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VIRTUAL EXPERIMENTAL MODEL AND DIGITAL PRESERVATION PATH OF TRADITIONAL WOODEN CARVINGS IN HUIZHOU TRADITIONAL DWELLINGS

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Abstract

In recent years, the protection of intangible cultural heritage (ICH) has garnered significant attention, emerging as a novel approach to cultural transmission. This article explores the integration of digital twins (DT) with the conservation of Huizhou traditional wooden carvings (Hu-TWC). Initially, the article outlines the principles of DT and then, using Hu-TWC as a case study, it examines the application of this technology in the preservation of cultural heritage buildings. The study analyzes the challenges encountered in digital preservation (DP) and the methodologies employed. DT facilitates the support necessary for ICH preservation and this paper provides a detailed analysis of methods to achieve DP within the digital twin framework, including digital reconstruction, geometric structuring, sensor data integration, photographic and imaging techniques and immersive experiences. The protection and inheritance of Hu-TWC are realized through virtual experiences and digital modalities. The findings highlight the potential and limitations of digital twin technology in the protection of cultural heritage, offering insights for future applications.

Keywords*: Hu-TWC; DT; Intangible cultural heritage conservation; Wooden carving*

Introduction

Recent implementations of rural revitalization strategies have prioritized the protection of intangible cultural heritage (ICH), with *Huizhou Three Sculptures*, recognized as a national-level ICH, exemplifying the rich traditional cultural values of local craftsmanship and history. Integrating such heritage, including *Huizhou Three Sculptures*, with digital technologies has become essential for effective ICH preservation. These technologies facilitate not only the virtual experience of ICH but also the development of robust digital preservation (DP) strategies. A primary challenge in preserving traditional crafts, such as wood carving, is their inherently intangible nature, which necessitates a thoughtful approach to integrating cultural significance, customs and traditional techniques into DP models [1].

Digital twins (DT) consist of physical assets, their digital representations and the data connections between them [2]. The advent of technologies such as Historical Building Information Modeling (H-BIM) and DT offers new avenues for creating virtual experiences and digital models [3]. These technologies, including virtual reality (VR), expand innovative possibilities for preserving Huizhou Traditional Architectural Woodcarvings (Hu-TWC). Enhanced governmental focus on ICH and the growing importance of DP have led to the development and implementation of pertinent laws and regulations, significantly advancing

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ICH conservation efforts. However, challenges persist. The extensive scope of public participation introduces variability in knowledge and social experiences, prompting concerns about the compatibility of DP methods with the intrinsic patterns of ICH development and the practicality of their technological implementation. These issues highlight the complexities of actualizing DP initiatives for ICH.

Fundamental Concepts of DT

DT is extensively utilized across multiple sectors such as manufacturing, energy, agriculture and ICH to tackle interdisciplinary challenges [4]. This technology enables the digital replication of real-world physical systems, which supports analysis [5], decision-making and the integration of complex systems. A digital twin merges with computational models with actual systems, as depicted in figure 1.

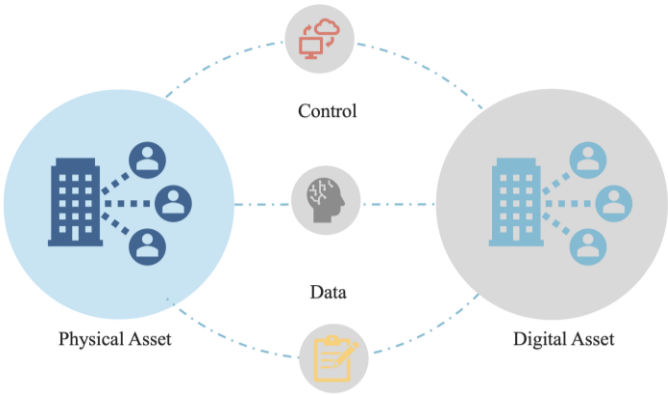

Fig. 1. Digital Twins and Physical World

Recent advancements in Internet of Things (IoT) technology, augmented by sensor devices and remote sensing techniques, facilitate real-time monitoring of the physical world [6], producing a substantial and continuous flow of data. Digital twin technology employs digital tools to construct virtual counterparts of real-world entities, which are instrumental for simulations, emulations and analyses. Consequently, a digital twin is poised to significantly impact the conservation of ICH.

The Advantage of DT in Heritage Conservation

This study examines the implementation of DT in conserving Hu-TWC and identifies key challenges and bottlenecks. It outlines essential criteria for digitizing intricate rural architectural decorations to adapt to contemporary needs. By establishing a hierarchical classification model for DT and creating three-dimensional data visualizations, the research develops a specialized digital twinning platform. This platform is designed to digitally preserve exemplary Ming and Qing dynasty wooden carvings, providing a blueprint for extending digital twin applications to other ICH projects.

The cultural, historical and economic significance of heritage buildings and their architectural ornaments are well recognized [7, 8]. Yet, these structures are vulnerable to degradation from human activity, natural events and environmental factors, underscoring the urgency of preserving their architectural details as illustrated in figure 2. At the heart of conservation efforts is the precise three-dimensional digitization and documentation of these decorations, generally achieved through detailed, reality-based 3D modeling. This technique not

only preserves the structural integrity of the architectural features but also facilitates their visualization and virtual exploration [9].

Fig. 2. Decorative wood carvings for traditional dwellings in Huizhou

Recent technological advancements in architectural conservation have spotlighted DT as particularly transformative, merging the physical and virtual realms effectively [10]. DT provides a comprehensive digital representation of architectural elements, playing a crucial role in the complete digitization of their lifecycle [11]. Moreover, DT aids in preempting detrimental conditions by enabling continuous data monitoring [12], thus offering innovative strategies for preserving heritage buildings and their intricate details.

Technological advancements have significantly reduced the costs associated with producing highly detailed, reality-based models [3]. There is a growing practical need to not only capture the geometric intricacies of Hu-TWC but also to manage and enhance virtual experiences for ICH projects. DP methods offer a sustainable solution for maintaining the integrity of ICH, ensuring its longevity. However, the preservation of traditional wooden architecture carvings often overlooks the application of classical architectural lifecycle concepts.

Moreover, digital twin technology extends its utility to the preservation and restoration of cultural relics. In practical applications, digitization allows for the detailed analysis and protective measures of ICH items. For instance, employing 3D scanning technology to digitize historic structures not only preserves but also aids in their restoration [13]. Digital twin technology innovates in the realm of ICH conservation by improving the preservation, inheritance and promotion of Hu-TWC.

ICH preservation traditionally relies on oral transmission and apprenticeship. However, regionalism and demographic aging pose threats to these cultural practices, risking their gradual disappearance. Hu-TWC faces similar challenges. Digital twin technology offers a solution by digitizing ICH artifacts and practices, allowing their preservation in virtual environments, which supports broader dissemination and facilitates research.

Public engagement in the digital dissemination of ICH critically depends on enhancing user experience [14]. Digital twin technology enables the representation of ICH in virtual spaces, catering to public experiential needs and bolstering their engagement and interest in cultural heritage. Digitally preserving ICH not only involves capturing its physical form but also addresses the broader, spiritual experiential needs of users. The DP strategy for wooden architectural carvings leverages information technology, originating from information service design. This approach integrates cultural, artistic and craft design innovations, aiming to significantly enhance user experience and engagement with the heritage.

Challenges Faced by DT in the Conservation of Traditional Wooden Carvings

DP of ICH marks an evolutionary step in heritage conservation. This approach is not initially designed to meet the specific preservation needs of ICH but rather evolves through conceptual understanding and practical application. Consequently, applying DT technology to

the conservation of traditional architectural woodcarvings presents unique challenges and complexities.

Difficulties in Data Acquisition and Processing

High-quality data acquisition on residential woodcarvings is fundamental for constructing accurate digital twin models. Digital twin technology requires comprehensive support, including detailed geometric and material property data. However, the disparate distribution of these carvings and their exposure to various environmental conditions often restrict data accessibility, posing significant challenges, particularly when carvings are concealed or difficult to access. Technical and financial challenges often emerge during data processing, where the precision and completeness of data collection are critical to ensuring the fidelity of the digital twin model. The intricate and textured nature of woodcarvings complicates the capture of detailed structural characteristics essential for the integrity and precision of the digital model.

Furthermore, the absence of standardized technical norms restricts the expansion and application of DT [10], leading to interoperability issues among different systems and limiting DT's development and deployment. Managing and storing large volumes of woodcarving data demands substantial computational resources and storage solutions, presenting significant obstacles for extensive woodcarving collections. Addressing these technical and infrastructural challenges is essential for the effective use of DT in conserving traditional architectural woodcarvings.

Cultural Background and Context

DT has made significant advancements in replicating the appearance and structure of residential woodcarvings, yet capturing their rich cultural and historical contexts remains challenging. Preservation efforts must extend beyond merely safeguarding physical forms to also encompass the deeper cultural significance and historical value these carvings represent. As embodiments of historical culture, residential woodcarvings serve as crucial repositories of folk traditions, religious beliefs and artistic styles, reflecting diverse aspects of human life and aesthetics. These carvings provide insights into family inheritance, social customs and cultural concepts, preserving the collective memory and cultural heritage of communities.

Moreover, as distinctive regional art forms, residential woodcarvings encapsulate local cultural and humanistic spirits, showcasing unique regional and ethnic characteristics through their form, theme and craftsmanship. Therefore, conserving residential woodcarvings involves not only maintaining their physical integrity but also protecting the diversity and richness of regional cultures, thereby fostering cultural transmission and exchange. Effective preservation and inheritance of these traditional art forms can only be achieved by merging digital technologies with conventional craftsmanship and enhancing research into their cultural and historical significance.

Influential Factors in the Practical Conservation of Hu-TWC

Traditional wooden carvings in residential buildings are inherently vulnerable to weathering, moisture and pest damage. These factors necessitate robust preservation strategies, including regular maintenance, moisture-proofing and anti-corrosion treatments. Additionally, the high market value of these carvings increases the risk of theft and illegal trade, further complicating their protection.

The diminishing number of artisans and a lack of successors threaten the continuity of woodcarving traditions. It is critical to support the transfer and development of woodcarving skills by enhancing educational programs, training initiatives and safeguarding traditional crafts. Digital twin technology also offers virtual learning opportunities, encouraging the younger generation to engage with and sustain these practices [15].

Regions lacking comprehensive protection policies face significant challenges in conserving traditional architectural woodcarvings. Establishing a robust protection system that includes legislative, policy and regulatory frameworks is imperative. Moreover, fostering

awareness and participation across various societal sectors is essential for the collective preservation of this valuable cultural heritage.

Technological innovation plays a pivotal role in enhancing woodcarving protection. Utilizing advanced technologies such as artificial intelligence and big data analytics can improve the effectiveness of DT and woodcarving conservation efforts [16]. Artificial intelligence (AI), for instance, enables intelligent monitoring and analysis of data within DT, swiftly identifying and responding to potential damage or threats. Such advancements not only bolster the efficacy of protection measures but also ensure the sustainable preservation and inheritance of woodcarving as a significant cultural heritage.

Data Collection and Implementation of DT

In the conservation of traditional woodcarvings within Huizhou dwellings, DT necessitates specific technical approaches for effective realization. The digital collection and modeling phases are pivotal in preserving and inheriting ICH [17], aiming to digitally capture cultural artifacts, sites, or skills using sophisticated techniques like laser scanning, photogrammetry and 3D modeling [18]. Laser scanning swiftly and accurately records geometric details of objects, providing a robust foundation for digitizing cultural heritage [19]. Photogrammetry complements this by capturing surface textures, colors and structural details, thereby enhancing the authenticity and richness of the digital models [20].

The digital collection and modeling process entails a comprehensive evaluation of technical, engineering and cultural factors. Selecting the right digital tools and ensuring data accuracy and integrity are crucial from a technical standpoint [21]. Different cultural artifacts may require varied digital techniques to fully capture their unique characteristics and significance. Culturally, it is vital to uphold the traditions and uniqueness of the intangible heritage, adhering to preservation standards and ensuring that digitization does not distort or damage the original artifacts.

The effectiveness of digital twinning relies on meticulous digital reconstruction and sensor data acquisition, as depicted in figure 3.

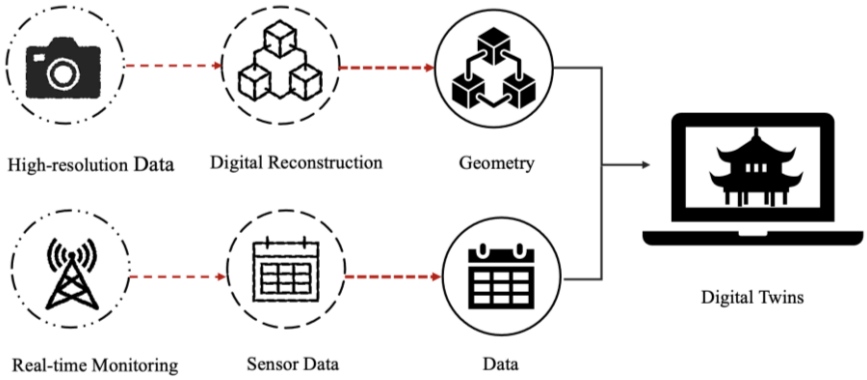

Fig. 3. Digital Twins

Digital reconstruction optimizes geometric structures, aiding in the detailed representation of object morphology and spatial layouts. Concurrently, sensor data acquisition plays a critical role by capturing a spectrum of physical characteristics such as temperature, humidity and pressure, providing insights closer to physical reality.

Synergistic processing of digital reconstruction and sensor data facilitates comprehensive simulation and representation of object or scene characteristics and behaviors, thereby enabling the effective construction of DT. Digital reconstruction lays the groundwork for spatial structuring, while sensor data enriches the understanding of physical properties and actions. Together, they form the foundation necessary for implementing digital twin technology.

For the acquisition of high-quality, detailed 3D models and comprehensive DT, specific technical measures are essential. Various technological conditions support different levels of fidelity in DT (Table 1). High-precision, finely detailed 3D models are crucial for accurate digital twin representation. The pathways for data collection and implementation crucial for the DP of Huizhou woodcarving art are detailed in figure 4.

Table 1. DP Strategies and Techniques for Huizhou Wood Carvings

Preservation Item	Technological Means	Equipment Required	Technical Demands	Investment Costs
Huizhou Woodcarving Literature	High-resolution Photography, Optical Character Recognition	Cameras, High-definition Cameras, Scanners (with OCR capabilities)	Moderate	Moderate to High
Huizhou Woodcarving Tools	3D Scanning, High-resolution Photography, 3D Modeling	3D Scanners, High-definition Cameras, 3D Modeling Software, High-performance Computers	High	Relatively High
Contemporary Creative Process of Huizhou Woodcarvings	High-resolution Photography	Cameras	Moderate	High
Huizhou Masters and Their Works	Laser Scanning, High-resolution Photography, 3D Modeling, Laser Scanning	High-resolution Photography, Laser Scanners, GPS, 3D Modeling Software, High-performance Computers,	High	Relatively High
Ming &Qing Dynasty Architectural Woodcarvings of Huizhou	Laser Scanning, High-resolution Photography, 3D Modeling Technology	High-definition Cameras, 3D Modeling Software, High-performance Computers, Laser Scanners, GPS	High	Relatively High

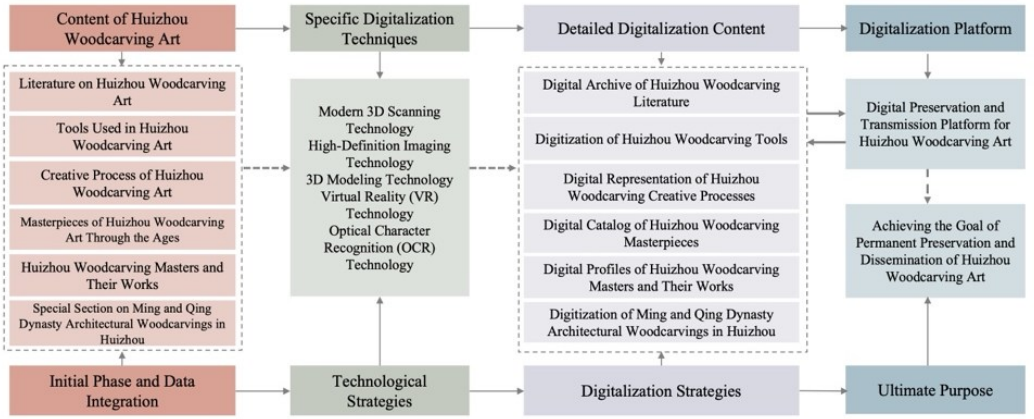

Fig. 4. Conceptual Framework and Data Collection Strategies for DP of Huizhou Woodcarving Art

Digital data collection and modeling constitute intricate and detailed tasks that necessitate interdisciplinary collaboration and specialized technical support. For instance, employing unmanned aerial vehicles (UAVs), such as the Autel Evo 2 Pro, allows for the capture of medium-accuracy models and extensive scanning of large areas. This technology facilitates rapid scanning and moderate computational processing, enabling swift reconstruction of predefined scenes.

Digitization of the ICH not only facilitates its conservation and heritage but also supports related research, exhibitions and educational activities, providing essential data and technical assurance. It also offers solutions in terms of compatibility of materials and preservation-restoration processes [22, 23], but also in terms of historical and humanistic assessments from the perspective of sustainable development in correlation with new urban

trends and ideas [24]. DT enhances the protection and restoration of cultural heritage by enabling the analysis of digital models for the early detection of damage and aging, which in turn informs the implementation of protective measures. Moreover, DTs are instrumental in the virtual restoration and reconstruction of artifacts, allowing them to be returned to their original state. Consequently, digital collection and modeling are indispensable in safeguarding ICH, meriting further research and broader application.

Conclusions

The integration of digital technology in preserving traditional woodcarving art within Huizhou dwellings exemplifies a modern approach to safeguarding ICH. This article explores the scientific and technical dimensions of digitizing and conserving these traditional arts, addressing the challenges encountered in both preservation and contemporary dissemination. DT technology enhances this process by offering advanced experiential and interactive capabilities, thus providing a superior method for cultural inheritance and broader dissemination.

DT enables the virtual recreation of real-world environments, crucial for tasks such as the digitization and quantitative analysis of spatial culture and the dynamic DP of traditional woodcarving art in Huizhou's ancestral homes. This approach also involves addressing complex technical issues related to data storage, model construction and data visualization. Moreover, leveraging big data and artificial intelligence in digital twinning is vital for overcoming existing barriers and ensuring the effective protection and dissemination of ICH.

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References

[1] S. Cursi, L. Martinelli, N. Paraciani, F. Calcerano, E. Gigliarelli, *Linking external knowledge to heritage BIM*, **Automation in Construction**, **141**, 2022, Article Number: 104444. DOI: 10.1016/j.autcon.2022.104444.

[2] J.M. Davila Delgado, L. Oyedele, *Digital twins for the built environment: Learning from conceptual and process models in manufacturing*, **Advanced Engineering Informatics**, **49**, 2021, Article Number: 101332. DOI: 10.1016/j.aei.2021.101332.

[3] M. Radanovic, K. Khoshelham, C. Fraser, *Geometric accuracy and semantic richness in heritage BIM: A review*, **Digital Applications in Archaeology and Cultural Heritage**, **19**, 2020, Article Number: e00166. DOI: 10.1016/j.daach.2020.e00166.

[4] C. Pylianidis, S. Osinga, I.N. Athanasiadis, *Introducing digital twins to agriculture*, **Computers and Electronics in Agriculture**, **184**, 2021, Article Number: 105942. DOI: 10.1016/j.compag.2020.105942.

[5] M. Batty, *Digital twins*, **Environment and Planning B: Urban Analytics and City Science**, **45**(5), 2018, pp. 817–820. DOI: 10.1177/2399808318796416.

[6] X. Cao, Y. Sun, Y. Wang, Y. Wang, X. Cheng, W. Zhang, *Wetland digital twin technology and its application*, **Bulletin of Surveying and Mapping**, **0**(2), 2024, pp. 32–38. DOI: 10.13474/j.cnki.11-2246.2024.0206.

[7] C. Tweed, M. Sutherland, *Built cultural heritage and sustainable urban development*, **Landscape and Urban Planning**, **83**(1), 2007, pp. 62–69. DOI: 10.1016/j.landurbplan.2007.05.008.

[8] E. Bowitz, K. Ibenholt, *Economic impacts of cultural heritage – research and perspectives*, **Journal of Cultural Heritage**, **10**(1), 2009, pp. 1–8. DOI: 10.1016/j.culher.2008.09.002.

[9] F. Remondino, *Heritage recording and 3D modeling with photogrammetry and 3D scanning*, **Remote Sensing**, **3**(6), 2011, pp. 1104-1138. DOI: 10.3390/rs3061104.
[10] F. Tao, J. Cheng, Q. Qi, M. Zhang, H. Zhang, F. Sui, *Digital twin-driven product design, manufacturing and service with big data*, **The International Journal of Advanced Manufacturing Technology**, **94**(9-12), 2018, pp. 3563–3576. DOI: 10.1007/s00170-017-0233-1.
[11] S. Haag, R. Anderl, *Digital twin – proof of concept*, **Manufacturing Letters**, **15**, 2018, pp. 64–66. DOI: 10.1016/j.mfglet.2018.02.006.
[12] X.W. Yang, *Application of Digital Twin Technology in the Monitoring of the Grand Canal World Cultural Heritage*, **China Ports**, **S2**, 2023, pp. 889–895.
[13] R. Aburamadan, C. Trillo, V.A. Cotella, E. Di Perna, C. Ncube, A. Moustaka, C. Udeaja, K.G. Awuah, *Developing a heritage BIM shared library for two case studies in Jordan's heritage: The House of Art in Amman and the Qaqish House in the World Heritage City of As-Salt*, **Heritage Science**, **10**(1), 2022, Article Number: 196. DOI: 10.1186/s40494-022-00836-w.
[14] H.J. Guo, D.H. Zhuang, *User Experience of Digital Transmission of Intangible Cultural Heritage*, **Hundred Schools in Arts**, **33**, 2017, pp. 239–240.
[15] J.T. Wei, L.M. Ren, *Research on the Transformation of Intangible Cultural Heritage Design under the View of Digital Twins*, **Packaging Engineering**, **44**(06), 2023, pp. 302–310. DOI: 10.19554 / j.cnki.1001-3563.2023.06.033.
[16] T.J. Wang, A.Q. Liang, Y. Luo, W. Zhang, B. Xie, *Analysis and application of inertial navigation big data based on digital twin technology*, **Cyber Security and Data Governance**, **42**, 2023, pp. 76–81.
[17] M. Shahzad, M.T. Shafiq, D. Douglas, M. Kassem, *Digital twins in built environments: An investigation of the characteristics, applications, and challenges*, **Buildings**, **12**(2), 2022, Article Number: 120. DOI: 10.3390/buildings12020120.
[18] X. Yang, *Application Research of Digital Technology in the Protection and Restoration of Historical Buildings*, **China Real Estate**, **21**, 2021, pp. 74–79.
[19] F. López, P. Lerones, J. Llamas, J. Gómez-García-Bermejo, E. Zalama, *A Review of Heritage Building Information Modeling (H-BIM)*, **Multimodal Technologies and Interaction**, **2**(2), 2018, Article Number: 21. DOI: 10.3390/mti2020021.
[20] L. Klein, N. Li, B. Becerik-Gerber, *Imaged-based verification of as-built documentation of operational buildings*, **Automation in Construction**, **21**, 2012, pp. 161–171. DOI: 10.1016/j.autcon.2011.05.023.
[21] M. Brovkova, V. Molodtsov, V. Bushuev, *Implementation specifics and application potential of digital twins of technological systems,* **The International Journal of Advanced Manufacturing Technology**, **117**(7-8), 2021, pp. 2279–2286. Special Issue SI. DOI: 10.1007/s00170-021-07141-z.
[22] I.C.A. Sandu, C. Luca, I. Sandu, *A study on the compatibility of the old, traditional artistical techniques with the new materials and methods used in the restauration, preservation processes. I. Theoretical aspects,* **Revista de Chimie, 51**(7), 2000, pp. 532-542.
[23] L. Nica, V. Vasilache, A. Drob, S. Pruteanu, I. Sandu, *Preservation and Restoration of an Old Wooden Icon with Complex Carved Ornaments, in a Conservation State of Precollapse*, **Applied Sciences-Basel, 12**(10), 2022, Article Number: 5073. DOI: 10.3390/App12105073.
[24] R. Blazy, M. Lysien, I.G. Sandu, J. Dudek, *Historical and Current Humanist IC Values in Contemporary Urban Trends and Ideas,* **International Journal of Conservation Science, 13**(4), 2022 pp. 1159-1172.

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