Craft and Repair Heritage: From Capture to Dissemination in Digital Space

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Abstract

The preservation of construction and repair knowledge necessitates a shift from static documentation toward the dynamic capture of the embodied and collaborative nature of craft. This paper proposes a framework that leverages motion capture technologies to record and archive whole-body movements associated with traditional and contemporary construction practices. Drawing on historical motion studies and aligning with international heritage charters, the approach addresses the limitations of conventional documentation methods, which often overlook tacit knowledge, human-machine and tool interaction, and the situated processes of making. By integrating motion data into digital preservation workflows, the proposed method facilitates the transmission of intangible cultural heritage (ICH), supports repairability, and enhances the resilience of architectural documentation. The research underscores the ethical, legal, and cultural considerations necessary for documenting sensitive practices and advocates for metadata-enriched, context-aware digital archives. Ultimately, this work contributes to a broader redefinition of architectural preservation that values embodied knowledge and promotes access to craft expertise across temporal, geographic, and disciplinary boundaries.

1. Rethinking Preservation for Digital Applications

With intangible heritage and building complexities, the recording and archiving of construction processes have become important. Prevalent methods in recording buildings for maintenance and repairs have, to date, focused on the static state of buildings through photogrammetry, scanning, and measurement technologies. Such methods leave out the importance of iterative design, fabrication processes, and the living embodied tradition of construction. Moreover, the insufficient documentation of the human-machine collaboration, the obsolescence of the digital environment, and the intricate construction logic challenge their long-term preservation. This lack indicates gaps in knowledge and signifies that efforts are required to reproduce and curate documentation, record human motion, and capture craftsmanship in a database for archival and transfer. This results not only in a cared-for architecture but also in the preservation of repair and maintenance knowledge, thereby countering the loss of heritage skills. The paper focuses on the documentation of architectural care practices and asks: (1) Why should craft knowledge about construction techniques and production processes be transferred into the digital realm? (2) How can it be preserved for authentic and long-term use? and (3) Can repair knowledge be optimized, universalized, and transferred to other projects?

Craftsmanship knowledge has traditionally been transmitted through interpersonal relationships and embodied practices. In recent decades, however, there has been a marked shift toward the systematic archiving of data and knowledge, increasingly facilitated by digital technologies. These tools not only preserve information but also repurpose it for diverse applications such as predictive analytics. In the Architecture, Engineering, and Construction (AEC) sector, this trend is exemplified by the growing adoption of Building Information Modeling (BIM) and digital twins, which aim to provide continuous digital representations of buildings and construction processes. While these models suggest a sense of completeness, they often obscure the absence of documentation related to labor and craftsmanship. This raises critical questions about how intangible heritage, particularly embodied knowledge, can be preserved and reinterpreted in the digital age.

The onset of the first machine age marked a turning point in building technology, gradually undermining traditional construction methods. Industrialization facilitated the widespread implementation of standardized, segmented techniques and the use of globally sourced materials, leading to the displacement of local practices and the associated artisanal knowledge (Bock and Langenberg, 2014). This transformation has led to a devaluation of the skills and expertise of local builders in contemporary contexts (Karakul, 2015). In response, UNESCO operated the *Living Human Treasure* (UNESCO, 1993) program from 1993 to 2003 and subsequently established the *Convention for the Safeguarding of the Intangible Cultural Heritage*, aiming to protect and revitalize cultural practices (UNESCO, 2003). The initiative granted recognition to tradition bearers contributing to the transmission of their knowledge and skills to future generations. Before establishing this system, some member states, like Japan and South Korea, already recognized the embodied intangible heritage of specific individuals and groups regarding their high craftsmanship. These countries designated individuals who were masters of a particular art or craft as the *Bearers of Important Intangible Cultural Assets*. However, nowadays, for localized work, having mentors and trainees on-site to teach, learn, and perform architectural repairs in the traditional sense is arduous. The documentation and access of this embodied knowledge, therefore, become vital. With innovative technologies, such as human motion and tracking, recording specific craft techniques for future reproduction is possible.

The proposed method draws upon a broad base of historical, technical, and ethical reflections, analyzing a diverse range of examples to identify both challenges and limitations in the preservation of repair heritage. Building on this foundation, it offers a carefully developed model for documenting and transmitting craft knowledge. The approach is particularly inspired by Frank and Lillian Gilbreth's *Motion Studies*, Mierle Laderman Ukeles' *Maintenance Practice*, and the recent *KIT Whole-Body Human Motion Database*, which together inform a nuanced methodology for recording embodied techniques and practices central to craftsmanship. At the turn of the 20th

century, with the machine's integration in the workplace and the beginning of human-machine collaboration, the optimization of workers' motion became prevalent. The Gilbreths developed a system to track workers on a metric grid background. The motion was recorded, mapped, optimized, and taught with wires to increase the efficiency of tasks, reduce fatigue for the worker, enable a novice to work intelligently, and document the knowledge handed down by word of mouth from journeyman to apprentice (Gilbreth, 1911). More than a century later, the adapted mapping method of the Karlsruher Institut für Technologie (KIT) database promises a seamless transmission for different users. With reference kinematics and dynamics model of the human body, movements can be scaled and tracked for optimal mapping and learning (Mandery et al., 2015). Specific motions can be accessed, scaled, and superimposed with projection mapping to foster embodied learning for on-site repairs and maintenance. This method complies with the Venice Charter Article 16 on the *documentation of preservation works*, with the Burra Charter Article 27 on *managing change,* and Article 32 on *records*. The motion documentation allows the user to address damages, promotes thinking while doing, and doing as a thinking process, thus favoring intangible heritage preservation, creative architectural adaptation, and a novel training process.

Repairing a building requires reinterpreting established preservation concepts and applying them creatively (Langenberg, 2023). Digital technologies and fabrication techniques frame how to address questions of aging, durability, and repairability. Overall, not only could the immaterial value of a building be higher than the material value of its original substance, but it could also prove invaluable in the preservation of the building (Langenberg, 2017).

2. Intangible Heritage and Documentation: From Charters to Digital Frameworks

The concept of heritage and its documentation has evolved markedly over the past century. Initially focused on conserving physical monuments, it now encompasses *intangible cultural practices* like craftsmanship and embodied knowledge. This shift parallels a transformation in documentation methods, moving from static records to dynamic digital frameworks. Key international charters and conventions illustrate this evolution and help position the proposed method within a broader heritage discourse.

In the early 20th century, amid global tensions, UNESCO was established to promote transnational cooperation in cultural heritage preservation. This led to the adoption of the *Athens Charter* which laid the foundation for international conservation principles (ICOMOS, 1931). Following the Second World War, the *Venice Charter* (ICOMOS, 1964). formalized modern conservation practices. Article 4 emphasized the necessity of ongoing care and repair, while Article 10 supported the use of scientifically validated modern techniques when traditional methods proved insufficient. Petzet reinforced the integration of modern technologies when necessary to safeguard historic fabric (Petzet, 1995). Article 16 introduced systematic documentation through analytical reports and visual records. This paper proposes extending these principles to include contemporary tools as augmented reality, digital design tools, machine collaboration, and advanced digital recording methods. While the *Venice Charter* remains foundational, it does not fully address the preservation of living architectural traditions, such as craft skills, rituals, and embodied knowledge. These intangible aspects require broader frameworks that recognize the cultural and social relationships embedded in the production and reproduction of heritage. The *Burra Charter* explicitly incorporates intangible heritage, defining conservation as the ongoing process of maintaining cultural significance ("The Burra Charter," 1979; revised 2013). Article 1.4 frames conservation as multifaceted and transdisciplinary, while Article 4 emphasizes the value of both traditional and modern knowledge, skills, and techniques. Articles 27.2 and 32 highlight the importance of documenting a site's fabric, use, meaning, and evolving states and ensuring public access to historical records, with sensitivity to cultural contexts. The *Madrid Document* emphasizes the importance of producing and publicly archiving records, as stated in Article 2.7 (ICOMOS, 2011). In alignment with the *Burra Charter*, Article 3 highlights the need to research and develop repair methods tailored to specific construction types, including the use of new techniques. These provisions affirm that cultural significance may not always be immediately visible and that maintaining "living records" is essential for informed and authentic conservation. Achieving this requires rigorous, context-sensitive data management to ensure accessibility, accuracy, and ethical stewardship. Similarly, the *Nara Document on Authenticity* builds on the *Venice Charter* by emphasizing the importance of heritage and authenticity across diverse cultures ("The Nara Document On Authenticity," 1994). It challenges Western-centric preservation models and recognizes that cultural diversity enriches global heritage. This research draws on these principles to reorient architectural preservation from material substance toward *immaterial significance*. A decade after the *Burra Charter*, the *Faro Convention* marked a major shift by emphasizing the participatory and societal value of cultural heritage ("Faro Convention," 2005). It challenges the notion of heritage as static, promoting a people-centered approach that supports community involvement in shaping collective heritage. Echoing Article 1.2 of the Burra Charter, it views cultural meaning as dynamic and evolving. The *Faro Convention* underscores sustainability and digital accessibility. Article 9 promotes sustainability with ongoing maintenance, traditional skills, and professional accreditation. This reinforces the value of craftsmanship and high-quality conservation standards. Similarly, Article 9.3 of the Madrid Document (ICOMOS, 2011) supports professional education in heritage, noting challenges due to a "lack of specific professional experience with their repair" (Brenner et al., 2024). Article 14 of the Faro Convention highlights the role of digital technologies in improving public access to cultural heritage, especially for education, while protecting intellectual property rights. These provisions support democratizing heritage, promoting sustainability, and integrating technological innovation. Since their inception, UNESCO and ICOMOS have guided heritage preservation through charters and conventions, expanding the concept beyond material conservation to include social, economic, historical, technological, and environmental dimensions. This shift, exemplified by the *Faro Convention*, has influenced how architectural documentation is created and preserved, which is increasingly managed in digital formats. While historical documentation through photography and film is acknowledged, this paper focuses on dynamic, embodied documentation that enables collaborative, updatable, and participatory information practices.

The previous section traced the evolution of architectural preservation through international frameworks, highlighting a shift toward more inclusive understandings of heritage. This section addresses the practical implications of that shift in the digital realm. As architecture increasingly relies on digital tools, preservation must adapt to include digital records, formats, and

workflows. This transition introduces challenges and opportunities in ensuring the longevity, accessibility, and authenticity of digital design data. Architectural digital preservation encompasses tools and systems that support long-term access to design records. Central to this effort is determining *what* should be preserved and *why*. This inquiry reflects the changing nature of the technological apparatus of architectural practice, particularly the integration of fabrication tools and processes.

Despite the introduction of key frameworks such as the *2022 Standards for 3D Data Preservation* (Moore et al., 2022), the *OAIS reference model* (Lavoie, 2000), the *Durable Architectural Knowledge in Digital Preservation* (DURAARK, 2014), and the *Library of Congress Report on Architectural Digital Assets* (Library of Congress and Leventhal, 2018), the AEC industry has been slow to adopt and implement comprehensive digital preservation standards. Among the pressing challenges are the development of platform-independent file formats, the establishment of archival protocols grounded in robust record-keeping principles, and the management of continuously evolving design records. Additional concerns include the handling of unpredictable file behaviors and the obsolescence of software environments (Library of Congress and Leventhal, 2018). A broader and increasingly critical issue is the preservation of intangible heritage, such as craft and repair knowledge, and its integration into both digital and physical preservation frameworks. The growing recognition of digital data and craftsmanship as intrinsic components of architectural heritage underscores the necessity for innovative documentation methodologies. The following section examines the processes involved in recording, preserving, and transmitting craft knowledge related to construction techniques and production workflows. It highlights the rationale for digitizing such knowledge, with particular emphasis on ensuring its authenticity, longevity, and adaptability. Furthermore, it explores the potential for repair knowledge to be systematized and standardized, thereby enhancing its applicability across diverse architectural contexts, different users, and future restoration efforts.

3. Recording: Challenges and Opportunities in Capturing Labor Practices

The preservation of craft knowledge requires either comprehensive documentation or sustained embodied transmission. However, as discussed in the previous section, the AEC industry has yet to widely adopt systematic documentation practices. Meanwhile, embodied transmission, reliant on direct interaction between skilled practitioners and apprentices, is increasingly challenged by factors such as geographic separation, generational discontinuities, and the decline or extinction of certain traditional crafts. Furthermore, intangible heritage conveyed through oral traditions and imitation is inherently susceptible to transformation over time through processes of collective reinterpretation and adaptation (UNESCO, 1993). Learning through making thus emerges as a situated, embodied practice shaped by the learner's context and interpretive engagement. According to the *Guidelines for the Establishment of Living Human Treasures Systems*, an effective strategy for safeguarding intangible cultural heritage involves the systematic collection, recording, and archiving of knowledge, followed by ensuring its accessibility and transmission (UNESCO, 1993). This approach underscores the importance of integrating both tangible and intangible dimensions of heritage into preservation frameworks, particularly in the context of evolving digital environments.

3.1 Disappearing Skills: The Decline of Craft Knowledge

The definition and distinction between knowledge, skill, craftsmanship, and tacit knowledge are central to understanding the transfer of expertise in architectural practice. Knowledge refers to theoretical understanding, while skills are practical abilities developed through training. Craftsmanship integrates both with a sensitivity to context and is the intuitive attunement to materials, tools, and processes developed through sustained practice. A crucial component of craftsmanship is tacit or embodied knowledge, the experiential, intuitive understanding that is difficult to articulate or transfer. It is acquired through direct experience, repetition, and physical engagement. This form of knowledge resides in the body and actions rather than in explicit instructions or codified texts. In the industrial era, various forms of craftsmanship disappeared or were devalued in favor of machine-automated processes (Bock and Langenberg, 2014). In this context, manual practices such as maintenance and repair emerge as acts of resistance, preserving embodied knowledge and cultural continuity. This resistance counters the "inexorable loss of building traditions, which always depicted individual histories in their material traces" (Will, 2010). Consequently, manual labor has not only retained its relevance in architectural practice but has also been embraced within performance and conceptual art, where it serves as a medium for critical reflection and cultural expression. In recent years, the *Swiss Baukultur Report* has emphasized the importance of renovating and upgrading existing buildings in ways that preserve their social and cultural significance, while also integrating ecological, technical, and economic considerations ("Davos Declaration," 2018) (Bundesamt für Kultur BAK, 2020). Complementing this perspective, the *German Baukultur Report* highlights a renewed emphasis within the construction sector on skilled craftsmanship and manual labor. This shift underscores the value of embodied knowledge, particularly the cognitive and sensory intelligence inherent in motor functions (Baukultur Bundesstiftung, 2023). The transformation of built environments over time is intrinsically linked to the transformation of the craftspeople themselves and of the craft through time. What is at stake is not merely the engineering of materials or their functional deployment, but the cultural and heritage values embedded within them. Constructing such a vision entails not only technical challenges but also profound ethical considerations. Ultimately, the preservation of architecture extends beyond the conservation of physical structures; it encompasses the safeguarding of the intangible cultural practices and knowledge systems that shape them. This is acknowledged in the *European Cultural Heritage Skills Alliance*, which developed a strategy with twelve recommendations and suggestions on how actions can be implemented to achieve a "well-functioning heritage ecosystem" (Charter Consortium, 2024). Recommendations 2: *Counteract the loss of Heritage Skills*, and 4: *Offer future-focused education and training*, are particularly relevant for the capturing, recording, and transmission of craft knowledge. Foremost, these recommendations acknowledge the endangerment of traditional practices within the architectural sector, highlighting a critical shortage and uneven distribution of skilled craftspeople. This deficit contributes to the gradual disappearance of essential knowledge and techniques. In response, strategies such as community-based engagement and the integration of digital training platforms are proposed as viable pathways for cultivating and educating the next generation of craftspeople, ensuring the continuity and evolution of heritage skills.

3.2 At-Risk Practices: Safeguarding Intangible Heritage

Recognizing repair as a distinct yet specialized subset of craftsmanship underscores the need for dedicated documentation. This section explores how repair and maintenance knowledge, often overlooked or embedded within broader craft traditions, can be identified and recorded as a vital component of intangible cultural heritage.

Before the adoption of the UNESCO *Convention for the Safeguarding of Intangible Cultural Heritage* in 2003, several countries had already implemented national legal frameworks to protect the custodians of intangible cultural practices. Notably, Japan enacted the *Law for the Protection of Cultural Properties* in 1950 ("Law for the Protection of Cultural Properties," 1950), and South Korea followed with its *Cultural Property Protection Law* in 1962 ("Cultural Property Protection Law," 1962). These early efforts recognized the significance of safeguarding the knowledge and skills embodied by individuals designated as *Bearers of Important Intangible Cultural Assets* (UNESCO, 1993). Since the establishment of the UNESCO Convention, the Representative List of the *Intangible Cultural Heritage of Humanity* has expanded annually, reflecting the growing international recognition of diverse cultural expressions. However, this recognition remains uneven. Certain countries continue to be underrepresented or absent from the list, and many cultural traditions still lack formal acknowledgment by UNESCO. This disparity highlights the need for more inclusive and equitable mechanisms for identifying and safeguarding intangible heritage on a global scale. The United Kingdom exemplifies a national approach to safeguarding traditional craftsmanship through its *Red List of Endangered Crafts*, maintained by the Heritage Crafts Association, which systematically identifies and monitors at-risk artisanal practices (Heritage Crafts Association, 2025). Similarly, since 2012, Switzerland, despite being partially represented on UNESCO's *Intangible Cultural Heritage list,* has developed its own national inventory, the *Proposed List of Intangible Cultural Heritage*, to document and preserve its cultural practices (Schweizerische Eidgenossenschaft, 2014). Across many countries, there is growing recognition of the vulnerability of traditional crafts, prompting the issuance of alerts regarding endangered practices and the implementation of strategies for their documentation and preservation. However, the processes of recording and archiving intangible heritage are themselves susceptible to loss, obsolescence, and restricted accessibility, underscoring the need for robust and sustainable preservation frameworks.

3.3 Digital Vulnerability: The Fragility of Files

In the context of architectural digital preservation, the effort and resources required to retrieve and utilize archived digital files often far exceed those needed to properly archive them at the point of creation. This imbalance is largely attributed to the rapid pace of technological obsolescence, the physical degradation of storage media, institutional restructuring, and the inherently dynamic nature of design professions. Architectural digital craft, in particular, is characterized by iterative workflows involving numerous files, directories, collaborators, software platforms, and media formats, factors that contribute to a fragmented and non-linear archiving process. Moreover, digital assets such as native file formats, datasets, and the tools and hardware used in their production are frequently rendered inaccessible with each transition to new operating systems, office relocations, or hardware upgrades (Lynn, 2013). These vulnerabilities are compounded by the ephemeral nature of digital media and the structural characteristics of digital practices. The Digital Preservation Coalition's *Bit List of Endangered Digital Species* identifies architectural files and software as particularly at risk (Digital Preservation Coalition, 2023). The Coalition concurs with the findings of the *Library of Congress Report on Architectural Digital Assets* in underscoring that the design process resists standardization and systematic archiving, especially in cases where ideas remain unrealized or are never translated into conventional documentation formats such as printed drawings (MacDonough, 2019). Faced with the loss of heritage skills and the endangerment of both craft practices and their documentation, it becomes increasingly urgent to transfer construction techniques and production processes to a digital stable, accessible, and open archive. This approach aligns with contemporary preservation strategies aimed at safeguarding craft knowledge and facilitating its transmission across temporal and geographic boundaries.

4. Preserving: Visualization in Digital Space

Expanding on the preceding discussion of the vulnerabilities surrounding craftsmanship and digital documentation, the following sections introduce a methodological framework designed to preserve and transmit Intangible Cultural Heritage (ICH). This framework prioritizes both the authenticity of the recorded knowledge and its long-term accessibility, addressing the complex challenges of preservation in the digital age.

4.1 Motion Capture and Tracking: Tools for Skilled Labor

Technologies such as human motion capture and tracking enable the precise recording of manual techniques, facilitating their future reproduction. This method has demonstrated significant value in educational contexts and in advancing human-machine collaboration. By the late 19th century, innovations such as chronophotography and motion studies emerged as methods for capturing movement through sequential still images, enabling the analysis of discrete bodily positions. These techniques provided artists and scientists with new tools to observe, dissect, measure, and scale human motion. In the early 20th century, Frank and Lillian Gilbreth extended this analytical approach to the study of labor efficiency and craftsmanship training. Their pioneering work in time and motion studies, as well as fatigue analysis, aimed to reduce what they termed "humanity's greatest unnecessary waste: motion" (Gilbreth and Gilbreth, 1919). They sought to quantify human factors in order "to enable the worker to do his work, with the least fatigue and hence in less time" (Gilbreth, 1911). Among their notable contributions was the optimization of bricklaying techniques, which significantly improved worker productivity, leading to enhanced wages and better working conditions.

The continuity of traditional and historic construction methods has long depended on the effective transmission of technical knowledge and embodied know-how (Karakul, 2012). Historically, this transmission evolved from oral instruction to physical guidance, as seen in the Gilbreths' use of wires to direct motion, and to visual representation through 2D drawings. Over time, these methods advanced into 3D modeling and are now increasingly integrated into extended reality environments. The combination of 3D visualization with augmented reality overlays of human motion presents new opportunities for embodied learning through making. In this context, digital tools can guide human action via machine input or corporeal augmentation, engaging both explicit and tacit

knowledge. While digital systems encode and process explicit knowledge, the user internalizes and enacts tacit knowledge through physical interaction. By merging digital technologies with sensory feedback, novel workflows can support intuitive and spontaneous learning, enabling users to engage directly with fabrication tools in a highly informed design process (Johns, 2014). For instance, apprentices could access archived motion data, plan tasks on-site, adapt designs in real time, and correct errors dynamically. This integration of human decision-making into generative and learning processes enhances design exploration and innovation. Interactive user interfaces and immersive design environments further stimulate creative collaboration between humans and digital tools (Felbrich et al., 2018). Collaborative workflows, such as those combining augmented reality with motion capture and tracking, strengthen the resilience and autonomy of fabrication processes, thereby supporting the broader adoption of craft-based practices (Mitterberger, 2023). Ultimately, these methods not only facilitate the teaching and learning of specific fabrication techniques but also contribute to the preservation of invaluable craft knowledge while alleviating the demands placed on highly skilled labor. Recent studies in the field of engineering have demonstrated that augmented reality (AR) significantly enhances users' knowledge acquisition and retention (Hidayat and Wardat, 2024). This improvement is attributed to several factors, including the novelty of the technology, its immersive qualities, and the interactive environments it creates, all of which contribute to the development of spatial reasoning and practical skills. Digital tools combined with AR have been shown to foster deeper cognitive engagement, increase motivation, and support the long-term retention of knowledge. Furthermore, immersive technologies such as augmented reality (AR), mixed reality (MR), and virtual reality (VR) have the potential to elevate both the quality of user experience and the effectiveness of educational outcomes by stimulating the senses in more vivid and natural ways. Devices such as head-mounted displays (HMDs) and mobile-mounted screens enhance users' perception of different environments by overlaying digital information and virtual cues onto the physical world. This integration results in a more immersive and emotionally engaging experience. Importantly, digital technologies, such as AR, can foster new paradigms of thinking and making and reshape traditional approaches to learning (Langenberg, 2018). Within this framework, apprentices can be remotely guided by expert craftspeople, recognized as *Bearers of Intangible Cultural Heritage*, thereby enabling the transmission of specialized knowledge across distances and generations. Developing methodologies that center the role of workers while actively promoting and engaging their craft contributes to a more equitable distribution of tasks and promotes meaningful collaboration between skilled and unskilled labor, as well as between humans and machines. This approach not only enhances operational efficiency but also invites critical reflection on the recognition, documentation, and authorship of craftsmanship (Keijser et al., 2024).

4.2 Rituals and Ethics: Documenting Sensitive and Cultural Practices

In recent developments within the field of preservation, human motion has been increasingly integrated with digital tools to examine its implications for labor ethics, worker agency, and the evolving nature of work practices. Projects such as *Labor Domains* and *Labor Optics* have employed motion-tracking technologies to monitor worker activity on construction sites, offering insights into labor dynamics and site-specific behaviors (Griffiths, 2023a). Tools like the *Worker Activity Recognition tracker* utilize algorithmic models to identify and predict patterns of movement (Griffiths, 2023b).

While these technologies offer valuable analytical capabilities, their deployment necessitates careful ethical oversight. Without stringent regulatory frameworks, such systems risk being misused to monitor productivity in ways that infringe on workers' rights, restrict opportunities, compromise privacy, or limit access to essential resources. In recognition of these concerns, the White House issued the *Blueprint for an AI Bill of Rights* in 2022, underscoring the democratic risks posed by unregulated applications of AI, data, and automated systems (The Whilte House, 2022). Labor, in particular, remains a highly sensitive domain in the context of emerging technologies. Within the proposed methodology, motion capture, tracking, and archiving are employed exclusively as pedagogical tools aimed at enhancing learning, not as instruments of surveillance or control. Nevertheless, the implementation of such technologies must be guided by the respectful treatment of rituals, culturally sensitive practices, and due attention must be given to intellectual property rights, proper attribution, and the ethical treatment of all contributors. These considerations are essential to ensuring that preservation efforts do not appropriate, misrepresent, or commodify heritage, but rather support its transmission in ways that honor the values and agency of the communities from which it originates. For many communities, particularly minority and indigenous groups, intangible cultural heritage represents a vital source of identity, deeply embedded in collective memory and cultural continuity (UNESCO, 1993). Certain rituals associated with craft practices are at risk of being overlooked or undervalued, particularly those embedded in maintenance and repair work, domains historically undertaken by women. This is exemplified by Mierle Laderman Ukeles' *Maintenance Art* practice, which brought visibility to the often-invisible labor of care and upkeep. Some rituals tied to craft practices are culturally sensitive and not meant for documentation beyond their communities. In such cases, ethical and legal considerations are essential. UNESCO and the World Intellectual Property Organization (WIPO) have established frameworks to protect both tangible and intangible cultural heritage, including traditional expressions and folklore (WIPO, 2005). These frameworks recognize rights not only in physical outcomes but also in processes and narratives. Legal protections, such as copyrights, patents, and geographical indications, help ensure creators are acknowledged and their work respected. As (UNESCO, 2016) notes, intellectual property laws both reward creators and promote creation and innovation, supporting respectful and culturally sensitive heritage documentation.

Maintenance and repair work are often undervalued or overlooked within architectural discourse, despite their fundamental role in the ongoing care and preservation of the built environment. These practices, while frequently dismissed as mundane or peripheral, constitute essential rituals of architectural continuity. Performance art curator Bettina Knaup articulates the conceptual significance of care, suggesting that it occupies "an interstitial world, an in-between realm unable to fully repair leaks or clean up messes. Instead, it involves exposure to, attention toward, and engagement with the repetitive dissolution of solid forms" (Knaup, 2021). This framing positions care not as a definitive act of restoration, but as an ongoing, responsive engagement with material impermanence. Similarly, the artist Mierle Laderman Ukeles redefined the boundaries of her performance practice by foregrounding maintenance as a legitimate and critical form of creative labor. Her work challenges the marginalization of

discarded materials, repetitive labor, and care-based processes through a subversive artistic practice (Denis and Pontille, 2022). In her *Manifesto for Maintenance Art*, Ukeles asserts that architectural care is both a performance and a practice, elevating everyday acts of maintenance to the status of artistic expression. Through her performances, she closely observes and emulates the routines of maintenance workers, embodying the "movement patterns and daily choreographies that constitute this public system of care" (Phillips et al., 2016). By recording and replicating these gestures, Ukeles contributes to the preservation of maintenance knowledge, describing her practice as a "dismapping of the formal city, and a re-mapping of the entire living city from the care workers' perspective" (Ngo and Kuhnert, 2023). While architectural preservation extends beyond routine care and maintenance, encompassing complex questions of material integrity, cultural significance, and historical continuity, Ukeles' work underscores the epistemological and cultural value embedded in maintenance labor. Her practice invites a specific understanding of preservation, not merely as the upkeep of physical structures, but as an ongoing, embodied engagement with the social and material life of architecture.

The outcome of such practices is not only a form of architectural performance but also a manifestation of cared-for architecture, one that sustains the embodied knowledge of repair and maintenance. As Shannon Mattern articulates in her essay *Maintenance and Care*, "maintenance has taken on new resonance as a theoretical framework, an ethos, a methodology, and a political cause" (Mattern, 2018). Within this expanded framework, traditional knowledge systems and cultural expressions, including crafts, architectural forms, and rituals of care, can be legally and ethically protected (WIPO, 2005). However, a key limitation in the effective application of these legal protections lies in the dynamic and evolving nature of care and craft practices within communities. When such practices are recorded and archived digitally, they become entities that evolve independently from their physical counterparts. While the digital and physical environments are interrelated, each informing the other, they remain distinct, with their own interpretive frameworks and representational languages. This duality introduces new challenges for preservation, particularly in ensuring that digital documentation captures the full depth of embodied knowledge. As noted in the *Rights, Intellectual Property and ethical questions related to filming living heritage*, digital recordings of craft practices should "integrate detailed explanations and postures, and possibly even feelings related to the practice while recording" (Wendland, 2004) (Nikolić Đerić, 2023). Such enriched documentation provides future practitioners with the contextual and sensory information necessary to meaningfully replicate the activity, even as the cultural or physical context evolves. Although this paper does not focus on film or photography, it is worth noting that these media have evolved, particularly through democratized social platforms, to convey repair knowledge and DIY practices. While not fully embodied or dynamic, these visual formats reflect a generational shift toward learning through motion-based representation, suggesting new modes of knowledge transmission shaped by digital culture.

5. Transferring: Dissemination, Access, and Reuse

Having explored the rationale and methodologies for digitally recording and preserving craft and repair knowledge, the final section turns to the question of whether such data can be optimized, standardized, and effectively transferred. This process of codification is essential not only for ensuring the longevity and accessibility of knowledge but also for facilitating collaboration and continuity among diverse users. The creation and curation of data for storage and transmission should be understood as an active, interpretive process, one that involves the deliberate composition and dissemination of knowledge rather than passive accumulation. In this context, the digital realm is not merely a repository of content but functions as a performative space of communication with future learners and practitioners. It underscores the idea that storage and memory gain significance only through the continuous circulation and reinterpretation of information. Without the active transfer and reactivation of knowledge, preservation becomes inert. Thus, digital archiving is not an end in itself but a dynamic practice of knowledge-making and sharing across time and space.

5.1 Metadata as Context: Embedding Cultural and Legal Information

To operationalize this dynamic vision of digital knowledge transfer, it becomes essential to consider the mechanisms through which contextual integrity and authorship are maintained during dissemination. One such mechanism is the strategic use of metadata, which not only supports the ethical reuse of digital content but also embeds critical cultural, legal, and intellectual information directly into the data structure. This practice ensures that, even when the recorded motions are disassociated from their original performer for broader dissemination, essential contextual data, such as authorship, copyright, geographic origin, patents, trademarks, provenance, and other culturally sensitive details, are preserved. Embedding such metadata safeguards intellectual property rights by attributing ownership not solely to the physical artifact or its material expression, but to the underlying creative and intellectual contributions (WIPO, 2008). This approach is already standard in many human motion databases, where metadata serves as a critical layer of information that maintains the integrity, traceability, and ethical use of the recorded content. The Institute for Anthropomatics and Robotics – High Performance Humanoid Technologies (H²T) at the Karlsruher Institut für Technologie (KIT) has developed a comprehensive framework for the recording, organization, and archival of human motion data. Central to their research is the establishment of a reference model and database that systematically captures and structures human and object motion, as well as subject–object interactions. This process involves detailed techniques for recording, labeling, and organizing motion capture data, which are further enriched through annotations, descriptive metadata, and hierarchical data tree structures (Mandery et al., 2015). A key outcome of this work is the *KIT Whole-Body Human Motion Database*, designed to support applications in fields such as rehabilitation and robotics. Following data acquisition, the researchers implemented a unified, normalized, and anonymized representation of human subjects, adjusting for individual differences in height and weight through the use of a standardized kinematic and dynamic model known as the Master Motor Map (MMM) (Mandery et al., 2015). This approach is particularly innovative in its simultaneous consideration of both human motion and the motion of objects with which the subject interacts. The database's adapted mapping methodology facilitates seamless data transfer and reuse across different users and applications, including those proposed in this research. Moreover, the ability to scale and track body movements enhances the potential for precise motion mapping in augmented reality environments (Mandery et al., 2015).

5.2 Embodied Knowledge: Enabling Learning Through Immersive Technologies

As digital preservation of craft and repair knowledge advances, growing attention is directed toward capturing and transmitting *embodied knowledge*, the tacit, performative, and intuitive dimensions of skilled practice. Unlike data, which can be codified and stored, embodied knowledge is rooted in physical movement, sensory feedback, and contextual responsiveness. Its transmission requires more than textual or visual documentation; it demands immersive, interactive engagement that replicates the original conditions of learning. Recent interdisciplinary initiatives have begun addressing this challenge by developing technologies and frameworks that support the active transfer of embodied skills. The *Craeft Project* funded by the European Union, exemplifies this approach by combining anthropology, cognitive science, and advanced digitization to treat traditional crafts as both living heritage and sustainable practice (Partarakis and Zabulis, 2023). It employs immersive technologies, haptic interfaces, and workflow simulations to preserve and transmit craft knowledge, while also enabling certification, community building, and attribution of digital content to individual makers. Complementing this, the Center for Robotics at the École Nationale Supérieure des Mines de Paris has developed motion-capture datasets for crafts such as glassblowing, porcelain making, and silk weaving. These datasets, accessible via head-mounted or mobile-mounted displays, allow users to follow expert-recorded movements and open possibilities for integrating repair practices in architectural crafts like carpentry and masonry. Parallel developments at the University of Potsdam's Chair for Complex Multimedia Application Architectures include the *HandLeVR* project, which guides users in reproducing expert-recorded gestures. This system reinforces the pedagogical value of embodied repetition and feedback, especially where traditional apprenticeship models are no longer viable. These approaches align with El-Zanfaly's I3 framework—*Imitation, Iteration, and Improvisation*—which emphasizes learning through making in both physical and digital contexts (El-Zanfaly, 2015). By integrating motion capture with fabrication tools, this methodology bridges the gap between design and construction, fostering dexterity, judgment, and the reuse of craft knowledge across contexts and generations. While some institutions focus on high-tech solutions, others emphasize traditional, practice-based learning. The *Bauarchiv Thierhaupten* offers workshops in materials science, construction methods, and repair techniques, highlighting the value of hands-on training and knowledge archiving despite not yet using immersive technologies. In Switzerland, *Handwerk in der Denkmalpflege* provides regional training, maintains a registry of craftspeople, and supports certification in monument conservation, addressing the growing demand for specialized skills as noted in the aforementioned Swiss and German *Baukultur* reports. These initiatives show that transferring craft knowledge digitally must remain an active embodied process. Platforms such as *Craeft*, *HandLeVR*, and *HandwerkID* exemplify how immersive technologies can support situated learning, enabling users to interact with motion data, simulate repair tasks, and adapt techniques in real time. Rather than treating digital archives as static, these efforts frame them as dynamic practices of knowledge-making and sharing. This paper proposes a human-motion database for repair knowledge to enrich existing practices and support emerging craftspeople in acquiring and refining their skills through embodied, digitally mediated learning.

In the long term, this methodology also holds potential for application in the context of digitally fabricated buildings, where preserving digital craftsmanship and the often-overlooked human-machine collaboration in construction processes remains a critical challenge. Due to increasing building complexity, insufficient knowledge transfer, and inadequate documentation of programming and process data, some born-digital buildings pose significant challenges for repair and maintenance (Langenberg, 2017). Additionally, even highly automated processes often rely on manual procedures and human input. Therefore, accessible, comprehensive records of construction workflows are essential for restoring and preserving buildings according to their original digital craftsmanship and inherent design logic.

6. Toward a Model for Digital Craft Repair Preservation

This paper addressed the urgent need to preserve construction and repair knowledge in digital space by responding to three core research questions: why craft knowledge should be transferred into the digital realm, how it can be preserved authentically and long-term, and whether repair knowledge can be optimized and transferred across contexts. The proposed methodology, grounded in motion capture and augmented reality, demonstrates how embodied knowledge can be systematically recorded, archived, and reused, thereby supporting the continuity of intangible cultural heritage in architectural practice. By drawing on historical motion studies and aligning with international charters and digital frameworks, the research frames preservation as a dynamic process that includes digital tools, iterative design, and embodied learning. The findings highlight that digital preservation must extend beyond static documentation to include the sensory and cognitive dimensions of craftsmanship. This approach not only enhances repairability and resilience in preservation but also supports equitable knowledge transmission across generations and geographies. Ultimately, the integration of motion data into architectural care offers a scalable and ethically grounded model, reinforcing the cultural significance of manual labor and repair in the digital age.

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