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Modeling craftspeople for cultural heritage: A case study

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Abstract

Intangible heritage is often linked to human actions and performances. The use of digital humans (DHs) for its digital representation and therefore its preservation, allows reframing the way to transmit and deal with content that is difficult to visualize. To that end, the digital human becomes an important element establishing the connection between the action, the objects, the knowledge, and the environment. In this article, we describe the development of DHs acting as practitioners and storytellers for traditional craft processes within virtual environments. We present the process and the tasks involved in modeling, designing, and animating DHs, detailing the underlying technological background. Animations were completely based on real humans' motion extraction while working on the corresponding craft. As a result, we present the different DHs models created for three specific heritage crafts: mastic cultivation, glass blowing, and silk weaving as well as an AR application, built to augment exhibits of the Chios Mastic Museum. This article is a practical description of the steps to model and animate virtual humans. The work aims to bring a methodology for achieving DHs creation for CH applications.

KEYWORDS

3D animation, 3D modeling, cultural heritage, digital humans, heritage crafts, motion capture

1 | INTRODUCTION

Culture and history are traditionally related to the environment, the people, the objects, the materials, and even the habits that marked different populations and eras. For many years, researchers tried to find the optimal way to examine and simulate past cultures. Today, virtual reality or different kinds of realities (augmented, mixed) provided us with the most powerful, affordable, and effective means to achieve this goal. The reconstruction of virtual worlds, which have been very commonly used in the last years, allow visitors to interact with environments, buildings, artifacts, and even characters of previous cultures, of different historical times and places.[1] The role of digital humans (DHs) in such environments is essential, as they can simulate appearances, behaviors and they can interact with the environment or with the users themselves allowing them to feel as close as possible in the environment.

DHs can play different roles in a cultural heritage application, based on its needs, ranging from a storyteller, a guide, a craft worker or just to be a simple decoration. In some cases, the recreation of old cities demands the presence of

virtual crowds, like in the work of Maïm et al. who simulated Pompeii with crowds of virtual Romans.[2] Adding coherent DHs in virtual cultural heritage applications allows a better understanding of the use of the architectural structures, such as space dimensions as well as the use of objects in a virtual scene. Their use is significant in two main ways: for the contextualization of the different components of the virtual scene, and for establishing the link between the visual and the nonvisual environment such as 3D models of the actors, 3D environment, sounds, music, voices, gestures, and behavioral rules. In other words, the existence of DHs can make a virtual cultural heritage experience more human.

Tan and Rahaman have noted two types of DHs used, the one with the first-person control, where the user can control the navigation and the view and thus the DHs can provide real-time interaction and feedback to the user, and the guided-tour type immersions, where users can passively watch a predefined scenario.[3] However, nowadays it is a trend to use intelligent agents that can represent and simulate human behavior and personalities traits.[1] DHs need to be designed as realistic as possible not only in terms of appearance but also in terms of personality and need to be able to interact both verbally and nonverbally to ensure the engagement and the immersion of the user. Thus, the design, choice, and integration of DHs in VR cultural heritage environments is a challenging and complex procedure.

In this article, we present a case study where digital humans have been used for preserving cultural knowledge and for giving a consistent simulation of craft processes that need to be preserved through time. This study is conducted in the framework of a European project[4] which aims at representing and making accessible both tangible and intangible aspects of crafts as CH.[5,6] These crafts, mastic and glass, are mainly conveyed from family to family over time and thus, the need for preservation is crucial. The existence of digital humans augments the motivation of users and visitors for further knowledge and enhances the experience by providing more substantial information. The article is structured as follows: Section 1 provides an introduction and an state of the art on the use of DHs in heritage crafts. In Section 2, we give an overview of the different phases that were necessary to complete the modeling and the animation of the DH models, as well as the specific technical restrictions inherent to the different visualization platforms. Section 3 describes the different scenarios of the glass and mastic crafts where the resulting DH models are integrated. Last, Section 4 presents the discussion and the future work to follow.

1.1 | State of the art

Current VR technologies offer a very realistic experience to users, allowing them to visit 3D-reconstructed sites or to learn actively about heritage crafts.

The implementation of DHs involves tasks of several technological backgrounds that each application needs to address. First, to generate a DH the most common approach is manual modeling.[1] There are several methods to achieve that, either using 3D modeling software or using a depth camera to create the skeleton and extract a mesh. Alternate methods have been used, like the one of Feng et al. who generated rapidly an avatar by using auto-rigging qualities in automatic avatar generation pipelines.[7] However, it is important to achieve a high level of DHs' diversity so that realism is ensured and creating a model from scratch is not the ideal approach.[1] Thus, it seems more efficient to generate animated 3D avatars via the production of a morphable human model from 3D data that can easily be scaled. Then, another challenge is the simulation of human clothes as clothes must have also their proper animations to deal with the mechanics of the body and the fabrics. One platform that answers to that is the Fashionizer platform by Senecal et al.[8] The next step is the ability of DHs to interact verbally with the users to simulate properly the human behavior. The integration of speech has been resolved in studies with different ways of speech recognition.

Fulfilling all these requirements for their design, DHs have been used with different roles in virtual cultural heritage environments. A common VR application in cultural heritage is the reconstruction of ancient cultural or historical places and the representation and presentation of heritage crafts.[9] Foni et al. tried to simulate the church of Hagia Sophia, located in Istanbul using DHs with the appropriate appearance and behavior based on historical findings.[10] A bit later, Papagiannakis and Magnenat-Thalmann integrated DHs to simulate the ancient city of Pompeii via a real-time mixed reality mobile application.[11] Vlahakis et al. used virtual athletes to reconstruct the stadium in ancient Olympia, in Greece.[12] They used frames where the athletes actively train and compete in the stadium, and they reported that this feature provided the users with a better understanding of the historical site. Another example is the one of Bogdanovych et al. who virtually reconstructed the ancient city of Uruk and was completely based on the existence of DHs.[13] They tried to immerse the user in a virtual society by presenting a summary of a family's typical day at that period. DHs can also play specific roles by representing specific historic characters. Kennedy et al. recreated the St Andrews

Cathedral and used interactive virtual humans as specific characters, like Bishop William de Lamberton.[14] A similar example is the one of Vosinakis and Avradinis who simulated an ancient Greek agora, using characters of specific roles and behaviors.[15]

An interesting example of a ceremony simulation is the one of Papagiannakis et al. who implemented a 16th-century virtual representation of the Namaz pray of a simulated Ottoman Imam.[16] The authors wanted to use their character-based story to make the historical site more interesting for the user. Of the same concept was the work of Carrozzino et al. who simulated the engraving handcraft.[17] Barreau et al. used DHs to explain the on-board living conditions of the Le Boullogne ship of the 18th century using also sound effects of weather and the environment and a complete naval simulation.[18]

As mentioned above, large number of DHs have also been used as crowds to simulate big cities. Examples of such a simulation is the past and present virtual representation of George Town[19] or the virtual Romans in the city of Pompeii.[2] DHs have also been used as tour guides or storytellers. Chittaro et al. examined the usability of virtual characters as guides in virtual museums applications by using an agent as a companion of the users in a 3D virtual environment.[20] Rodriguez-Echavarria et al. used the ARP toolkit and integrated a female agent as a guide in the 17th-century German town Wolfenbüttel.[21] Their agent was responding to users' questions and had a basic natural behavior by gesture animation and natural language understanding. Studies have also tried to compare different digital humans acting as storytellers in different aspects of virtual museums environments, like a historical sculpture and they concluded that the use of DHs can stimulate the visitors' interest and involvement.[22,23] In the TinajAR project, the authors simulated ancient Spanish cellars, called calados and they used DHs as craftworkers to show how to create ceramic pieces.[24] In[25] a system architecture has been recently developed to be used in several cultural heritage contexts as storyteller, enabling natural interactions with the users. In[26] an interactive realistic human avatar is described used as a guide and a storyteller.

Except from the virtual reality application or the guiding virtual museums, it is a trend to use serious games for augmenting the understanding and the learning process in cultural heritage. Such serious games are usually completed by the presence of DHs that makes the experience more engaging. Vourvopoulos et al. proposed a brain-computer interface system where the user can navigate non-invasively its avatar inside ancient Rome and can interact with other DHs.[27] A similar example is the one of De Paolis et al. but regarding a town of the Middle Ages.[28] Jang et al. with their game called Muru in Wonderland approached children motivating them to learn the history of the city Gwangju.[29] Another serious learning-based game is the Hippocratica Civitas game where users visit the thermae of San Pietro and the Palazzo Fruscione in Salerno, and they are asked to solve a puzzle.[30] Recently, Isa et al. developed a serious game to preserve the brassware of Terengganu, which is becoming extinct due to mainly lack of apprentice and interest from the young generations.[31]

The affective and emotional impact of virtual characters in such contexts have ready been examined, highlighting the level of engagement and persuasiveness the former can achieve.[23] In general, it has been argued that digital humans in such roles can stimulate the attention and the involvement of users, also enhancing the level of learning.[22] Museum's approach to storytelling has been evolved and it follows the needs and expectations of the users.[32]

2 | THE MAKING OF THE VIRTUAL CRAFT WORKERS

Traditional crafts are perhaps the most tangible manifestation of intangible cultural heritage (UNESCO). The use of animated DHs is fundamental when dealing with intangible cultural heritage[13] as this type of heritage is often related to human actions, skills, and knowledge which is difficult to describe and represent utilizing texts or photos. Due to technological advancements, motion capture techniques, applied to the artisans while producing their crafts, bring a safeguarding possibility to the know-how[33] and a new dimension in communicating skills and knowledge onto others.[34] Indeed, the visualization of craft processes within inhabited virtual environments increases the usability and educational value of craft representation.[35] The making of this virtual representation takes into consideration motivations and constraints. One part is linked to the visual communication and the user's requirement while the other is dealing with the limitations inherent to the visualization platform.

This section details the most important tasks involved in the making of and the design of DHs, reenacting the process of making a carafe Bontemps' style, the mastic cultivation, and the silk weaving. These examples are taken from the work carried out in the framework of the European research project Mingei.[5,6] It describes the different tools and methods used for achieving the desired results for each craft representation.

2.1 | Character creation

The design of the character starts with collecting the sources and references for inspiration and idea generation that helped in the creation of the desired overall impression. Looking at the case of the mastic case study, we worked closely with the heritage partner to understand the role of the practitioners and acquire the relevant material for creating DHs.

The main objective of the partner was to enrich an area of the Chios Mastic Museum which is dedicated to the old factory of the Chios Gum Mastic Growers Association, and it consists of old machines that the association used for processing mastic until the 1980's. The role of the DHs is to show how it was to work in the old factory of the association by adding in the exhibition the human factor and experience.

For the creation of the DH workers, the heritage partner provided a detailed description of fictional exemplary workers of the factory based on archives of oral testimonies of people who worked at the association. The descriptions contained background information about their childhood, education, personal history, age, clothing, work experience and so forth. More precisely, for the creation of the DH workers' clothing, the partner prepared a selection of photographs of workers of the association for us to have direct visual information according to their age and working post (i.e., the mechanic wore a specific uniform whereas women workers either wore their clothes in some posts or had working dresses in other posts).

This material came directly from the association's archive which the partner holds and manages. Another visual material was also used through snapshots from a Greek film named "The Tree We Hurt," which was filmed in Chios in 1987 by the Greek director Dimos Avdeliodis. The film depicts the local society of the mastic villages in southern Chios and served as an additional reference of how women dressed in their everyday life at that time.

These references are meant to inspire the esthetic of what we are working on and capture the feeling we want for our DHs (Figure 1). After having gathered all the cultural and historical information and sources, the preparation of the 3D DHs with their corresponding garments and accessories has been carried out according to the specific restrictions relevant to the different VR applications that have been developed in the framework of the anonymous project.

2.2 | 3D modeling of the DHs

This section gives an overview of the different necessary phases for the creation and the completion of the pipeline, from modeling the DH to exporting the animated model toward the Unity 3D platform which is used in our case study. The definition of the 3D meshes and the design of the skin surfaces of the DH body models have been conducted employing a customized pipeline that uses different commercial solutions.[36–39] The latter allows automatic generation methods, coupled with manual editing and refining.

Two types of DHs have been created for our study: realistic talking avatars, which are defined as storytellers for the on-site exhibition with full body and facial animation capabilities, and low-resolution animated avatars for mobile applications.

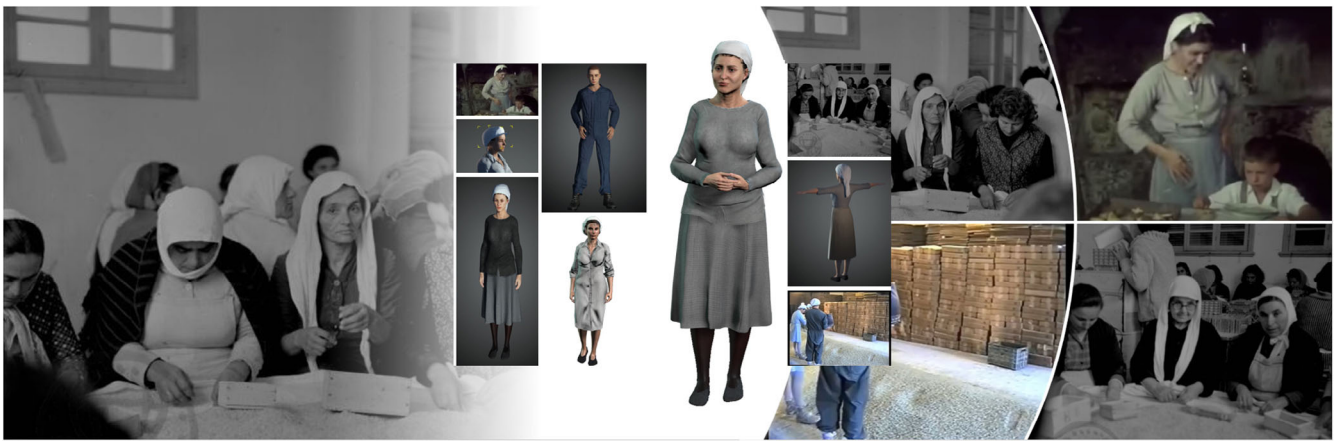

FIGURE 1 Creating the look of the virtual workers according to the background references and sources

The DHs for the mobile application are created with a combination of different 3D software. Adobe Fuse CC/Mixamo is used for creating the body character (Figure 2), the clothes, the hair, and the rigging. The generated model is then imported into Autodesk 3DS max for geometry optimization and single mesh conversion. Manual methods, by using the editable poly tools, are preferred. They allow us to keep the regularity of the topology while the automatic methods generate a mesh geometry which is not suitable for skin deformation, nor for a regular UV texture map generation.

The DHs dedicated to conversational agents, are meant to be part of the storytelling scenario of the mastic factory's machine area. They are composed of eight clothed DHs, fully rigged and with facial animation (Figure 3).

Our approach utilizes a full character creation solution software for creating bodies, coupled with 3D modeling software for clothes and accessories. Such a combination has several advantages, like the fully rigged model, ready for facial blend shapes which is required in our case for the storyteller DH. Moreover, the wide range of customization points for modifying the 3D model makes the creation of many unique DH easy and different bodies can be generated easily and modified to proportions that fit the Silhouette of the desired concept. The requirement for the blend shape system concerning the facial animation was a little tricky as it had to be combined with external mocap files in BVH format for the

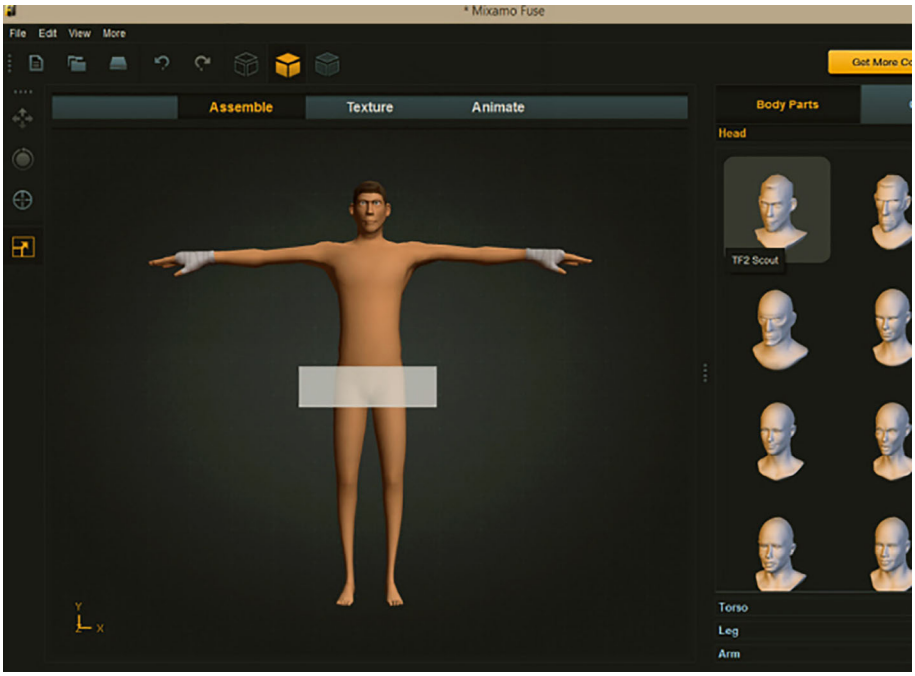

FIGURE 2 Body creation with fuse solution

FIGURE 3 Fully rigged female avatar with face and body control—CC3/Reallusion solution

animation of the body. Toward this goal, the reallusion digital human pipeline[37] fits all these requirements since it provides a motion controller for face, body, and hands and is fully compatible with the game engine for real-time applications. Once the character is created, it can be directly exported to iClone[39] for motion retargeting and editing.

2.3 | Virtual 3D garment design

The collected data, such as images and written descriptions, are used as a base for the design of the different types of clothes and accessories according to the different scenarios. The method of creating the garments depends on the complexity of the models. Some of them are created from existing cloths libraries (Figure 4) and they are transformed and adapted by editing manually the 3D mesh, while others are modeled from scratch in 3DS max by using cloth simulation tools (Figure 5).

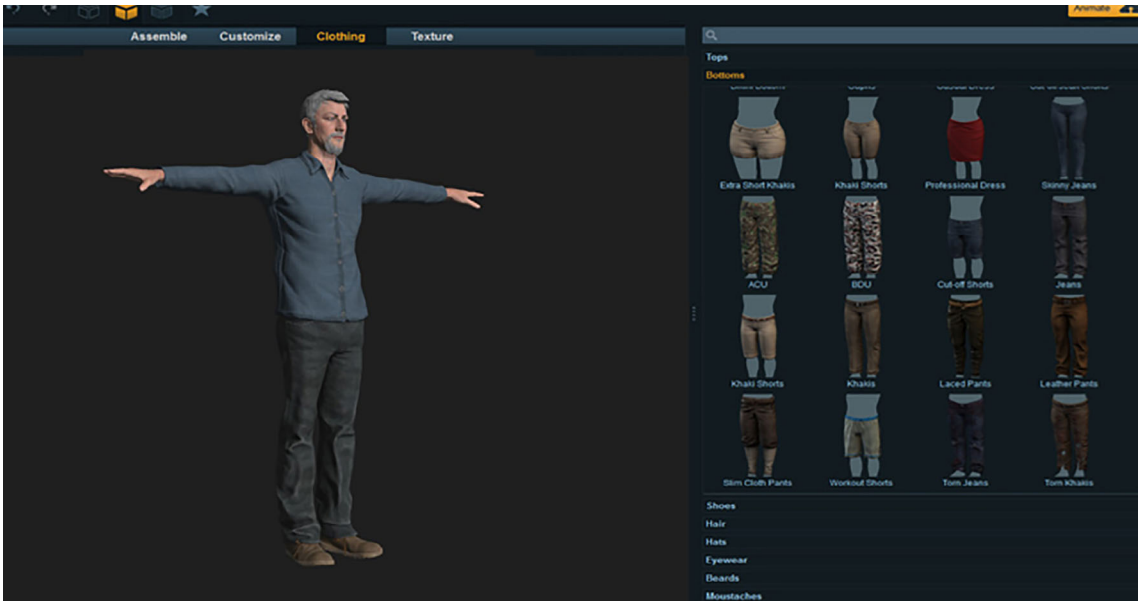

FIGURE 4 Cloths from existing libraries

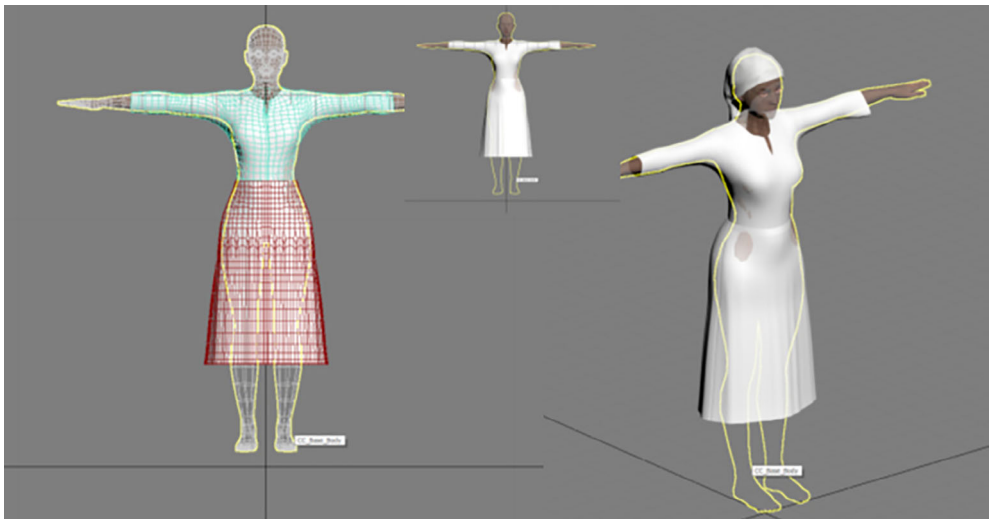

FIGURE 5 Cloths manual modeling

The obtained model is then imported into the character creator software[30] and conformed to our rigged DH (Figure 6). To avoid the body character breaking through the clothing mesh, the conforming tools allow the automatic calculation of collision by iteration which resolves most of the issues. For hard-to-fix issues, manual mesh editing ability is used (Figure 7).

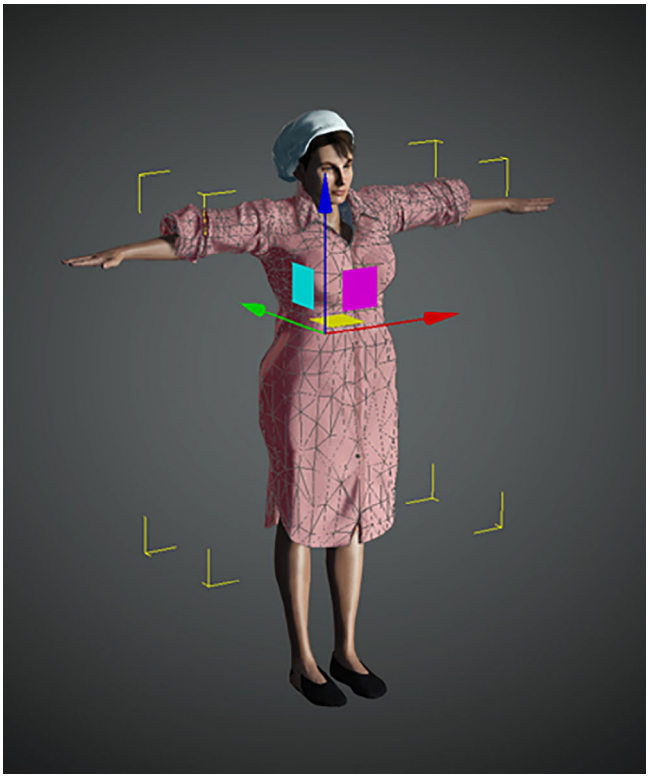

FIGURE 6 Placing and conforming an imported 3D mesh of a dress

FIGURE 7 Tuning the skinning to fix collision issues between the layers

2.4 | Animating the DH

2.4.1 | Rigging

Since the generated models are automatically rigged either by Mixamo[36] or by CC3,[38] an additional checking is needed to make sure that the rigging is applied correctly, and the bones are well adjusted to the 3D body. Hence, after the conforming step of the clothes and accessories, posable functionalities are used to test the skinning values and the collision between the body and the garment or accessory (Figure 8).

2.4.2 | Animating VHs

To create the animation files that are applied to the digital humans, a Motion Capture system[40] has been used. The output BVH files have been imported into iClone[39] software via the 3DXchange[37] pipeline to be edited, refined, and then applied to the virtual characters. 3DXchange pipeline is important since it allows the conversion of the imported external files (BVH) into a nonstandard structure compatible with the hierarchy used for the rigging, and compatible with the unity game engine (Figure 9).

Once converted, the animation file is imported into iClone[39] and automatically loaded into the DH (Figure 10). At this step, the motion editing panel will be used to perform the motion retargeting, taking the advantage of the human IK and the keyframing options for modifying all the body parts of the character.

3 | RESULTS

Based on a creation process optimized for real-time visualization (Figure 11), different DHs were created for each of the craft case studies: eight DHs for the mastic craft (Figure 12), one for the glass craft, and one for the silk craft. More than 15 movements for each craft have been produced and adapted to the DHs. Motion capture files were used to animate the DHs, the recorded movements were segmented into sub processes actions that correspond to a specific task presented in a certain order to enable the visitors to follow and understand the production process of each craft. The digital workers are also narrating their story and their function as part of the factory's production process, offering information about the machines used for the production process.

FIGURE 8 Posable functionalities to test the skinning values

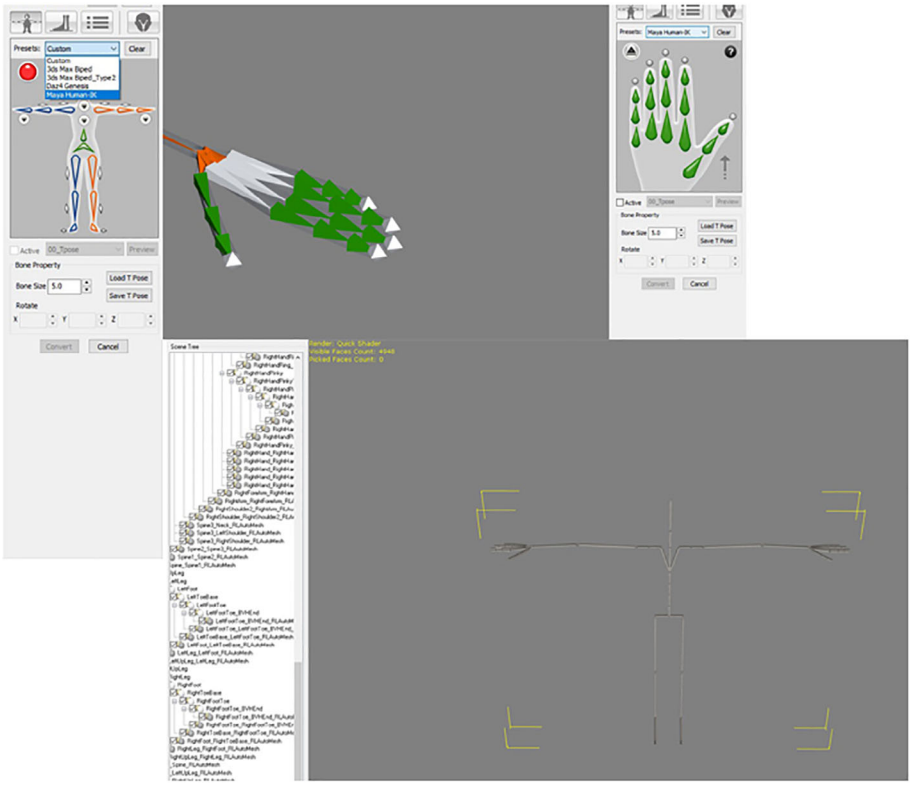

FIGURE 9 Converting the BVH structure to the nonstandard skeleton in 3DXchange tool

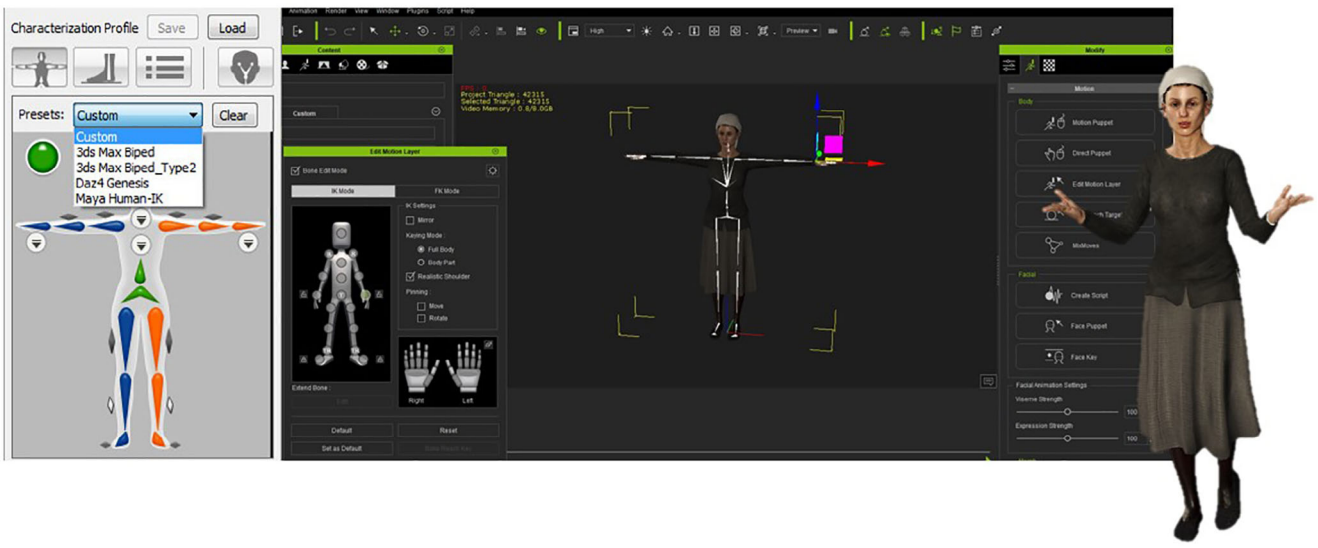

FIGURE 10 Motion editing and retargeting

3.1 | AR storytelling experience

In the context of Mingei project, an AR application has been built to augment exhibits of the Chios Mastic Museum with DHs. DHs were created following the methodology proposed in this article. Viewing the machines through the museum's tablets, the visitors can see DHs standing next to them, ready to share their stories and explain the functionality of the

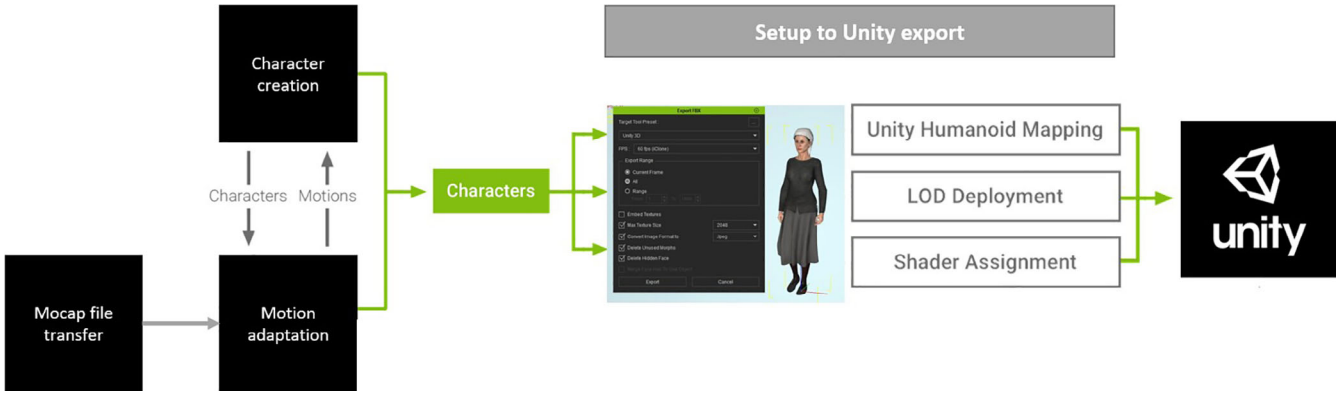

FIGURE 11 The overall workflow we adopt

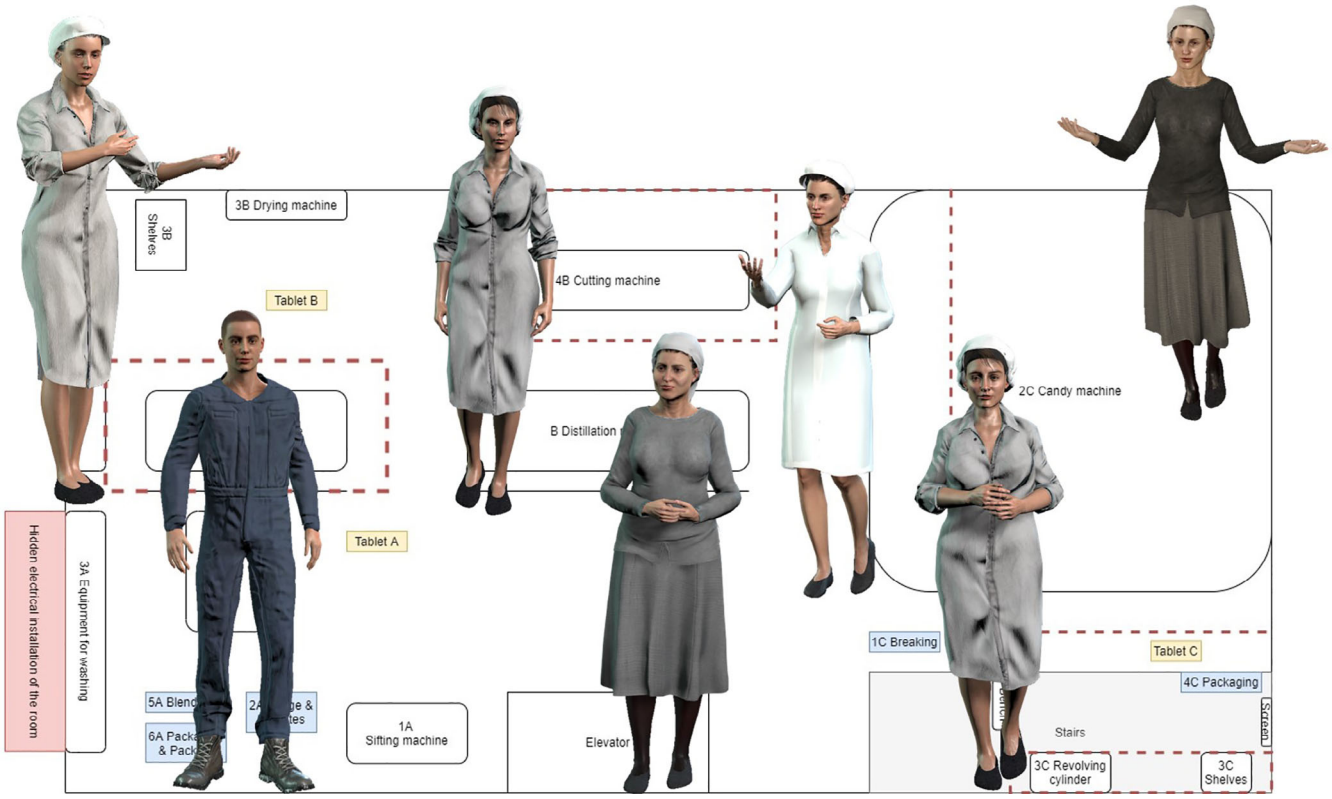

FIGURE 12 Workers DHs presenting the mastic factory

respective machines. The exact DH's location is instantiating by calibrating the tablets through special markers located at predefined spots in the exhibitions as presented in Figure 13.

When operated each of the tablets except from the localization feature described above uses plane detection from the image acquired through its camera to determine the positioning of points of interest and the scaling to be applied when presenting the DH. Furthermore, adaptations are done to the lighting of the DH to be visually close to the ambient light of the scene. An example of applying these transformations to make the DH appearing in front of persons being in a room are presented in Figure 14. Calibration occurs only once and when completed the tablets can be transferred to any location within the exhibition and operate seamlessly.

Overall, four tablets have been included in the exhibition space of the museum each on targeting a different museum location. An example of points of interest appearing from within the table screen is presented in Figure 15. In Figure 16 a screenshot of the application running within the museum space is shown.

FIGURE 13 Visual markets in the exhibition space and calibration

FIGURE 14 Plane detection, scaling, and lighting adjustment

FIGURE 15 Points of interest in the exhibition space

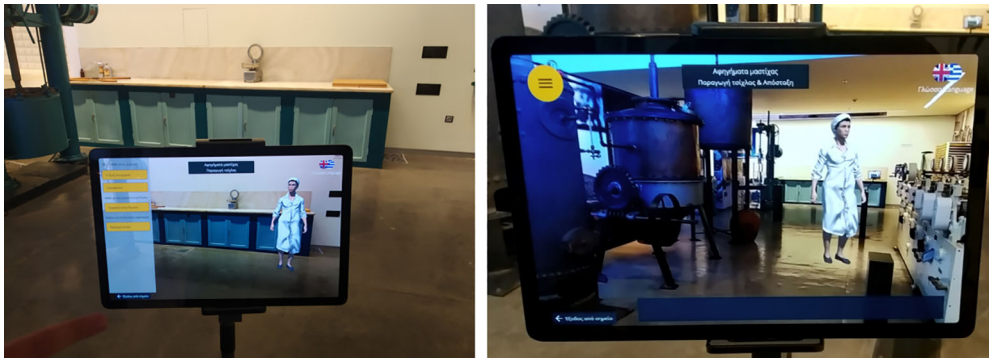

FIGURE 16 DHs narrating stories in the exhibition space

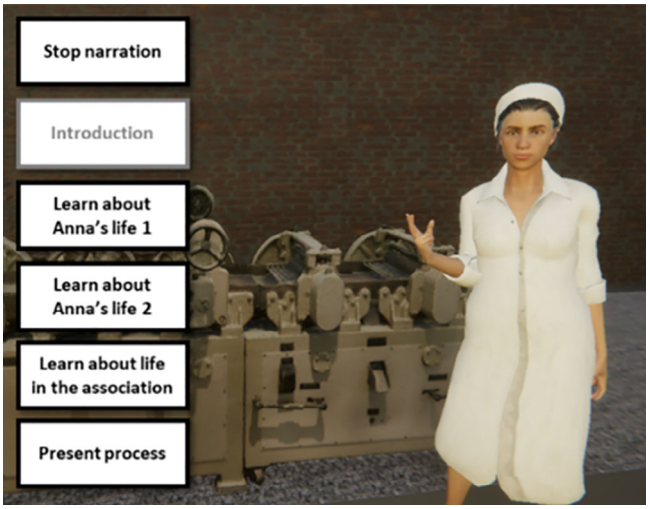

FIGURE 17 VHs narrating Mingei stories and demonstrating the relative processes

3.1.1 | The virtual factory experience

The virtual factory experience occurs in a 3D representation of an old mastic factory, where visitors can discover the machines met in the chicle and mastic oil production line and interact with VHs standing before them. Each machine carries out a specific task in the mastic chicle/oil production line. They have been reconstructed from the machines that are exhibited in the Chios Museum; the machines were thoroughly scanned using a handheld trinocular scanner. Finally, the 3D data were further processed using the blender 3D creation and editing software.[41] Overall, seven machines were reconstructed, namely, (i) the sifting machine, (ii) the blending machine, (iii) the cutting machine, (iv) the candy machine, (v) the revolving cylinder, (vi) the printing machine, and (vii) the distillation machine. All of them are met in the chicle production line, except the distillation machine that is used for producing mastic oil. The 3D model of the factory building was initially created in Unity and then imported in blender for further processing (e.g., windows and doors were cut, and a high dynamic range (HDR) environment texture was used, to provide ambient light in the scene). We have used Unity 2020 with the high-definition rendering pipeline (HDRP). We have used the same DHs as the ones in the AR application. Each DH is placed next to its respective machine and is ready to explain the functionality of the machine, explain how the process step was performed at the factory before and after the machine acquisition, and narrate stories about their personal and work lives (Figure 17).

4 | CONCLUSION

In this article, we have presented a heritage craft case study where DHs have been created to be used for preserving cultural knowledge and for giving a consistent simulation of different craft processes.[4] These craft processes have been conveyed

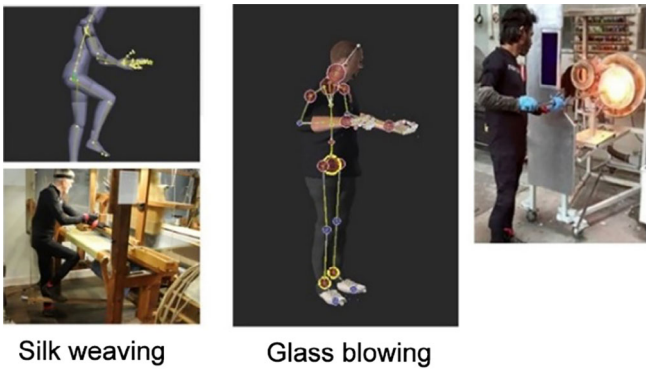

FIGURE 18 Comparative issues: real versus virtual after mocap transfer

from family to family over the years and thus their representation and preservation are important. The existence of DHs enhances this effort by providing additional information and motivation to users.

Two types of DHs were created according to the needs of the project scenario: realistic talking DHs, acting as storytellers for the exhibition sites, with full body and facial animations, and low-resolution DHs for the online version of the mobile application. The choice of the proper software used for each type of DHs was made based on the final goal and the capabilities that DHs needed to have.

Virtual restitution has required accurate choices for each phase of the modeling, texturing, and special attention and must be always used when the models are prepared for real-time simulations. Furthermore, reliable source data are important for a historically and scientifically correct and accurate restitution. Comparative issues are also necessary when the restitution is targeting intangible heritage such as gestures and motions (Figure 18). Such virtual heritage simulations bring a new dimension in communicating skills and knowledge, becoming a fundamental aspect for the full understanding of the historical and social development of vast communities.

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REFERENCES

1. Machidon OM, Duguleana M, Carrozzino M. Virtual humans in cultural heritage ICT applications: a review. J Cultural Heritage. 2018;33:249–60.
2. Maïm J, Haegler S, Yersin B, Mueller P, Thalmann D, Van Gool L. Populating ancient Pompeii with crowds of virtual romans. Proceedings of the 8th International Symposium on Virtual Reality, Archeology and Cultural Heritage-VAST (No. VRLAB-CONF-2008-151); 2007.
3. Tan BK, Rahaman H. Virtual heritage: reality and criticism, CAAD Futures, 2009. p. 143–56.
4. Mingei Project's Website; 2021. Available from: https://www.mingei-project.eu/.
5. Zabulis X, Meghini C, Partarakis N, Beisswenger C, Dubois A, Fasoula M, et al. Representation and preservation of heritage crafts. Sustainability. 2020;12:1461. https://doi.org/10.3390/su12041461
6. Zabulis X, Meghini C, Partarakis N, Kaplanidi D, Doulgeraki P, Karuzaki E, et al. What is needed to digitise knowledge on heritage crafts? Mem Rev. 2019;4:1.
7. Feng A, Casas D, Shapiro A. Avatar reshaping and automatic rigging using adeformable model, in: Proceedings of the 8th ACM SIGGRAPH Conference on Motion in Games. New York, NY: ACM; 2015. p. 57–64.
8. Sénécal S, Cadi N, Arévalo M, Magnenat-Thalmann N. Modelling life throughtime: cultural heritage case studies in mixed reality and gamification for cultural heritage. Springer International Publishing; 2017. p. 395–419. https://doi.org/10.1007/978-3-319-49607-8_16
9. Partarakis N, Zabulis X, Antona M, Stephanidis C. Transforming Heritage crafts to engaging digital experiences; 2020.

10. Foni A, Papagiannakis G, Magnenat-Thalmann N. Virtual hagia sophia: restitution, visualization and virtual life simulation Proceedings of the UNESCO World Heritage Congress; Vol. 2, 2002.
11. Papagiannakis G, Magnenat-Thalmann N. Mobile augmented heritage: enabling human life in ancient pompeii. Int J Archit Comput. 2007;5(2):396–415.
12. Vlahakis V, Ioannidis M, Karigiannis J, Tsotros M, Gounaris M, Stricker D, et al. Archeoguide: an augmented reality guide for archaeological sites. IEEE Comput Graph Appl. 2002;22(5):52–60. https://doi.org/10.1109/MCG.2002.1028726
13. Bogdanovych A, Rodríguez JA, Simoff S, Cohen A, Sierra C. Developing virtual heritage applications as normative multiagent systems. Proceedings of the International Workshop on Agent-Oriented Software Engineering. Berlin Heidelberg: Springer; 2009. p. 140–54.
14. Kennedy S, Fawcett R, Miller LD, Sweetman R, Field A, et al. Exploring canons cathedrals with open virtual worlds: the recreation of St Andrews cathedral, StAndrews day, 1318 Digital Heritage International Congress (Digital Heritage). IEEE; 2013. p. 273–80.
15. Vosinakis S, Avradinis N. Virtual agora: representation of an ancient Greek agora in virtual worlds using biologically-inspired motivational agents. Mediter Archaeol Archaeom. 2016;16(5):29-41.
16. Papagiannakis G, Foni A, Magnenat-Thalmann N. Real-time recreated ceremonies in VR restituted cultural heritage sites. Proceedings of the CIPA XIXth International Symposium; 2003:30.
17. Carrozzino M, Lorenzini C, Evangelista C, Tecchia F, Bergamasco M. AMICA: virtual reality as a tool for learning and communicating the craftsmanship of engraving digital heritage. IEEE; Vol. 2, 2015. p. 187–8.
18. Barreau JB, Nouviale F, Gaugne R, Bernard Y, Llinares S, Gouranton V. An immersive virtual sailing on the 18th-century ship Le Boullongne. Presence Teleoperators Virtual Environ. 2015;24(3):201–19.
19. Kim LC, Lam TK, Chee CY. A multi-modal virtual walkthrough of the virtual past and present based on panoramic view, crowd simulation and acoustic heritage on mobile platform. Int J Comput Electr Automat Control Info Eng. 2016;10(10):1780–90.
20. Chittaro L, Ieronutti L, Ranon R. Navigating 3D virtual environments by following embodied agents: a proposal and its informal evaluation on a virtual museum application. Psychol J. 2004;2(1):24–42.
21. Rodriguez-Echavarria K, Morris D, Moore C, Arnold D, Glauert J, Jennings V. Developing effective interfaces for cultural heritage 3d immersive environments. Proceedings of the 8th International conference on Virtual Reality, Archaeology and Intelligent Cultural Heritage, Eurographics Association; 2007. p. 93–9.
22. Carrozzino M, Colombo M, Tecchia F, Evangelista C, Bergamasco M. Comparing different storytelling approaches for virtual guides in digital immersive museums. Proceedings of the 5th International Conference on Augmented Reality, Virtual Reality and Computer Graphics; 2018. p. 292–302.
23. Sylaiou S, Kasapakis V, Gavalas D, Dzardanova E. Avatars as storytellers: affective narratives in virtual museums. Pers Ubiq Comput. 2020;24:1–13.
24. Martínez B, Casas S, Vidal-González M, Vera L, García-Pereira I. Tinaj AR: an edutainment augmented reality mirror for the dissemination and reinterpretation of cultural heritage. Multimodal Technol Interact. 2018;2(2):33.
25. Duguleană M, Briciu VA, Duduman IA, Machidon OM. A virtual assistant for natural interactions in museums. Sustainability. 2020;12(17):6958.
26. Testón AM, Muñoz A. Digital avatars as humanized museum guides in the convergence of extended reality. MW21: MW 2021. Published February 1, 2021. Consulted June 24, 2021.
27. Vourvopoulos A, Liarokapis F, Petridis P. Brain-controlled serious games for cultural heritage. Proceedings of the 2012 18th International Conference Virtual Systems and multimedia (VSMM). IEEE, 2012. p. 291–8.
28. De Paolis LT, Aloisio G, Celentano MG, Oliva L, Vecchio P. Experiencing a town of the middle ages: an application for the edutainment in cultural heritage. Proceedings of the Communication Software and Networks (ICCSN) IEEE 3rd International Conference. IEEE, 2011. p. 169–74.
29. Jang SA, Baik K, Ko KH. Muru in wonderland: an immersive video tour with gameful character interaction for children. Proceedings of the 2016 ACM Conference Companion Publication on Designing Interactive Systems. New York, NY: ACM, 2016. p. 173–6.
30. Andreoli R, Corolla A, Faggiano A, Malandrino D, Pirozzi D, Ranaldi M, et al. A framework to design, develop, and evaluate immersive and collaborative serious games in cultural heritage. J Comput Cultural Heritage (JOCCH). 2017;11(1):1–22.
31. Isa WMW, Zin NAM, Rosdi F, Sarim HM. Serious game design for Terengganu brassware craft heritage. Proceedings of the 2019 IEEE Conference on Graphics and Media (GAME). IEEE; 2019. p. 13–7.
32. Wyman B, Smith S, Meyers D, Godfrey M. Digital storytelling in museums: observations and best practices. Curator Museum J. 2011;54(4):461–8.
33. Dimitropoulos K. Capturing the intangible an introduction to the i-treasures project. Proceedings of the 2014 International Conference on Computer Vision Theory and Applications (VISAPP); 2014. p. 773–81.
34. Carrozzino M, Lorenzini C, Duguleana M, Evangelista C, Brondi R, Tecchia F, et al. An immersive VR experience to learn the craft of printmaking. In: De Paolis L, Mongelli A, editors. Augmented reality, virtual reality, and computer graphics. AVR 2016. Lecture notes in computer science. Volume 9769. Cham: Springer; 2016. https://doi.org/10.1007/978-3-319-40651-0_30
35. Stefanidi E, Partarakis N, Zabulis X, Papagiannakis G. An approach for the visualization of crafts and machine usage in virtual environments. ACHI 2020 Proceedings of the 13th International Conference on Advances in Computer-Human Interactions; 2020.
36. Mixamo. Available from: https://www.mixamo.com/#/. Accessed May 2021.
37. Reallusion. Available from: https://www.reallusion.com/. Accessed May 2021.
38. Reallusion, Character creator. Available from: https://www.reallusion.com/character-creator/. Accessed May 2021.
39. Iclone. Available from: https://www.reallusion.com/iclone/. Accessed May 2021.

40. Rokoko. Available from: https://www.rokoko.com/. Accessed May 2021.
41. Blender. Available from: https://www.blender.org/. Accessed May 2021.

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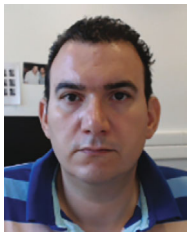
Nadia Magnenat Thalmann has pioneered research into Virtual Humans over the last 30 years. After being a Professor at University of Montreal in Canada, she moved in 1989 to the University of Geneva where she founded the interdisciplinary research group MIRALab. She has published landmark papers on the modeling of 3D faces and bodies as well as pioneered the field of physical modeling of clothes. Recently, she advanced the field of social robotics with her humanoid robot Nadine that can show emotions, speak naturally and remember facts and emotions. She has received many Awards and several honorary doctorates. Her CV as well as her rich filmography can be seen on https://en.wikipedia.org/wiki/Nadia_Magnenat_Thalmann.

Danae Kaplanidi is an independent socio-cultural anthropologist based in Greece. She studied Cultural Technology and Communication (BA) at the University of the Aegean and Cultural and Social Anthropology (MA) at the University of Vienna. Recently, she collaborated with the Piraeus Bank Group Cultural Foundation (Athens, Greece) in the EU's H2020 research and innovation program Mingei–Representation and Preservation of Heritage Crafts.



Nikolaos Partarakis is a post-doctoral researcher at ICS-FORTH. He received a Diploma in Computer Science, an M.Sc. in Information Systems and a Ph.D. in Ambient Intelligence technologies in 2004, 2006, and 2013, respectively, from the University of Crete, Greece. He is member of the Human Computer Interaction Laboratory of ICS-FORTH since 2003, former leader of the Accessible Web development group, and currently actively engaged in X-Reality visualizations and interactive experiences for the Cultural Heritage (CH) sector. Furthermore, he is an active contributor of the Ambient Intelligence Program of ICS-FORTH since its establishment.

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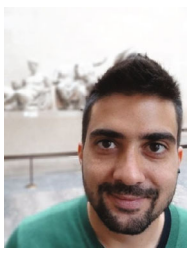

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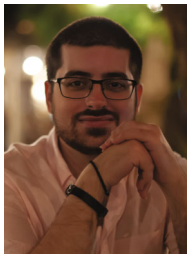

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