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From Culture and Computing to Cultural Computing: A Scoping Review

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ABSTRACT

Digital technologies evolve faster than different cultures adapt to them. HCI researchers and practitioners must know the human, social, and cultural factors that shape this design space. This article provides an overview of the evolving field, examining the various aspects and dimensions of culture and computing. We analyzed all proceedings of the "Culture and Computing" conference series from 2010 onwards. Since 2020, this conference series has been run under the umbrella of the HCI International conference. We also offer a literature study on cultural computing and the development of the field through keyword searches. In this scoping review, we focus on four key domains in more detail. Computing for cross-generational interaction between older adults and younger generations requires a thorough understanding of the inherent social norms, viewpoints, preferences, expectations, and concerns of the social ecosystem. We examine concepts that emerge in cross-generational interactions and how they inform the design of novel interactive technologies. These range from technology asymmetries, communication patterns and rhythms, and digital adoption, to social and cultural factors, such as the collectivistic/individualistic dichotomy and asymmetric societal expectations. Tangible cultural heritage investigates computing technologies in preserving, documenting and disseminating tangible cultural heritage, including artifacts, monuments, and historical sites. We examine current research trends related to 3D acquisitions, virtual and augmented reality, and virtual reconstruction while discussing emerging directions such as immersive and multisensory experiences, serious games, and challenges, including the preservation of digital platforms and apps. Intangible cultural heritage explores the role of computing technologies in the preservation and communication of an inherently more ephemeral heritage, such as social practices, performing arts, craft skills, and oral traditions. We explore current research trends, motion capture, data sculpting, and emerging applications of immersive technologies that intertwine both tangible and intangible heritage experiences. We also explore new research directions and the broadening inclusion of heritage elements, dance, and craft skills. The cultural analytics and modernity section introduces cultural analytics by addressing bie-modernity analytics in more detail. Using modernity analysis as a cross-cutting analytical lens for interpreting how computing technologies mediate cultural change, cultural representation, authenticity, and social transformation across the reviewed domains. Within this broader overview, bie-modernity analytics is discussed as one recent and still developing example of a unique analytical approach to modernity. In summary, over the last three decades, the research field of cultural computing has combined well-established areas with emerging and evolving ones. Several underexplored research areas are identified.

KEYWORDS
Cultural analytics; cultural computing; scoping review; cross-generational interaction; tangible cultural heritage; intangible cultural heritage; modernity

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1. Introduction

This scoping review aims to provide an overview of the evolving field of cultural computing research, encompassing its various components. This article also seeks to identify gaps and potential development directions. However, this article cannot replace a comprehensive textbook.

According to Rauterberg (2006), the word culture (from the Latin "colo-ere," meaning "to cultivate," "to inhabit," or "to honour") has been defined and used in many ways throughout different contexts. For example, Kroeber and Kluckhohn (1952) compiled a list of more than 160 additional definitions of culture. They cluster all these definitions as follows: (a) descriptive, (b) historical, (c) normative, (d) psychological, (e) structural, (f) genetic, and (g) incomplete definitions.

> Finally, they conclude that *"Culture consists of patterns, explicit and implicit, of and for behavior acquired and transmitted by symbols, constituting the distinctive achievement of human groups, including their embodiments in artifacts; the essential core of culture consists of traditional (i.e., historically derived and selected) ideas and especially their attached values; culture systems may, on the one hand, be considered as products of action, on the other as conditioning elements of further action"* (Kroeber & Kluckhohn, 1952, p. 181).

One of anthropology's most popular definitions of culture is a complex web of shifting patterns that link people in different locales and that link social formations of various scales; culture integrates human behavior, including attitudes, norms, values, beliefs, (inter)actions, communications, language, and groups (ethnic, religious, social, etc.) (Bennett, 2015; Persson, 2001); hence, culture is one of the most crucial concepts in anthropology (Rapport & Overing, 2000, p. 92ff).

> *"A consequence of human evolution that had the most profound impact on human nature and human society was the emergence of culture, which can be defined as sets of learned behavior and ideas that human beings acquire as members of society together with the material artifacts and structures that human beings create and use. Our cultural heritage allows humans to adapt to and transform the world around us through our interactions with material structures and objects in the communities where we live, through the connections we form with other people and other living organisms, through the actions and skills of our individual bodies, and through the ideas and values of our minds. The cultural heritage of the human species is both meaningful and material, and it makes us unique among living creatures"* (Lavenda & Schultz, 2018, p. 6).

According to White (1959), the processes and artifacts with which humans of a particular culture interact are the foundations and fundamental building blocks of that culture. The sum of all invariant structures of these dynamic events determines a specific culture (Centre for Contemporary Cultural Studies, 2013). The three main parts are (i) interaction with other humans (e.g., communication using a particular language; see Figure 1A), (ii) treating oneself (e.g., belief, food, and dressing; see Figure 1B) and (iii) dealing with other living and non-living systems (e.g., hunting, farming, housing, and manufacturing, see Figure 1C). Richard Handler summarizes the definition of culture as consisting of: (1) "the idea that a culture is a pattern of values that gives significance to the lives of those who hold them," (2) "that people's participation in the pattern is instinctive – in other words, unconscious," (3) that in the case of genuine culture "the patterning of values is esthetically harmonious," and (4) that this harmony is expressive of "a richly varied and yet somehow unified and consistent attitude toward life" (Handler, 1983, p. 225).

For the future development of cultural technology, access to the cultural foundations of these culture carriers is necessary (Rauterberg, 2022a). One relevant aspect of this cultural foundation is the distinction between non-living things and living systems. Culture can be preserved, transported, and adapted by non-living things and living systems. Cultural development is only possible through living systems (e.g., humans). Non-living things (e.g., books, fossils, paintings, sculptures) are for preserving, archiving, and displaying the past. But what are the driving factors?

To understand the nature of driving forces for cultural development, we must distinguish between a physical and an ideal realm. However, the ontological status of the ideal realm in relation to the physical realm is a matter of considerable debate. We argue for the necessity and relevance of both realms; both are connected through the actions of agents based on their mental concepts. Motivation is one of the most relevant mental concepts for linking the ideal realm with the physical realm. Heckhausen and Heckhausen describe the two main universal characteristics of motivated behavior as (a) control striving and (b) the organization of action into phases of goal engagement and goal disengagement (Heckhausen & Heckhausen, 2018, p. 20). The dynamic forces of the ideal realm driving actions in the physical realm

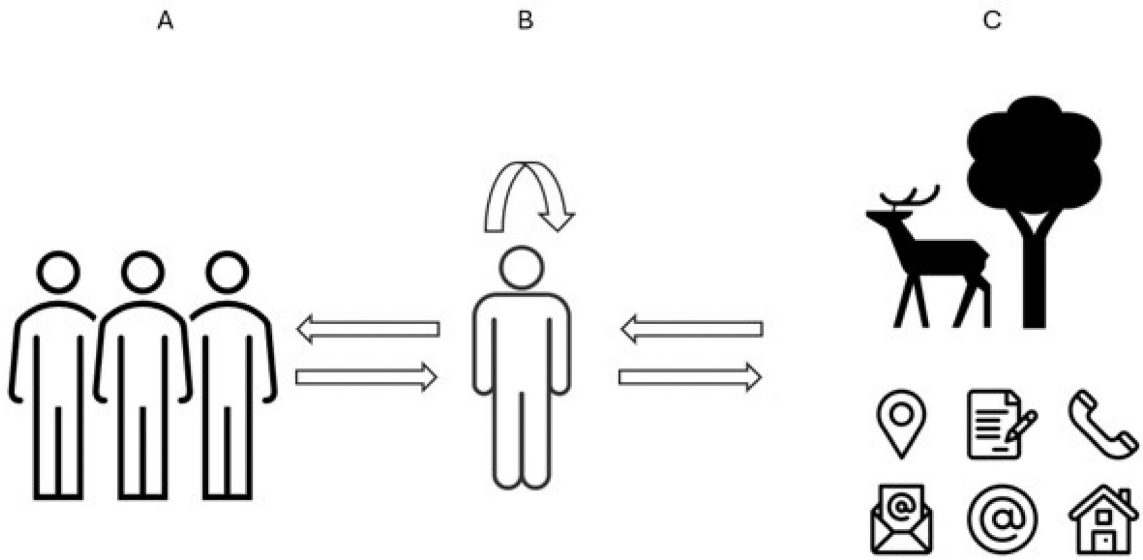

Figure 1. The three major building blocks of cultural content: (A) interaction with other humans, (B) dealing with oneself, and (C) interacting with other living systems and non-living artifacts.

are key drivers of cultural development (Rauterberg & Saariluoma, 2023). Cultural development occurs through the continuous and dynamic process of inventing, creating, sharing, and adapting knowledge, values, and technologies across generations. It is driven by social interaction, cross-cultural exchange, and adaptation to environmental or economic changes, often accelerated by technological advances (e.g., the smart phone) and the need to solve complex societal problems. In the ideal realm, cultural development takes place, while in the physical realm all tangible cultural heritage passes through culture to the next generations.

In recent decades, with the collapse of industrial and manufacturing models of economic organization, urban societies have faced significant cultural, social, environmental, and financial challenges. We must adopt new paradigms of development that incorporate social and intangible dimensions within the framework of what drives growth and development (Acri et al., 2025). The value of culture is recognized within these new paradigms of development, orientated toward a human-based approach and sustainable outcomes.

> *"We pledge to foster intercultural understanding, tolerance, mutual respect, and an ethic of global citizenship and shared responsibility. We acknowledge the natural and cultural diversity of the world and recognize that all cultures and civilizations can contribute to, and are crucial enablers of, sustainable development"* (General Assembly Directorate, 2015, p. 10).

We can distinguish between intra- and intercultural or cross-cultural approaches. Intra-cultural approaches are meant to support cultural development within the same monocultural context. Inter- or cross-cultural approaches are employed to bridge multicultural barriers and extend into diverse cultural contexts (G. C. N. Hall et al., 2016). Realo and Allik (2002) argue that even in intra-cultural studies, the cultural variety can be as extensive as in inter-cultural studies. Ting-Toomey (2018) provides a detailed explanation of why intercultural communication is so challenging. The author explains in detail when and why the clashes appear and how to resolve them.

1.1. What is cultural computing?

Culture and Computing (C&C) in general and Cultural Computing (CC) in particular, can be interpreted in three different ways:

1. Computing technology is used to represent and simulate cultural content, mainly for preservation and conscious reflection through interaction (Tosa, 2016). Tosa's ZENetic computer is a good example.

2. Computing technology is used to improve cultural development in terms of progress based on technological developments (Nakatsu et al., 2010). Video games as an emerging cultural technology are a good example in this regard (Huizinga, 1950; Muriel & Crawford, 2018).
3. Cultural development is intended as a kind of unconventional computation for a deeper understanding of complex issues (Adamatzky, 2018). There are two different approaches to realize unconventional computing: (a) the implementation of computing systems in non-silicon substrates, e.g., electricity, chemical systems, plants, and slime molds, and (b) with dissident thinking by challenging current stereotypes and dogmas entailed in the ideal realm of a particular culture.

In CC, we embrace a broad computational framework based on an expansive definition of ʻcomputing" that encompasses both artificial (Minsky, 1967) and biological (Brodland, 2015) systems. Natural computation—compared to all physical processes based on abstract manipulation and objects (see, e.g., Minsky (1967))—is computation occurring or inspired by that in nature. Computation occurs naturally, as seen in information processing within the brain, the immune system, and through evolution by natural selection; indeed, the entire discipline of cognitive science is centered around computational models (MacLennan, 2004). In CC, we will also use computing in the sense of "genetic engineering" (Nicholl, 2008). We define CC as the approach to capture tangible and intangible cultural heritage with computing technology (Angileri & Palmero-Iglesias, 2024; Marshall, 2011).

CC can be more than integrating cultural aspects into a human-computer interaction. It is about allowing the user to experience an interaction closely related to the core aspects of their culture, enabling them to engage with computer-mediated technology in meaningful ways. For instance, current advances in the design of rapidly emerging technologies, such as Virtual / Augmented / Mixed / Extended Reality environments (Liarokapis et al., 2025) and Human-Centered Artificial Intelligence systems (Shneiderman, 2022) highlight the explicit consideration of human values and attributes of their own culture in a way to shape the future of technology so as to better serve human needs. Therefore, understanding one's cultural determinants and how to convey them during interaction effectively is essential.

> As Tosa (2016, p. 2) puts it: *"These topics are the field of cultural computing; that is, using computing to explore the essence and inner lives of cultures, including sensitivity, national traits, and folklore. The essence of cultural computing integrates verbal and non-verbal information, which proposes a prosperous field in which computers can improve the exchange of cultural information by using cultural models."*

1.2. Why is cultural computing critical?

In 2010, Toru Ishida started the conference series on "Culture and Computing" at Kyoto University, Japan. As computing technology (e.g., the internet, multilingual translation) spreads globally, its design is confronted with cross-cultural issues.

> *"In the near future, international communities will face tough global issues, such as problems with population, energy, the environment, and food. Although it is necessary to build a consensus to resolve these issues, there are difficulties with communication between cultures. Contributions from information and communication technologies are required to understand and overcome these difficulties"* (Ishida, 2010, p. v).

Although CC started by addressing the challenges of automatic translation between different languages, today this technology is a commodity. The most activities in CC are clearly in the area of digitalization of the *tangible* cultural heritage part (Demartini et al., 2021). To demonstrate the potential of CC also for intangible cultural heritage, some research projects focused on capturing cultural content in an emerging new interactive user experience (Nakatsu et al., 2017). These projects do not only capture relevant cultural concepts but also engage the user in a new type of interaction with those -mainly unconscious- concepts; this is new compared to all projects that digitize cultural concepts in a kind of dynamic simulation (Artstein et al., 2016; Orphanidou et al., 2024).

> *"In the 21st century, we are entering the era of 'cultural computing,' where computers are able to handle specific forms and human characteristics that hide behind each culture. … we introduced and discussed still-*

unveiled possibilities of cultural computing, analyzing and visualizing substantial cultural issues such as sensitivity, memory, spirituality, storytelling, cultural diversity, etc., that have not been dealt with in computer science and engineering so far" (Nakatsu et al., 2010, p. vii).

Different cultures around the world have varying approaches to address their unique cultural determinants. In the East, the project "ZENetic Computer" is the first and most promising approach to CC that addresses Eastern cultural determinants as part of the Japanese intangible cultural heritage (Tosa, 2016). In the West, Rauterberg (2006) proposes an interactive experience based on the narrative "Alice"s Adventures in Wonderland' to address relevant concepts of the Western intangible cultural heritage (Nakatsu et al., 2017). CC is critical because it challenges the notion of technology as a neutral tool, instead recognizing that digital systems are cultural products that embed specific values, biases and, when properly designed, can preserve and transmit cultural heritage to the next generations. To which extent video game technology can play an important role as cultural carrier, the future will show (see, e.g., https://museedujeuvideo.org/en).

1.3. Where is cultural computing coming from?

The term "cultural computing" was used very early in the title of a paper by Swett (1986). Unfortunately, Swett did not define CC but wrote about several initiatives aimed at introducing computers in schools to support multilingual training.

We analyzed Google Scholar results for the keywords "cultural computing" over the last decades. Since the first international conference on "Culture and Computing" (Ishida, 2010), there has been exponential growth, measured by the hit rate (see Figure 2). Until 2017, we referred to this research field as emerging and, since then, we have called it evolving.

2. Methods and materials

2.1. Why a scoping review?

There are several ways to provide an overview of a research field: a scoping review (Gupta et al., 2023), a review article (Dhillon, 2022), and a meta-review article (Borenstein et al., 2009). For evolving fields like C&C and CC, we chose the scoping type. A scoping review article is essential to provide an overview, identify potential knowledge gaps, and serve as a precursor to systematic reviews. It also helps guide the scope of future research and the parameters that must be considered in future studies.

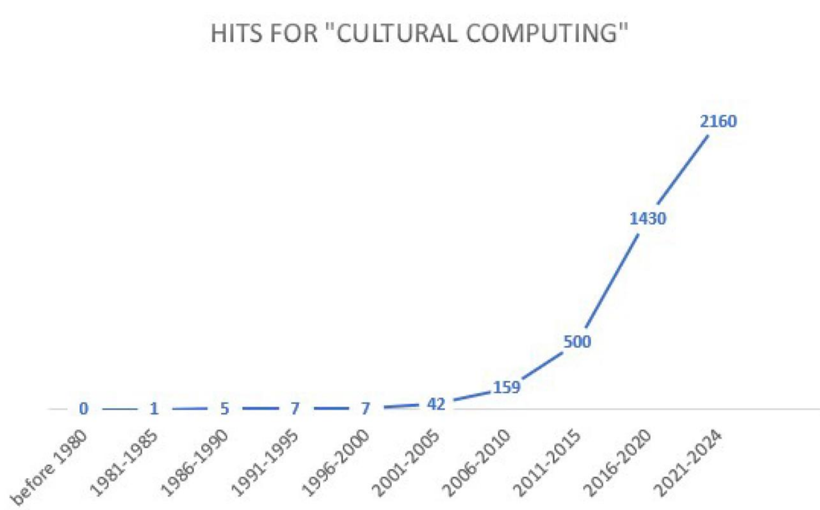

Figure 2. The development of the term' cultural computing' over time is represented by the hit rate in Google Scholar for the indicated 5-years periods.

Table 1. Overview of categories as presented in the table of contents in culture and computing conference proceedings (2010–2017; sorted alphabetically).

Year	Category in proceedings	No of papers	No of authors	Mean authors
2010	*Culturally Situated Agents*	4	11	2.75
	Culture and Computing for Art and Heritage	4	6	1.50
	Culture and Computing in Regional Communities	4	20	5.00
	Intercultural Collaboration and Support Systems	5	17	3.40
2011	*Asian Culture-Based Media Art*	11	32	2.91
	Digital Humanities	16	56	3.50
2013	*3D/VR Application for Culture*	4	16	4.00
	Computer Technologies for New Culture	5	24	4.80
	Culture-Based Media Art & Music: Posters	4	10	2.50
	Digital Archives	4	11	2.75
	Digital Humanities: Posters	6	19	3.17
	Digital Museums	5	23	4.60
	Historical Documents	3	6	2.00
	Information Environments for Analysis of Culture	4	13	3.25
	Information Technologies for Culture and Art	4	10	2.50
	Intercultural Communication and Collaboration	4	17	4.25
	Music-Based Art for New Culture	4	12	3.00
	Performance, Religion, and Philosophy for New Culture	6	21	3.50
	Service Design and Culture	4	11	2.75
2015	*Art and Design by Information Technologies*	2	6	3.00
	Culture in Social Networks	5	16	3.20
	Digital Storytelling	4	8	2.00
	Information Environments for Analysis of Culture	2	7	3.50
	Intercultural Communication and Collaboration	4	12	3.00
	Open Data for Culture and Computing	2	5	2.50
	The City's Intangible Cultural Heritage	3	10	3.33
	VR and Agents in Culture	5	12	2.40
2017	*Cultural Heritage and Archiving*	4	19	4.75
	Human Behaviors and Culture	5	16	3.20
	Information Technologies for Performing Arts	4	12	3.00
	Intangible Cultural Properties	6	12	2.00
	Language and Infrastructure for Culture	5	15	3.00
	Media Art and Culture	2	8	4.00
	Music and Culture	2	9	4.50

2.2. Conference series

The main body of content is presented in the proceedings of the conference series on C&C, which began in 2010 in Kyoto, Japan (see the list of all proceedings below). Table 1 lists categories for all published papers up to 2017, and Table 2 lists categories up to 2024. Since 2020, the conference series has been held annually at various locations around the world. We employ multiple approaches to analyze the available knowledge in C&C, including text-based analysis of the proceedings' content and providing the state of the art in selected research areas.

The list of all analyzed C&C conference proceedings is as follows: Ishida (2010), Hachimura et al. (2011), Hachimura et al. (2013), Ishida et al. (2015), Ishida et al. (2017), Rauterberg (2020), Rauterberg (2021a), Rauterberg (2021b), Rauterberg (2022b), Rauterberg (2023), and Rauterberg (2024). Although the conference series was initially planned as an annual event, organizing it outside of the Kyoto area proved challenging (Table 1). Since 2020, this conference series has been organized annually under the umbrella of the HCI International conference, as one of its affiliated conferences held worldwide, and published by Springer's Lecture Notes in Computer Science (LNCS) series.

In Tables 1 (2010–2017) and 2 (2020–2024), we provide an overview of the content of all published proceedings with the title 'Culture and Computing. The former program chairs of each organized conference have categorized the papers that were published in those proceedings. The chosen categories sufficiently reflect the grouping content of the papers presented at that conference. The additional data, such as the number of documents and authors per category, indicates a growing interest in international research on various cultural issues in the field of computing over time.

2.3. Approach for analysing the proceedings

This scoping review examined the proceedings of the "Culture and Computing" conference series from 2010 to 2024. Given the intermittent nature of the conference and its publication in various venues,

Table 2. Overview of categories as presented in the table of contents in culture and computing conference proceedings (2020–2024; sorted alphabetically).

Year	Category in proceedings	No of papers	No of authors	Mean authors
2020	*HCI and Ethics in Cultural Contexts*	11	27	2.45
	Interactive and Immersive Cultural Heritage	13	45	3.46
	Preservation of Local Cultures	10	29	2.90
2021	*Design Thinking in Cultural Contexts*	10	22	2.20
	Digital Humanities, New Media and Culture	12	14	1.17
	ICT for Cultural Heritage	11	59	5.36
	Perspectives on Cultural Computing	9	22	2.44
	Technology and Art	10	28	2.80
	Visitors' Experiences in Digital Culture	9	24	2.67
2022	*Culture and Computing in Arts and Music*	9	31	3.44
	Interactions with Tangible and Intangible Cultural Heritage	6	15	2.50
	Reflections on ICT and Culture	6	9	1.50
	User Experience, Culture, and Technology	11	51	4.64
2023	*Advancements in Cultural Heritage Preservation*	7	29	4.14
	Creativity and Design in Arts and Architecture	10	23	2.30
	Cross-Cultural Perspectives in Humanities and Technology	11	37	3.36
	Culture and Technological Innovations	10	32	3.20
	Experience Design in Exhibitions and Public Installations	9	18	2.00
2024	*Bie-modernism and Cultural Computing*	5	12	2.40
	Innovations in Digital Cultural Representation	6	21	3.50
	Technology, Art, and Culture	7	37	5.29
	User Experience Design for Seamless Cultural Experiences	9	24	2.67

including Springer and IEEE, editorial standards and formats varied significantly, necessitating a flexible approach to data collection. Text extraction methods were used to identify and retrieve key metadata from articles, including titles, authors, affiliations, abstracts, keywords, and article types. The extracted text was processed using the OpenAI API (GPT-4o mini) to classify and structure the data into a consistent JavaScript Object Notation (JSON) format. To mitigate the risk of "hallucinations" or context bleeding between entries, the articles were processed as discrete units rather than in batches, ensuring that the analysis of each text segment remained independent. The structured data was compiled into a unified data set, allowing a longitudinal analysis of publishing trends, keywords, and authors within the field.

To verify the precision of this automated classification, we have a random sample of 40 articles (approximately 10%) from the total corpus of 437 articles underwent manual verification against the original proceedings. No errors were detected within the sample, likely due to the structured nature of the source material, though we acknowledge that a 10% sample provides limited statistical power for detecting rare error types.

We acknowledge the potential biases and limitations inherent in AI-driven processing; specifically, articles exhibiting nonstandard formatting, highly specialized terminology, or irregular stylistic conventions may be susceptible to misclassification. Furthermore, the model's reliance on contextual signals for thematic keyword extraction can theoretically limit its sensitivity to domain-specific nuances relative to manual coding. However, given the highly structured nature of conference proceedings metadata, based primarily on titles, abstracts, and author-provided keywords, we consider this risk to be substantially mitigated in this application. Ultimately, this approach represents a pragmatic tradeoff, ensuring the scalability and efficiency necessary to longitudinally map over a decade of proceedings.

This AI-assisted method specifically addresses the logistical challenge of processing large, diverse datasets that would otherwise be impractical to review manually. Although our approach aligns with the core objectives of broadly mapping a research field, it adapts the methodological rigor of data charting found in structured frameworks, such as the PRISMA-ScR, to accommodate computational assistance (Tricco et al., 2018). This reflects a complementary approach wherein computational tools manage data scale and structure, allowing keywords to be extracted and analyzed for overarching themes while reserving critical interpretation for researchers.

Analysis of keyword frequencies enabled the identification of key themes, emerging trends, and future directions in C & C research, providing insights into the field's evolution and current research landscape. Regarding future implications, the advancement capabilities of LLMs show further promise in automating aspects of scoping reviews, particularly for multilingual corpora or heterogeneous sources. However, care must be taken to ensure such tools support, rather than replace, human expertise and experienced knowledge (Shneiderman, 2022).

2.4. Additional materials

The Springer Series on Cultural Computing was established in 2013, with Ernest Edmonds as the founding editor and Craig Vear as the series editor. This series has already published over 40 books on various topics, covering the fields of C&C and CC.

> *"Cultural Computing is an exciting, emerging field of Human-Computer Interaction, which covers the cultural impact of computing and the technological influences and requirements for the support of cultural innovation. Using support technologies such as artificial intelligence, machine learning, location-based systems, mixed/virtual/augmented reality, cloud computing, pervasive technologies, and human-data interaction, researchers can explore the differences across a variety of cultures and cultural production to provide the knowledge and skills necessary to overcome cultural issues and expand human creativity. This series presents monographs, edited collections, and advanced textbooks on the current research and knowledge of a broad range of topics, including creativity support systems, creative computing, digital communities, the interactive arts, cultural heritage, digital culture, and intercultural collaboration"* (Vear, 2012).

3. Results

Based on our statistical analysis of the developing field of CC (represented by all ten available published proceedings), we identified four topics that inductively emerged from the reviewed literature. These selected topics structure the analysis reported in this scoping review as follows: (1) cultural computing for cross-generational interaction, (2) computing for tangible heritage, (3) computing for intangible heritage, and (4) cultural computing and modernity. Each of these four sections is divided into "overview," "current research trends," and "new research directions and future challenges."

3.1. Cultural computing for cross-generational interaction

3.1.1. Overview

Mediating cross-generational exchanges (e.g., facilitating social interaction among different generations within a family) has increasingly gained the attention of researchers and designers alike (Thang, 2002). This mediation involves studying, designing, and evaluating novel socio-technical and domestic computing systems grounded in the acceleration of population aging in both developed and developing countries (Liebowitz et al., 2007). Naturally, addressing human, social, and cultural factors in this application domain is critical, as they shape the overarching set of viewpoints, concerns, expectations, values, and user needs that sustain technology acceptance and appropriation.

The focus on cultural computing for cross-generational interaction and its implications for domestic computing solutions has been a recurring theme within the C&C conference series (see Figure 3). This can be summarized in two waves: first, by the need for current and contextualized research on the cultural and social factors we required as a community to deal with this uncertain and rapidly evolving scenario during the decade of the 2010s; and more recently, with the increasing adoption of new technologies, such as XR—and AI—mediated environments, alongside their ethical concerns that need to be addressed in design.

One of the most extensively studied application domains in cross-generational interaction is the enabling and promotion of social exchanges among family members, particularly involving older adults. In fact, given the accelerated rate of aging in both developed and developing countries, encouraging the participation of family members in informal care for older adults turns out to be a critical asset in helping mitigate the political and economic stress on public services. Given the divergent experiences and viewpoints regarding aging and technology adoption across cultures, we argue that designers and developers alike should explicitly consider the underlying human, societal, and cultural values and

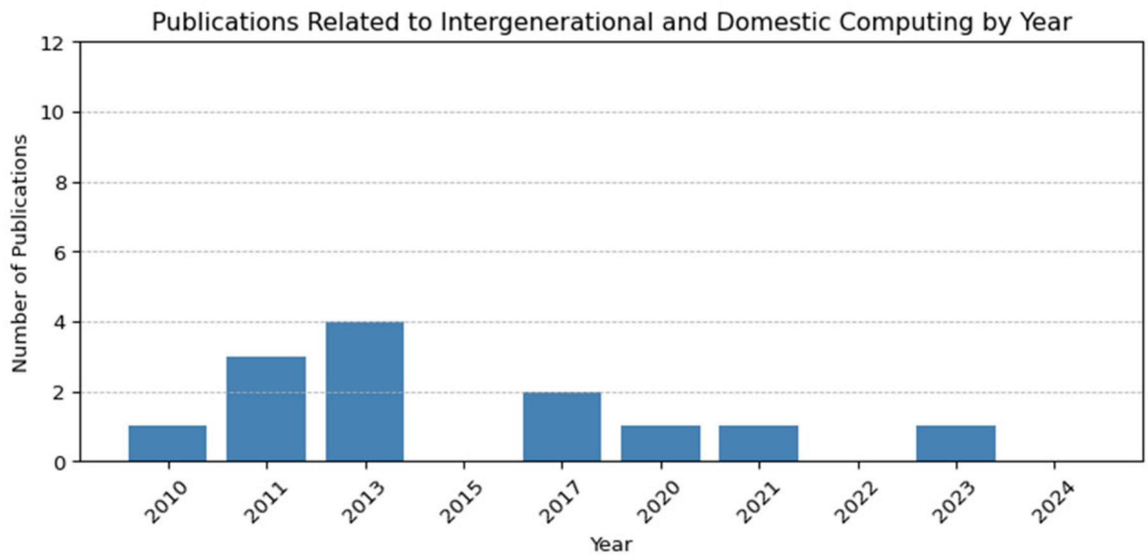

Figure 3. The following keywords were used for filtering the C&C proceedings: asymmetry, collaboration, collectivism, daily life, domestic computing, elderly, family, human values, inclusive design, individualism, intergenerational communication, older adults, silver economy, social expectations, social networks, social relationships.

expectations to understand how these socio-technical determinants inform and guide technological advancement.

3.1.2. Current research trends

3.1.2.1. The dichotomy between collectivism and individualism. Although design guidelines focused on the effects of age-related changes in older adults' progressive physical and cognitive decline are usually reusable regardless of the cultural and social background in which they are implemented, supporting social interaction tends to be less reusable, as people behave differently across cultures. One key framework that sustains this divergence is the collectivistic and individualistic dichotomy. In this respect, while individualism emphasizes individual self-identity, personal agency, and values, prioritizing individuals over colleagues, collectivism emphasizes collective identity, collective agency, and values, prioritizing colleagues over individuals (Chen & Unal, 2023). Furthermore, acknowledging WEIRD (Western, Educated, Industrialized, Rich, and Democratic) biases in HCI research (Sturm et al., 2015), cultural and societal differences are critical to addressing socio-technical and domestic technology design. Therefore, culture appears as a significant design dimension that should be considered when envisioning the reuse of existing HCI knowledge and exploring its convergence and divergence in broader socio-technical interaction scenarios.

In this respect, Gutierrez et al. (2019) reviewed the last two decades of HCI research with older adults, highlighting the importance of considering culture as a crucial factor in the design of intergenerational technology. The essential challenges that sustain the design rationale of socio-technical and domestic computing systems mediating the interaction with older adults are: (1) understanding intra-family communication patterns, rhythms, and asymmetries; (2) addressing the autonomy and independence of family members respecting inherent expectations around active aging and aging in place; (3) respecting that privacy concerns are perceived differently across generations; (4) addressing the diverging preferences concerning face-to-face encounters across different generations; (5) respecting the wide variety in technology adoption across different socio-geographical contexts; and (6) understanding the complexity of collaboration dynamics, invisible work, and social network tensions around informal caregiving in favor of older adults. For example, older adults in individual cultures do not typically have as much contact with their grandchildren as they would like (Harwood & Lin, 2000), and the fact that technology acceptance among older adults is usually higher in the Global North, which makes this population to be more independent, empowered, and more reluctant to ask for assistance to their fellow family members (Nef et al., 2013; Waycott et al., 2013), as stated by Lindley et al. (2008, p. 77), *"they* [older adults] *may view the exercise of familial obligation as an assault on their dignity and moral worth."* In contrast, older adults in Latin America, which is predominantly a collectivist culture, are still considered in most cases a fundamental pillar in the family structure, where adults are prompted to support their older parents following a personal commitment that is grounded in affection and societal expectations, such as filial obligation (Stuifbergen et al., 2008). This divergence in viewpoints, expectations, and concerns underscores the importance of understanding the range of human values and socio-cultural expectations that shape the design ecosystem.

3.1.2.2. Addressing culture in the design of socio-technical and domestic technology. To address cultural and social factors in design (e.g., identifying the core values, expectations, viewpoints, and concerns across generations within a family), socio-technical researchers and practitioners typically employ ethnocentric approaches, such as ethnography and contextual inquiry. Kheirandish and Rauterberg (2020) proposed HuValue, a design tool for daily life product design, to support designers in this task. This instrument aims to identify human values throughout the design process. The authors synthesized critical design concerns into a tangible card-based toolkit comprising a value wheel, 45 value words, and 207 picture cards. By using such a toolkit, designers can be aware and sensitive to human values. These considerations reflect a more thorough examination of human values and the challenge—and duty—of HCI experts to broaden the field's scope and adopt new methods to be helpful in 21st-century socio-technical environments (Sellen et al., 2009). Saariluoma (2021) has resonated with this argument when contrasting contemporary technology design challenges, highlighting the need for a more thorough discussion around the overlap between human research and natural science when designing socio-technical and intelligent technology. More concretely, this reflection—grounded in both HCI and design science and practice—highlights the importance of addressing human and cultural values to inform the development of novel systems that enhance technology acceptance and potential adoption. This argument follows the reflection of Shneiderman (2022) on explicitly addressing the user attributes of their own culture to advance technology in ways that better serve human needs.

In an attempt to integrate cultural factors and social relationships in the design of socio-technical systems, Lipi et al. (2010) crossed Hofstede's cultural dimensions (i.e., hierarchy, identity, gender, uncertainty, and orientation) and Spencer-Oatey's social relationships criteria (i.e., power, mindedness, frequency of contact, and length of relation) to model cultural profiles for informing the design of embodied conversational agents. To do so, the authors empirically identified the emerging traits and showed diverging verbal and non-verbal postural behavior variations between Germany and Japan. Such empirical data was then processed statistically to estimate parametrized features and identify non-verbal attributes that could be inferred from any culture or social relationship, particularly intergenerational interaction.

Due to the rapid advancement of supporting technology in the silver economy market (i.e., design prototypes and ready-to-market computing systems addressing the active involvement of older adults), Leikas et al. (2020) raise several concerns regarding the ethics and responsibility that should be addressed in this ecosystem. In concrete terms, the authors state that the following ethical principles must be assessed when designing home care technology: (1) integrity and dignity, (2) autonomy, (3) informed consent and right to decline, (4) privacy, (5) reliability, (6) social justice and e-inclusion, and (7) meaningfulness. Home care technology should be aware of co-creating value among the various stakeholders involved in the process, which goes beyond the interests of older adults, their caregivers, and management. Following a similar line of reasoning, Begnum and Bue (2021) propose a framework that merges the principles of inclusive design, universal design, and empathic design methods with service design techniques to sustain a promising approach for building a new and integrated methodology to address social and cultural concerns when conceiving novel interactive computing systems.

3.1.3. New research directions and future challenges

In an ever-evolving technological environment, interaction asymmetries and supporting hardware raise progressive—and, at times, disruptive—challenges that should be addressed throughout the design process (Saariluoma, 2021). For example, extended reality environments (encompassing virtual and augmented paradigms) and AI present several design opportunities regarding technology adoption and ethical considerations.

As an exploratory case study, Zhou and Ahn (2023) proposed the design rationale of a set of AR glasses aimed at older adults, focusing on raising awareness of air pollution. Such an initial prototype aims to bridge older adults into the so-called metaverse, providing a more nuanced integration of broader populations into a novel interactive ecosystem. In a similar application domain, Baker et al. (2019) investigated the potential effectiveness of VR environments in promoting social interaction among older adults. This approach opens a particular and challenging design scenario which must effectively integrate hardware (such as head-mounted displays and moon trackers) with accessible software elements (such as avatars and virtual environments). This approach has been successful in scaffolding reminiscence among older adults (Baker et al., 2021), which supports social exchanges for groups of geographically dispersed older adults.

Finally, in terms of ethical concerns, the system design should also account for potential mismatches in the perception of the effectiveness and suitability of technology. For instance, while aging adults usually opt to age "in place," in-home monitoring systems are deployed to monitor the real-time status of older adults and their whereabouts. While this situation may raise concerns about safety, privacy and autonomy, the literature suggests that the needs and concerns regarding information sharing in this ecosystem are not necessarily aligned between older adults and their informal caregivers and family members (Li et al., 2023). This observation certainly opens space for further research, particularly regarding convergence and divergence around social and cultural considerations.

3.2. Computing for tangible heritage

3.2.1. Overview

Tangible cultural heritage includes physical artifacts, buildings, monuments, and other material objects of cultural significance. As described by UNESCO, tangible heritage refers to elements of cultural heritage that have a physical presence, distinguishing them from intangible heritage, such as traditions, languages, and rituals[1]. Tangible heritage includes movable, immovable, and underwater heritage. Although intangible heritage captures the living practices and expressions of a culture, tangible heritage preserves its material legacy. This section focuses specifically on how computing technologies help tackle specific challenges and opportunities in the context of tangible heritage.

The focus on cultural heritage and digital preservation has been a fundamental and enduring theme within the C&C conference series, as shown in Figure 4. Notable early contributions, such as Okada and Shoji's exploration of digital conservation methods (Okada & Shoji, 2010) and the "Virtual Kyoto Project," which presented a digital diorama of Kyoto's historical and cultural landscape (Nakatsu et al., 2010), are well-known examples.

Over time, research presented at the C&C has evolved to include projects such as Kenderdine et al.'s omnidirectional 3D visualization of the Tripitaka Koreana (Kenderdine et al., 2011), which showcased the ability of technology to handle large-scale and intricate cultural artifacts, and Tosa et al.'s works on using projection mapping to celebrate traditional Japanese art (Tosa et al., 2015). More recent contributions continue to innovate by integrating Machine Learning (ML) and interactive platforms, as evidenced by research into regenerated traditional art forms and virtual museum design (Dasgupta et al., 2021).

The application of digital technologies has become a pillar of tangible preservation, documentation, and accessibility of heritage. Cultural computing contributed to safeguarding cultural artifacts threatened by decay, natural disasters, war, and climatic conditions. Digital technologies today enable us to create lasting records of heritage assets, provide virtual access to previously inaccessible sites, and support conservation through detailed analysis and restoration. Integrating cultural computing in this area has improved the physical preservation of cultural heritage and democratized access to it, ensuring that it can be accessible to global audiences.

Significant milestones have marked the historical development of computing in cultural heritage (see Parry, 2005). The early efforts at digitization involved the essential documentation of artifacts through photography and text-based databases. The advent of 3D scanning technologies in the latter half of the

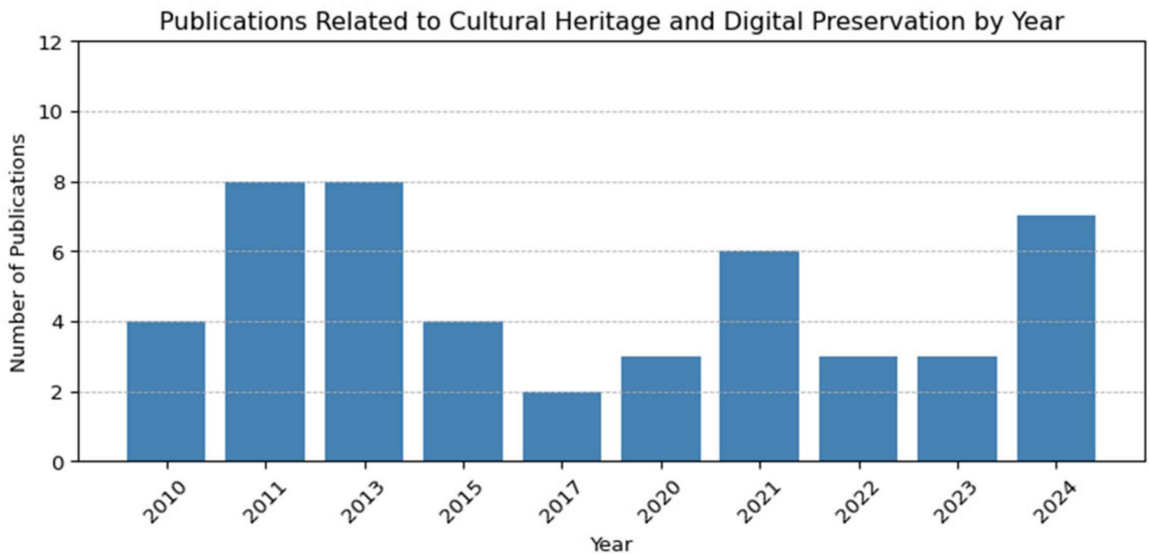

Figure 4. The following keywords were used for filtering the C&C proceedings: cultural computing, cultural heritage preservation, digital archives, digital cultural communication, digital cultural heritage, digital gazetteers, digital humanities, digital preservation, intangible cultural heritage, virtual museum.

20th century revolutionized the field, enabling the creation of precise digital replicas of objects and sites. By the early 2000s, VR and AR emerged, opening new avenues for immersive exploration and interpretation of heritage. Digital archives have become more advanced, incorporating multimedia content and metadata to provide rich and accessible repositories of cultural knowledge. These milestones illustrate the more significant application of high-end computing technologies in cultural heritage management, transforming research methods, and public engagement practices.

From preserving ancient monuments to creating virtual museum exhibits, cultural computing has continually expanded the possibilities for safeguarding and disseminating tangible cultural heritage. As the field progresses, the combination of historical practices with new digital technologies emphasizes the potential of cultural computing to address emerging challenges and inspire innovative cultural heritage management practices.

3.2.2. Current research trends

3.2.2.1. 3D scanning and digital preservation. One of the most critical trends in tangible heritage computing is the use of 3D acquisition technologies, such as photogrammetry and laser scanning. These technologies are central to recording and preserving tangible cultural heritage, making it possible to create highly accurate digital models of cultural artifacts and sites while preserving intricate details that may be lost over time (Remondino, 2011). These methods capture the precise physical details of objects and sites, producing high-resolution digital models that constitute comprehensive records. A substantial amount of relevant published work focuses on photogrammetry projects, utilizing overlapping photographs to create 3D reconstructions (Kasapakis et al., 2024). Other published work focuses on laser scanning, which uses laser beams to precisely measure and map the geometry of surfaces (Balado et al., 2022). Such models are instrumental in restoration projects, enabling conservators to apply wear analysis, identify vulnerabilities, and plan interventions without handling fragile originals (see, for example, Tucci et al., 2017). In addition to examining how these technologies can make heritage artifacts more accessible to broader audiences, such digitization processes have also been increasingly investigated in relevant literature to enable computational analyses of 3D forms of cultural artifacts so that objects can be categorized, clustered and analyzed by scholars and citizen scientists (Ch′ Ng et al., 2013).

Computer-aided reconstruction of archaeological fragments has been a predominantly active area of research in recent years. Most published work has been specific to the joining of fragmentary pottery ("potsherds") and the reconstruction of ceramic artifacts (see, for example, Di Angelo et al., 2022;

Kampel & Sablatnig, 2004; Ming et al., 2023), though a significant body of work has addressed the reconstruction of statues (see Fazio et al., 2022; Jo et al., 2020; Spallone et al., 2022) and murals, papyri and parchment (see Abitbol et al., 2021; Ben-Dov et al., 2022; Soto-Martin et al., 2020).

Due to historical practices, fragmented artifacts that were once part of the same object may be separated within a single collection or between different collections in various museums. For example, Collins et al. (2017) achieved a virtual long-distance join of fragments of the famous Atrahasis cuneiform flood tablet that were housed 1000 km apart in the British Museum in London and the Musée d'Art et d'Histoire in Geneva (Woolley et al., 2018). The creation of digital replicas has also been discussed in relevant research as a form of insurance against loss caused by natural disasters, war, or degradation, with many studies focusing on the use of 3D models for documentation, virtual exhibitions, and restoration projects as a virtual safeguard against loss (Kantaros et al., 2023).

3.2.2.2. Virtual and augmented reality. Research focusing on VR and AR is steadily growing, and relevant publications focus on exploring new ways to access and interpret tangible heritage through the recreation of cultural sites and artifacts in immersive environments. We consider the topic "emerging" despite its historical presence (as seen in Figure 5) due to its alignment with recent technological advancements, particularly in AR, VR, and MR, as well as the growing interest in leveraging digital mediums for cultural preservation and innovation. Immersive platforms are becoming increasingly essential for institutions seeking to revitalize user engagement post-pandemic either through on-site interactive application or with remote-access solutions.

More specifically, relevant research on VR applications focused on enabling immersive explorations of reconstructed historical environments, allowing users to "visit" cultural sites that may be geographically distant, inaccessible, or lost to time (Lee et al., 2020). For example, VR applications have been used to recreate ancient cities or simulate archaeological digs, providing users with a firsthand understanding of historical contexts or even bringing to life paintings and other artifacts in museums (Shehade & Stylianou-Lambert, 2020). Research, such as the Virtual Kyoto Project and the Open City Museum, further demonstrates the potential to visualize historical, cultural, and future scenarios (Kallergis et al., 2020; Nakaya et al., 2010).

AR, on the other hand, has been increasingly explored in the relevant literature, particularly over the last decade, as a critical heritage interpretation tool for enhancing real-world experiences by overlaying digital content onto physical spaces (Boboc et al., 2022). Relevant research has also focused on the increasing use of AR applications in museums and heritage sites, with many projects developing applications that provide contextual information, such as animations or historical narratives, enriching visitors' interactions with exhibits (Ding, 2017). Relevant published work has also focused on the potential of AR and MR for cultural tourism (Han et al., 2019) to enhance the tourist experience through applications such as AR virtual guides (see, for example Koo et al., 2020). Applications in digital museums and AR-driven cultural tourism exemplify how these technologies respond to contemporary user demands (Dasgupta et al., 2021).

A common element of relevant published work, at least in the last decade, is the emphasis placed on the potential of both VR and AR to bridge the gap between physical heritage and digital interpretation, offering many advantages relating to the expansion of access to and engagement with heritage, with a special emphasis on the engagement of younger audiences.

3.2.2.3. Digital storytelling. Digital storytelling is an emerging trend in current research, and relevant studies explore how interactive narratives and multimedia content can help bring tangible heritage to life. Relevant studies describe projects that utilize textual information, images, audio, video, and animations to create digital storytelling platforms that engage audiences further and provide educational experiences for diverse groups (Katifori et al., 2018). Applications developed in recent years also include mobile apps that guide users through historical sites with audio tours and augmented visuals (see, for example, Sanchis et al., 2020; Vrettakis et al., 2019), interactive museum kiosks that allow visitors to explore the history of artifacts through videos and animations (Apollonio et al., 2025), and online platforms that host user-generated stories related to cultural artifacts (Khundam, 2020; Lacet et al., 2022).

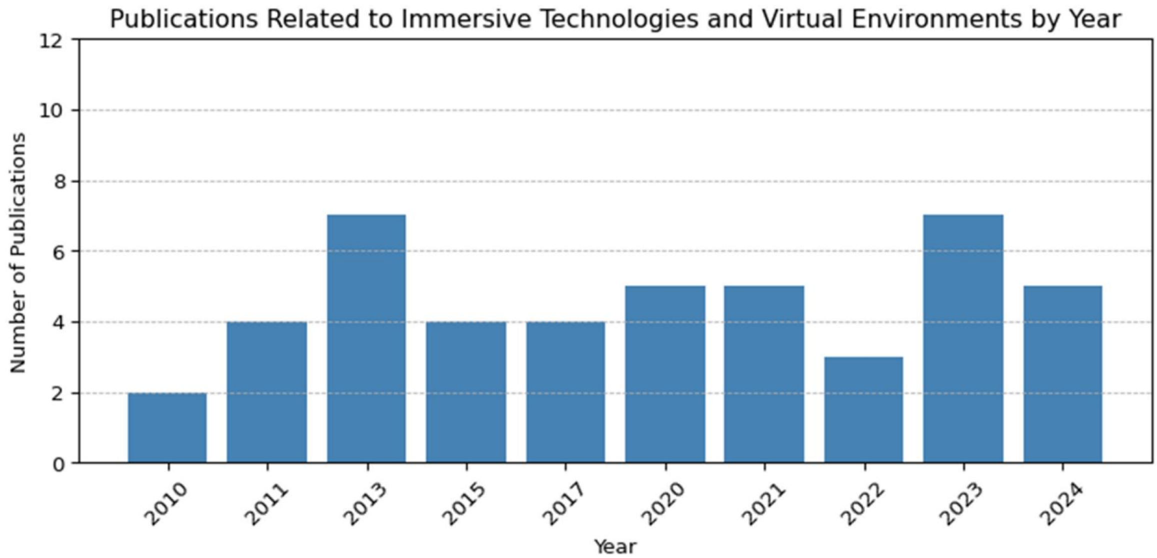

Figure 5. The following keywords were used for filtering the C&C proceedings: augmented reality, avatar-guided museum, digital museum, immersive exhibition, immersive space, immersive visualization, interactive art, interactive storytelling, metaverse, mixed reality, spatial augmented reality, virtual museum, virtual reality, virtual reconstruction, volumetric video.

In the context of archaeological sites, digital storytelling has become increasingly used to simulate events such as battles or celebrations that took place in specific locations. In contrast, relevant studies for museums have used digital narratives to convey the lives and contributions of historical figures associated with objects on display (Liu & Lan, 2021; Wyman et al., 2011). Research focusing on digital storytelling approaches in cultural heritage emphasizes its interpretive value for tangible heritage and its ability to empower communities to share their heritage creatively, thereby strengthening their connection to their cultural identities. Many relevant studies increasingly focus on exploring the effects of such practices in fostering emotional connections and making cultural narratives more relatable and memorable (Liu & Lan, 2021; Podara et al., 2021).

3.2.2.4. Serious games and tangible heritage. Serious games appear increasingly popular in the relevant literature as a new, and more engaging form of interaction with tangible cultural heritage (Mortara et al., 2014; Pyae, 2018). These games typically aim to educate players while entertaining them, offering new opportunities to explore historical settings and address heritage management challenges. Relevant applications in the literature include games simulating archaeological excavations (or restoration practices), allowing users to virtually uncover and piece together ancient artifacts while enhancing their understanding of archaeological methods (see, for example, Murtas & Lombardo, 2024). Urban planning simulations based on historical cities are also explored in relevant research, allowing players to navigate the dilemmas of managing heritage within evolving urban environments (Bontchev, 2015). In addition, serious games often incorporate puzzles or narratives based on cultural artifacts, allowing players to appreciate their historical significance. Most of the applications presented in current relevant research aim to explore the potential of serious games in promoting interactive learning and enhancing public engagement with tangible heritage, while also contributing to the accessibility of cultural heritage to diverse and younger audiences. This seems to be a typical driver in most of the research areas presented in this section.

3.2.3. New research directions and future challenges

3.2.3.1. Multi-sensory experiences and multimodal interactions with heritage. Multi-sensory experiences are increasingly gaining attention as a new way of engaging with tangible cultural heritage (Marto et al., 2022). In this context, technologies such as multisensory VR and AR systems that integrate tactile, auditory, olfactory, and even gustatory elements to create a fully immersive exploration of heritage sites or artifacts are increasingly being explored in the relevant literature (see, for example, Cantoni et al., 2018; Carulli & Bordegoni, 2020).

In recent years, emerging technologies such as haptic interfaces, Brain-Computer Interfaces (BCIs), and Magnetic Resonance Imaging (MRI) are paving the way for multimodal interactions with tangible heritage. Haptic interfaces, especially, have attracted a lot of attention in recently published works, with relevant applications focusing on new ways of simulating the sensation of touch to allow users to "feel" the textures of artifacts or architectural features without risking physical damage (Brewster, 2017) or help blind or partially sighted visitors. Other studies also focused on multisensory museum exhibits utilizing haptic gloves and scent-dispensing devices to strengthen interaction with artifacts (see, for example Blundell, 2023; Fallows et al., 2022). MR, which combines elements of AR and VR, has also garnered significant attention in the relevant literature, with many studies focusing on the potential effects of MR on the engagement of younger audiences (see Buhalis & Karatay, 2022).

Finally, recent work has highlighted new opportunities for exploring the use of emerging technologies to explore new dimensions of presence and embodiment, allowing users to feel physically present in recreated historical settings or interact with cultural artifacts in profound ways (Shehade & Stylianou-Lambert, 2023). Recent studies emphasize the potential of these approaches to deepen emotional engagement and provide unique educational opportunities, making heritage exploration more relatable and memorable, and thus promising in expanding the accessibility and experiential quality of heritage exploration.

3.2.3.2. AI and machine learning for tangible heritage. AI and ML hold immense promise for advancing the preservation and understanding of tangible heritage (Fiorucci et al., 2020). This expected impact is also increasingly discussed in the current literature, which emphasizes the potential of AI in automating the analysis and classification of heritage objects, significantly reducing the time and resources required for manual cataloguing. As demonstrated in Figure 6, the significant increase in AI publications in recent years reflects the growing attention to this field.

AI is increasingly being used to preserve cultural heritage, as seen in projects such as La Scala Theatre's opera preservation and Ruichang bamboo weaving, which utilize machine learning (Avanzini et al., 2020; Liu et al., 2020). AI-driven models have also been developed to predict structural degradation in monuments or artifacts, enabling preemptive conservation efforts (Ghaith & Hutson, 2024). Deep learning techniques, such as Convolutional Neural Networks (CNNs), have been explored in recently published work to restore damaged artifacts by predicting missing elements and reconstructing

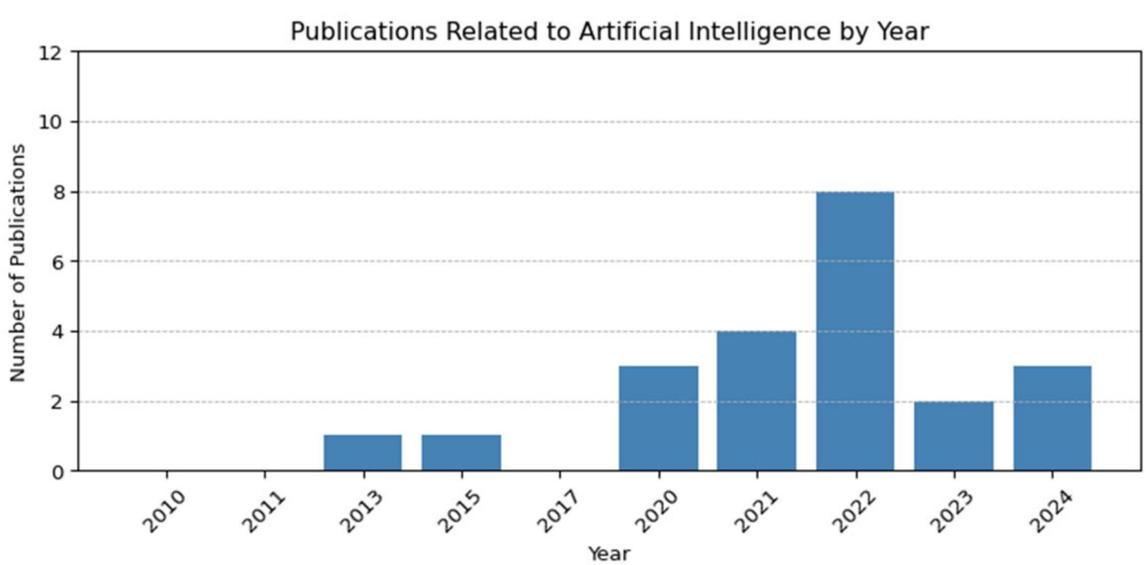

Figure 6. The following keywords were used for filtering the C&C proceedings: AI design, AI ethics, and interactive AI, artificial intelligence, deep learning, generative adversarial networks, generative models, human-AI collaboration, large language models, machine learning, natural language processing, recommendation systems.

original forms (Paolanti et al., 2019). The potential of these methods to identify patterns in heritage data that human researchers might overlook has also been explored recently, with scholars emphasizing the new insights that can be gained concerning historical contexts or artistic practices (Gaber et al., 2023).

Its creative potential is also explored in collaborative human-AI projects, such as creating Chinese landscape paintings and textile designs using generative adversarial networks (see Chang & Huang, 2021; Liu & Zhou, 2022). Therefore, recent research in this area, along with its relevant applications, highlights the growing potential of AI in cultural heritage, creating new research opportunities that can facilitate effective heritage management and restoration practices.

Moreover, the integration of AI in cognitive mimetics and ethical AI development is illustrative of the work arising from integrating AI into the field (Karvonen, 2020; Salo-Pöntinen, 2021), addressing moral dilemmas in AI deployment and the need for cultural preservation in a digital age. As AI evolves beyond technical problem-solving into areas that reflect human creativity, social norms, and cultural dynamics, it is poised to shape the future of CC research significantly.

3.2.3.3. Serious games and AI potential. The evolution of serious games includes more complex narratives and advanced interaction mechanisms to support diverse educational needs. New research directions focus on integrating AI for personalized learning experiences or employing MR technology to bridge the gap between physical and digital heritage (Borda & Molnar, 2024). For instance, future studies can further explore how AI-driven narratives can become more dynamic, adapting to players' decisions, and providing more advanced, personalized storytelling and learning experiences. Thus, utilizing AI in serious games presents new opportunities for enhanced immersion and a wider dissemination of cultural knowledge.

3.2.4. Future challenges and the need for evaluation

Despite promising advances, significant challenges remain in digital heritage applications. The rapid pace of technological development raises concerns about the long-term sustainability and preservation of digital heritage artifacts and repositories (Champion & Rahaman, 2019, 2020). These challenges stem from the inherently transient nature of digital technology and the lack of investment in digital resources and repositories. In addition, there is often insufficient funding to maintain software, applications, and digital content once the short life cycles of heritage projects are over. Therefore, digital preservation of 3D models, metadata, and interactive applications requires robust strategies to mitigate data loss and obsolescence risks. Furthermore, the ethical implications of digitizing and sharing cultural heritage, particularly for indigenous or sensitive content, must be adequately assessed (Santana Quintero et al., 2019).

In particular, robust evaluation frameworks are crucial for measuring and assessing the effectiveness and impact of these technologies, ensuring that they meet the needs of both heritage professionals and the public. Recent research reveals that, despite the numerous digital solutions for tangible heritage being developed within research projects, there is a lack of emphasis on evaluating their effectiveness, gathering visitor feedback, or addressing the real needs of the heritage sector. Many applications are created primarily with the aim of technological innovation, thus creating a disconnection between digital innovation and actual user engagement. Future research should focus on assessing the impact of these applications, ensuring that they align with the needs of heritage professionals and their audiences. Improving evaluation systems will bridge this gap and realize the potential of digital heritage tools in meaningful and sustainable ways.

Especially with respect to immersive experiences, future research should also consider the social dimension of heritage experiences, as social interaction is an essential part of museum or heritage site visits. Many immersive installations, as technologically innovative as they are, risk excluding participants from shared experience and collective engagement. Museums are social spaces that promote discussion, interaction, and group learning to enhance the overall experience. Therefore, digital applications must be designed to foster collaboration, dialogue, and shared exploration, not solely individual experiences. Addressing these social dynamics will ensure that immersive technologies contribute positively to the social and educational aspects of cultural heritage experiences. By addressing these challenges, researchers and practitioners can maximize the potential of digital tools while protecting the integrity and authenticity of tangible cultural heritage.

3.3. Computing for intangible heritage

3.3.1. Overview

Intangible cultural heritage encompasses traditions, practices, and knowledge passed down through generations. Unlike physical (tangible) heritage artifacts, intangible heritage is found in human memory and practice, including oral traditions, performing arts, rituals, and traditional crafting methods. The UNESCO Treaty for the Protection and Promotion of Intangible Cultural Heritage (ICH) (2003) identified the following examples:

a. oral traditions and expressions, including language as a vehicle of the intangible cultural heritage,
b. performing arts,
c. social practices, rituals, and festive events,
d. knowledge and practices concerning nature and the universe,
e. traditional craftsmanship.

Although tangible heritage, such as monuments, artifacts, and cultural properties, has long been documented, exhibited, and visited, the ephemeral, impermanent, and immaterial nature of intangible heritage has challenged its curation and protection. These challenges are often intensified by the pressures of time when curating ICH that is in decline. Interactive technology plays a crucial role in the preservation of ICH (Zhang et al., 2025).

Interactive technology themes (e.g., HCI, UX) have also contributed to ICH studies involving interface designs and usability evaluations. Foundational studies have focused on adapting user interfaces to cultural contexts to ensure accessibility and effectiveness. For example, early work on multilingual accessibility examined how cultural nuances in language could affect user interaction, contributing to principles for the localization of user interfaces (Weiss & James, 2013).

User experience evaluation has also been important to this field, particularly in assessing user satisfaction and system efficiency across diverse demographics. Research such as the Bayesian Network of Culture-Dependent Behaviors explored predictive models for user interactions, providing frameworks for evaluating cultural variables within interface usability testing (Lugrin et al., 2015). Furthermore, studies on interactive evaluation techniques in digital systems, such as testing cultural heritage applications, have advanced methodologies for measuring engagement and cognitive impact in cross-cultural settings (Martin & Ko, 2011). As shown in Figure 7, the growing trend in the "Culture and Computing" proceedings highlights the growing academic interest and participation in HCI research, as well as its evolving themes.

Threats to ICH include the erosion of distinctive local and regional differences, the closure of cultural venues, insufficient training or learning opportunities, a scarcity of essential materials, and economic difficulties, for example, when heritage practitioners cannot earn a living. However, the most common threats to ICH are that they are not regularly practiced or not passed on to future generations, for example, where there is community diffusion or where practices become solely tourist attractions. Digital and computational advances have created numerous opportunities to acquire and preserve ICH. However, it should be noted that digital technologies have in the past focused primarily on tangible rather than intangible heritage preservation projects. Indeed, digital and computational innovations have tended to be object-centric (Hou et al., 2022).

3.3.2. Current research trends

3.3.2.1. Innovations in cultural engagements. Digital tools are increasingly used to improve ICH experiences in museums, cultural sites, and other settings (Arcos-Pumarola et al., 2023; Qiu et al., 2022). This trend extends beyond conventional multimedia installations, encompassing immersive

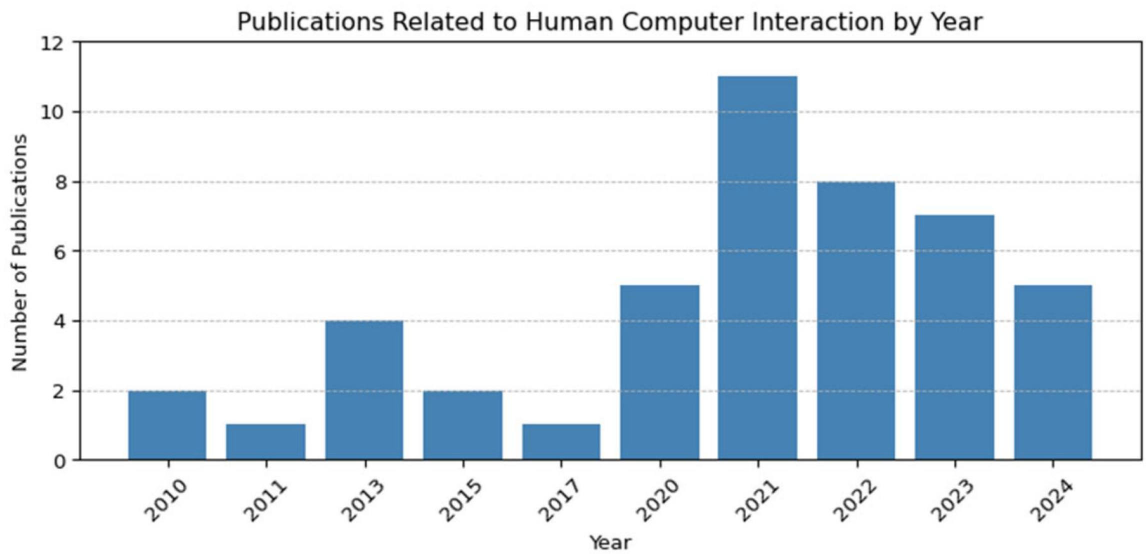

Figure 7. The following keywords were used for filtering the C&C proceedings: accessibility, adaptive interfaces, augmented feedback, conversational interfaces, gesturing, human factors, human-agent interaction, human-computer interaction, intelligent user interfaces, interaction, interaction design, interaction pattern, interaction principles, multimodal interaction, service design, tangible user interface, usability engineering, user experience design, user interface design, user research.

experiences that incorporate VR, AR, gamification, serious games, storytelling, projection mapping, and data sculpting.

3.3.2.2. Virtual, augmented and mixed reality, and game-based experiences. 3D technologies are crucial to acquire tangible heritage, ranging from small artifacts (Collins et al., 2019) to large-scale heritage sites (Teruggi et al., 2021). These technologies create virtual assets and environments to situate virtual ICH. For example, digital reconstructions of historical sites offer contextual backgrounds for virtual performances, allowing remote participants to engage with heritage experiences. AR apps can improve museum visits by overlaying information on physical artifacts. Additionally, AR apps can enable users to collect, curate and interact with 3D replicas of these artifacts, thus enriching their understanding and appreciation of cultural heritage (Woolley et al., 2020). Although gamification and serious games are not new concepts, they are increasingly applied innovatively in museology and heritage projects to create engaging experiences that draw visitors into the heritage narrative (Rhodes et al., 2024). By fostering a sense of participation and connection to cultural practices, the notion of a shared virtual space (akin to Meta's "Metaverse") is also emerging as a platform of ICH interest to attract participation intention from new heritage audiences (Cao et al., 2024).

3.3.2.3. Projection mapping, storytelling, data sculpting, and artificial intelligence. By superimposing virtual projected media on physical heritage locations, projection mapping affords a MR experience with many heritage applications. When combined with storytelling, projection mapping can bring a range of cultural narratives to life, for example, depicting changes in settlement architecture and seasonal cultivation practices (Nikolakopoulou et al., 2022). This approach enlivens tangible heritage experiences and makes intangible heritage narratives accessible to broader audiences. VR and storytelling have also been explored in urban heritage research, which aims to record and preserve built digital heritage alongside local crafts, foods, and festivals (Udeaja et al., 2021). Data sculpting (Hou et al., 2022) combines interactive display systems with extensive digital archives to create new ways to visualize and interact with motion-captured cultural heritage. For example, visitor interaction opportunities such as martial arts pose matching.

At the time of writing, there is considerable interest in AI following the success of OpenAI's GPT large language models and the ChatGPT interface. There are, of course, many other generative and non-generative AI models and methods. For example, Glushkova et al. (2023) employed an AI algorithm to correct the posture of participants engaged in real-time glass-blowing. Pistola et al. (2021) used AI tools for ICH digitization, which included dance recognition and textual analysis.

3.3.3. New research directions and future challenges

In a review of digital cultural heritage (DCH) research, Lian and Xie (2024) identified significant key trends in the academic literature in (i) interaction design, (ii) interactive digital storytelling, (iii) digital archaeology, and (iv) wearable technology. The authors also discussed the diverse global approaches to DCH, highlighting "*The dominance of some countries (e.g., China and the United States) in DCH research reflects possible regional differences in global DCH practices. Such differences stem from the unevenness of technology adoption, policy support, cultural values, and resource allocation. DCH research and practice are contextualized in different regional and cultural environments. Europe may focus more on digitizing historical buildings and artifacts, while Asia may concentrate on the digital documentation of intangible cultural heritage and folklore*" (p. 29).

> In a state-of-the-art embodied ICH review, Hou et al. (2022) observed that "*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" (p. 1). They also observed that "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*" (p. 1).

ICH works benefit from contemporary and complementary technological research in 3D visualization, modeling, and motion capture (Skublewska-Paszkowska et al., 2022), as well as 3D pose estimation and dance digitization (Rallis et al., 2020; Reshma et al., 2023), and creative authoring tools (Pistola et al., 2021).

3.3.3.1. The blending of technologies and tangible and intangible heritage. Future research directions are expected to advance the integration of methods and technologies, such as combining digital storytelling, immersive VR experiences (Men & Chen, 2023), and serious games for Intangible Cultural Heritage (ICH), including traditional folk dancing (Xie et al., 2024). There is also growing recognition of the intertwined nature of tangible and intangible heritage as essential components in shaping identity, preserving history, and fostering a sense of continuity and belonging (Gallou, 2022) and that the preservation of both tangible and intangible cultural assets is essential for maintaining the richness and diversity of human cultures (Buragohain et al., 2024).

3.3.3.2. Inclusive and expanding ICH. Future ICH research is expected to further broaden the range of included heritage domains beyond visually dramatic, spectacular, or ceremonial practices, such as martial arts or pagan rituals, to include embroidery (Yan & Chiou, 2021), cooking (Lee, 2023), and weaving (Hwang & Huang, 2024; Portalés et al., 2021). ICH's expansive and evolving nature poses challenges to researchers and heritage resources. One such challenge is documenting and preserving contemporary memories, such as the industrial histories of miners and factory workers. Although these narratives may be collated by retirees, family members, and other community participants on websites, blogs, or social media platforms, there is no assurance that they will be preserved over time. Unfortunately, these community-generated digital assets are generally precarious cultural assets. However, it is hoped that new tools (Dix et al., 2024) and AI technologies (Hannaford et al., 2024) may support their survival.

3.4. Cultural analytics and modernity

3.4.1. Overview

Modernity is a recurring but often implicit theme in CC (Held & McGrew, 2003). It appears wherever computing technologies mediate cultural change: in cross-generational interaction, where digital adoption, media preference, communication rhythm, and family roles differ between older and younger users; in tangible heritage, where museums, monuments, and artifacts are reconstructed through 3D acquisition, VR/AR/XR, and interactive visualization; and in intangible heritage, where oral traditions, performance, craft skills, rituals, and everyday practices are recorded, simulated, interpreted, and re-presented through computational systems (Schäfer & Van Es, 2017). From this perspective, *modernity* is an important philosophical topic within CC (Wagner, 2012). It is one of the conditions under which cultural data, cultural memory, and cultural experience are technologically transformed and analyzed by cultural analytics (Hall, 2013; Manovich, 2020). This approach leverages computational tools to analyze, visualize, and distribute knowledge in history, literature, philosophy, and linguistics, fundamentally transforming how we understand human culture (Goldenstein et al., 2026; Griffin & Hayler, 2016).

This section treats modernity as a cross-cutting analytical lens rather than as a separate domain equivalent to cross-generational interaction or heritage computing. Modernity can be studied through questions such as (see also Harrison, 2013): how do computing technologies change cultural transmission; how do digital platforms reshape cultural authority and authenticity; how are traditional practices translated into data structures and interaction designs; and how do AI systems classify, preserve, reconstruct, or reinterpret cultural materials? These questions are consistent with the broader definition of CC as an area using artificial intelligence, machine learning, mixed / virtual / augmented reality, cloud computing, pervasive technologies and human-data interaction to explore cultural differences and cultural production (Jones, 2013; Vear, 2012).

Within this broader frame, bie-modernity is discussed here as one recent example of a modernity-orientated analytical approach within CC (see Figure 8). Bie-modernism is one of several theories concerned with modernity (Venn & Featherstone, 2006; Wang, 2014, 2017). The Chinese term *bie* indicates separation, distinction, or differentiation. In the context of *bie*-modernity, it refers to distinguishing mixed social and cultural states in which pre-modern, modern, and post-modern elements coexist. The theory has been described as a globally observable phenomenon (Zenko, 2022), although it may be more visible in underdeveloped contexts, such as time (Ren, 2019).

The most relevant contribution of this approach is to show how modernity can be operationalized as an object of computational analysis, such as bie-modernity analytics (Berry, 2012; Manovich, 2020). The metaphor of gold fineness or proportion analysis can be translated into engineering terms: a cultural object, literary text, film, design case, or social dataset may contain different proportions of modern, pre-modern, post-modern, and pseudo-modern features. In cultural analytics, one must define observable indicators, encode them as features, and analyze their distribution through computational methods (Connerton, 2009). This makes the approach relevant because it links cultural interpretation to data modeling, feature extraction, classification, and human-AI interpretation, and also contributes

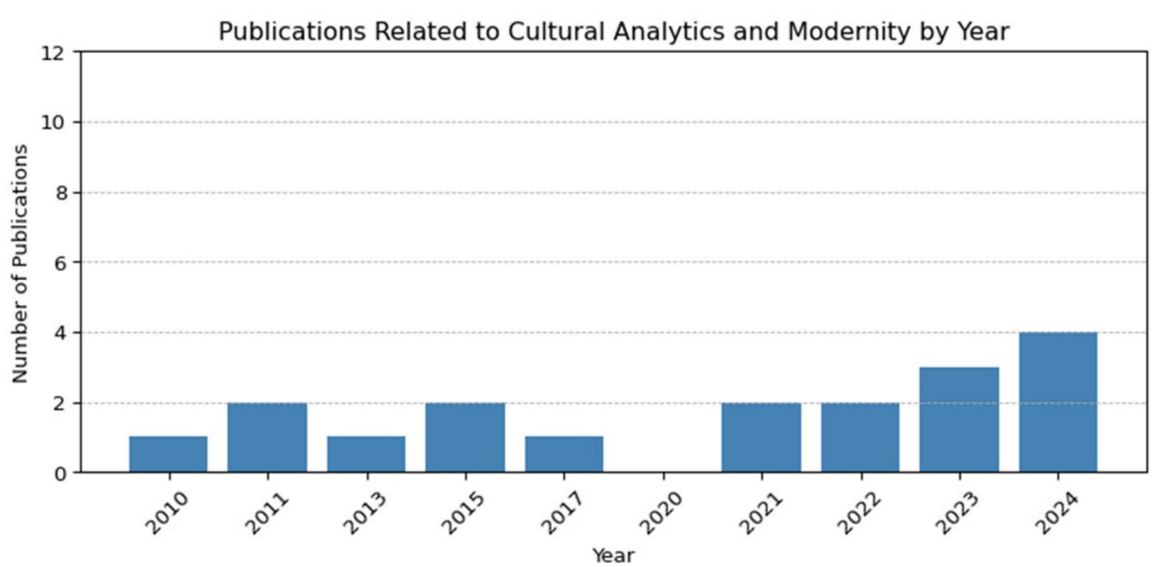

Figure 8. The following keywords were used for filtering the C&C proceedings: bie-modern, bie-modernism, bie-modernist cultural computing, bie-modernist culture computing, computational humanities, cultural analytics, digital humanities, modernity, post modernity.

to the emerging field of digital humanities (Jones, 2013). Although digital humanities research has focused on text data (Burdick et al., 2012), cultural analytics has a particular focus on massive cultural data sets of visual material, both digitized visual artifacts and contemporary visual and interactive media (Manovich, 2016; Schäfer & Van Es, 2017).

At the same time, this framing requires caution. Any computational analysis of modernity depends on assumptions about what counts as modern, pre-modern, post-modern, authentic, or pseudo-modern. These assumptions are culturally situated and may be contested (Handler, 2005). Therefore, bie-modernity analytics should not be treated as a neutral measurement system or as a universal conclusion. In this scoping review, it is presented as an emerging and debatable analytical lens that illustrates how CC can extend from heritage representation into the computational study of modernization, authenticity, and social transformation (see, e.g., Goldenstein et al., 2026).

3.4.2. Current research trends

The first trend concerns the computational representation of modernity in texts and cultural symbols. In bie-modernity analytics, sentence or word vector expressions are trained on contextual relations and background knowledge, and the trained model is then used to classify unknown words, sentences, or cultural descriptions. This links bie-modernity analytics to broader AI-based cultural analysis, where natural language processing, embedding models, supervised classification, and explainable AI can assist human researchers in identifying patterns that are difficult to detect manually. The aim is not to replace interpretation, but to provide computational evidence that can be checked by domain experts.

Wang and Chen (2021) provided an early formulation of bie-modernity analytics by connecting bie-modernist interpretation with computational techniques. Their example of distinguishing the real and fake Monkey King in Journey to the West demonstrates how a classical literary problem can be reframed as a recognition and classification task. Qi et al. (2022) further developed this line using the Word2Vec algorithm and the transformer network model to recognize characters through features such as appearance, behavior, and language. These studies treat literary and cultural characters as feature sets rather than as objects of traditional textual commentary.

A second trend is the proportion analysis of modernity in cultural artifacts. Wang et al. (2023) applied bie-modernity analytics to estimate the proportion of modernity in literary works, including novels by Nobel Prize winner Mo Yan and Er Yue He's The Yongzheng Emperor. Wang et al. (2024) extended this approach to Dao Lang's lyrics, while Lin and Sui (2024) analyzed the literary works of the Three Musketeers of Tie Xi. These studies suggest a possible computational-humanities workflow: define categories, annotate textual evidence, calculate proportions, and interpret the resulting distribution in relation to literary and cultural history. The engineering challenge is to make such annotation rules transparent and reproducible (Manovich, 2016, 2020).

A third trend is the application of modernity analysis to visual and media culture. J. Chang (2023) analyzed bie-modernist features in China's New Gods series of contemporary animated films. This case connects bie-modernity analytics with film studies and cultural media analysis, and it also relates to earlier CC concerns with visual representation, interaction, and cultural experience. Similarly, Xu and Wang (2024) introduced bie-modernity analytics into pedagogy by examining the influence of ChatGPT on writing education and proposing a human-computer symbiotic approach. These examples connect modernity-oriented CC with current issues in generative AI, authorship, creativity, and education.

A fourth trend points toward computational social analysis. Peng (2024) used machine-learning prediction to study social welfare from the perspective of bie-modernist life equity theory, drawing on data related to the economy, education, housing, and healthcare. This example should be read cautiously because its normative assumptions require debate (Gold & Klein, 2019; Hall et al., 2016). Nevertheless, it shows how modernity-orientated cultural analytics may intersect with computational social science: the cultural categories provide research hypotheses, while statistical and machine-learning methods test patterns across structured data.

3.4.3. New research directions and future challenges

The first future direction is to connect modernity analysis more explicitly with the three main CC domains discussed in this article. In cross-generational interaction, modernity can be operationalized through digital literacy, technology asymmetry, communication preference, and family roles. In tangible heritage, it can be studied through the transformation of artifacts into 3D models, immersive reconstructions, and platform-dependent museum experiences. In intangible heritage, it can be analyzed through the translation of embodied skills, oral memory, performance, and ritual practice into data, interfaces, and AI-mediated experiences. In each case, the issue is not simply whether computing modernizes culture, but how it changes the form, authority, and meaning of cultural transmission.

The second direction is methodological. If bie-modernity analytics or any other theory of modernity is to become useful for CC, it must be translated into clear datasets, coding schemes, feature definitions, and evaluation procedures. Future work should report how categories are defined, how examples are selected, how inter-annotator agreement is measured, and how model errors and cultural bias are handled. For AI-based approaches, explainability is essential: the system should show which textual, visual, behavioral, or social features contribute to a classification result.

The third direction is comparative and multilingual. Since modernity is experienced differently across regions, languages, and cultural histories, CC should avoid building models from a single national or linguistic context. Multilingual corpora, cross-cultural datasets, and mixed-method validation can help researchers compare how modernization, heritage preservation, and AI-mediated cultural production vary across contexts. This also allows bie-modernity analytics to be placed alongside other modernity theories rather than being treated as the sole explanatory framework.

In summary, modernity analytics is valuable here as a recent example of how research has attempted to transform the question of modernity into computational procedures, including vector representation, classification, proportion analysis, and machine-learning prediction. Its assumptions and ideological positioning must be made explicit and its claims should be tested through transparent data and reproducible methods. Reframed in this way, the research area contributes to the overall review by showing how CC may move beyond preservation and interaction design toward the computational analysis of cultural change processes itself (Trouillot, 2003).

4. General discussion and conclusions

We present selected research areas, some of which are declining, while others are emerging or evolving. Each of the research areas described above provides a good overview of the research field of culture and computing. With an ongoing trend of merging advanced interactive technology and cultural aspects, we are witnessing the emergence of the field of cultural computing.

Developing socio-technical systems to promote cross-generational interaction requires a thorough consideration of cultural factors that are critical to sustaining technology use, acceptance, and appropriation. For example, social expectations, such as the dichotomy between collectivism and individualism, and asymmetric values, expectations, viewpoints, and concerns across generations, shape the grounds for potentially effective design. Current challenges in cross-generational interaction are related to the rapidly evolving technology landscape, where extended reality environments and AI pose several design opportunities and challenges. These range from technology adoption (e.g., intelligent ambient systems to effectively support aging in place) to ethical considerations (e.g., asymmetric perceptions across generations regarding safety, privacy and autonomy).

The application of computing technologies to tangible cultural heritage has led to advancements in 3D scanning for digital preservation, as well as VR and AR for immersive engagement, digital storytelling for enhanced interpretation, and serious games for interactive learning. Despite these innovations, challenges persist, particularly in relation to the sustainability of digital heritage repositories, the preservation of digital assets, and the limited availability of long-term funding for digital resources. The lack of a robust evaluation of the effectiveness of these technologies to ensure their long-term viability and impact on heritage preservation and participation has also been identified as a critical challenge. Future research directions focus on multi-sensory experiences through haptic and MR interfaces, as well as AI and ML for artifact restoration, classification, and integration.

This scoping review has explored the evolving landscape of digital technologies in the preservation and promotion of intangible cultural heritage. While traditionally more focused on tangible heritage, digital innovations are increasingly being applied toward intangible heritage, addressing its ephemeral nature through immersive experiences and virtual performances on digital stages. Current trends highlight the use of VR and AR, gamification, projection mapping, data sculpting, and AI to engage audiences and preserve cultural practices. Future directions for research include blending the tangible and intangible, as both play essential roles in maintaining the richness and diversity of human cultures. Challenges remain to ensure that the collected data itself will be preserved; these assets, particularly community-generated digital assets, can be as precarious as the tangible artifacts that accompany them. However, new tools and advances may allow these digital assets to survive.

Advanced computing technology is also available for analyzing cultural development, with a focus on *modernity*. Cultural analytics blends cultural critique, computational methods, and socio-political analysis to study, for example, modernity. Its core methodologies, quantitative computing with proportionality analysis, can quantify modernity in texts, reconfigure cultural signifiers, and advance a theory of Life Equity that proposes realizing basic security for all through the redistribution of gross domestic product. However, a double challenge remains: cultural analytics discuss ethics and the risk of authoritarian data narratives distorting authenticity. Future research must prioritize ethical safeguards and critically humanistic algorithms. Although the unique bie-modernity analytics is rooted in Chinese modernity, it now spans the philosophy of technology, biopolitics, and cultural ecology, reflecting its interdisciplinary adoptability. By bridging digital innovation and cultural critique, modernity analytics transcends traditional humanities disciplines to provide a dynamic framework for the complexities of global modernity. Its expansion depends on a balance between scientific rigor and socio-ethical responsibility.

Note

1. For the distinction between *tangible* and *intangible* heritage, refer to the 2003 UNESCO Convention for the Protection and Promotion Intangible Cultural Heritage (UNESCO, 2003).

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Data availability statement

The data supporting the results and analyses presented in this paper can be found at: https://zenodo.org/records/16603183

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