

Digitizing Intangible Cultural Heritage Embodied: state of the art

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Intangible cultural heritage (ICH) as a field of research and site for digital efforts has grown significantly since the UNESCO 2003 Convention for the Safeguarding of Intangible Heritage. In contrast to tangible heritage, where cultural identities are manifested through physical objects, intangible cultural expressions are defined through tacit reliances and embodied practices. Such practices are usually bodily communicated, enacted, socially transmitted, and constantly evolving. Burgeoning trends in computational heritage and ICT applications have played a crucial role in safeguarding ICH as they produce versatile resources while making them accessible to the public. Nevertheless, most of the inventions are object-centric and cater to conserving material-based knowledge bases. Few endeavors thus far have fully supported the recording, representing, and reviving of the living nature of ICH.

One of the challenges now faced is to find appropriate forms, together with efficient methods, to document the ephemeral aspects of intangible heritage. Another barrier is to find effective ways to communicate the knowledge inextricably linked to people. In response, recent efforts have embarked on capturing the “live” and “active” facets of the embodied cultures, which entails addressing technological and curatorial complexity to communicate the material and immaterial aspects within a meaningful context. Meanwhile, advancements in experimental museology have opened up new modes of experiential narratives, particularly through visualization, augmentation, participation, and immersive embodiment. Novel practices of cultural data computation and data sculpting have also emerged toward the ideal of knowledge reconstruction.

This article outlines state-of-the-art models, projects, and technical practices that have advanced the digitization lifecycle for ICH resources. The review focuses on several critical but less studied tasks within digital archiving, computational encoding, conceptual representation, and interactive engagement with the intangible cultural elements. We aim to identify the advancements and gaps in the existing conventions, and to envision opportunities for transmitting embodied knowledge in intangible heritage.

CCS Concepts: • **Applied computing** → **Arts and humanities**; **Digital libraries and archives**.

Additional Key Words and Phrases: intangible cultural heritage, digitization, computational archives, embodied knowledge, knowledge representation, live transmission

1 INTRODUCTION

Intangible cultural heritage (ICH) as a field of research and locus of digital efforts has grown significantly since the UNESCO *Convention for the Safeguarding of the Intangible Cultural Heritage* affirmed the significance of

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1556-4673/2022/1-ART1 \$15.00

<https://doi.org/10.1145/3494837>

preserving folklore and traditional cultural knowledge in 2003. According to the Convention, intangible heritage refers to “the practices, representations, expressions, knowledge, skills – as well as the instruments, objects, artifacts and cultural spaces associated therewith – that communities, groups, and in some cases, individuals recognize as part of their cultural heritage” [148]. Globalization in tandem with incessant changes, particularly natural disasters and global pandemics, has exposed intangible treasures to ever-increasing risks. There is an urgent need for action, especially for sustaining the living cultures of vulnerable populations.

Digitization and ICT (information and communications technology) applications have been recognized as effective means to safeguard cultural heritage (CH), simultaneously producing a significant body of resources. Such capacity is demonstrated in the *Europeana* project, which opened new pathways of scientific and public access to CH assets [4].¹ Archivists today have a suite of tools for creating digital copies, ranging from scanning, photography, and 3D volumetric photogrammetry to film-making techniques. However, many of these have emerged as fundamental apparatuses for material-based ICH archives [94]. Few endeavors thus far have adequately supported structured encoding, documentation, representation, and exhibition of the living nature of ICH. It proves more challenging to restore the tacit and evanescent knowledge, both tangible and intangible, toward a meaningful context.

A number of research projects have made notable progress. For instance, the *i-Treasures* project brought the “living human treasures” into focus in an attempt to capture and educate the intangible know-how.² It carried out a series of research to digitize four ICH assets, covering traditional dances, folk singing, craftsmanship, and contemporary music composition [45, 66]. Among their contributions, we must highlight the innovative approaches to computing and disseminating forms of performative ICH and educational applications to enhance knowledge transmission [36]. Similarly, *Terpsichore* project aimed to integrate ICT strategies with storytelling to advance affordable digitization of ICH content related to traditional dances, ultimately reaching a wide range of users.³ These efforts yet mainly concentrated on choreographic performances, whereas related cultural concepts were sparsely represented or restricted to static mediums, such as images and textures of physical sites.

Recent studies into cultural computing, otherwise known as the interdisciplinary field of “digital humanities”, have triggered a growing number of algorithmic advancements to facilitate ICH data usage, which deserves a systemic collation. In parallel, innovative paradigms of cultural user experience [16], 3D reconstruction [99], visualization [59] and augmented narratives (VR/AR/MR) [100] have opened up possibilities for creating novel presentation of body-mind practices [150]. Finally, new applications in immersive pedagogy, experimental data sculpting, and embodied storytelling have reformed cultural communication.

In the light of these experimentations, this essay outlines state-of-the-art models, projects, and technical practices concerning the whole lifecycle of ICH digitization, with a specific focus on transmitting embodied knowledge. We highlight in these pages some critical projects yet leaving under-researched issues. Section 2 interrogates the rationales behind digital archiving, where we underline the potential of new capturing methods and the necessity of designing archives with multimodality. Section 3 is dedicated to a discussion about computational inventions for programmatic consumption of the archival assets. We collate relevant studies to examine a direction for encoding the embodied characters of intangible knowledge and representing them holistically in their cultural context. Regarding the node of transmitting ICH in the public sphere, we present in Section 4 some instances and frameworks that are promising for interactive storytelling, embodied museology, and gamified engagement with intangible cultural elements. As we review these aspects, we aim to identify the

¹*Europeana* Collections provides access to over 50 million digitized items with tools for accessibility. <https://europeana.eu>.

²The *i-Treasures* project, funded by the European Community from 2013 to 2017, aimed to use advanced ICT technologies to digitize ICH resources for knowledge exchange. <http://www.i-treasures.eu/>.

³*Terpsichore (Transforming Intangible Folkloric Performing Arts into Tangible Choreographic Digital Objects)* was funded by the European Union’s Horizon 2020 research and innovation program from 2016 to 2020. <http://terpsichore-project.eu/>.

contributions and gaps in the existing conventions, and to envision opportunities for improving the transmission of intangible heritage.

2 DIGITAL ARCHIVING ON THE MOVE

Documentation using new technologies has been continuously employed for preserving intangible heritage. These practices have meanwhile provoked scholarly arguments stressing that, rather than static digitization, archivists should approach culture as a renewable and replaceable resource [96]. Indeed, traditional ICH archiving is limited to using conventional modalities. Resulting from this gap, the collation of archival contents generally hinges on a single dimension, such as image-based, object-centered, or linear manifestation. However, countless instances have revealed that, although memory may be invested in physical things, objects are not necessarily the key nodes of cultural transmission [94].

Recent efforts have embarked on capturing the living dynamics, with the human body as a principal site of cultural repertoire. Achieving this requires solving a myriad of technological and curatorial complexities, which will be examined in Section 2.1. In the meantime, there have been inquiries about how to represent tacit knowledge while restoring its authentic context through multiple entities associating people, places, objects, or artifacts. It is also essential to tackle the challenges of reconstructing the material and immaterial aspects in an evolutionary manner for the benefit of diachronic studies. These problems consequently call for multimodal solutions, as to be explained in Section 2.2.

2.1 Capturing the “live” and dynamics

If we wish to grasp the specific character of intangible cultural heritage, we need above all to reflect and acknowledge the fundamental role which the human body plays as its carrier. [158]

The embodied facet of ICH not only refers to the knowledge of the body, but also of that which is dwelling in and enacted through the body [37]. Moves and gestures are considered typical mediums to express and process mindfulness. In various cases, they also mediate interactive processes, such as human-environment communication and knowledge formation. Movement data usually documents the active dimension of mankind’s creativity over time. Hence, as Tim Ingold’s argument delineates, instead of targeting solely result-driven examinations [136], the ideal usage of such data should facilitate a new mode of computation conveying the open-ended information embedded in the bodily practices.⁴ In accordance with this ideal, Motion Capture (MoCap) technologies have gained increasing popularity in ICH archiving. MoCap allows data collection to be neutral, simultaneous, “beyond the frame and within the volume” [43], thereby fostering a perceivable human presence in the virtual CH environments, as surveyed by [25].

MoCap’s renown originated from its early usage in film-making [42] and video games [117]. It has been commonly adopted for biometric synthesis in sports training [39, 160], in ballet performance [29], and in complex movements [30]. More recently, MoCap has become a key recording tool for movements or maneuvers of performative cultures, such as Cypriot folk dances [143], Southeast Asian traditional dances [119], contemporary dances [19, 147], martial arts [28], combative sports [161], as well as reference gestures of traditional crafts [125]. There is also a contemporary trend to exploit MoCap as an extended interface for augmented performance [63–65], real-time dance evaluation [11, 74, 101, 139], embodied training and education [80, 134], and human-computer co-improvisation [103].

In technical terms, MoCap is accomplished in different ways, subject to the requirements and affordability of specific archival contexts. In general, MoCap techniques are categorized into mechanical, magnetic, and optical capture, leveraging systems that are camera-based, sensor-based, or a hybrid of both for optimal harvesting with

⁴Tim Ingold argued that some movement is “automatic and rhythmically responsive” to its surroundings and “along multiple pathways of sensory participation” [77].

precision and information. Further investigation into technologies can be found in [123] with a comparative study on the real-world applications, [95] inspecting the dance-focused capturing projects, [118] with a systematic review of the emerging systems, and [131] listing the milestones of MoCap-enabled choreographic analysis. The shared merits of motion capture systems are grounded in their documentation of the omnidirectional geometry of body movements. It denotes the capacity of MoCap methods to record the parameters of physical features, positions, rotations, joint angles, and kinematic metrics exhaustively. These features altogether allow for the reconstruction of moments barely quantified in plain formats as audio-visual recordings, especially those containing complex moves [143]. Assisted with machine learning and modeling methods, MoCap empowers multifaceted understandings of human motion in themed activities, dance being an exemplar [81, 131]. As such, it lays down the computational basis for tangible visualization, immersive engagement, and active narratives to communicate knowledge through a magnified sense of embodiment.

Aside from capturing, reenactment has emerged as another favored documentary modality of sustaining vital practices that are historically lost yet demonstrating a cultural identity. Unlike classic repositories where cultural objects are accentuated as vessels of memory, reenactment forfeits its indexical link between the footage and original events. Other than retrieving the objects, acts, or contexts from well-documented grounds, it pursues a close-to-authentic recreation of the past moments [120]. Therefore, this archival modality requires extensive studies to complement and sometimes correct the misrecorded entries in order to accomplish a rigorous enactment.

The *Remaking of Confucian Rites* project is a prime example of comprehensive reenactment, specifically because of its archival process. It involves renewed scrutiny and extensive cross-referencing of the archaeological, archival, and textual materials, alongside the production of theatrical scripts, venues, characters, and object replicas based on the “close reading” of *Yili* (Book of Etiquette and Rites) [87, 126]. Such comprehensive reenactment revives li-rites studies as a system of awareness and embodied self. Subsequently, this research cradles a series of applications and interactive interfaces that enliven the re-envisioned performances for a much wider audience.

In another experimental project, researcher Daniel Jaquet used his own body to investigate the functionality of late medieval harness [78]. To this end, he conducted performing tests while wearing a scientific replica to quantify its influence on movement liberty and energy expenditure. Furthermore, Jaquet inspected the underlying design rationales. This reenactment involves the in-depth study of material culture (arms, armors, and clothing) to reproduce the objects, together with a detailed dissection of technical literature to resume the moves and environments. It also suggests a shift of embodied knowledge research from merely theoretical verification to experiential validation.

Beyond documents, media-making and cinematic tools are powerful to foster the narratives of history and indigeneity along with reenactment performances [35]. One instance is *Cut Off My Tongue* [60], a long-running show composed of collecting poetry, music, dance, satirical vignettes, and performing pieces with traditional African instruments. The project centered on an effort to revitalize the postcolonial national identity of Kenya through re-performing a series of ethnic dances at Bomas of Ken, realized through artistic communications in different communities and local audiences. Such living production shares more traits with the profound notions of tacit knowledge and repertoires of transmission, also consistent with the establishments of sensory education.

2.2 Multimodal archives for meaningful moves

A *making live* schema in digital archiving is capable of embracing both robust and fragile dynamics delivered through the living practices. This schema transcends the use of digital powers more than placing multimedia collection online [150]. In parallel, although performance can be transmitted by practicing and preserved through lively documentation, cultural heritage is more often formed through the interpretation of plural manifestations involving both material and performative approaches [163]. It is further remembered through the evolving recreations of its distinctive creators and cultural owners [102].

Taking up the concept of “heritage kinesthetics”, Savova denoted five major dimensions concerning the interaction between the heritage sites and their audiences, which are: visual (capturing; seeing versus looking), ambulatory (inspecting and exploring), performative (enacting and being guided), oral (telling stories and imagining history), and acoustic (re-creating place-specific sounds; sonifying) [137].⁵ Besides, numerous scholars have asserted that ICH digitization should serve for the holistic construction of cultural spaces with person-object-event meanings and thus calls for hybrid solutions [22, 107]. Originated from linguistic analysis, multimodality has acted as one of such solutions. Here, it designates a state where different modes within single artifacts - through a combination of related multimodal documents - are synthesized to co-generate the meaning [15, 149].

Digital archives, with a correspondingly vast multimedia collection and metadata sources, have innovated the modeling strategies to re-imagine heritage entities. 3D digitization is one of the methods to virtually recreate an ICH object. In this regard, the *Hong Kong Martial Arts Living Archive* (HKMALA) has forged a new paradigm by situating motion capture data of masters’ performances within multimodal documentation. The archive encompasses a comprehensive strategy to document diverse aspects of martial arts knowledge comprising movements, rituals, traditions, histories, and stories of practitioners. While the archival formats cover videos, audio, photographs, drawings, texts, 3D reconstructions, creative visualizations, and motion-over-time analytics [28]. Such a diverse collation can form a complete inventory representing the whole-of-environment knowledge and nourish generous interfaces [154] for cultural dissemination.

In another example, [10] presented an extensive data collection along with the digitization of Cypriot folk dances. This research recorded data about dancing motions associated with other cultural aspects, such as the name, age, and gender of the performer, location and descriptions of the performance, and an emotion annotation recognized by the algorithms [8]. By employing a relational database schema that structures the dance data and metadata information, Aristidou et al. instantiated a multimodal database and made it accessible for public consumption.⁶

Nonetheless, holistic re-creation is ensured based on the formal study of archaeological clues about colors, shapes, materials, and architectures from documentation [69]. Due to the growing amount of multimodal ICH data assets, interoperability solutions turn out to be indispensable as they locate distinct entities in one system utilizing metadata models at different levels (schema level, record level, and repository level) [71, 99]. In this regard, Lourdi et al. presented comprehensive research on the issues of interoperability and metadata schema for digitizing folklore collections [107].

Among the applications, KIRA [5], a content system for art collections, retrieves cultural items by relating them to their correspondent heritage environments, such as museums, archaeological sites, and physical places. This system organizes various entities in the distributed repositories, yet a predominant object-location network. In another project, the *Digital Exploration of Cultural Heritage Objects* (DECHO) [3] introduced a framework that integrates heterogeneous data sources with historical information, including images, solid visualization, and 3D acquisition. Such relational accessibility unlocks ontological access to various data and thus allows investigating findings in contiguous relation to historical, social, economic, and geographical contexts.

According to a summary by Maree et al. of the distinctive CH content approaches, linkage-based structures can serve the needs of materialized archaeological investigation [114], but extensions serving dynamic documentary are indispensable for archiving intangible cultural expressions. Besides, our survey above reveals that contemporary archives always come with exclusive data structures. For this reason, we contend that new semantic groundings are necessary to support standardized computational frameworks alongside fine-grained archival narratives [88, 113]. Models interrelating entities pertained to culturally relevant knowledge sets are required in

⁵Although Savova’s definition in 2009 mainly addressed the relationship between visitors and static cultural sites, it provides a solid basis for us to extend a modern understanding concerning intangible heritage.

⁶Dance Motion Capture Database (DMCD), 2019. <http://dancedb.cs.uey.ac.cy/>.

particular. As such, we expect solutions on both representational and conceptual levels for two specific reasons. On one hand, these can facilitate a collaborative archival convention that embraces shared contributions from different research communities and grants interlinked access among distinct cultural contexts. On the other hand, such an integration capacity may empower crowdsourcing-like participation in the archival formation, where the audience collaborates with the archivists, and sometimes remediate, in the documentary process.

3 TOWARD A CONCEPTUAL FRAMEWORK

Digital curatorial conventions of ICH are becoming increasingly interdisciplinary, data-driven, and multimodal. Such characteristics stand out through producing numerous heterogeneous contents, as well as advancing technical innovations beyond object-centered display. Such shifts have led us to reconsider the archive as a more analytical, semantic, and interlinked entity [162].

The ability to archive and catalog cultural items is subject to the existence of shared models for representing them on a meta-level [20]. However, as will be detailed in Section 3.2, formal models that encapsulate intangible cultural elements are far from the maturity of those found in traditional CH. Extended investments have been directed to improving accessibility for digital repertoires of ICH, which calls for formal representations competent to encode the meanings of living and embodied elements.

To bridge this gap, motion encoding has emerged as a potential solution to “transform the performed cultures into tangible choreographic digital objects” [50]. This current is occurring alongside experiments of applying computer vision accompanying machine learning algorithms to movement recognition, classification, and annotation (see Section 3.1). In combination, these efforts have forwarded the development of novel applications and systems for ICH data management, which involves multimedia processing, metadata creation, and manipulation. Besides, we have seen interests in new ontological approaches that operate in a related, pragmatic, and conceptual manner. The latter unlocks unified access for efficient search, retrieval, storage, and exploitation of the distributed archival datasets [24, 81].

3.1 Encoding motion in the context

Technologies of motion data capture have been prominently used to visualize, analyze and synthesize choreographic knowledge, especially for dance-related ICH [10, 55, 104, 134]. Among various approaches, feature-based motion extraction and auto-annotation prove effective in combination with the established notation systems, e.g., Labanotation [75] and Benesh [18], that provide standard rules and vocabularies to describe the movement. Motion-encoded representation also empowers knowledge access through metrics of perception and action. To fulfill a more intelligent and unsupervised encoding process, the creative usage of machine learning methods is giving rise to various investigations.

For instance, Aristidou et al. proposed a Laban-based retrieval framework to compare motion components, including physical geometry of the human body and stylistic characteristics of the dance movements [12]. This research transformed body movements into a high-dimensional feature space and extracted common yet descriptive short-term segments, namely *deep motif* via machine learning. The distribution of *deep motifs* was then used to define a bag-of-words (BoW) model for motion indexing, temporal segmentation, and retrieval [9]. Similarly, El Raheb et al. consolidated posture recognition and dance-notation languages into a web-based system to assist with multimedia annotation in a multidisciplinary research collaboration [55].

Algorithmic advancements from other fields, exceptionally vision-based recognition [34], spatio-temporal action classification [44, 97], and content-aware video analysis [140], have demonstrated their promising usage in cultural analytics. The *Gesture Atlas* is one such example.⁷ It displays depictions of the Annunciation via the image-corpus clusters of poses and gestures learned from unsupervised learning [17], but still with no reference

⁷*Gesture Atlas*, 2019. <https://biblhertz.github.io/atlas>.

model to further organize them. Another project named Query-by-dancing [146] offered a cross-media retrieval method by comparing pair-wise similarity from a massive hip-hop video collection. Taking one step further, [72] readapted this approach to enable search-by-instance in the less-annotated videos of re-performing Confucian li-rites. Nevertheless, these inventions tackled a limited scenario for similarity-based search and retrieval.

Featuring programmatic scalability, a highly compressed *deep signature* was introduced by [153] to encode a moving body feature sequence as binary codes. This method features a significant boost of runtime performance in large-scale databases. It also shows the capability of indexing, retrieving, and even reconstructing basic moves from a single signature. Also aiming at scalability, Sedmidubsky's version of *motion word* invented a text-like representation of 3D skeleton sequences and thus made the benefits of text-training models applicable to a more complicated context [138].

From a different standpoint, motions are getting attached to the contextual data for illustrating performing movements with their background knowledge. [159] provided a classic video analyzing framework, namely *mutual context* for identifying activities upon co-occurrence and spatial relations between human poses and objects. El Raheb et al. exploited the fundamental structure paved by notation scores and transferred dance choreography into a set of human-readable and machine-readable DanceOWL concepts [54]. In a more interactive format, *BalOnSe* created a novel application for users to search as well as annotate ballet videos via the ontological tags of movements [56].

Toward the direction of intelligent reasoning, Mallik et al. leveraged algorithmic recognition to denote performative hand gestures, facial expressions, and body postures in Indian classical dance. On this basis, acquiring heritage media into a specialized ontology became automated at both the knowledge and feature level [109]. Furthermore, [27] introduced the use of a probabilistic framework, namely Multi-Entity Bayesian Networks (MEBNs), for analyzing movements in dance with additional information. [62] presented a metadata schema following the three-level logic of the FRBR (Functional Requirements for Bibliographic Records) model and based on the practical validations through *Terpsichore's* folklore dance experiments [50].

The projects reviewed above have taken unprecedented steps to develop descriptive encodings for embodied nuances, notably a holistic investigation of the folk dance recordings. But as some researchers have pointed out, the cross-field inspection for denoting motion in ICH contexts other than dances, especially the non-choreographic practices like circus [151] and martial arts [2], much as they too may involve practices founded on choreography, remains under-researched. It is worth stressing that the intangible and embodied knowledge is defined through diverse factors: not only poses, gestures, or sequential moves, but also agents, locations, objects, in addition to rituals and traditional notes. Therefore, an interlinked network of multimodal entities plays a significant role in contextualizing actions within a conceptual space. In addition, as scalability remains a real-world challenge in the consumption of cultural heritage archives, compact models are fundamental to encode such rich information. In this regard, generative approaches may turn out useful to enable creative reconstructions of less-recorded performances or enrich interactions for cross-modal retrievals [38, 53], therefore a possible means to scale ICH transmission.

3.2 Beyond movement: Linking data for knowledge

In line with Vaughan's statement during their experimental design of a living archive for circus performances, intangible cultural knowledge does not necessarily "lie" in each independent dataset but between all that accrete around [151]. Cultural presence in the heritage field needs to reassemble the multimodal elements to form the sensation of "being there" [129]. For this reason, formal ontologies are appropriate as they serve as a logical and interconnecting theory that seeks to elucidate the meaning of a specific domain, otherwise to act as a link between different domains [68].

Ontology as a formal and representational model has been applied to numerous CH instances. Extensive development has been in place to standardize data integration via the links manifesting material and physical aspects [48], e.g., the famous CIDOC-CRM [47], Europeana data models [49], and International Image Interoperability Framework (IIIF) [141]. Meanwhile, some projects have enforced pragmatic data accessibility by aggregating digital records based on the cultural coordinates [10, 22, 111]. The ArCo ontology is emblematic in this sense, being the first occurrence of a formal model that explicitly partitions cultural traits into tangible and intangible [24]. On an ongoing basis, the Mingei project endeavors to establish new representations for capturing tangible and intangible dimensions of Heritage Crafts.⁸ Additional examples of the latest semantic models and linked data usage in CH have been reviewed by [162] and [41].

While ontologies for traditional CH have achieved a degree of generality, models that warrant a particular immaterial dimension for ICH have been sparse in the existing research. Among the few, [23] signifies an ontological approach to describing visuals via iconographical representations. With regard to the dimension of experience, the projects of LED and READ-IT produced respective models to catalog the phenomenological aspects of listening and reading [1, 7]. The latter also marks a case of interoperability sought with CIDOC-CRM and its extensions. Personality and inner traits, when they are archetypal and stereotypical through arts and literature, can also characterize intangible cultural items. Early efforts in capturing this dimension include employing ontologies to extract personality traits as expressed by authors through texts [51, 52].

Traditions and folklore are considered elements of ICH that are particularly difficult to model. Nevertheless, they may contribute to generalizing certain notions into a concept that can be labeled as cultural exchange and modeled as a catalogable item. [67] derived one such ontology, *CuCoO*, using a bespoke rule system on top of a domain ontology.⁹ It was built as a use case for inferring cultural exchange in Ancient Roman Spain through the minting of coins. Similarly, as ancient coins can be the vehicle of communicating the presence of intangible cultural elements - for example, style, cultural exchange, or experience - so too can gestures and motion become carriers of ICH features. This aspect allows us to argue in favor of scrutinizing the existing formal models carried out in different fields, such as literature, music, paintings, and folklore. Because of that, the material testimony that they bear can potentially betoken the media and documents where motion or pose are encoded.

Drammar is a good case in point which presents an integrated model enfolding the terminology for preserving and annotating dramatic media objects as sets of evolving entities [105]. It tackles the representation of drama via a three-layered ontology design: an action layer that organizes a succession of incidents consistent with the literary chronology; a motivational layer centered on the intention of the embodied agent who is achieving a goal; and finally, a dramatic layer predominantly structured on the scenes. The latter directly accounts for the orchestration of the conflicts between the agents through their actions [106]. Also dealing with storytelling in the ICH domain, the Narrative Ontology, or known as NOnt, offers a modern approach to representing crafts knowledge in the context of the Mingei project. Implemented using OWL 2 DL and SWRL languages, it operates as an extension of the standard vocabularies of CIDOC CRM, FRBRoo, and OWL Time [116].

On the other hand, building ontologies for enacted cultures requires information-intensive mapping to explain the knowledge from media resources, which entails encapsulating intangible elements from performative events, features, facts, contexts, and cultural objects [22]. Its construction should allow for scholarly inquiries at different levels, by means of notation and reference in particular [32]. For instance, [54] proposed a multi-layer framework combining formal movement symbols, domain-specific vocabularies, and natural language descriptions to serve as an infrastructure to link semantic categorizations. With a different approach, *Nrityakosha* implemented an ontological knowledge system using Multimedia Web Ontology Language (MOWL), a domain-specific paradigm

⁸Mingei (Representation and Preservation of Heritage Crafts), from 2018 to 2022, is an EU-funded project under Horizon 2020. <https://www.mingei-project.eu/>.

⁹The Cultural Contact Ontology. <https://github.com/paulagranados/CuCoO>.

inter-linking multimedia for representation [111, 112]. Assisted by an annotation tool to involve domain experts' knowledge, this work formalized the semantic linkage between different modalities. The resulting interface enabled users to search digital artifacts via correlated concepts in the heritage collections of Indian Classical dance [110].

To summarize this section, although there has been an increasing focus on movement studies and linked data for performances, the construction of explanatory ontologies for embodied knowledge in ICH remains one of the lesser studied areas. The lack of high-quality digital and, more critically, computable resources available to research communities forms one of the hindering factors. Besides, correcting a rigorous system of cultural semantics is necessary to enforce meaningful interpretations of the entities detected from data. For this reason, it is fundamental to interrogate the cultural groundings closely and thus urges cross-disciplinary collaborations to bridge the gap between computational practitioners and relevant domain experts.

4 INTERACTING WITH LIVING KNOWLEDGE

Intangible heritage is inherently a living entity, a cultural space that incorporates a know-how process that is anecdotal, oral, embodied, shared, and in evolutionary adaptation to its various audiences [102, 151]. Hence, apart from mediating between digitizers and specific ICH holders, it is equally crucial to upgrade the communication paradigms with the general public toward a form of interactive transmission prioritizing knowledge creation [88, 157].

When disseminating ICH at the community level, GLAM (Galleries, Libraries, Archives, and Museums) institutions and heritage sectors have been acting as the official sites where the CH “intellectual capital” gets exhibited. To achieve a cultural dialogue with public audiences, Kenderdine has promoted a framework named “embodied museography” to disrupt the ways of displaying by attributes of immersion, interaction, and participation [85]. To this end, we will use Section 4.1 to discuss the remarkable instances of building an ICH learning environment via visualization and virtual embodiment.

To fulfill the ideal of “live transmission” at the individual level, an entirely interacting and participating modality has been advised for designing experience with personal resonance [142]. This encompasses cross-modal presentations for users, sometimes visitors, to restore an authentic living cultural space entangled with “the instruments, objects, artifacts and spaces” [148]. Consistent with this notion, Section 4.2 will showcase the innovative projects that leverage edutainment and creative interfaces to convey the ICH knowledge for its potential holders. In such circumstances, serious games play a critical role in engaging users to interact with the data content. In the meantime, computational models can significantly enhance the digital realm for knowledge explanation.

4.1 Augmenting cultural user experience

Cultural user experience (CUX) has gathered strong momentum in the GLAM and CH studies as it adds a crucial dimension to uplifting the visitor's interaction with cultural objects. As summarized in [100], a good CUX design generally highlights three lines as follows: it exhibits relevant sources and instruments to activate a learning experience; it presents an ambiance where visitors play an active role in their cultural explorations; it conveys a universal language to engage the audiences from different backgrounds. Consistently, digital media and ever-upgrading virtual technologies have got advocated for augmenting the overall experience of cultural dialogues.

Within this context, interactive digital storytelling (IDS) is considered a critical strategy following the CUX rationales. As a means to communicate experiential factors, IDS promotes a curatorial combination of technologies and perception channels. It also emphasized customizing the narratives in compliance with the attention span of the digital natives today, as they have been accustomed to receiving fragmented information and not always

patient in watching long content. As revealed by some latest studies, IDS entails addressing challenges from different aspects. These include the design of the entire storytelling experience, the deployment of presenting formats, and the inhabiting configuration of the spatial or virtual environment. The ultimate goal of IDS is to achieve an involving state that is able to stimulate personal resonance via the narrated contents [82, 124, 128, 133].

As mentioned above, the ever-upgrading virtual technologies, comprising reality (VR), augmented reality (AR), mixed reality (XR), and extended reality (XR), has substantially empowered CUX by injecting creativity and flexibility into the interfaces. Virtual museums have enabled the public to appreciate object collections wherever they are, instead of going to the museums. That may also apply to disseminating intangible cultural materials. The Virtual Dance Museum [13] acts as a novel paradigm by visualizing dressed folk dance performances of a 3D character in multiple virtual interfaces, including an online 3D environment, a VR head-mounted display, and mobile-based augmented reality.¹⁰ This platform allows the users, wherever they are, to access the visual, cultural (music and clothes), and descriptive properties of dances directly. By way of photorealistic 3D visualization and VR demonstration, Partarakis et al. implemented AnimIO, a public tool from the Mingei project, to present the reconstructed recordings of traditional craft gestures [125].

The employment of virtual means (VR/XR) integrating physical environments triggers a sense of embodiment. It immerses the users in a multi-dimensional experience and thus helps the pedagogical formation of knowledge. The Immersive Learning Level Editor (iLLE) is one such system. Leveraging real-time embodied interactions while enhanced by real-world visual and auditory feedback, iLLE creates an in-situ learning context not only for practical knowledge educations but also for life-sized reconstructions of ICH dissemination [93]. With a consistent goal, the *Moments in Time in Immersive Virtual Environments* (MoTIVE) project embarks on devising new methods for enlivening historical rock concerts using VR, with the intent to revive the perception of being there (Place Illusion) and the sense of reality (Plausibility).¹¹

Formulated through visualization, hypermedia, and multiple sensoria, embodiment plays a vital role in generating an active visiting experience in the museum space. This capacity converges on the outlook of the *Intangible Cultural Heritage and Museums Project* (IMP), which re-situates museums as the “contact zone” between tradition, innovation, and communities, stitching space and time of people for disseminating knowledge of living heritage [33, 121].

To this end, Kenderdine has investigated a framework entitled “experimental museology” [86], advanced from “embodied museography” [85], to break the boundaries of museological spaces and the representation of cultural archives. Within this framework, the human body turns into a five-tiered vehicle of the embodied self, including the biological, phenomenological, ecological, cultural, and social body. With extensive usage of stereoscopic 3D visualization and panoramic storytelling [83, 91, 92], “experimental museology” stresses the factors of architectural integration, immersive interaction, mobilized participation, and cinematic presentation to facilitate the heritage presence through augmented cultural “aura” [70, 79, 84].

Among the building blocks of embodiment, visualization is at the heart of allowing new levels of cognition, information, and analytics [73, 93, 154]. Regarding displaying on a planar screen, [156] has given a thorough study on state-of-the-art systems, principles, and design challenges of visualizing cultural heritage collection data. The power of visual narration, when moving to a physical space, can be further amplified through spatial ambiance, interactive new media, and technological interventions [121]. In addition, as Witcomb affirmed, that knowledge exhibition should favor the usage of dynamic, relational, and open-ended narratives, which produces long-term engagement and more effective pedagogical effects [157].

¹⁰Virtual Dance Museum (<http://dancemuseum.eu/>) is an outcome of the running project SCHEDAR (*Safeguarding the Cultural HEritage of Dance through Augmented Reality*): <https://www.schedar.eu/>.

¹¹MoTIVE is an ERC-funded project from 2018 to 2023. <https://cordis.europa.eu/project/id/742989>.

As an instance of such rich yet embodied narratives, Kenderdine and Shaw presented a new form of motion-over-time visualizations involving the human body, through the installations profiled in the exhibitions of *300 years of Hakka Kung Fu* – digital vision of its legacy future [89] and *Kung Fu Motion* [90]. In another format, *Living Archive* invented a techno-human demonstration of Bharatanatyam dance works by investing AI in choreographic creativity.¹² These innovations evidence that bodily narratives can expand the psycho-visual aesthetics of performance and connect the organic to the digital on an experiential level [14].

In summary, building an interactive and interpretive digital experience is the key to transmitting cultural heritage, which encompasses the phenomenological design of spatial definitions, sonic landscape, shaping of movement, and social presence. Such a paradigm evokes the presence of the past and enhances sentient engagement in digital expressions. Consequently, visitors can remember, perceive and imagine encounters with the heritage [58, 61]. Sophisticated model-making or artistic creation might not be essential in this process. Nonetheless, they are vitally concerned with producing sensory engagement and also meaningful cultural learning experiences for the general public [85].

4.2 Edutainment in “live transmission”

Originated from the 2003 Convention, the term “live transmission” emphasizes a lively educating process that allows simultaneous interaction between the teacher and learner [142]. Entertainment has long been acknowledged as a motivating factor in educational applications to foster a motivating environment for active learning [155]. Edutainment, the combination of entertainment and education, has also gained interest in the heritage sector. An enjoyable experience is significant because it engages the audience emotionally, intellectually, physically, and socially, thus generating long-lasting impressions for cultural transmission [104].

As experiments in a physical space, [132] trialed a hyper-storytelling method by employing multimedia in cultural heritage for in-class teaching. Such a modality proved effective in terms of boosting the learners’ motivation according to their pedagogical experiments. Scholars in China integrated the edutainment components in building an ICH theme park. They validated through experiential studies that entertaining and participatory activities, such as live performances and imitative craft-making experiences, can enhance public learning engagement [108].

In the digital realm, serious games (SGs) have emerged as a fashion of enriching interactivity and participation, also gained recognition for building tangible virtual environments for cultural learning [76]. [6] has summarized a framework to design, develop, and evaluate immersive and collaborative games of cultural heritage. Whilst [115, 122] adopted SGs to facilitate heritage accessibility for impaired persons.

At the same time, gamification remains relatively under-studied for intangible heritage contents, but some projects have embarked on the exploration. The *i-Treasures* project, for example, has released a 3D visualization sensorimotor learning framework and implemented it with seven body-motion-game prototypes for the transmission of folk cultures [40, 46, 98]. Likewise, the *Transmission through Imitation* project has invented an interactive martial arts application based on the computational usage of high-fidelity 3D motion data. The accompanying installation allows 1:1 scale real-time interaction between a human novice and a digital master.¹³

Virtual and immersive approaches have proved to uplift edutainment for performance-related teaching and assessment. As an early example, [26] developed a VR dance training system based on the MoCap infrastructure and simulated real lessons by animating a virtual instructor presenting and recognizing the learner’s moves. Consistently, [80] provided a virtual Taekwondo training environment to exploit VR systems in tandem with MoCap computation as an alternative to the existing Taekwondo training approaches.

¹² *Living Archive: An AI Performance Experiment* was a collaboration between Studio Wayne McGregor and Google’s Arts and Culture Lab in 2019. <https://waynemcgregor.com/productions/living-archive>.

¹³ *Transmission through Imitation: Transforming Intangible Cultural Heritage Archives through Virtual Reality and Sports Science*, EPFL, 2020. <https://www.epfl.ch/labs/emplus/projects/page-155235-en-html/>.

More comprehensively, [11] has presented a dance evaluating system based on the principles of Laban Movement Analysis (LMA) for motion style identification and comparison. [139] lately extended the scheme to a gamified virtual environment for salsa dance learning interaction. Positioned as modern experimentation on dance education, the *WhoLoDancE* project [31] produced a suite of tools for dance teachers and practitioners.¹⁴ Among them, *Choreomorphy* featured a gamified whole-body interactive system for choreography improvisation. It uplifted the learning experience by producing aesthetic visualization as a real-time reflection of the dancers' movements [57, 130].

In a more creative format, [152] introduced a multi-user 3D environment in the gaming scenario of *Ancient Agora of Athens*, an archaeological site located beneath the northwest slope of the Acropolis. In addition to solely representing tangible elements and defined moves, this game included embodied characters known as NPCs (non-player characters) that interactively communicate with the users. This novel application revealed the potential of augmenting ICH SGs by adding personalized intelligence to the contexts. It also signals a direction to compose an all-inclusive heritage environment combining historical stories, dialogues, daily life activities, conventions, rituals, and habits.

The gaming vernaculars discussed in this section have focused on disrupting the conventional models for communication and have fostered the participant's understanding of heritage presence. Some of them tried to create corporeal conjunction between the characters to elicit motion-sensory memories [145]. To this end, Sylaiou has indicated the potential of adding AR interaction to the virtual heritage games through an assessment [144]. Indeed, forms of virtual technology (VR/AR/MR) are promising, especially for engaging bodily practices in receiving the knowledge of intangible heritage. But the portability of apparatus and the compatibility of different platforms demand proper solutions so that such technologies can scale outside laboratories [31]. Another challenge of developing SGs is to ensure high-end usability for the target users. SGs are outstanding educational tools when they successfully rationalize the cultural materials and bridge them to well-designed gaming reactions. Otherwise, they may result in player disappointment and expedite withdrawal instantly.

5 DISCUSSION AND CONCLUSIONS

The oeuvres and practices of intangible cultural heritage (ICH) have played a significant role in the cultural identity of human beings. These cultural products of both historical and modern communal values are, however, at times confronted with the view that many of them have become superfluous or replaceable by the others [158].

Digital efforts have been increasingly employed in recent years to preserve and disseminate ICH assets. Yet many of them were working with object-orientation or restricted to choreographic documentation. As a result, living and embodied facets of ICH are seldom represented with meaning in its representation. A strategic shift has been advised to recognize the human body as a vehicle for traditions and memories [135]. We should re-examine the rationales behind the whole lifecycle of ICH digitization, which encompass what to document, how to archive, the schema of encoding and modeling, and lastly, the forms of presenting and interpreting knowledge proper for active transmission.

As such, this article provides a critical review of the state-of-the-art research projects, all having advanced the digital practices for transmitting ICH but still left some less-studied issues.

In the first place, the new modality of lively captured archives has posed a challenge to their accessibility, both programmatically and intellectually. As an appropriate answer to this issue, the dimension of human movement is encouraged to enforce more intuitive and universal queries into the archives. This proposition calls for effective ways to encode and index movements in a descriptive yet generalizable format. Accordingly, algorithmic advancements in human motion recognition have provided various pathways, which boast the potential of enhancing data integration, fighting against the issue of distributed intellectuals and the ever-increasing scale of

¹⁴ *WhoLoDancE*, from 2016 to 2018, was funded under the EU Horizon 2020 Programme. <http://www.wholodance.eu/>.

living archives. Nevertheless, such intelligence gets effective only if archive-specific training has been fulfilled. Besides, since the determining process of machine learning, especially deep learning models, tend to operate as a “black box” [21], it appears necessary to stress human-centered modeling in combination with explainable AI in the computational design for ICH [127].

Interoperability has appeared as another key to bridging the gap of accessibility by way of conceptual representation for the multimodal cultural archives. As such, archival curation is transforming from cataloging high-level delineated documentation to computing with a paradigm of formalized semantics. This trend also articulates establishing culture-specific ontologies and linked data models. Specifically, this paper highlights two aspects during the modeling: the multimedia assets and the embodied narratives. Both are critical but lack research. In parallel, questions on how to apply semantic technologies to interactive storytelling for cultural heritage, especially in the GLAM spaces, stay to be answered. When properly transformed into finely curated contents, massive multimedia archives may serve as tools to enable novel exploitation for public engagement and contexts to connect them. With this notion, a recent project, *Narratives from the long tail*, has initiated to fulfill the “narrative coherence” by dynamically revealing the spatial, temporal, social, affective, and aesthetic patterns of massive audiovisual materials in a 360-degree 3D visualization while the audiences navigate.¹⁵

To conclude, education and knowledge discoverability have acted as the shared motivators for both technical and cultural heritage sectors [41]. In practice, collaboration needs to be fostered based on an in-depth understanding of each side. Such a grounding ensures the technology to be utilized to its full potential, not merely to produce tools for exhibiting the collections, nor to exploit cultural data just as a challenging dataset to satisfy the algorithms. Yet, from a museological perspective, the urgency to unfold the massive multimodal ICH repositories in front of the public is beyond doubt. It is necessary to augment the data curation lifecycle at a systemic level through a marriage of computational approaches and novel forms of in situ engagement for narrative making. The innovative practices have implied the prospect of intersecting immersive visualization, visual analytics, aesthetics, and cultural data for knowledge production. Accordingly, we shall highlight the roles of participation, cognition, cinematography, and embodiment for producing new interpretations toward an effective ICH transmission.

ACKNOWLEDGMENTS

This work was supported by the EPFL-UNIL Collaborative Research on Science and Society (CROSS) Program.

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