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CULTURAL-INTELLIGENT INTERFACES: AN ADAPTIVE FRAMEWORK FOR RECREATING IRANIAN HERITAGE MOTIFS AND MEANING THROUGH ARTIFICIAL INTELLIGENCE

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ABSTRACT

This paper proposes an adaptive and culturally intelligent user interface framework that uses artificial intelligence (AI) to recreate and preserve Iranian heritage motifs. The aim of this research is to contribute to the development of design-driven AI systems that are sensitive to cultural context and foster heritage preservation, cultural identity, and creative innovation.This framework not only enables the creative production of traditional motifs, but also helps preserve cultural identity and enrich user interaction with Iran's visual heritage by considering cultural sensitivities. The paper also demonstrates the potential applications of this approach, explores its technical and ethical challenges, and proposes criteria for evaluating the effectiveness of culturally aware design systems. Overall, this research is an effective step towards developing AI systems that are aligned with cultural values while facilitating creative innovation in the field of cultural heritage design.

KEYWORDS: Iranian Heritage Motifs, Human-Computer Interaction, Generative Artificial Intelligence, Adaptive Interface, Motif Ontology.

1. INTRODUCTION

Iranian art and architecture are recognized worldwide for their rich motifs, including Islamic geometry, calligraphy, plant designs, tiling, mirror work, and muqarnas. These motifs serve not only as decoration but also express cosmological, religious, philosophical, and social values, having evolved over centuries in technique, regional styles, and materials. Factors like climate, tools, local resources, religious rules, linguistic traditions, and political history have influenced this development.In the digital age, there is a growing interest in preserving, studying, and creatively reusing these motifs, both to safeguard cultural heritage and to develop new forms of expression.Traditional Iranian motifs are more than insignificant enhancement; they encapsulate centuries of social, otherworldly, and cultural significance(1).These motifs serve as visual carriers of collective memory and social personality; however, computational approaches for their preservation and entertainment often drop brief in capturing their symbolic implications and contextual subtleties(2). Current generative strategies, while able to duplicate patterns with high visual devotion, ordinarily disregard the semantic profundity, historical hierarchy, and cultural interpretation embedded in these designs (3, 4).

To confront this issue, we need a framework that is culturally informed and meaning-driven, rather than data-driven reproduction(5). The establishment of such a framework necessitates interdisciplinary partnerships, including art historians, traditional craftspeople, semioticians, cultural theorists, and computational designers (6). Fusing these forms of knowledge provides the only means to ensure computational models have the appropriate interpretive layers to define what constitutes the identity and importance of Iranian heritage motifs(7).

Despite advances in digitization of motifs and generative AI, integrating formal motif knowledge, semantic generative models, adaptive user feedback, and context-sensitive mechanisms into a single framework remains a major challenge. This hinders the production of beautiful and meaningful motifs by AI and, consequently, effective user interaction with cultural heritage content.In order to bridge this gap, this paper proposes a multi-levelled, culture-sensitive framework that integrates a formal ontology of Iranian motifs maintaining their historical, symbolic, and aesthetic properties with a meaning-sensitive generative model that can synthesize motifs in accordance with cultural semantics. The system also comprises an adaptive user feedback loop to enable repeated refinement and cultural alignment, and evaluation criteria intended to assess cultural authenticity and ensure that motifs created maintain symbolic and contextual integrity.

2. LITERATURE REVIEW

2.1. Heritage Motifs in Iranian Art

Iran's artistic heritage is diverse. Traditional motifs include geometric patterns (girih, girih-star polygons), vegetal/arabesque forms (Islimi), calligraphy (Nastaʿlīq, Kufic, Thuluth), tilework (haft rangi, mosaic glaze), muqarnas, and so on(8).

Studies such as O'Kane (1987), Grabar (1973), and more recent works by Necipoglu, Golombek, and others have catalogued motifs, their origins, meanings, and regional variations(9). These motifs frequently carry symbolic meaning: geometry conveys cosmic order; vegetal forms may imply growth, paradise, or nature; calligraphy often carries religious texts; the interplay of light and shadow in muqarnas suggests spiritual ascension. Recognizing meaning is therefore essential(10). Table 1 compares the literature on heritage motifs.

Table 1: Recent Research on Heritage Motifs.

NO	Reference	Year	Keyword(s)	Result
1	(8) Rajazmay Azari M.	2023	Girih / Islamic geometric patterns (IGP)	Review the state of knowledge of IGP, identify design principles, gaps (e.g. need for structural bonding, reliability and application in contemporary design). Suitable for referencing the list and geometric principles
2	(11) Naserabad AA. Ghanbaran M.	2023	Girih generation / Algorithm	Parametric/algorithmic presentation for generating various girih systems (including 7-systems)—application for digitization and motif preservation
3	Azizi Naserabad A.(12)	2024	6-point girih / Motif classification	Classification of motifs in a 6-corner framework and distinction between primary and secondary motifs—useful for morphological analysis of motifs
4	Hirsch L, et al. (5)	2024	HCI, culturally-aware interfaces, multiperspectivity	Proposing an HCI framework for the retextualization of cultural heritage; emphasizing interdisciplinary solutions and context-aware designs—directly related to "culturally aware user interfaces." (MDPI)

NO	Reference	Year	Keyword(s)	Result
5	Khanzadeh M. (13)	2024	Islamic architecture / Mosque entrances	Analyzing the aesthetic and historical functions of mosque entrances and examining patterns (tiles, patterns, Islamic); suitable for exemplifying and environmental application of motifs.
6	Ahmed M.(14)	2022	Muqarnas / Light-Shadow Symbolism	Geometric and symbolic analysis of the Muqarnas; discussion of the impact of the play of light and shadow on semantic experience and "spiritual elevation"
7	Risser RE.(9)	2022	Arabesque / Islimi / Calligraphy	Exploring the role of arabesques and their relationship to calligraphy and meaning; helping to explain that Islamic calligraphy is not just "decoration" but also has symbolic meaning
8	Hasanpour Loumer S.	2023	IGP / Sustainability and identity	IGP is not only beautiful, but also creates identity in contemporary works and conveys messages of social sustainability; a strong citation for "social meaning" to motifs.
9	Recognition of Girih tiling and Ghavarebari patterns(15)	2023	Pattern Recognition / Field Studies	Methods for identifying and recognizing patterns in historical fields; useful for documentary applications and motif digitization
10	(16) A. Computational approach in presentation a parametric method to construct hybrid girihs	2024	Algorithmic / Parametric	Parametric modeling for the production of "hybrid girihs"; related to the recording and reproduction of motifs in 3D/contemporary spaces

2.2. *Generative AI and Style Transfer*

In recent years, generative adversarial networks (GANs), neural style transfer, variational autoencoders, transformers, and diffusion models have been employed widely to generate or restyle imagery. In cultural heritage domains, models have been used to reproduce famous painting styles, generate ornament patterns, reconstruct damaged artworks, or produce hybrid styles. For example, neural style transfer techniques allow separating content and style, applying the "look" of traditional tilework or arabesque onto new content; GANs have been trained to generate patterns in Islamic geometric design However, these efforts often centre on visual appearance—shape, color, texture—without explicit modeling of meaning, symbolic content, or user interpretation. Moreover, many systems assume fixed datasets, unchanging styles, or global datasets that blur regional distinctions.

Table 2: Recent Studies on Generative AI and Style Transfer in Cultural Heritage (2023–2024).

Author(s) & Year	Title / Source	AI Technique / Model	Cultural Focus / Application	Key Contribution / Insight
Li et al., 2023	Image Neural Style Transfer: A Review, Computers & Electrical Engineering	CNN-based NST	General artistic domains	Comprehensive review highlighting gaps in semantic modeling and cultural contextualization
Zhang et al., 2023	Diffusion-based Visual Generation and Cultural Style Synthesis, Pattern Recognition Letters	Diffusion model	Cultural pattern synthesis	Achieves higher fidelity in stylistic transfer; focuses on aesthetic accuracy
Chen et al., 2024(17)	Style Transfer of Chinese Wuhu Iron Paintings Using Hierarchical Visual Transformer, Sensors	Transformer-based	Chinese traditional painting	Captures hierarchical stylistic layers; preserves multi-level features of traditional art
Almeida & Zhang, 2023(18)	Cultural Symbolism and Machine Learning: Beyond Aesthetic Reproduction, Digital Heritage Quarterly	Deep generative models	General heritage interpretation	Critiques AI's lack of symbolic and semantic understanding in cultural reproduction
Zhou et al., 2024(19)	Construction of Cultural Heritage Knowledge Graph Based on Graph Attention Neural Network, Applied Sciences	GAT-based Knowledge Graph	Chinese heritage ontology	Integrates semantic reasoning into cultural data modeling for meaningful AI generation
Li et al., 2024(20)	Semantic-Aware Generative AI for Cultural Artifact Restoration, Heritage Science	Semantic-guided GAN	Artifact reconstruction	Embeds symbolic context and regional metadata into generative restoration systems

2.3. *Cultural-User Interfaces and Adaptive Systems*

In the field of human-computer interaction (HCI), a branch of research examines culture, identity, and the adaptation of interfaces to cultural norms. Research by Boedker, Nardi, and Durish (on culture as embedded practice) and Marcus and Gould (on culture in interface design) shows that culture influences interaction gestures, metaphors, rhythmic patterns, color and shape symbolism, spatial arrangement, and narrative metaphors beyond appearance. Adaptive interfaces (systems that adapt to the user's preferences, context, or culture) have been developed in areas such as language localization and theme adaptation, but have rarely been used in meaningful reproduction of heritage motifs.

Table 3: Recent Research on Cultural-User Interfaces and Adaptive Systems.

Author(s) & Year	Title / Source	Approach / Technology	Cultural Domain	Key Findings / Relevance
Reinecke & Bernstein (2013)(21)	Knowing what a user likes: Cultural adaptation in interface design (MOCCA), TOCHI	Cultural User Model + Ontology-based adaptation	Multicultural web interfaces	Early ontology-based system adapting layout and icons to user culture; improved perceived usability
Bourges-Waldegg (1998)(22)	Meaning and Culture in HCI, Interacting with Computers	Cultural semiotics in design	Cross-cultural interface meaning	Highlights "meaning" as the core dimension in cultural HCI, not only aesthetics
Smith & Sun (2021)(7)	Cross-cultural design metaphors in adaptive UI, International Journal of HCI	Design metaphors, adaptive UX	Educational interfaces	Proposes dynamic metaphor switching based on Hofstede dimensions; meaning-centered adaptation
Wang et al. (2025)(23)	Adaptive Fusion of Multi-Cultural Visual Elements Using Deep Learning, Scientific Reports (Nature)	CNN + Attention + GAN	Cross-cultural web/app UI	Uses deep learning to fuse cultural visual patterns; dynamically personalizes visual identity
Capece et al. (2024)(24)	Smart Adaptive Interfaces for Cultural Heritage Experiences, Heritage Science	Sensor-based & AR adaptive system	Museum & heritage environments	Integrates narrative personalization, spatial adaptation, and semantic tagging of exhibits
Liu (2023)(25)	Context-aware adaptive UI for inclusive design, ACM UIST	Reinforcement learning + user modeling	Inclusive multicultural systems	Introduces adaptive reward functions reflecting user cultural values and preferences

The literature review shows that although adaptive interfaces are well established in terms of usability and localization, they remain underexplored in heritage-aware cultural design. The integration of AI-based user modeling, cultural ontologies, and semantic matching is a promising avenue for future research. In the context of Iranian heritage, such systems can adapt motifs, color symbolism, and narrative layers in real time, respecting both regional aesthetics and cultural depth.

2.4. Gaps in Existing Research

Despite the growing interest in using artificial intelligence to recreate cultural motifs, current research has yet to answer important questions. Studies show that existing approaches, while strong in technical reproduction, are incapable of capturing the deep cultural, symbolic, and contextual layers of Iranian heritage. The following gaps require further attention. A close look at the literature reveals that although digital recreation of Iranian motifs has advanced technically, several crucial dimensions remain unknown. These gaps not only reveal shortcomings in existing work, but also indicate areas in which future research can meaningfully contribute. Figure 1 shows AI-based cultural motif recreation.

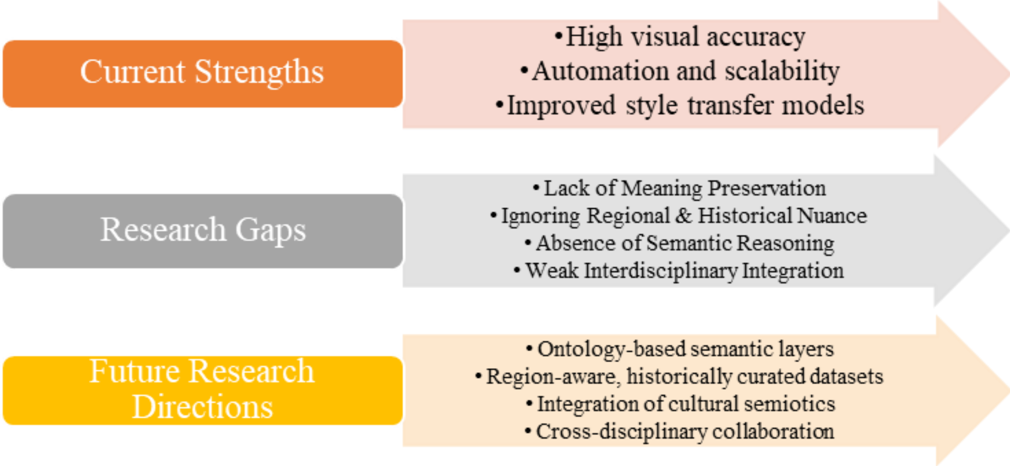

Figure 1: AI-based Cultural Motif Recreation.

3. PROPOSED ADAPTIVE FRAMEWORK

3.1. Motif Ontology & Semantic Layer

In motif level ontology inclusion supports descriptions structured with motifs, categories and visual elements including symbolic meaning and its history and cooccurrence relationships. Comprehending and regenerating Iranian patterns is more than matching shapes and colors; it is about structuring that knowledge so that computers can think about them in the same manner as historians, artisans, and architects: That is, by recognizing categories, their symbolic value and their use context. The motif ontology, and with it its semantic layer, fulfills this crucial function. The ontology provides a systematic and flexible arrangement of links between groups of motifs, their elements, historical-regional context and meanings. That is, the motif is treated not as merely a picture but rather a concept with attributes, historical sources and semantic relations to other motifs. The semantic layer fills the gap between source data and interpreted data.Key features:

3.1.1. Motif Taxonomy

A taxonomy of motifs—a disciplined categorization of the patterns into categories and subcategories—sits at the foundation of the ontology. Irannu ornament In Iranian ornamentation we find a very rich field in which, however, some main divisions may be defined covering scores of centuries and both architectural and decorative arts. The Categories and Characteristics of Islamic Ornamental Motifs are shown in Table 4.

Table 4: Categories and Characteristics of Islamic Ornamental Motifs.

Category	Description	Common Submotifs	Example Usage
Geometric	Based on mathematical grids, symmetry, and proportion.	Star polygons (5-, 6-, 8-, 10-, 12-pointed), girih tessellations, intersecting circles.	Mosque domes, tile panels, wooden lattice (mashrabiya).
Vegetal / Arabesque	Stylized plant forms, scrolling vines, leaves, and flowers.	Continuous arabesque scrolls, palmettes, split leaves.	Stucco panels, carpets, painted manuscripts.
Calligraphic	Use of script as decorative form.	Kufic, Thuluth, Nastaliq scripts forming geometric patterns.	Epigraphic friezes, portal inscriptions, ceramic borders.
Figurative / Animal	Representations of animals, mythical creatures, or human figures (rare in religious contexts, more in secular).	Simurgh (mythical bird), hunting scenes, zodiac signs.	Palace murals, metalwork, manuscripts.
Muqarnas / 3D Forms	Stalactite-like vaulting, complex 3D ornamentation.	Tiered cells forming honeycomb patterns.	Domes, iwans, squinches, tomb ceilings.

3.1.2. Symbolic Meaning Mapping

What makes Iranian motifs so powerful is that they are not merely decorative—they are symbolic. A well-designed ontology must therefore include meaning associations.For example, Islamic floral motifs traditionally symbolize heaven, eternal growth, and spiritual renewal, and geometric patterns symbolize cosmic order and the infinity of creation. Calligraphic motifs carry the word of God or poetic verses, connecting the viewer to the sacred or the intellectual. Table 5 summarizes symbolism and spirituality in Islamic Ornamental Motifs.

Table 5: Symbolism and Spirituality in Islamic Ornamental Motifs.

Motif Type	Symbolic Associations	Philosophical / Religious Context
Vegetal / Arabesque	Life, fertility, growth, paradise, eternal renewal.	Quranic descriptions of paradise gardens; Sufi poetry.
Geometric	Cosmic order, harmony, unity, infinity.	Neoplatonic geometry, Islamic cosmology, sacred mathematics.
Calligraphy	Divine word, wisdom, authority, identity.	Quranic verses, royal decrees, poetic homage.
Figurative	Power, myth, history, storytelling.	Epic traditions (Shahnameh), royal iconography.

This symbolic layer allows AI systems to not only draw a pattern, but also to choose a pattern based on the meaning the designer wants to convey. For example, if the goal is to convey the idea of divine order in a digital interface, the system might prioritize geometric tessellations over plant scrolls.

3.1.3. Material and Medium Attributes

The meaning and appearance of a motif are deeply influenced by its medium—whether it is painted on ceramic, carved into stone, woven into a carpet, or applied as a fresco. Islamic ornament isn't just "decoration"—it's a visual language. Over centuries, artists across the Muslim world developed five main styles, each with its own voice. Geometric patterns speak to a love of order and the unseen structure of the universe.Calligraphy turns sacred words into art.

Figurative art—animals, people, mythical creatures—does appear, but usually in palaces, books, or everyday objects, not mosques. It shows that Islamic art isn't "against" images—it's about context. In secular spaces, storytelling and symbolism flourish. Finally, muqarnas transform architecture itself into ornament.They're engineering and poetry combined.

A semantic layer that ignores medium risks producing designs that look implausible when realized physically. For instance, a very fine, detailed vegetal motif may be suited for manuscript painting but impractical for large-scale stucco carving. Figure 2 is a typical case.

Figure 2: A Typical Case.

3.1.4. Temporal and Regional Qualifiers

Iran's artistic history spans millennia, and motifs evolved dramatically across dynasties. Safavid tilework tends to be more colorful and ornate compared to the austere Seljuk patterns. Qajar ornamentation, meanwhile, is known for its playful color palettes and figurative themes.

Similarly, regional differences—between Isfahan, Shiraz, Qazvin, Yazd, and Tabriz—reflect not only local tastes but also available materials and workshop traditions. Encoding these temporal and spatial qualifiers allows AI syste

Table 6: A Framework for Categorizing Artworks.

Dimension	Sub-categories	Example Value	Scholarly Use
Temporal	Historical period, date	Safavid (1600–1700 CE)	Tracing stylistic developments over time
Spatial	City, region, workshop	Isfahan, Royal Atelier	Comparing regional differences and artistic exchanges
Material & Technique	Tile type, glaze, method	Haft-rang tile, alkaline glaze	Studying technological and material changes
Visual Features	Dominant color, motif, layout	Turquoise blue, arabesque, geometric pattern	Identifying aesthetic patterns
Social Function	Location, intended use	Friday Mosque, mihrab decoration	Exploring the social and ritual role of art

Systematically classifying the temporal and geographical attributes of artworks makes it possible to trace the evolution of motifs and colors with greater precision. Such structured documentation allows researchers to identify correlations between styles and regions, and to reconstruct the developmental paths of Iranian art. The results of this analysis are invaluable for restoring damaged pieces, selecting historically accurate colors for conservation projects, and inspiring contemporary design. The table3 proposes a framework for categorizing artworks according to temporal, spatial, and aesthetic dimension.

3.1.5. Co-occurrence and Composition Rules

Motifs are rarely isolated, but rather used in precise combinations: geometric frames with vegetal scrolls, calligraphy edging central medallions, or muqarnas supporting star-shaped domes. By encoding these rules of association, ontology ensures the compositional integrity of the outputs and prevents awkward juxtapositions.

3.2. Generative Model Layer with Meaning Modulation

Building upon the aforementioned, this component incorporates generative AI that is proficient not only in style transfer but also in meaning modulation—specifically, it generates motifs that embody or adjust symbolic meaning or function.

1. Conditioned Generation with Cultural Metadata Rather than supplying the model with merely an image, we enhance it with detailed tags: motif type (for instance, "geometric + calligraphic"), symbolic intent (such as "divine unity," "paradise garden"), region (including "Ottoman," "Mamluk," "Safavid"), and medium (like "ceramic tile," "stucco," "wood inlay"). By employing conditional diffusion models or GANs, the system acquires the ability to create patterns that correspond with these specifications. For instance, when requested for a "paradise-themed vegetal motif in Mamluk style for stucco," it will not generate sharp Kufic script or rigid grids—instead, it will prefer flowing vines, split leaves, and soft, carved textures.

2. Semantic Guardrails, Not Just Aesthetics Style transfer alone might warp calligraphy into illegible swirls or break geometric symmetry in ways that violate traditional rules. To prevent this, we embed semantic constraints directly into the generation process. Calligraphic elements are kept legible by preserving stroke order and letter proportions. Geometric patterns are required to adhere to valid symmetry groups (e.g., 8- or 12-fold rotational symmetry) and interlocking logic (like girih tiling rules). These aren't post-hoc filters—they're built into the model's architecture or loss function.

3. Meaning-Aware Latent Space We organize the internal structure of the model (the hidden space) in such a way that movement along each direction corresponds to meaningful changes. For example, movement along one axis makes the design more vegetal, another axis makes it more geometrically solid, and a third axis adjusts the "spiritual intensity"; that is, it changes the design from non-religious floral motifs to Quranic inscriptions or abstract unity. This allows designers to consider not only the appearance, but also a sense and purpose, such as "more contemplative" or "festive," with cultural roots.

In short, this layer treats Islamic ornamentation not simply as a decorative surface, but as a visual language. The AI does not just draw "beautiful patterns," but learns to speak with the same intent and purpose as expert artists of past centuries. The result is not simply innovation, but a new work that inspires a sense of belonging, respect, coherence, and meaning.

3.3. Contextual Awareness & Output Channel Adaptation

The design of the motif must be both aesthetically unified and functionally functional, taking into account the context. The chosen medium imposes constraints; the appropriate properties for ceramic tiling are different from those for textiles or stone reliefs. Functional considerations are also important; religious architectural patterns require symbolic coherence and visual balance distinct from commercial or fashion designs. The display environment also influences design decisions; a virtual reality design may emphasize dynamism and saturation, while a physical design must consider material properties, production, and cost. Careful adjustment of scale, color, and rhythm ensures the design is proportionate and feasible.

1. Interaction of Components: System Architecture The proposed structure is operated through a set of interconnected modules, each of which is responsible for a separate layer of design workflow. At the fundamental level, oncology and cementic layer integrates the existing motifs in a structured classification in a structured classification in a structured classification. The data cures layer then processes images of raw motifs and allied metadata to create a well organized dataset through anotation, cleaning, and spato-temporal tagging. The user interface and feedback loop offers an interactive environment in which scholars, designers, or mentor can evaluate the output, improve, and refine the repetitive results through preference learning. Finally, the relevant adaptation module ensures that the resulting motifs are complied with moderatespecific obstacles, appropriate scale, and functional references, yield design that are consistent and practically executable of aesthetics. Table 7 is a proposed architecture showing how components communicate.

Table 7: A Proposed Architecture Showing How the Components Communicate.

Module	Inputs	Processing	Outputs
Ontology & Semantic Layer	Expert knowledge, literature, existing motif corpora	Build structured ontology; define taxonomy and meaning tags	Taxonomy, meaning descriptors for motifs
Data Curatorial Layer	Raw motif imagery, metadata	Annotation, cleaning, tagging, regional/temporal labeling	Dataset with rich metadata
Generative Model	Datasets + meaning + region + medium + style parameters	Conditional generation; style transfer; latent manipulations	Generated motif proposals
User Interface / Feedback Loop	Generated proposals + user inputs (adjustments, corrections)	Adaptation, correction, retraining, preference learning	Refined motif outputs
Context Adaptor	Functional constraints (medium, scale, context)	Constraint enforcement, adaptation of patterns	Final motif designs suited to context

4. DISCUSSION

The aim of this framework is to connect the technical abilities offered by generative AI with the cultural depth embodied in heritage motifs. Properly executed, it can offer benefits beyond the visual novelty of the design to include increased cultural identity, the preservation of endangered motifs and techniques, the power of makers to innovate more responsibly, and heightened awareness in the general public. The success of this project relies on the efforts of Iranian art researchers, makers, local communities, AI researchers, and designers to work together, because authenticity is both social and collective in nature. A critical tension is the balance of diversity and preservation; heritage motifs have always been dynamic, and preserving them without new interpretation can inhibit creativity; alternatively, excessive reformulation can lead to distorted authenticity. The system would require flexibility and transparency so users would understand the consequence of their input (in semantic labels and model conditioning) on the degree of divergence. Finally, resource allocation is an additional obstacle: the creation of ontologies, data annotation, and interface design requires money, and support by funding and institutions (i.e., cultural institutions, universities, or not-for-profit organizations).

5. CONCLUSION

With the rapid move of cultural heritage into the digital space, we want to ensure that rich cultures become deprived of their meanings, simply visual shells. Iranian motifs have considerable symbolic, philosophical, regional, and spiritual meanings. Cultural intelligent interfaces offer a framework to incorporate meanings, cultural context, adaptability, and user participation into generative AI systems to re-create motifs.

In the future, we want to create prototypes, study usability in Iran, and with artisans, curators, and students, and iteratively refine ontologies, and look for applications to restoration and design. The goal is we could co-create systems that, if built with intentionality and partnerships, do not archive our cultural heritage as a visible past but allow it to be utilized as a dynamic cultural heritage for current and future applications.

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