game engine

Further, all the characters and the exhibition space models were exported in.fbx format which helped in keeping the texture maps, rigging, facial blends, and animation intact. These were then imported into a game engine for future development. These gaming platforms are usually used to develop games, animations, and visual effects. For this

Fig. 5 Modern (**a**) and Historical (**b**) exhibition space

study, the UNREAL game engine was adopted as it is an open-source platform. Writing the script in UNREAL is highly user-friendly as it works with blueprints and has a straightforward application. It facilitates exporting of the outcome in the form of a website. After placing the components of the exhibition and freedom fighters at suitable locations in the UNREAL 3D space, lighting conditions for the exhibition ambiance were adjusted using area lights to highlight the freedom fighters. The use of 8 K (8192×8192) resolution HDRI maps for the entire environment was done to mimic natural light in the 3D space for a realistic effect. Multiple cameras were installed in the space with appropriate focal length and depth of field so that the user could view it through that perspective as they approached the exhibition.

Interactions inside the exhibition were developed through scripts in UNREAL, which uses blueprints as a visual way of approaching coding for guiding people who are not well versed with computer languages like C++, Java, and Python. Upon completion of the interiors, a walkthrough for the exhibition spaces was created, enabling swift navigation of the users inside the exhibition. In addition, the display of the freedom fighters was supported with information menus with proper location and buttons in the 3D space to activate their information. To make this experience more accessible and interactive for the visitors, audio profiles were created for dictating the information.

The movements of freedom fighters were detailed using UNREAL with the help of a live link to detail out the facial expressions. The live link feature connects with the iPhone and uses its camera to capture facial expressions by creating a temporary mesh on the human's face. This expression is then replicated onto the digital human's face in real-time along with their audio profile, with the help of the above-mentioned facial blending tool. The rigged humans replicating the actions of actual humans in Mocap suits connect simultaneously to the UNREAL engine and imitate actual human's different movements in the 3D space. These movements are pre-recorded and played when the visitors interact with the freedom fighters in the exhibition's interiors. Additionally for capturing the voice, platforms like Speechify and Audacity were utilized for voice development.

2.3 Phase 3- Head-mounted display

To visualize virtual space, head-mounted displays are used. These are typically worn in front of the eyes and help the user get a holistic 360-degree view of the environment corresponding to the user's head movement. For this study, HTC Vive was used, it has dual display screens through which users can visualize a 3D environment virtually, and inbuilt headphones to access audio profiles. It also incorporates proximity sensors that sense surfaces and disables the display when nearing the surface for the user's safety while using the Head-mounted display. Once the virtual space display is disabled, a Head-mounted display will show the real physical space around the user with the help of cameras. It comes with two hand-operated controllers to interact with the exhibition. They improve the navigation in the virtual space by making the menus, audio profiles, and other information accessible. Finally, through these head-mounted displays users were able to have the experience of virtual exhibition interactively. As part of the next phase, to gain insight from users, the user experience is evaluated through presenting prototypes along with a survey.

3 Results

To understand the user experience of digital humans in virtual exhibition space, a user study was carried out. Three digital humans of freedom fighters – Subhash Chandra Bose, Jawaharlal Nehru, and Bhagat Singh were created applying the methodology as discussed earlier. The three digital humans were housed in a virtual exhibition space and shown to participants.

3.1 Questionnaire design

Based on the survey questionnaire of DynaMus [8], a questionnaire was developed to understand how users experience virtual exhibitions. The questionnaire was modified as per the requirement of the present research. The questionnaire was consisted of ten questions and was presented in a Five-point Likert scale, where 1 stood for least preference and 5 stood for maximum preference. The focus of the questionnaire was on realism of freedom fighters, the resemblance of exhibitions, depiction of cloths style, details of cloths, the appearance of freedom fighters from perception, ease of interaction, invoke of interest in history, helpful teaching students and overall experience.

3.2 Participants

To verify the user experience of the virtual exhibitions, prototypes were presented to 115 participants. Out of 115 people, 90 were male and 25 were female. At the time of survey, the participants were studying undergraduate or postgraduate courses in design and information technology.

3.3 Procedure

To take user insights both augmented reality and virtual reality were considered accordingly. As each model was developed as per their available height information therefore the scale of digital humans were verified through augmented reality. Figure 6(a) shows the visualization of Subhash Chandra Bose in augmented reality. Followed by this, Virtual reality was applied to understand the user's ability to interact with the virtual

Fig. 6 **a** Augmented reality testing **b** virtual reality testing

space contributing to their overall experience. It was done by presenting digital humans and virtual exhibition space through HMD (head-mounted device). Figure(b) show the screen for visualization of virtual exhibition using HMD. Furthermore, the different architectural styles of the virtual exhibition space, I.e., historic era and modern era were presented separately. Finally, the questionnaire was provided to the user to give their feedback on the presented virtual exhibition.

3.4 Outcome

Through User testing and survey questionnaire, it was found that 51% of people gave the realism of freedom fighters a five rating, while 39% gave it a four rating. 60% of people gave a 5 rating and 30.7% of people gave a 4 rating for the depiction of clothes. A majority of people rated it a 5 on the scale of usefulness for teaching students, with 81.6% rating it as very useful. 42.1% gave 5 rating and 32.5% gave 4 rating for invoking interest in history. 62.3% gave 5 and 32.5% gave 4 rating for overall experience, a combined 94.8%. Furthermore, for the exhibition, users preferred the architecture styles of the historic era over the modern era, as it was more relatable with freedom fighters. The detailed responses can be seen in Fig. 7.

User testing and a survey indicate that the whole virtual space is realistic and people are able to interact with the exhibition easily. Therefore, students can benefit from using the virtual exhibition for learning purposes. By invoking interest in history, it can help them learn about Indian freedom fighters. Moreover, it preserves information about Indian freedom fighters in a digital format. Finally, users were able to have an immersive experience in the exhibition with ease.

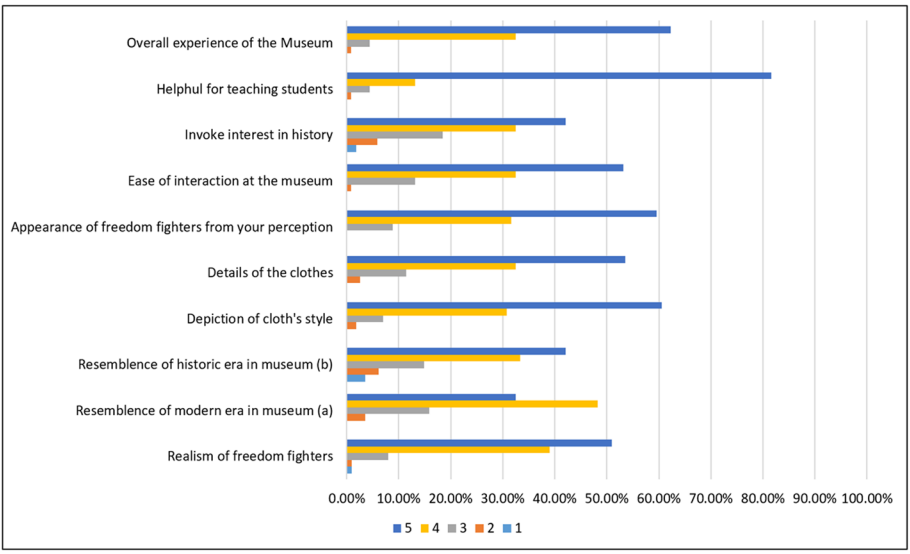

Fig. 7 Five-point scaled responses of the questionnaire for user testing

4 Conclusion & discussions

Using 3D modeling as a tool to promote culture can have widespread benefits. Virtual exhibitions eliminate the hassle of traveling to different parts of the world [35]. This allows more people to access the cultural wealth of multiple regions from the comfort of their homes, schools, or other institutions. In this study, the virtual exhibition developed was based on Indian history, yet it can be adapted to suit the understanding and needs of anybody unfamiliar with the topic. Even though the information has become easily accessible, people continue to be intimidated by the voluminous nature of knowledge. Virtual exhibitions assist to provide cultural information in a more user-friendly and accessible way [36]. Thus, virtual exhibitions help create stronger learning environments for children, adults, and tourists alike. Personalities hold great significance in shaping the political, social, and historical landscape of countries, regions, and the world. Despite their high level of importance, the representation of personalities is restricted to printed material like books, comics, photographs, or audio-visual material like films, plays, and video clipping. The application of digital humans in recreating these personalities broadens the scope for people to know these personalities. Digital humans are merely a means to compliments pre-existing representations of personalities. Creating a framework for digital human personalities allows us to preserve, promote, and educate cultures throughout the world.

To address the research questions, this study has proposed a framework for modelling and exhibition of digital humans in virtual space. The framework consists of three phases, where the phase 1 depicts the digital modelling of the deceased personalities such as, Indian freedom fighters. In phase 2, the process for the interaction of developed digital humans such as body movements and facial expressions have been conferred. In subsequent phase, the process for creating virtual environment space has been discussed, by taking two types of virtual exhibition environment spaces. Both digital humans and virtual exhibition space has been tested through head mounted devices, such as, HTC-Vive. The result depicts that the participants found the developed digital humans as realistic representations of the Indian freedom fighters based on their appearance, clothes and style. This addresses the first research question (RQ1) i.e., the proposed framework is useful for developing digital human model of deceased personalities in virtual space considering viewers' perception. While it was asked about preference of exhibition space for displaying the developed digital human, participants preferred historical era exhibition space over modern era. Consequently, the overall experience of the exhibition space has been rated highly by the participants that in turn invokes the interest to learn history. This addresses the second research question (RQ2), i.e., digital model of deceased personalities could be displayed in virtual exhibition space having resemblance with historical era to evoke interest in history. Therefore, the proposed framework for development of virtual exhibition space and digital humans can preserve past personalities in digital format and can be implemented in virtual reality. As shown in the case study of Indian history, this framework enhances the awareness of cultural heritage through modern media.

The participants on whom the survey was conducted had at least a passable awareness of Indian history but little to no experience with virtual reality. The virtual exhibition was designed with high levels of scripted interactions. Due to limited scripting and the lack of a natural language processing engine, the system could not generate spontaneous responses in real time and could not understand complex questions or requests.

Equipping the virtual exhibition with future-ready innovations like artificial intelligence can offer personalized and immersive experiences for visitors. AI-powered historical

figures can provide real-time information and answer inquiries, enhancing visitor engagement and knowledge acquisition. Intelligent algorithms can analyse visitor preferences and behaviours, enabling personalized recommendations for exhibits and activities. Virtual and augmented reality technologies can be utilized to create immersive simulations, allowing visitors to explore historical events with more immersive distant locations. Furthermore, AI can be leveraged to generate dynamic and engaging narratives, transforming static exhibits into interactive storytelling experiences through historical figures. By combining these technologies, an educational and user-friendly interactive exhibition can deliver a personalized, captivating, and enriching experience for visitors of all ages.

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Data availability Since no datasets were created or analysed in the current study, data sharing is not applicable to this article.

Declarations

Conflict of interest The authors hereby declare that there are no conflicts of interest in this research.

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