MULTIMODAL FEATURE FUSION FOR INTELLIGENT JADE CARVING DESIGN: A HUMAN-AI COLLABORATIVE APPROACH

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Abstract. Multimodal feature fusion offers a transformative approach to intelligent jade carving design by integrating human expertise with artificial intelligence to enhance creativity in traditional crafts. As a traditional Chinese art form, jade carving faces modern challenges such as limited efficiency, restricted adaptability, and the difficulty of merging traditional workflows with digital innovation. This study introduces an intelligent design framework that employs human–AI collaboration and multimodal structured feature fusion to inspire creativity while maintaining cultural authenticity. The proposed system applies a three-stage reference image recommendation process involving material-feature extraction, thematic and compositional analysis, and design-decision support. Using deep learning segmentation and color-space thresholding, key geometric and color features of jade materials are extracted and structured as encoded vectors. These are then matched with a database of traditional compositions through multimodal models that generate semantic labels and apply weighted similarity scoring. The system integrates automatic screening with human evaluation to ensure accuracy, diversity, and cultural sensitivity. Experimental outcomes indicate improvements in design efficiency, precision, interpretability, and reduced cognitive load for designers. This research underscores the value of AI-assisted systems in preserving traditional craftsmanship while driving innovation, offering a framework that connects deep learning with human creativity for the sustainable transformation of cultural heritage design.

Keywords: *Human–AI, jade carving, jewellery design, multi-modal feature fusion, cultural heritage preservation*

Introduction

Jade carving and jewellery design are traditional arts with profound cultural and historical significance, representing both material craftsmanship and intangible heritage knowledge. These crafts rely heavily on expert skill, embodied techniques, and the transmission of tacit knowledge across generations (Manfredi Latilla et al., 2019). However, in the digital era, these practices face challenges such as limited efficiency, constrained adaptability, and difficulties in integrating traditional workflows with contemporary creative demands (Chen and Li, 2025). Recent developments in human–AI collaboration have demonstrated the potential to enhance creativity and efficiency in design practices across multiple domains). AI systems, particularly those leveraging multi-modal feature fusion, can process geometric, color, and semantic information simultaneously, providing context-aware and culturally aligned design recommendations. This approach allows designers to explore novel ideas while maintaining alignment with traditional aesthetics and cultural meanings. In the field of jewellery design, AI-assisted tools have been shown to support ideation, pattern

generation, and workflow optimization, enabling designers to integrate heritage motifs with contemporary styles (Lyu et al., 2024). Similarly, studies on cultural heritage preservation highlight the role of AI in safeguarding intangible knowledge by capturing expert gestures, material properties, and design principles that are otherwise difficult to document or transmit.

Despite these advances, significant gaps remain. Few studies investigate the cognitive mechanisms underlying human–AI collaboration in heritage craft domains, particularly how designers negotiate AI-generated suggestions with traditional knowledge constraints. Additionally, the integration of multi-modal AI tools in jade carving workflows has not been extensively explored, and there is limited evidence on how such systems can simultaneously foster innovation, usability, and cultural authenticity. Addressing these gaps requires a framework that considers cognitive interfaces, task-technology fit, and heritage preservation, thereby enabling effective co-creation between humans and AI in traditional craft design. The primary objective of this study is to investigate how human–AI collaborative systems, leveraging multi-modal feature fusion, can enhance design innovation in jade carving and jewellery design while preserving cultural heritage. Specifically, the research aims to understand how cognitive interfaces mediate designers' creative decision-making, how AI-generated recommendations are integrated with traditional knowledge, and how these systems support both workflow efficiency and the safeguarding of intangible craftsmanship practices. Related to the objective, here is a comprehensive research question aligned: (1) What are the DIMENSIONS (cognitive, technological, and cultural factors) that influence designers' integration of AI-generated recommendations into traditional creative workflows? (2) How can human–AI collaborative systems utilizing multi-modal feature fusion enhance design innovation in jade carving and jewellery design while ensuring the preservation of cultural heritage?

In the digital era, intangible cultural heritage practices such as jade carving face significant challenges, including limited efficiency, constrained adaptability, and difficulties in integrating traditional workflows with contemporary creative demands. Jade carving relies on deep cultural symbolism, material knowledge, and skilled craftsmanship, yet these qualities are at risk as design practices modernize. Advances in artificial intelligence and multi-modal feature fusion offer opportunities to support innovation while preserving heritage, with human-AI collaborative systems shown to enhance creative performance by combining human expertise with machine-generated suggestions. However, research gaps persist, as few studies examine how cognitive, technological, and cultural dimensions influence AI integration into traditional craft practices. Existing approaches often overlook tacit knowledge, material constraints, and cultural authenticity, limiting their practical applicability. This study aims to investigate the key factors within these dimensions that affect human-machine collaboration in jade carving design, with the goal of enabling creative innovation that respects and sustains intangible cultural heritage.

Literature review

Transformation of creative design through Artificial Intelligence

The integration of artificial intelligence (AI) into creative design domains has transformed traditional practices, offering new opportunities for innovation, efficiency, and cultural preservation. In particular, jade carving and jewellery design, both deeply

rooted in cultural heritage, face challenges in the digital era, including constrained workflow adaptability, limited design efficiency, and the risk of knowledge loss among artisans. Recent advances in multi-modal feature fusion enable AI systems to process and integrate geometric, color, and semantic features from reference materials, providing designers with context-aware, culturally aligned recommendations. By fostering human–AI collaboration, such systems support creative ideation while preserving the symbolic and historical significance of traditional crafts. Despite these technological advances, few studies have explored the cognitive mechanisms, workflow integration, and heritage preservation implications of AI-assisted design in jade carving and jewellery design. This research addresses this gap by examining how multi-modal AI tools can enhance designers' creativity, support informed decision-making, and contribute to the safeguarding of intangible cultural heritage.

Human-AI

The integration of artificial intelligence (AI) into creative industries has transformed the role of the human designer from sole creator to co-creator (Rossato et al., 2024). Meanwhile, Lyu et al. (2024) emphasize that human–AI co-creativity requires systems designed around designer-centric guidance, where human intuition and emotional intelligence remain at the core of creative decision-making. Similarly, Jiaxin (2024) propose a collaboration spectrum ranging from assistive AI tools to autonomous co-creators, suggesting that the level of interaction must align with the complexity and cultural context of the creative domain. This framework is particularly relevant to heritage crafts such as jade carving and jewellery design were tacit knowledge and cultural symbolism guide aesthetic judgment. A systematic review of co-creative systems and highlighted that effective human–AI collaboration depends on transparency, feedback mechanisms, and user control. Their findings underscore the importance of explainable interfaces to build trust among artisans adapting traditional workflows to digital tools. In parallel, Lyu et al. (2024) explored generative AI in jewellery design, revealing both opportunities for creative expansion and challenges in maintaining cultural authenticity. This tension between innovation and heritage preservation echoes broader concerns in digital transformation of traditional arts. Wu and Lin (2025) illustrates how AI-assisted jewellery design can complement traditional jade carving by generating design inspirations that respect material properties and cultural context while enhancing efficiency and creativity. Together, these studies show that jade carving is not merely decorative but forms a critical bridge between heritage and modern design innovation.

Jade carving

Recent studies indicate that traditional crafts such as jade carving and jewellery design are undergoing significant transformation due to the integration of modern technology. Gao and Sa-Ngiamviboon (2024) highlights that contemporary jade carving engages with intangible cultural heritage while incorporating modern artistic expression, demonstrating how designers negotiate between material constraints, symbolism, and innovation. Similarly, Ma (2025) examines the inheritance and innovation of ancient Chinese jade craftsmanship, showing that designers balance historical techniques with new creative possibilities, laying a foundation for understanding how human creativity interacts with technological tools. In the context of jewellery design, the previous

research illustrates the role of AI-assisted systems in enhancing both creativity and efficiency, emphasizing the collaborative interaction between designers and AI to generate novel design outcomes. Collectively, these studies underscore the importance of understanding how designers navigate traditional craftsmanship, cultural authenticity, and technological support. Despite these insights, there remains a lack of empirical research specifically examining how human designers interact with AI tools in heritage-rich domains such as jade carving, where both creative intuition and cultural preservation are critical. Addressing this gap can provide valuable knowledge on cognitive processes, workflow adaptation, and the integration of AI to support innovation while safeguarding intangible cultural heritage.

Jewellery design

Jade carving is an important part of Chinese cultural heritage, and it plays a key role in jewellery design by turning raw jade into meaningful, wearable art. It combines traditional skills, symbolism, and creativity, helping designers preserve cultural values while creating modern designs (Ma, 2025). Studies show that jade carving keeps cultural stories alive and adds uniqueness to jewellery products. AI tools can support this process by giving designers new ideas and helping them work more efficiently without losing the traditional meaning of the designs (Fan and Wardi, 2025). However, there is still little empirical research on how designers actually use AI while working with jade carving. Understanding this interaction can help improve AI tools, support creative processes, and ensure that jade jewellery maintains its cultural authenticity. Designers often draw uniqueness from the inherent properties of materials, such as the color, texture, and translucency of jade, gold, or gemstones. The way these materials are shaped, carved, or combined influences the individuality of each piece (Ma, 2025). Pieces that embody a narrative, emotion, or concept tend to be more distinctive. Designers integrate personal, cultural, or symbolic stories into their creations to evoke meaning beyond aesthetics. Designers often combine traditional techniques with modern tools such as AI-assisted ideation, 3D modeling, or generative design to explore new forms and concepts. This hybrid approach can generate novel patterns while respecting material and cultural constraints (Zhang et al., 2025).

Multi-modal feature fusion

Lee and Kim (2021) examined the development and application of multimodal fusion technology, highlighting its growing relevance in diverse research domains. Their findings indicate that multimodal fusion models demonstrate strong performance in complex analytical and recognition tasks, reflecting their potential to enhance both interpretability and accuracy in intelligent systems. Technical perspectives on multimodal data fusion, as discussed by Zhao et al. (2024) and Gao et al. (2020), provide essential insights for developing intelligent design systems capable of integrating geometric, color, and semantic features from reference materials. Such approaches can enable more context-aware and culturally aligned design recommendations. The GIA (2023) further reports on practical adoption of generative AI in jewellery design studios, emphasizing ethical, regulatory, and authenticity considerations that parallel the cultural sensitivities in jade carving. Despite these advancements, there remains a lack of empirical studies examining how artisans cognitively and emotionally interact with AI tools in traditional creative processes.

Current literature largely focuses on technological performance rather than the designer's cognitive adaptation, decision-making flow, and cultural negotiation within AI-assisted environments. Addressing this gap will provide deeper understanding of how multimodal AI systems can enhance creative ideation, support informed decision-making, and preserve the cultural significance of heritage crafts such as jade carving and jewellery design. Based on the understanding developed through literature review and professional design experience, this section presents a comparative analysis between AI-assisted and traditional design approaches (*Figure 1*).

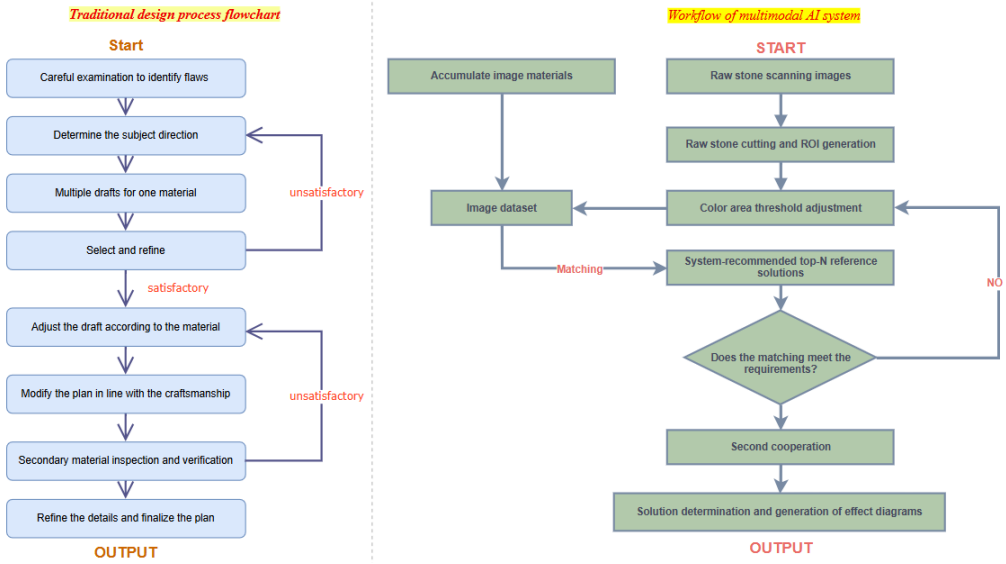

Figure 1. *Comparison of design workflows between the traditional process flowchart and the multimodal AI system.*

This study highlights the transformative potential of human–AI collaborative systems in traditional craft domains such as jade carving and jewellery design. By leveraging multi-modal feature fusion, AI tools can provide interpretable, culturally informed design recommendations that balance innovation with heritage preservation. The research demonstrates that such systems enhance design efficiency, support tacit knowledge transmission, and foster creativity while maintaining cultural authenticity. These findings provide both theoretical insights into human–AI co-creation processes and practical guidance for developing intelligent design tools that respect and sustain traditional craftsmanship, offering a model for the digital evolution of cultural heritage practices.

Materials and Methods

This study employed a qualitative research design using a case study approach to investigate human–AI collaborative processes in jade carving design. A qualitative approach was selected to capture the complex, context-dependent, and tacit knowledge inherent in traditional jade carving practices and to explore the cognitive, technological, and cultural dimensions that influence designers' interactions with AI systems. The case study approach facilitated an in-depth analysis of specific instances of human–AI co-creation, allowing for detailed observation of workflow integration, design decision-making, and creative ideation in real-world craft settings (*Table 1*).

Table 1. *Participant selection criteria and characteristics.*

Expert	*n*	Selection Criteria	Key Contribution
Expert Jade Carvers	2	10+ years' professional experience in jade carving. Mastery of traditional techniques including qiao se (color-enhanced carving). Provincial-level recognition or intangible cultural heritage inheritor status	Provided expert evaluation of Top 10 design recommendations Assessed cultural authenticity and practical feasibility. Validated matching accuracy between jade materials and traditional painting compositions
Senior Design Consultants	3	Extensive experience in traditional jade carving design. Familiarity with cultural heritage preservation practices. Ability to articulate design decision-making processes. Experience with AI-assisted design tools. Background in jewellery or jade carving design. Exposure to modern digital design methods.	Participated in semi-structured interviews. Evaluated system explainability and practical utility. Provided insights on cognitive load reduction and workflow efficiency. Contributed perspectives on technology adoption. Assessed human-AI collaborative framework. Provided feedback on interface usability and design iteration.

Note: The study primarily focused on expert evaluation with 2 provincial-level jade carving experts conducting comprehensive assessments of 100 candidate design proposals (10 jade samples × Top 10 recommendations). Additionally, 3 senior experts participated in qualitative interviews to explore system explainability and practical utility.

This methodology ensured a comprehensive understanding of how AI-assisted systems can support creativity while safeguarding intangible cultural heritage in jade carving and the results are presented in *Table 1*. The study also incorporated a human–AI co-creation framework in which participants interacted with a multi-modal feature fusion system for design reference recommendation. This framework enabled exploration of cognitive acceptance, task-technology fit, and the balance between innovation and heritage preservation. Data analysis followed thematic coding procedures, identifying patterns related to the cognitive, technological, and cultural dimensions influencing design outcomes. Participants were selected using purposive sampling and included expert jade carvers, apprentices, and contemporary jewellery designers who had experience collaborating with AI-assisted design tools. Data was collected through in-depth semi-structured interviews, participant observation, and document analysis. Interviews focused on designers' experiences with AI recommendations, strategies for integrating machine-generated suggestions, and perceptions of cultural authenticity. Participant observation allowed researchers to capture procedural and tacit aspects of carving techniques that could not be fully articulated verbally. All interviews were audio-recorded with consent and transcribed verbatim for thematic analysis.

Results and Discussion

This study offers both theoretical and practical contributions. Theoretically, it advances understanding of human–AI collaboration in heritage crafts by identifying how cognitive, technological, and cultural dimensions shape designers' creative decision-making. It provides a framework for analyzing the integration of AI tools in specialized artisanal workflows, bridging gaps in creativity research, design studies, and cultural heritage preservation. Practically, the findings inform the development of AI-assisted systems that enhance design efficiency, support tacit knowledge transmission,

and foster innovation while safeguarding cultural authenticity. By offering guidelines for effective human–machine co-creation, this research contributes to the sustainable digital transformation of traditional crafts such as jade carving and provides insights applicable to other heritage art domains.

Bridging cultural authenticity and technological innovation

The findings demonstrate that effective human–AI co-creation requires a balance between cognitive alignment, technological functionality, and cultural sensitivity. The integration of multi-modal AI tools can enhance creative innovation, preserve intangible heritage, and optimize workflow efficiency in traditional jade carving. The analysis revealed several key factors influencing human–AI collaboration in jade carving design, organized around cognitive, technological, and cultural dimensions (*Table 2*).

Table 2. *The attributes involved to measure the study exposure.*

Category	Description	
Cognitive Alignment	Designers' ability to integrate AI-generated suggestions with traditional knowledge significantly affected creative outcomes. High alignment facilitated smoother ideation and rapid problem-solving, while misalignment often required adaptation of AI outputs to maintain cultural and symbolic relevance.	
Innovation Enhancement	AI-assisted multi-modal feature fusion expanded creative possibilities, enabling designers to generate novel motifs and patterns while respecting heritage aesthetics. Participants reported that AI suggestions stimulated experimentation beyond conventional designs, supporting both innovation and skill development.	
Cultural Authenticity	Designers carefully evaluated AI-generated recommendations against symbolic, historical, and community norms. Designs were more readily adopted when AI outputs preserved traditional meanings and craftsmanship values, highlighting the importance of culturally informed algorithms.	
Usability and Acceptance	System usability and perceived utility influenced designers' willingness to engage with AI. Intuitive interfaces, transparent recommendations, and interpretability enhanced trust and collaboration effectiveness.	
Tacit Knowledge Preservation	The AI system facilitated the documentation and transmission of tacit skills, including hand gestures, tool manipulation, and procedural knowledge, supporting training and safeguarding of intangible heritage.	
Human–Machine Interaction	Iterative feedback and collaborative decision-making were critical for successful co-creation. Designers maintained agency over final outputs, with AI serving as an assistive partner rather than a replacement.	

The findings of this study highlight the critical role of human–AI collaboration in enhancing creativity while preserving cultural heritage in jade carving design. The cognitive alignment observed between designers and AI-generated suggestions aligns with prior research emphasizing the importance of task-technology fit and user cognition in successful AI adoption. High alignment enabled designers to integrate AI insights effectively, demonstrating that AI tools function optimally when they

complement rather than replace human expertise. Innovation enhancement through multi-modal feature fusion confirms the potential of AI to stimulate novel design ideation without compromising traditional aesthetics. This supports previous studies in jewellery and craft design, which suggest that AI can serve as a creative partner, expanding the boundaries of human creativity while respecting domain constraints. Cultural authenticity emerged as a decisive factor, reflecting the need for AI outputs to respect symbolic meanings, historical accuracy, and community norms. This finding extends the literature on digital heritage preservation, indicating that AI systems must incorporate culturally aware algorithms to support heritage-sensitive innovation Usability and acceptance reinforced the role of human-centered interface design in facilitating trust, engagement, and effective co-creation. The preservation of tacit knowledge demonstrated that AI systems can document and transmit embodied craftsmanship skills, addressing a critical gap in heritage studies where intangible practices are often at risk of being lost. Finally, the observed human–machine interaction dynamics underscore that iterative feedback, agency, and collaboration are essential for maintaining the balance between innovation and tradition. Theoretically, this study contributes to understanding the integration of cognitive, technological, and cultural dimensions in human–AI co-creation. Practically, it offers guidelines for developing AI-assisted systems that enhance creativity, optimize workflow efficiency, and safeguard intangible cultural heritage, providing a model for other traditional crafts facing digital transformation.

Research gaps in AI-assisted heritage craft design

In recent years, artificial intelligence has become a significant driver of transformation in creative industries, offering new possibilities for innovation and cultural preservation. However, despite the growing attention to AI in design, there remains a limited understanding of its application within traditional crafts such as jade carving and jewellery design. Most current studies focus on technical advancements and algorithmic efficiency, often neglecting the deeper human aspects of design practice. The cognitive dimension, which involves artisans' intuition, perception, and creative decision making, has not been sufficiently examined in relation to how designers engage with AI-generated inputs. Likewise, the technological dimension, particularly how tools support or disrupt established craft workflows, is underexplored in empirical contexts. The cultural dimension also requires greater attention, especially in understanding how AI systems influence authenticity, symbolism, and the preservation of traditional values. This lack of comprehensive investigation across cognitive, technological, and cultural perspectives limits the potential for meaningful integration of AI within heritage craft design. Addressing this gap is essential to ensure that technological innovation contributes to the sustainable evolution of traditional craftsmanship while safeguarding its cultural essence.

Conclusion

This study shows that human–AI collaborative systems using multi-modal feature fusion can enhance creativity, efficiency, and heritage preservation in jade carving design. Successful co-creation depends on integrating cognitive, technological, and cultural dimensions. Cognitive alignment with AI suggestions and culturally aware outputs supported ideation without compromising authenticity. Multi-modal fusion

preserved tacit knowledge, while usable and interpretable AI interfaces increased trust and engagement. Theoretically, the study advances understanding of human–AI co-creation in heritage crafts, and practically, it provides guidance for designing AI-assisted systems that foster innovation while safeguarding intangible cultural heritage, applicable to jade carving and jewellery design. Future research could explore the application of these collaborative AI systems across other heritage crafts and cultural contexts, examine long-term impacts on skill transmission and apprenticeship, and investigate adaptive AI algorithms that dynamically respond to evolving designer preferences. Expanding the study to quantitative and mixed-method approaches could further validate the effectiveness of human–AI collaborative design in preserving cultural authenticity while fostering creative innovation.

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Conflict of interest

The authors confirm that there are no conflicts of interest with any parties in this research. The study was conducted independently, in alignment with its stated objectives, and the methods and results may differ from those reported in other studies.

REFERENCES

[1] Chen, Z., Li, X. (2025): Digital Integration of Traditional Craft Motifs in Mobile AR/VR Interactive Art Creation. – International Journal of Interactive Mobile Technologies 19(13): 148-161.
[2] Fan, Z., Wardi, R.H. (2025): Digital Design Tools'impact On Organizational Performance: A Model For Chinese Graphic Design Agencies. – Quantum Journal of Social Sciences and Humanities 6(1): 181-190.
[3] Gao, Y., Sa-Ngiamviboon, A. (2024): Dushan Jade Carving Art: Material Culture and Design Innovation in the Context of Inheriting China's Traditional Cultural Heritage. – Mahasarakham University 186p.
[4] Gao, Z., Li, Y., Wan, S. (2020): Exploring deep learning for view-based 3D model retrieval. – ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM) 16(1): 1-21.
[5] Gemological Institute of America (GIA) (2023): GIA to Update Gemological Reports for Colored Stones. – GIA 139p.
[6] Jiaxin, S. (2024): AI Integration for Advancing Jewelry Education Productivity. – Advances in Vocational and Technical Education 6(4): 56-61.
[7] Lee, Y.J., Kim, S. (2021): Feature-based fashion flat sketch design using automatic module alignment algorithm. – International Journal of Clothing Science and Technology 33(5): 824-837.

[8] Lyu, Y., Shi, M., Zhang, Y., Lin, R. (2024): From image to imagination: Exploring the impact of generative AI on cultural translation in jewelry design. – Sustainability 16(1): 20p.
[9] Ma, S. (2025): The Inheritance and Innovation of Ancient Chinese Jade Craftsmanship. – Frontiers in Art Research 7(1): 6p.
[10] Manfredi Latilla, V., Frattini, F., Messeni Petruzzelli, A., Berner, M. (2019): Knowledge management and knowledge transfer in arts and crafts organizations: evidence from an exploratory multiple case-study analysis. – Journal of Knowledge Management 23(7): 1335-1354.
[11] Rossato B., Tenuta L., Testa S., Cappellieri A. (2024): Beyond the Machine: Human-AI
[12] Collaboration in Jewelry Design. – In: 10th International Conference on Higher Education Advances (HEAd'24) 8p.
[13] Wu, W., Lin, B. (2025): Exploration of Conservation and Innovative Design for the Ming Dynasty Prince of Lu's Headwear from the Perspective of Artificial Intelligence. – In International Conference on Human-Computer Interaction, Cham: Springer Nature Switzerland 16p.
[14] Zhang, L., Wang, Z., Yang, R., Yi, Q. (2025): Digital presentation and interactive learning for intangible cultural heritage preservation using artificial intelligence. – IEEE Access 16p.
[15] Zhao, F., Zhang, C., Geng, B. (2024): Deep multimodal data fusion. – ACM Computing Surveys 56(9): 1-36.