Transferring Traditional Crafts from the Physical to the Virtual World: An Authoring and Visualization Method and Platform

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Visualizing human motion is a topic that has gained increasing attention in the domain of cultural heritage, due to the need for capturing intangible dimensions, existing for example in theatrical performances, dances, and crafts. In this respect, virtual humans are typically employed to re-enact human motion, executing movements reproduced through predefined animations, or physics simulation engines. In the case of traditional crafts, a defining point is how to model the interaction of virtual humans with craft-related objects and how to transfer it from the physical to the digital world. Toward a more effective and generic modeling and visualization of the interaction of humans with tools and machines utilized in crafts, this article proposes a novel methodology for the modeling and visualization of crafts and presents a platform enabling the authoring and visualization of craft processes. We contribute a way of visualizing craft processes within virtual environments, aiming to increase the usability of craft representation. As an example, we present and analyze the case of the craft of weaving with the use of a loom.

CCS Concepts: • **Human-centered computing → HCI theory, concepts and models**; **User studies**; Interaction design; **Visualization**; **Human computer interaction (HCI)**; *HCI design and evaluation methods*; *Usability testing*; • **Computing methodologies → Computer graphics**; Motion capture;

Additional Key Words and Phrases: Traditional crafts, cultural heritage, motion visualization, authoring tool, loom weaving

ACM Reference format:
Evropi Stefanidi, Nikolaos Partarakis, Xenophon Zabulis, Ilia Adami, Stavroula Ntoa, and George Papagiannakis. 2022. Transferring Traditional Crafts from the Physical to the Virtual World: An Authoring and Visualization Method and Platform. *J. Comput. Cult. Herit.* 15, 2, Article 35 (April 2022), 24 pages.
https://doi.org/10.1145/3484397

This work was supported by the EU Horizon 2020 Innovation Action under grant agreement no. 822336 (Mingei).
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1556-4673/2022/04-ART35 $15.00
https://doi.org/10.1145/3484397

1 INTRODUCTION

In the current fast-paced technological world, industrialization and globalization have substantially benefited societies; however, they have also challenged **Traditional Crafts (TCs)** in an unprecedented manner. A craft is an activity performed by humans, including the usage of tools and/or machines. Crafts comprise a diverse range of human activities, expressing the author's creativity, conceptual ideas, or technical skill. Realizing the need for preserving TCs, *traditional crafts* have been defined as "practices which employ manual dexterity and skill and an understanding of traditional materials, design and techniques, and which have been practiced for two or more successive generations" [8]. At the same time, practicing a TC is considered a form of **Intangible Cultural Heritage (ICH)**, featuring numerous dimensions, such as dexterity, know-how, and skilled use of tools.

The significance and urgency of **Cultural Heritage (CH)** preservation has motivated many digitization efforts. To date, most of the digitization efforts have regarded static objects and focused on capturing the visual appearance of objects, collections, or sites. With regard to the intangible dimensions, human motion plays a particularly important role, as it regards the actual execution of the craft by the practitioner, thus constituting a central point in the experience and delivery of the craft. Moreover, the role of the practitioner should be valued—that is, the presentation of a TC needs to be closely tied to the people practicing it and accurately represent the movements of the practitioners, which is the essence of the craft. Thus, the appropriate digitization and simulation of the person performing the craft is necessary, because crafts are practiced by humans and machines and tools are designed for use by them. **Virtual Humans (VHs)**, which are 3D avatars with human-like appearance and characteristics, present a solution in this direction, as outlined in our previous work [52, 69, 70]. The digital presentation of crafts via VHs, as compared for example to video, allows for flexibility and multimodality, as we can visualize different angles, focus on the hands of the practitioner, perform analytics on the data, be immersed in a workshop with the practitioner, and so forth. In addition, an avatar type of solution can be used in many contexts, and human motion can be recorded once and used in many scenarios.

This work supports the wider vision of representation and preservation of TCs, exploring the possibilities of representing and making accessible both tangible and intangible aspects of craft as CH. This work builds upon the capture of the motion and tool usage of TC practitioners to illustrate and preserve skill and tool manipulation. Aiming to help in the preservation, dissemination, and sustainability of TCs, this article proposes a novel methodology for their visualization in **Virtual Environments (VEs)**, within which the practitioner is represented by a VH, and objects through their 3D models. Practitioner actions are reproduced by animating the VH based on motion capture (MoCap) recordings. At the center of the proposed approach is a conceptual, twofold decomposition of craft processes into actions, and of machines into functional components that comprise their physical interface. Using this approach, a multitude of craft instances and machines can be modeled by decomposing crafts to simple motion-driven operations, and machines to **Fundamental Machine Components (FMCs)**. Furthermore, we present MoViz, an authoring and visualization tool to support the proposed methodology, allowing users to create and experience craft usage scenarios. In more detail, MoViz provides users with an authoring tool to create their own scenes, where actions and machine parts are assigned to VHs (in the form of 3D avatars), so as to create **Motion Vocabularies (MVs)**, representing the craft process; in this way, users can re-create, re-enact, and represent available crafts in VEs. Moreover, MoViz allows the playback of these scenes, by simulation in a VE (3D) or in **Virtual Reality (VR)**, where a training mode is also available. Thus, our contribution lies in the aforementioned process, which aims to deliver an efficient way of visualizing craft processes within VEs, targeted to increasing the usability and educational value of craft representation, and opening the way to a variety of new applications for craft presentation, education, and thematic tourism, based on the value of tradition and ICH. In the context of this article, the focus lies on the craft of loom weaving, a craft bringing together researchers and practitioners from many fields, including archaeologists, anthropologists, artists, designers, heritage workers, museum curators, craftspeople, business, and enterprise owners. However, the MoViz platform is generic, for representing any craft, after its decomposition according to our technique.

The rest of the article is structured as follows. Section 2 presents the state-of-the-art and related work, whereas Section 3 analyzes the proposed methodology. In Section 4, the developed methodology is applied for creating MoViz, the authoring and visualization platform for craft experiences. Section 5 reports a user-based evaluation experiment that was conducted for assessing the usability of the MoViz platform, whereas Section 6 presents a discussion and our conclusions. Finally, Section 7 discusses planned future work.

2 BACKGROUND AND RELATED WORK

In the next sections, we elaborate on background theory, on which our work was based and which motivated our approach, as well as related work. In particular, we discuss (1) previous efforts in the representation and preservation of TCs, (2) approaches for motion visualization, (3) previous work on authoring tools for experiences and tool usage demonstration, (4) how VR has been employed for training and education, (5) how VHs have been used as embodied agents, (6) research work regarding the modeling and affordances of the interaction between VHs and objects, and (7) previous approaches with regard to virtual heritage.

2.1 Representation and Preservation of TCs

The representation of TCs includes tangible (e.g., tools, machines, and craft materials) and intangible (e.g., dexterity, skill, tradition, and knowledge) dimensions, both indispensable for accurate representations. Regarding tangible dimensions of CH, a lot of work has already been performed, mainly in the direction of assets' digitization, as the representation and preservation of TCs with the aid of technology has been closely coupled with their digitization. The most common digitization modality is photographic documentation, for digitization of 2D (e.g., documents, paintings) or 3D (e.g., materials, objects) items. Besides digitizing artifacts and objects, efforts have also been made toward the digitization of humans, employing RGB and RGBD cameras that are suitable for VR, **Augmented Reality (AR)**, or **Mixed Reality (MR)** experiences and modern software techniques [50].

Regarding the intangible dimensions of TCs, a comprehensive picture of the studied assets is missing: the representations need to include both visual and structural information, as well as the stories and experiences tied to the crafts with their cultural, historical, and social context, and their evolution over time. A key component of many forms of ICH is human motion, which has been the focus of ICH digitization with research efforts targeting singing, dancing, theatrical performances TCs, and so on [14, 20–22]. Digitization of human motion has been achieved via a number of methods, which vary in terms of intrusiveness (having to wear an apparatus or requiring an installation), and robustness to occlusions when visual components are employed. In particular, two main method categories are motion capture, which requires human subjects to wear technological items [10], such as markers or sensors, and visual tracking methods, which do not impose such requirements. Regardless of the technology used to acquire the recordings, the resulting data is a chain of coordinate frames and their differences in position and orientation.

2.2 Motion Visualization

Regarding 3D motion visualization, various approaches have been used in different domains. "Key Probe" is a key frame extraction technique, relying on an appropriate algorithm for rigid-body and soft-body animations, which converts a skeleton-based motion or animated mesh to a key frame–based representation [32]. Another methodology is "action snapshot," which enables selecting a representative moment from a performance and automates the process of generating meaningful snapshots, by taking dynamic scenes as input and producing a narrative image as output [64]. Regarding human motion visualization in particular, a prevalent technique in human motion visualization is "action summarization," as it can produce motion effects in still image frames. "Action synopsis" takes human movements as input, encoded either as MoCap animations or videos, and presents motion in still images [4]. Another approach proposes the creation of compact narratives from videos, by composing foreground and background scene regions into a single interactive image, using a series of spatiotemporal masks [17]. An important parameter in human motion visualization is depth information of animations, which assists summarization of 3D animations in a single image, extracting the most important frames from the animation sequence, according to their contribution to the overall motion gradient [42, 57].

2.3 Authoring Tools for Experiences and Tool Usage Demonstration

One of the key features of authoring tools is enabling users with little or no technical expertise to utilize them. The software architecture of such a system empowers users with the necessary tools for content creation, by (1) supporting them with intuitive and easy-to-use methodologies (visual scripting, editors), and (2) providing advanced users with enhanced tools to extend the capabilities of the system. Such a tool is M.A.G.E.S. [51], a VR SDK supporting a visual scripting editor, scene customization plugins, custom VR software patterns, and Unity editor tools, for rapid prototyping of VR training scenarios. In addition, it offers ToolManager, a plugin designed for usage and manipulation of tools in VR environments, allowing developers to transform any 3D model of a tool (e.g., pliers, hammer) into a functional and interactive asset in VR applications. Another tool is ExProtoVAR [54], which allows the generation of interactive experiences in AR for designers and non-programmers, without much technical background in AR interfaces. ARTIST [41] is a platform featuring methods and tools for real-time interaction between non-human and human characters to generate reusable, low-cost, and optimized MR experiences, using semantic data from heterogeneous resources.

2.4 VR for Training and Education

Education can benefit from the use of technological tools, rendering the learning process more enjoyable, effective, active, and meaningful, and increasing the interaction and motivation of learners. In particular, VR can successfully be deployed as a training tool, as demonstrated by collaborative VR applications for learning [27], studies on the impact of VR in exposure treatment [9], as well as surveys on human social interaction [49]. VR learning also supports cognitive learning, which is an active, constructive, and long-lasting type of learning [25, 26].

Many existing VR platforms, such as Facebook Spaces, Bigscreen, VRChat, AltpaceVR, and Rec Room, provide VEs to meet and discuss with other users while supporting collaborative mini-games for entertainment purposes; their main focus is on social interaction between the users, thus not addressing training and education. Furthermore, many VR simulators' primary goal is to provide training, neglecting the educational aspect [24]. However, there are various applications focusing on education, such as a virtual art museum for children [33], an immersive learning environment to teach U.S. army soldiers basic corrosion prevention and control knowledge [65], and a CAVE-based system for teaching Mandarin [15]. Other research has focused on analyzing the impact of training while immersed in a VE, as embodiment can have a profound positive impact on learning scenarios: studies have shown that its effective and realistic deployment can positively affect skill transfer during learning in virtual multimodal environments [34]. Moreover, immersive VEs can be beneficial when training motor or spatial activities [59], and the training capabilities of VR simulations can offer skill transfer from VR to real life, reflecting the educational aspect of such systems [6, 31, 56].

2.5 VHs as Embodied Agents

Virtual characters, and particularly VHs, constitute an important aspect of 3D applications, building upon innate familiarity with human-like individuals. We can distinguish two different styles in the representation of VHs—human-like and cartoon-style avatars, each one serving a different purpose and fitting into specific applications. Users can more closely relate to human-like avatars, due to their natural appearance [43]. However, imperfect human-likeness can provoke dislike or strangely familiar feelings of eeriness and revulsion in observers, a phenomenon known as the uncanny valley [47]. Studies suggested that interaction and animation can overcome the valley in affinity due to matching and common human non-verbal cues [58]. In our platform, we use human-like VHs for pursuing a realistic representation of tool and machine usage in the context of TC processes simulated in a VE (e.g., most cartoon-style avatars do not have five fingers, resulting in poor and unrealistic handling capabilities with tools).

In the context of VEs, VHs have already been utilized for explaining physical and procedural human tasks [35], simulating dangerous situations [62] and group and crowd behavior [71], and assisting users during navigation, both by showing the location of objects/places and by providing users with additional information [16]. Although it is not feasible to provide a human tutor for every learner in the real world, embodied agents can aid anyone with access to a computer, enabling individualized instruction for a massive number of learners. In addition, VHs can take the role of museum storytellers, due to their inherent ability to simulate verbal as well as nonverbal communicative behavior, facilitated by multimodal dialogue systems, which extend common speech dialogue systems with additional modalities similar to human-human interaction [61]. However, utilizing VHs as believable dialogue partners encompasses challenges, as it not only requires a reliable and consistent motion and dialogue behavior but also appropriate nonverbal communication and affective behavior. Over the past decade, there has been a considerable amount of progress in creating interactive, conversational virtual agents, including Ada and Grace, a pair of virtual museum guides at the Boston Museum of Science [61], the INOTS and ELITE training systems at the Naval Station in Newport and Fort Benning [13], the SimSensei system designed for healthcare support [19], and the FearNot! application for bullying prevention education [5].

2.6 VH-Object Interaction: Modeling and Affordances

Although human-object interaction has been addressed in the literature (e.g., object recognition and detection [67], action recognition [68]), the research focusing on modeling the interaction between VHs and virtual objects is limited. One of the most relevant works suggests including all the necessary information of how to interact with an object within its description, and facilitates the identification of object interaction features through a respective tool [38]. Building on this idea, Abaci et al. [1] add artificial intelligence planning to the concept, to address adaptation to new situations and solving dynamic problems.

An important aspect to consider when modeling the interaction between virtual agents (humans) and objects is the object's affordances, defined as the intrinsic properties of the object [30]. The notion of affordance is one of the most fundamental concepts in the field of human-computer interaction (HCI), as well as a prevalent research topic in robotics and computer vision. To detect an object's affordances, various approaches have been used, such as inferring them from human demonstration [39], or using attributes for fine (affordance related to core traits of an object, e.g., graspability, rollability) and high-level (e.g., drinkability or pourability of a glass) affordance detection [29]. In the context of this work in the domain of TCs, approaches based on inferring the affordances of objects used in the crafts to be visualized in VEs would not be the best road to follow. TCs entail creativity, and special studying of the way that practitioners interact with each tool and machine part needs to take place. It is therefore essential to involve the practitioner in the process of decomposing the craft to its essential actions and of the machines used in their essential parts. We thus define the affordances of each FMC, allowing replicability of our approach.

2.7 Virtual Heritage

Simulating TCs with the help of new technologies, such as VR, offers new and exciting opportunities for preserving CH by providing the audience with new means to experience TCs [40]. A synonym of *cultural heritage* in VEs is *virtual heritage*, where digital media is used to reconstruct cultural elements from the past and the present [18, 37]. Virtual heritage is propagated via the new available media and technologies, enabling a wider audience to become culturally aware of CH, which is in danger of becoming extinct [12]. With the developed high-performance measurement techniques, realistic digitization of CH assets is facilitated [44]. This digitization of CH allows the creation of dynamic and interactive content, such as 3D video and AR applications, improving the visitors' experience [7]. An example is a methodological design for preservation and promotion of the CH value of traditional Indian art forms [40], focusing on the documentation and translation of a tangible traditional visual paradigm into an easily accessible contemporary virtual paradigm. In the work of Llerena-Izquierdo and Cedeño-Gonzabay [45], the Vuforia development kit is utilized to create a mobile application allowing users to access relevant historical information regarding the cathedral of San Pedro in Guayaquil, visualizing the photogrammetric images in "increasing reality" (a technique incorporating multimedia through markers in AR). Toward a practical pipeline from 3D digitization to an MR visualization of CH assets, Rahaman et al. [55] present a practical workflow that allows non-experts to produce image-based 3D models and share them online, and enables audiences to experience 3D content in an MR environment.

Various approaches for virtual heritage focus on the visualization and simulation of crafts in 3D, MR, AR, or VR environments. For instance, Xu and Xu [66] present a method for demonstrating and training processes of crafts, by constructing an interactive diagram model and simulation training system, and building a craft knowledge database, as well as 3D models for simulation in a 3D VE. Another interesting approach is the "Walkable MxR Map" [7]—interactive, immersive, and walkable maps enabling interaction with cultural content, 3D models, and different multimedia content at museums and heritage sites, utilizing Microsoft HoloLens. Based on the same idea of exploring heritage sites, Mah et al. [46] present a framework for creating virtual tours for the preservation of CH sites, using 360-degree cameras, and incorporating both the physical environment of the site along with the associated intangible and sociocultural elements, derived from interviews and historical archives. Finally, Hanes and Stone [28] promote constrained VEs, where the environment is presented via a series of reduced fidelity 2D scenes without exhaustive detail, claiming that the 3D ones can be costly, whereas the proposed approach is claimed to provide a similar experience of presence and motivation for information.

Overall, various approaches have been developed for motion visualization and virtual heritage, highlighting the importance and timeliness of the topic. However, current approaches are case specific or address heritage assets and sites, but not the entirety of a TC. Moreover, a comprehensive approach that leads to the visualization of crafts in VEs, utilizing the practitioners' real movements, does not currently exist. We therefore aim to fill this gap by proposing an integrated platform for the presentation of crafts in VEs. We argue that our methodology of decomposing (complex) machines into their functional components allows for generalization and facilitates replication. The efficient visualization of TCs can lead to their presentation to the general public in an attractive and engaging way, thus producing numerous benefits to various TCs stakeholders, such as preservation of TCs, enhanced museum and cultural tourism, and awareness of the general public.

3 TRANSFERRING CRAFTS TO THE DIGITAL WORLD: A NEW METHODOLOGICAL APPROACH

We propose a methodology for the transfer of crafts from the physical to the digital world. In brief, a craft can be described as a sequence of potentially interleaved activities, which are carried out by humans, using tools and/or machines. A craft also encompasses the knowledge of the practitioner, in the ways to hold and operate the tools/machines used, as well as the practitioner's motions while performing the craft. To transfer a craft from the physical to the digital world, we need to understand and model the craft components (Figure 1, left). With regard to understanding and modeling tools and machines, our methodology employs background theory regarding object affordances—that is, how humans can hold and operate an object, since this also needs to be transferred from the physical to the digital world, besides the utilized objects. Moreover, we are inspired by the theory of simple machines to introduce our own concept: FMCs, which constitute the functional parts of a tool/machine used in the craft. The following sections present these two background theory aspects.

3.1 Background Theory

3.1.1 Object Affordances. When discussing the operation of a handheld tool, the ergonomics of how to hold and use it play a key role, and thus the need to examine how humans grasp tool handles arises. According to Patkin [53], there are various types of hand grips, and different classifications of them exist. One approach is to classify them in the following six types: power grip, pinch, external precision grip, internal precision grip,

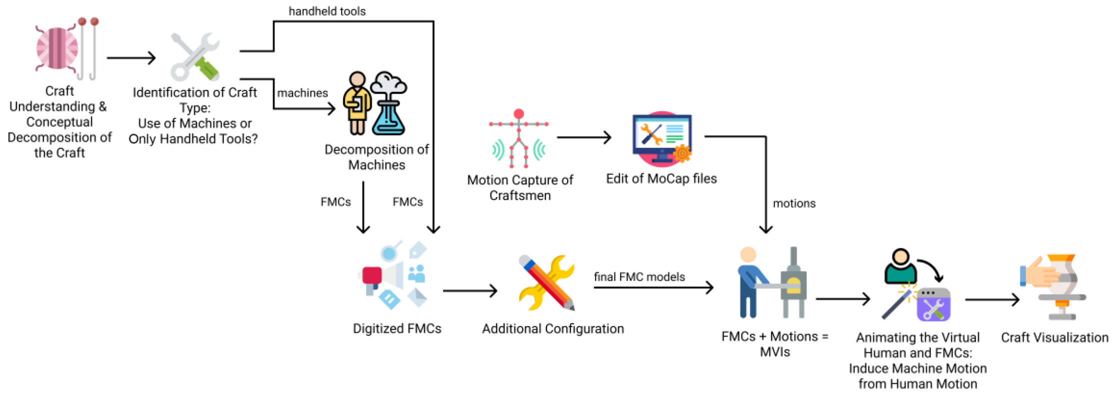


Fig. 1. The proposed methodology for craft visualization.[1]

ulnar storage grip, and other power grips. Therefore, to demonstrate the usage of tools in a correct and accurate manner, guidelines need to be followed regarding their handle design, which also apply to their presentation in VEs. Some of these guidelines include size, which can for instance affect the strength of the grip, as well as the skill of the person who will use the tool [53]. An example of the latter is steadying the two hands together to thread a needle, a simple element of movement that most skilled sewers are quite unaware of, yet an important one in terms of modeling and transferring the craft to the virtual world. This further underlines the importance of studying these various aspects of gripping handheld tools, before proceeding to their modeling. Our proposed methodology considers these aspects for the way VHs hold and operate the tools. In more detail, the definition of grips and postures of both the tool and the VH representing the practitioner are carefully selected and defined to transfer the craft from the real to the virtual world in a realistic and correct manner.

3.1.2 Fundamental Machine Components. To model the machines used in each craft, we propose their decomposition into their functional parts, inspired by the theory of simple machines [63]. In the context of this work, a relevant issue is to find a generic way to decompose complex machines, to eliminate the need of modeling every machine. Thus, as for example the basic mechanism of a bicycle consists of wheels, levers, and pulleys, we propose the decomposition of the machines involved in TCs into their functional parts. We call these functional parts of the machines *FMCs*. For instance, for the craft of weaving with a loom machine, the FMCs are the treadle, shuttle, and beater, where the treadle (pedal) of the loom can be further decomposed to the two following simple machines: a lever with a pulley. Through this iterative decomposition, any machine can be seen as a collection of fundamental components. Therefore, by modeling fundamental components, it is possible to achieve flexibility and reusability toward modeling complex machines. For instance, a pedal (treadle), with the same operational movement trajectory, can be used both in loom weaving and in pottery making; by modeling it according to our methodology, the same FMC can be used for visualizing the pedal and its movement in both crafts. In sum, the methodology described in the following leverages the theory of simple machines to create a new categorization, to help with the generic modeling of machines utilized in crafts.

3.2 Proposed Pipeline for Transferring Crafts from the Physical to the Digital World

Given a craft instance, which we want to transfer from the "real" to the "virtual" world, we propose the following pipeline, visualized in Figure 1.

Craft understanding and conceptual decomposition of the craft. First, it is necessary to study and understand the craft instance in question. In this respect, it is essential that practitioners are centrally involved (e.g., interviews,

[1]Figure 1 has been designed using resources from Flaticon.com.

co-creation collaborative sessions), to provide functional insight and emic understanding of the process to be represented. Subsequently, the craft can be conceptually decomposed into its essential composite actions, thus presenting an abstraction of the movements comprising the craft. We call each composite action a **Motion Vocabulary Item (MVI)** so that all the MVIs together form the MV of a craft, which can represent the craft as a whole.

Identification of craft type. The next step is to categorize the craft instance in question, depending on whether machines are used in the craft execution or this craft only includes the utilization of handheld tools. This is an important classification, because if the craft involves machines, they need to be decomposed in their functional parts (FMCs). In both cases, it is necessary to identify the correct grip postures, point(s), and orientation of the handheld tools, as well as the human body part that should operate each functional part of the machine. This means that both for handheld tools and machine parts, it is essential to identify their affordances—that is, their properties that show the possible actions that can be performed with them and how to interact with them.

Decomposition of machine components. If the craft includes machines, they need to be decomposed into FMCs. We achieve that by segmenting them into their functional parts, thus providing an abstraction of the machine. Especially in the case of complex machines, this approach presents a generic solution, as otherwise each machine would comprise a unique case, requiring its own modeling. In the case of handheld tools, since they already constitute a "single unit," the actual tool comprises an FMC.

Motion capture of practitioners. After the analysis and conceptual decomposition of the craft, the practitioners' movements need to be captured. We achieve this by performing MoCap sessions, the result of which are MoCap files, representing the human movement. The value of this is twofold: first, it allows for the exact and correct movements of the practitioners to be digitized so that they can be used for animating the VHs that will re-enact the craft; second, the practitioner's motions during the execution of the craft are digitally recorded, thus contributing to the craft's preservation. It is important to note that since MVs can be used to create sequences that encode different actions and procedures, they can encode a wider variation of actions and combinations of actions than the initial MoCap data used for their implementation.

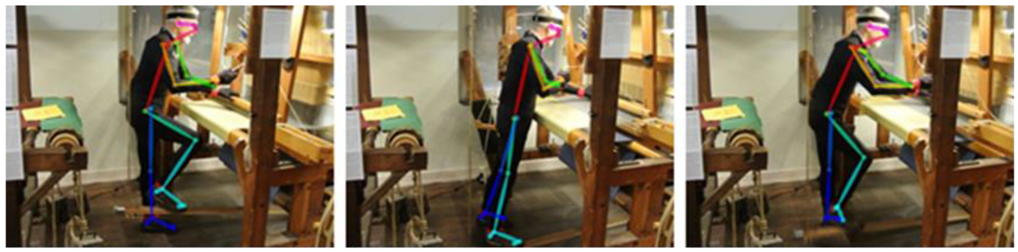
Association of tools and machine parts with motions. Having at hand the decompositions of both the actions and the machines used, we associate the actions with the corresponding FMCs used during their execution. Thus, the MV is formed, where each MVI essentially consists of a motion and its corresponding FMC.

Animating the FMCs. The VHs' movements to re-enact a craft in the VE are animated based on the MoCap files. However, we do not have MoCap for the FMCs (tools or machine parts); instead, we induce the machine motion from the human motion. Thus, having the human MoCap, the conceptual decomposition of the craft into its essential actions and FMCs, and a digitized version of the FMC, we can infer the FMCs' movements and visualize the whole MV that these "ingredients" compose. We argue that this approach allows for generalization of the process, and bypasses potential problems that would occur by trying to perform MoCap on tools and machines. Such problems include obstruction of using the machine or tool due to the presence of sensors, possibly rendering it unusable or altering the way that the practitioner is holding and operating it.

3.3 Applying the Proposed Methodology in the Context of the Loom Weaving Craft

The proposed methodology has been applied in the context of the TC of loom weaving, within the context of the Mingei EU H2020 Innovation action.[2] Regarding the *conceptual decomposition* of the craft, it is essential that practitioners are centrally involved in it, so as to provide functional insight and emic understanding of the represented process. In this respect, we collaborated with the practitioner community of the Association of Friends of **Haus der Seidenkultur (HdS)**, Krefeld, Germany.[3] HdS provided descriptions and testimonies, and allowed us to record functional demonstrations (MoCap, video) of the practitioners, to perform careful observation and analysis of the craft, as well as acquire the necessary motion capture files for re-enacting the practitioner's

[2] http://www.mingei-project.eu/.
[3] https://seidenkultur.de/.



(a) Press treadle and then push beater **(b) Move the shuttle sideways** **(c) Leave treadle and then pull beater**

Fig. 2. Motion capture sessions of a practitioner while loom weaving at HdS, Krefeld.

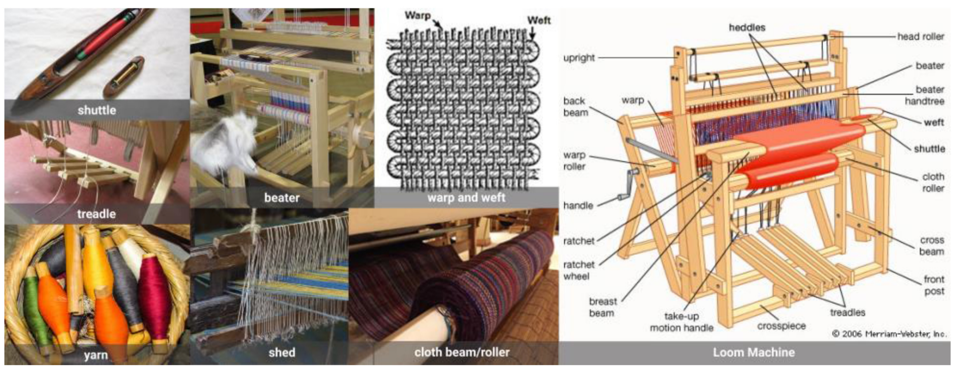


Fig. 3. Basic loom components.[4]

movements (Figure 2). At the same time, collaborative sessions enabled *craft understanding* and *identification of craft type* and provided insight from the perspective of the practitioner, toward a meaningful decomposition. Context definitions were then created, which are provided in the following and are depicted in Figure 3.

In the context of the *decomposition of machines* phase, the weaving process and the loom FMCs were further analyzed. In particular, the weaving process was decomposed into three actions, repeated for each thread of weft [2]: (1) *shedding*, in which warp threads are separated to form a shed, (2) *picking*, in which weft is passed across the shed using the shuttle, and (3) *beating*, in which weft is pushed against the fabric using the beater. This decomposition of the weaving process contains the interplay between human motion and components of the physical interface of the machine. The FMCs were defined as the *treadle*, the *shuttle*, and the *beater*. Initially, textual descriptions were created collaboratively for each action, which also identified the machine interface components and human body parts used to operate them.

We thus developed an analytical way to represent visually and textually a process comprised of actions that are performed on objects and machine interface components. In this collaborative process, the need for a representation that is intuitive to the practitioner and analytical enough for a semantic representation of the process was identified. To that end, storyboards were selected as a methodological approach to address this need. The loom weaving process was encoded as a sequence of actions and reviewed by the community of practitioners, finally producing the storyboard visible in Figure 4. Thus, the MV for the craft of loom weaving is comprised of

[4]Shuttle from Surya Prakash.S.A.: https://en.wikipedia.org/wiki/Loom#/media/File:Weaving_shuttles.JPG; treadle from Mandie: https://www.flickr.com/photos/captivated/327534047/; beater from shelly2dogs: https://www.flickr.com/photos/shelly2dogs/7629987778/in/album-72157629215531290/; warp and weft from Alfred Barlow, Ryj, PKM: https://en.wikipedia.org/wiki/Warp_and_weft#/media/File:Warp_and_weft_2.jpg; cloth beam by Syne Mitchell: https://www.synemitchell.com/2016; loom machine parts from Merriam-Webster Inc.

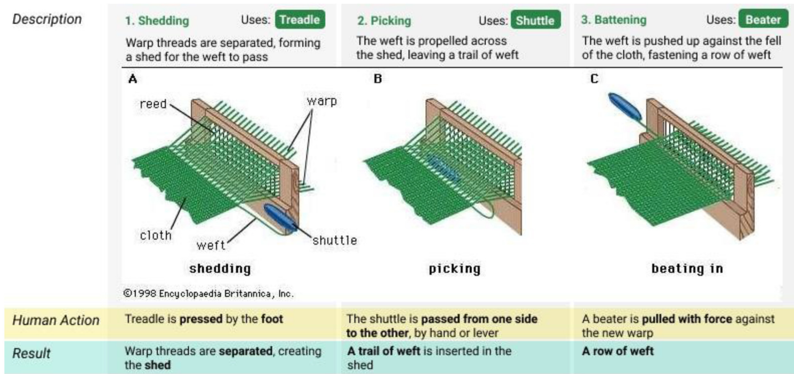
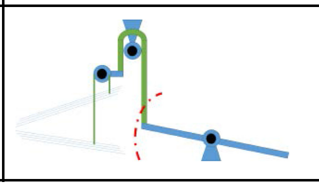
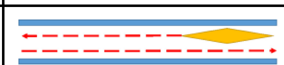
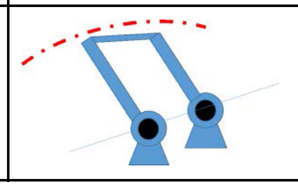


Fig. 4. Storyboard of the three stages of weaving and the machine parts[5] involved.

Table 1. Decomposition of Loom Weaving into MVIs

MVI	Shedding	Picking	Battening
Action	Treadle is pressed by foot.	The shuttle is passed side-to-side by hand.	The beater is dragged with force on the new warp.
Result	Warp threads are separated by the press of the treadle.	A row of weft is created by a pass of the shuttle.	Weft row completed using the beater.
Corresponding FMC			

Note: The dashed lines plot the feasible induced motion trajectories.

the following MVIs—shedding, picking, and battening—and we compiled the categorization and association of FMCs and motions (Table 1) [69].

Finally, to animate the FMCs of the loom, we induced the machine motion from the human motion (MoCap of the practitioners). Nevertheless, prior to any other actions, the 3D model of the machine[6] and the FMCs were acquired. To “attach” the 3D model of an FMC to the 3D object of the machine, some additional editing was required on the 3D model of the machine. In particular, the necessary skeleton joints were added in the FMC of the treadle and the beater so that they would be able to move correctly. In more detail, the treadle needs to behave like a hinge joint—that is, attached at one point and performing a rotational movement according to the force applied on its other side. However, the beater has two points of attachment to the base loom machine and needs to perform also a rotational motion, with these two points never moving. To facilitate understanding, Figures 5 and 6 show these joints and the motion that these two FMCs should perform. Subsequently, for each FMC, we induced its motion from that of the human body part operating it. A state machine was created for each of the three FMCs, to coordinate its motion depending on the state of the human body part. In particular:

[5] https://www.britannica.com/technology/loom#/media/1/347754/3726.
[6] https://3dwarehouse.sketchup.com/model/a4d5115a90e3f5534cf6cee9a1fdf035/Counterbalance-Loom.

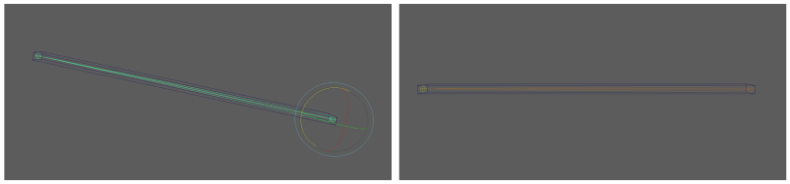


Fig. 5. Loom treadle model in its “max” and “min” positions, with joints visible.

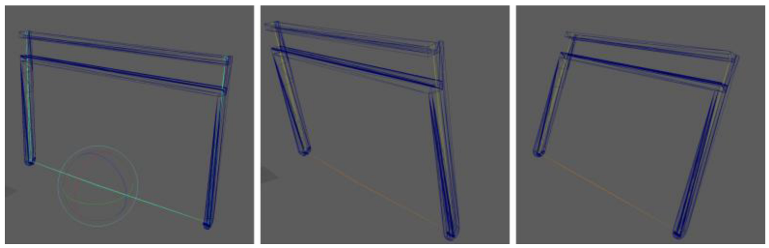


Fig. 6. Loom beater model in its idle state and “max” and “min” positions, with joints visible.

- The treadle has to complete a rotational movement, along an axis perpendicular to the ground and parallel to the treadle, around the point of intersection between the treadle and the base of the loom machine. Thus, when the treadle should move, which is decided by the state machine, a rotation is performed by an angle, which is calculated considering the previous and current position of the VH’s right foot. In other words, the treadle should move according to the movement of the right foot.
- The beater also has to complete a rotational movement, along an axis perpendicular to the ground and parallel to the beater, around the points of intersection between the beater and the base of the loom machine. Thus, when the beater should move, which is decided by the state machine, a rotation is performed by an angle, which is calculated considering the previous and current position of the VH’s left hand. In other words, the beater should move according to the movement of the left hand, since it is the one operating it.
- Finally, the shuttle conducts a linear motion, from the right to the left and vice versa. Thus, when the shuttle should move, it completes its motion from one side to the other, according to the movement of the VH’s right hand.

The trajectory of the movement of each FMC is clear in the pictures shown in Table 1 [60]. Thus, having applied the aforementioned steps for the craft of loom weaving according to our methodology, we transferred it from the physical to the virtual world. As an application of the proposed methodology, the MoViz platform was developed as a tool to allow TC stakeholders (e.g., museum curators, craft enthusiasts) to visualize craft practices in a VE. The following section presents the MoViz platform and exemplifies its usage in the context of the loom weaving craft.

4 THE MOVIZ PLATFORM

The MoViz platform enables the authoring, demonstration, and training of crafts in VEs, utilizing VHs as the practitioners. The correct attachment of the tools to the body parts of the VH that is operating them and the induced motion of the machine parts from the human motion are of key importance.

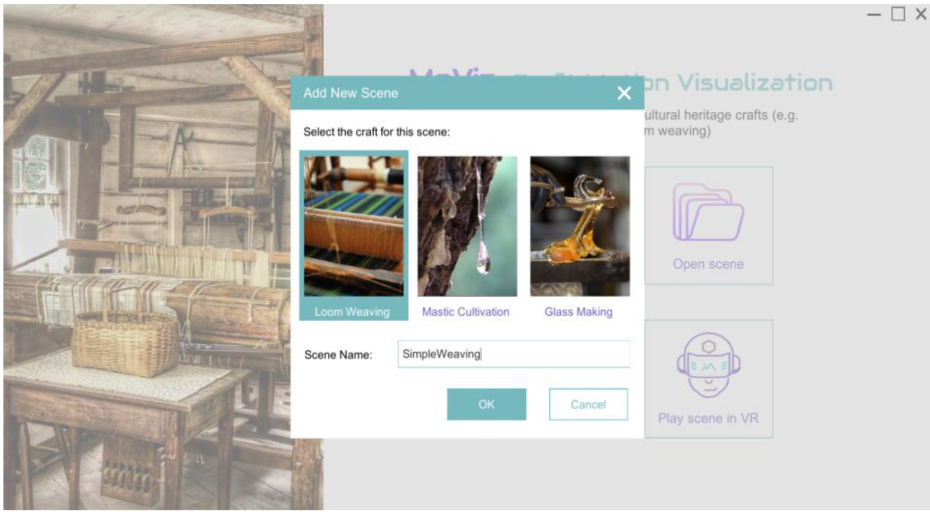


Fig. 7. MoViz start screen, with Add New Scene selected.

4.1 Method

The development of the platform followed the human-centered design approach [36], employing representative end users and stakeholders throughout the process, iteratively refining the produced prototypes. Context of use was defined as part of the craft understanding and conceptual decomposition, as described in Section 3.3, through interviews and co-creation sessions. Requirements were elicited through focus groups, brainstorming sessions, and field observations, conducted in the context of the Mingei project. Prototypes were developed following an iterative process of development and evaluation cycles. The first phase involved the creation of low-fidelity paper prototypes of the user interface, and subsequently of medium-fidelity prototypes. These mostly regarded the authoring of the scenes, as most of the functionality and complexity of the platform lies there. The prototypes were initially assessed by five **User Experience (UX)** experts during a cognitive walkthrough evaluation experiment to uncover any usability errors, revealing some issues regarding the conceptual design of the platform, as well as the complexity of the most frequently used functions. Subsequently, an improved vertical high-fidelity interactive prototype was created, integrating the feedback received, which was re-assessed by five UX experts via heuristic evaluation [48] to test the overall usability and address any problems before continuing the implementation. Following these two expert-based evaluations, the MoViz platform prototype was redesigned and implemented, using the Unity 3D Game Engine.

4.2 Platform Description

The MoViz platform allows users to create their own "scenes," corresponding to a specific craft (Figure 7), and add VHs and objects to re-enact the craft in question. In particular, the scene is the canvas on which the users can experiment and bring to life a specific craft, by associating available FMCs with corresponding human motions, thus creating MVIs. Users can save their progress and choose to load an existing scene for further editing, as well as choose to play back the MV they have constructed.

In more detail, when editing a scene, the platform provides users with a library of avatars, motions, FMCs, and scene objects for them to choose. They can choose to preview, add, or remove from the scene items from the aforementioned categories. An important step in the process is the addition of MVIs, which are visible along with other items added to the scene on the left side of the screen (Figure 8), and their association with an FMC

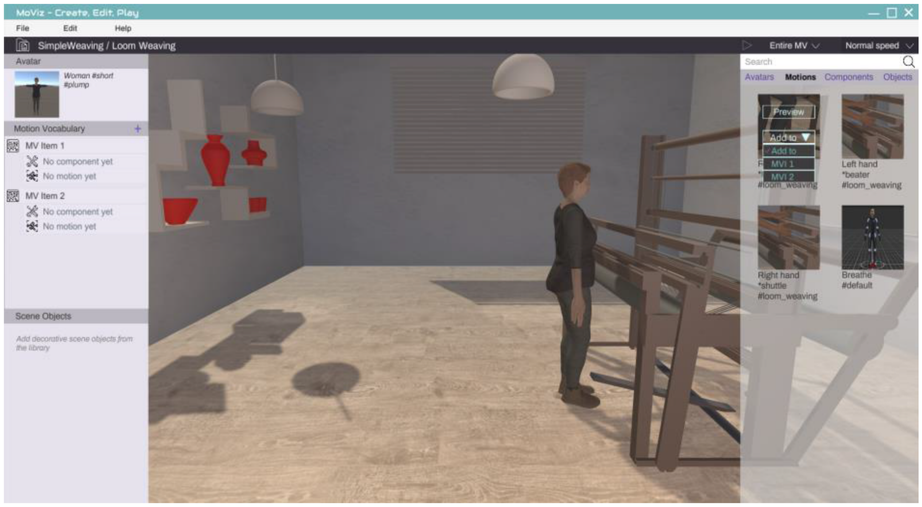


Fig. 8. Scene editing in MoViz. The user is about to add a motion to an MVI.

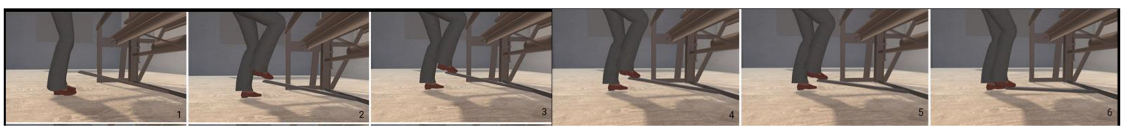


Fig. 9. Visualization of the MVI for the operation of the treadle in the craft of loom weaving.

and a motion, to generate a complete MVI. Users can choose to preview the MV they have constructed—that is, view the VH performing the craft and the corresponding machine parts moving along with them, according to our implementation of their induced motion. To that end, they can select which MVI they wish to preview, as well as the speed of the playback. Adjusting the speed of the playback is important for the users to be able to view the operation of the craft if they want to understand it better in a slower tempo. Once users are satisfied with the result, they can save the progress in their scene. Moreover, they can choose to "play" an existing scene in 3D or VR (i.e., visualize the craft process performed by the VH) by playing the list of MVIs in the scene. As an example, Figure 9 shows the playback of the MVI for the treadle (pedal) of the loom, in the case of the loom weaving craft. After configuring the type of playback (3D VE or VR), they can toggle the training mode in the VR case, where the ideal trajectories of each movement are visualized, and the user trajectories are recorded for comparison with the ideal ones. Thus, users can experience the craft process, step-by-step, and be guided as to how to complete them. Once they have completed the movement themselves, they can receive feedback about their performance. An example of this is visible in Figure 10, for the simple use case of a hammer, where the green hologram demonstrates where and how to operate the tool.

4.3 Architecture

The MoViz platform employs three main components: background behavior controllers, foreground behavior controllers, and craft-related behavior controllers (Figure 11).

Background behavior controllers are responsible for handling and manipulating the hierarchy of objects in a scene. In more detail, the Hierarchy Content Controller handles the entire virtual objects' hierarchy that is visualized to the user and can be manipulated through the VE, and namely avatars, MVIs, FMCs, motions, and

Fig. 10. Screenshots of the VR training module, showing the user how to operate a hammer.

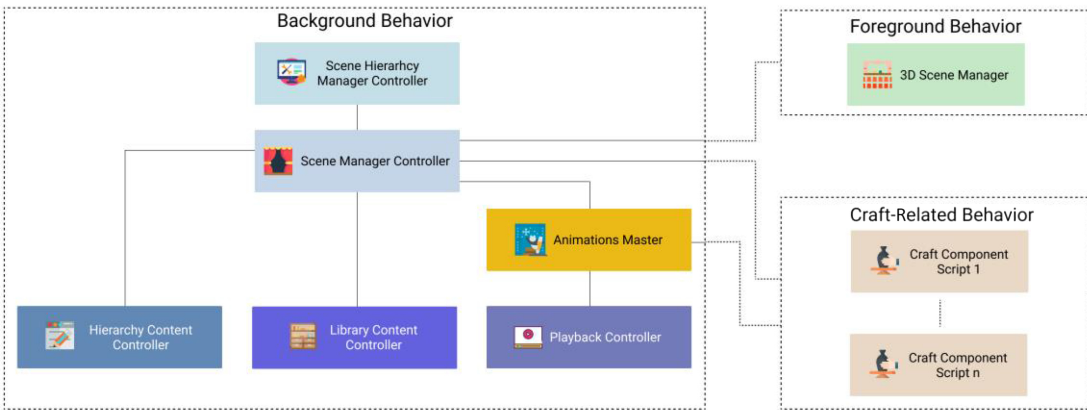


Fig. 11. The architecture of MoViz.[7]

scene objects. The Library Content Controller handles the library of available virtual objects and facilitates previewing and adding them to the virtual scene. The Playback Controller is responsible for events regarding the playback of an MVI or the entire MV. In this respect, it communicates with the Animations Master, which is the module for selecting the correct animation file to play, depending on the info received from the Playback Controller. The Scene Manager Controller handles global events and is responsible for the setup of the application upon execution, based on the state of the application (e.g., for creating a new scene or opening an existing one) and the transition of data between the different modes of the platform (i.e., 3D or VR). Last, the Scene Hierarchy Manager handles the scene hierarchy, which is the main (parent) structure holding the information of all the items added in the current scene.

Foreground Controllers are mainly assigned with all tasks related to the 3D Scene Manager, the component that is responsible for all the 3D items in the 3D scene: VHs, scene objects, and objects related to the selected craft. In more detail, it is responsible for adding and removing the "3D versions" of the objects visible in the visual hierarchy from the scene, which are essentially the items the user chooses to add to the scene. Moreover, this module handles the addition and removal of the Craft-Related Behavior Controllers that concern the craft-related scripts, which are dynamically added to the corresponding FMC objects, when the user creates a complete MVI (containing both the FMC and its relevant motion). These scripts implement the induced motion of the machine part from that of the human motion. They are organized as state machines, determining the behavior of the FMC at each point in time. The different states of this state machine are the result of the following: (1) the analysis of the human motion, as it has been described and derived from the conceptual decomposition of the actions and machines, with the help of the craft practitioners, and (2) the careful observation and analysis in steps of

[7]Figure 11 has been designed using resources from Flaticon.com.

the human motion with respect to collision detection and boundaries, regarding the FMC and the corresponding human body part that is operating.

5 USER-BASED EVALUATION

A small-scale formative user-based evaluation experiment [3] was conducted to assess the complete functionality of MoViz, and particularly of the Motion and Scene Editor, where most of the functionality of the platform lies. Including end users in the evaluation process can provide great insights by observing them interacting with the system and noting their comments and general opinion. The aim of the evaluation experiment was mainly to identify any unsupported features and uncover potential usability errors before planning a large-scale experiment. In particular, we wanted to explore the following research questions:

R1: Can users effectively and efficiently create a craft representation?
R2: What is their overall impression of the tool?
R3: Does the tool require extensive training or prior knowledge from users to create a craft representation?

5.1 Methodology

To explore the aforementioned research questions, the following metrics were recorded:

- Success rate and number of errors, to measure user effectiveness with the tool
- Time for each task and number of help requests, to measure user efficiency with the tool
- User satisfaction measured via two standardized relevant questionnaires: SUS [11] and UMUX [23].

A secondary goal of the current preliminary study was also to compare the two questionnaires, exploring the suitability of UMUX, which is quite shorter, for future evaluations of the system with larger audiences. To alleviate any bias, the order of the two questionnaires was interchanged; half of the participants filled in the SUS questionnaire first and the other half the UMUX.

In addition, to capture users' opinion, the think-aloud protocol was applied during the evaluation, asking participants to verbalize their thoughts as they moved through the user interface [3]. Taking into account that applying the think-aloud protocol may have an effect on task performance, and particularly on the time required to complete the task, the retrospective probing technique was applied [3], asking participants to explain their line of thought with regard to the task itself during the task execution but to hold their remaining comments for the time between tasks.

5.2 Participants

Ten users, recruited through convenience sampling, participated in the experiment. Users were selected to include an as wide as possible range of ages (four users in the age range of 20s to 30s, three in the range of 30s to 40s, and three in the range of 40s to 50s) and a balance in genders (five male, five female). Given the formative nature of the experiment, and that emphasis was not given in the craft representation itself but in studying the overall usability of the system, the domain knowledge was not considered a prerequisite for participation. In particular, the participant pool was constituted by a balanced sample of software engineers and UX designers, and none of the participants was familiar with the craft of loom weaving. Although these users are generally familiar with interactive systems, it was noted that each participant category provided valuable comments from their own field of expertise. For example, UX designers were very focused not only on the overall look and feel but also on terminology issues and consistency, information navigation, effectiveness, and efficiency. Therefore, although a small number of participants was involved and the convenience sampling approach was followed, the evaluation yielded useful suggestions for further improvement. Nevertheless, this constitutes one of the limitations of this study and is planned to be addressed in future evaluations by including users with more diverse skills and background.

5.3 Procedure

Participants were first welcomed and introduced to the aims and objectives of the evaluation experiment. The evaluation process and recordings ware explained, as well as issues related to the anonymization of participants' data, as described in the Informed Consent Form,[8] which was signed prior to the experiment. Subsequently, participants were introduced to the concept of MoViz, as a platform targeting the preservation of CH crafts through their representation in VEs, utilizing VHs and human motion. To ensure that evaluation of all the major functions of the authoring platform, a scenario was used, including seven tasks: (1) Create a new scene; (2) Add an avatar in the scene; (3) Define an MVI for loom weaving; (4) Add two more MVIs; (5) Add a decorative object in the scene; (6) Play the entire motion; and (7) Play an individual MVI in fast speed. After each task, a short discussion revolving around participants' experience followed, aiming to elicit any further comments and suggestions. Once all tasks were completed and questionnaires were filled in, participants were debriefed by the evaluator and thanked for their participation.

5.4 Results

5.4.1 Effectiveness. Effectiveness was studied by means of task success and number of errors made. A weighted approach to task success measurement was followed [3], employing four levels as follows: (1) Complete success without assistance: 1.0; (2) Minor Problems: The participant successfully completed the task but took a slight detour (one or two small mistakes but quickly recovered): 0.75; (3) Major Problems: The participant successfully completed the task but with major problems: 0.5; (4) Fail: Participant gave up or wrong answer: 0.

The final success score is calculated according to the following formula, where N_s is the number of successful task attempts, N_{minor} is the number of successfully completed tasks with minor problems, N_{major} is the number of successfully completed tasks with major problems, and N is the total number of task attempts:

$$\text{Success Rate} = \text{NS} + 0.75 * \text{Nminor} + 0.5 * \text{Nmajor}/\text{N}$$

The overall success rate for MoViz, as well as the success rates per task (Figure 12) were quite high, with three of the tasks executed without any errors at all.

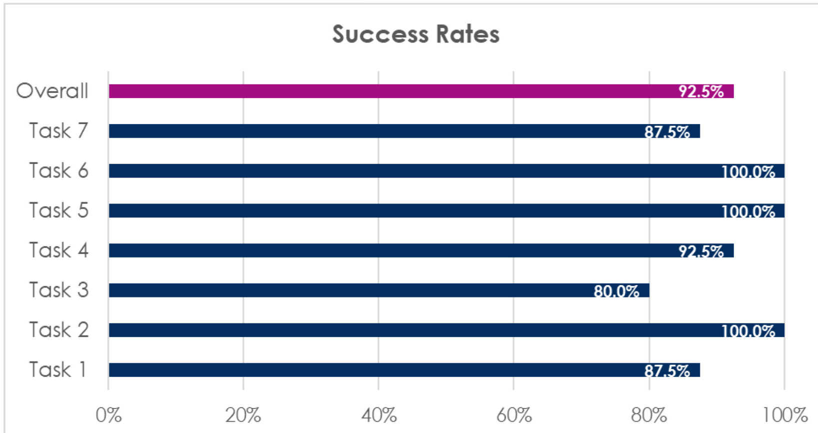
Further analysis of the number of errors that were made per task suggests that for the majority of the tasks, only a small number of errors were made (at most one error per participant). The only task that exhibited an increased error rate is Task 3, where users were asked to add an MVI by defining the corresponding avatar motion and loom component to be used. As all participants were first-time users, they made minor errors in trying to identify how to accomplish the task; however, all of them made at most two errors (which is a rather small number considering that error opportunity for the task was quite large). It is also noteworthy that Task 4—which asked participants to add two more MVIs, thus actually repeating the previous task actions—exhibited a rather low number of errors. This suggests that participants became familiar with the process very quickly.

Therefore, it can be concluded that users effectively created a craft representation with MoViz, exhibiting a high success rate (92.5%) and making a small number of minor errors in the process.

5.4.2 Efficiency. Time on task and number of help requests were used as indicators of efficiency when using MoViz. It is noteworthy that all participants completed the tasks without any assistance. This is probably an expected finding, as all the participants were expert computer users and therefore did not feel intimidated or puzzled when encountering difficulties. Instead, they commented on usability problems and suggested potential solutions or personal preferences, which are analyzed later in this section. Regarding the time that participants needed to complete each task, Table 2 summarizes the relevant statistics (in seconds) per task.

It is evident that the majority of the tasks were completed in a rather short time, most of them in less than a minute on average, and some of them in just some seconds. Task 3 is the only exception, which however is

[8]The study and its protocol were approved by the Ethics Committee of FORTH-ICS (Reference Number: 71/6-2-2020).



	Task 1	Task 3	Task 4	Task 7
Total number of errors	5	14	3	7
Minimum number of errors per user	0	0	0	0
Maximum number of errors per user	1	2	1	1
Percentage of users who made an error	50%	90%	30%	50%

Fig. 12. Success rates per task and analysis of errors.

Table 2. Time Statistics for Each Task (in Seconds)

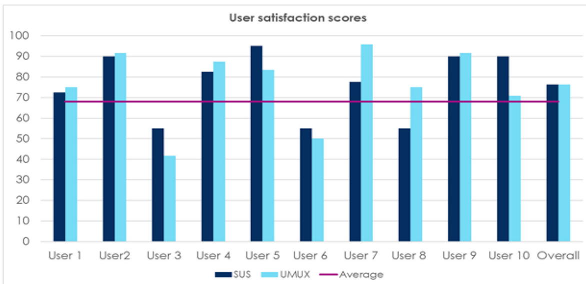
	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7
Mean	33.90	20.80	113.90	68.10	19.40	7.00	8.80
Geometric Mean	29.87	18.01	104.55	60.81	17.60	4.54	4.92
Standard Deviation	16.46	11.56	50.69	35.78	8.28	6.85	10.01
Minimum	12.00	6.00	60.00	25.00	6.00	1.00	1.00
Maximum	63.00	42.00	190.00	152.00	33.00	21.00	30.00
Conf. Level (95.0%)	11.78	8.27	36.26	25.59	5.92	4.90	7.16

aligned with the number of errors that participants made while executing the task, thus requiring more time to correct them. In addition, it is notable that Task 4, which required participants to execute two series of actions similar to the one requested in Task 3—that is, twice as many actions—was accomplished in almost half the time. This observation is also in line with task effectiveness metrics and confirms that participants easily learned how to accomplish the task at hand.

Therefore, it can be concluded that users were efficient in creating a craft representation with MoViz, requiring no assistance at all, and completing the requested tasks in reasonable time, ranging from a few seconds to nearly 2 minutes on average, according to the task complexity.

5.4.3 User Satisfaction and Overall Impression. User satisfaction was measured through two questionnaires: SUS and UMUX. User responses in both questionnaires were overall positive (Figure 13, left). The overall SUS score was 76.25, which is quite above average (an average SUS score has been calculated to be 68). In particular, according to the curved grading scale for SUS [104], MoViz received a B score overall.

Further investigation of the individual SUS scores reveals that 30% of the users rated it with a D (ranging from 51.7 to 62.6), 10% of the users with a B− (ranging from 72.5 to 74), 10% of the users with a B+ (ranging from 77 to



	SUS	UMUX
Mean	76.25	76.25
Median	80	79.166
Standard Deviation	16.083	18.114
Minimum	55	41.667
Maximum	95	95.833
Confidence Level (95.0%)	11.505	12.958

Fig. 13. Left: Satisfaction scores per user with SUS and UMUX. Right: UMUX and SUS results' comparison.

78.8), 10% of the users with an A (ranging from 80.8 to 84), and 40% of the users with an A+ (ranging from 84.1 to 100).

Such benchmarks are not available yet for the UMUX questionnaire, which was more recently developed, and therefore not so widely used and tested. Nevertheless, it is remarkable that both questionnaires yielded the exact same overall average score. Further statistical analysis regarding responses in each of the questionnaires is presented on the right side of Figure 13. Although further investigation is required, the high association of the results in terms of mean, median, and confidence level around the mean, as well as the significant positive association between scores (as tested with a Pearson correlation, $r(8) = .72$, $p = .01$), suggest that for future evaluations of MoViz, UMUX can be considered as a valid alternative to SUS, in cases where a shorter and simpler questionnaire is needed.

Regarding the individual scores, further analysis of the comments and usability observations of the three users who gave the lowest rates revealed that two of them encountered several difficulties with associating library objects to the MVIs, which was a point of distress for many users, and two of them expected a higher realism and immersiveness (as in games). User comments about the overall impression of the tool were positive, emphasizing its potential for craft representation ("Found the concept of the application very interesting, the fact that it is used to preserve things associated with an endangered craft!," "I like the concept —overall it is a very nice tool!"), and its learnability ("Just as every tool, we need some time to learn it. Once you do, it's quite straightforward").

In brief, besides any individual differences in scores, it can be concluded that users were satisfied with MoViZ, giving it a rather high average score (76.25), whereas 50% of the users rated it with an A or A+ score. At the same time, the overall impression was positive regarding the overall concept of a tool to assist in craft preservation.

5.4.4 Training and Prior Knowledge. The experiment explored if users—unfamiliar with the craft—could successfully create a craft representation. To compensate for users' lack of familiarity with loom weaving, Task 1 referring to an MVI explicitly dictated which motion to associate with a component of the loom machine. Subsequent relevant tasks did not provide any indication, and it was left to the users to infer the appropriate components that should be associated with avatar motions. Although for the MoViz prototype that was tested the available number of motions and components was rather low, participants requested some kind of automated guidance from the tool (i.e., highlight relevant components when a motion is selected and vice versa). This is a hypothesis that will be further evaluated in future evaluations with craft experts.

Furthermore, users had no prior expertise with MoViz; they were first-time users of the tool, without any training on the tool before the experiment. Nevertheless, all users exhibited high success rates in all tasks, and some tasks achieved a 100% success rate, resulting in a quite high overall success rate for MoViz (92.5%). In addition, to assess whether it is easy for users to learn how to add an MVI, they were asked to do it three times: once in Task 3 and twice in Task 4. It is interesting that although in Task 3 users required more time, and made several errors in total, the time required in Task 4 was nearly half (although the task required twice the number of actions), and the total number of errors was almost one-fifth compared to Task 3.

Observations of the user behavior during task execution revealed that participants easily learned that they can add objects from the library located on the right side, although most of them expressed their strong preference for an association of the library with the left panel. Along the same lines, user comments also suggested that they became quickly familiar with the "whereabouts" of the application.

6 DISCUSSION AND CONCLUSION

This article has delivered a generic methodology for presenting craft experiences in VEs, by employing VHs as practitioners. This work was motivated by the importance of re-enacting TCs, due to their significance and value, and by the lack of a comprehensive methodology for their visualization in VEs. The approach put forward in this article proposes a visualization, which aims to be attractive and engaging to the general public, contributing to the preservation of TCs. The proposed methodology consists of several steps, the development of which was the result of studying bibliography regarding crafts and tools, as well as of collaborative sessions with craft practitioners, using the pilot case of loom weaving as a template. The proposed methodology for transferring a craft from the physical to the digital world namely consists of the following steps:

(1) Understanding the craft in question and performing conceptual decomposition of the craft
(2) Identifying whether this craft includes (only) the use of handheld tools or (also) machines
(3) In the case that the craft utilizes machines, performing a decomposition of the machines into their functional parts, called *FMCs*
(4) Performing motion capture of the practitioners
(5) Associating the tools and machines used with their corresponding motions
(6) Animating the FMCs by inducing their motion from the human motion.

In the context of this work, the MoViz platform was developed, for the authoring and visualization of craft processes in VEs, employing VHs and MoCap for the movements of the practitioner. The resulting authored scenes can be visualized in 3D or VR, where training is also available for the user (the ideal trajectories of the movements of the craft are visualized, and the user can execute them and receive pertinent feedback).

The contributions of this work can thus be summarized as follows: we deliver (i) a novel, comprehensive methodology for craft visualization in VEs, (ii) an authoring tool for craft experiences, which allows even non-technical users to utilize the results of complex technologies to author their own scenes, re-enacting craft procedures, and (iii) a visualization of the authored scenes in 3D and VR environments, with the option of performing VR training for the handheld machine parts and tools; finally, we claim that (iv) our approach for the presentation and re-enacting of crafts in VEs can help in the representation and dissemination of TCs, and thus contribute to the efforts of their preservation. These are further discussed in the following sections.

6.1 Comprehensive Methodology for Craft Visualization in VEs

This article provides a novel methodology for the visualization of motion in VEs. Until now, interaction of VHs with tools and machines has mostly been addressed through predefined animations of both the object and the VH, or through the usage of physics engines. Our approach proposes the visualization of motion in the context of TCs, through MoCap of humans performing the craft, in combination with inducing the motion of the machine or tool that is used. To that end, we combine segmented MoCap animation files, according to their conceptual decomposition, together with articulations of the machines to their functional components, and create MVs, representing the craft.

An integral part of the methodology is identification of the kind of tools used—that is, (only) handheld tools or (also) of machines. In the latter case, we propose that the machines utilized in (traditional) crafts can be decomposed to their functional parts, inspired by the theory of simple machines, which in the context of this article we call *FMCs*. This allows understanding and generalization, as well as replication, since otherwise each unique machine instance would need to be modeled individually. Each FMC is then associated with a human motion, which provides the required data for the inference of its movement. Thus, both kinetic properties and constraints of the machine are facilitated, as well as artificially generated constraints in the machine's digital model, in the form of boundaries that trigger collision detection mechanisms, which allow to know when two virtual objects are in contact.

6.2 Authoring Platform for Craft Experiences

To the best of our knowledge, no other platform exists that allows users to author their own scenes consisting of VHs and 3D models of craft objects (machines and tools), as well as enables the association of motions with the corresponding machine parts/tools, so as to re-create and re-enact scenarios of craft usage. Furthermore, the proposed platform allows even non-technical users to utilize the results of complex technological advancements, such as motion capture, to author their own scenes. At the same time, it gives the opportunity to content owners, such as creative industries, museum curators, and exhibitors without programming knowledge to utilize this tool to share, disseminate, and promote their cultural content to the public, aiming to provide engaging, entertaining, and potentially educative content.

6.3 Visualization of Craft Experiences in 3D and VR

This work also proposes the visualization of the authored scenes in 3D, where users can experience the process of the craft, re-enacted by the VH. Moreover, users can choose to view the created scene in VR, allowing for immersion and a closer view on the process, as well as choose to perform VR training. In the last case, the ideal motion trajectories of each FMC are shown to the users, based on the motion that the craft practitioner performed; subsequently, the user's trajectories are recorded while they are executing the movement, to compare them with the ideal ones, and provide them with feedback regarding their performance (accuracy, time, etc.). It should be noted that, regarding VR training, our contribution does not lie in the development of the underlying platform facilitating the creation of these VR training scenarios [72] but rather in its deployment in the context of the MoViz authoring platform for training in the context of craft experiences, and particularly in those of TCs.

6.4 A Novel Method for the Presentation, Representation, and Preservation of TCs

Through the development of the proposed methodology, as well as of the authoring and visualization platform for craft experiences, this article proposes a novel method for the presentation of TCs in VEs. The methodology aims to aid in their representation and preservation, from which multiple user groups can benefit, such as (1) the practitioner whose work will be preserved and represented; (2) local communities in which the craft is practiced; (3) museum curators and exhibitors for the presentation of various TCs; and (4) people who do not necessarily possess knowledge or specialization regarding TCs, who are however interested in a TC and wish to learn more about it (e.g. tourists, teachers, school groups, craft enthusiasts).

Furthermore, employing the proposed approach allows modeling of a multitude of craft instances and machines, by decomposing crafts to simple motion-driven operations, and machines to FMCs, and modeling each craft as a series of actions (MVIs forming the MV of the craft). In addition, the use of VHs and 3D objects to represent the practitioners and the tools/machines, respectively, facilitates flexibility and multimodality; visualization from different angles, focus on particular movements and body parts operating a tool, and re-use of recorded human motion are some examples of the benefits of this approach. Through this process, we aim to deliver a more efficient way of visualizing craft processes within VEs, increasing the usability and value of craft representation, and thus opening the way to a variety of new applications for craft presentation, education, and thematic tourism, based on the value of tradition and ICH.

7 FUTURE WORK

Planned future work includes tackling all unaddressed issues discovered during user-based evaluations. A particularly important aspect that will be prioritized regards the improvement of the avatars' movements for a more realistic representation, by investigating how to ameliorate the motion retargeting from the available MoCaps. In addition, future user-based studies will focus on evaluating the perceived realism of the avatars and its impact on the overall user experience. Another issue that will be addressed regards the elimination of abbreviations and "technical terms" altogether, to increase the simplicity and user-friendliness of the platform. As well, a narrator will be added in the scenes—that is, the users will have the ability to add a second VH to their scenes, which will serve as a storyteller. This will require the careful consideration and redesign of the authoring tool, to include this capability in the platform seamlessly and in a user-friendly way.

We also plan to introduce a Craft Editor module to the MoViz platform so that users can author their own craft "templates". To that end, the Craft Editor will offer functionality for importing and configuring the motions associated with the craft, as well as the machines and tools, and for the definition of the FMCs involved. In addition, we would like to explore options to allow users to import their own avatars as well as scene objects. Additional configuration for the avatars might need to take place, such as with Unity's Avatar Muscle & Settings,[9] for configuration of the character's range of motion to ensure the character deforms in a convincing way, free from visual artifacts or self-overlaps. However, we would also like to explore other possibilities for online motion retargeting, to minimize the manual tweaking required.

After implementing these features, we will conduct new evaluation experiments to assess the platform's usability, as well as the user experience, with a target user number of more than 50 participants. Finally, it is part of our immediate future work to conduct an evaluation experiment with TC stakeholders, such as craft practitioners and content holders. A challenge entailed is that craft practitioners may not be familiar with computer applications and authoring tools, which will present an interesting case study for ameliorating our platform.

ACKNOWLEDGMENTS

We are grateful to project partner ARMINES (Association pour la Recherche et le Developpement des Methodes et Processus Industriels) for the acquisition of MoCap data and the Association of Friends of Haus der Seidenkultur (HdS) for their support on understanding the loom weaving craft. We would also like to thank the anonymous reviewers for their constructive criticism.

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Received October 2020; revised June 2021; accepted August 2021