COMPARATIVE STUDY OF THE DIGITAL DESIGN STATUS OF CULTURAL HERITAGE ON CHINA'S GRAND CANAL AND EUROPE'S DANUBE RIVER

Jing Zhao, Yiming Ma, Yuhong Han*, Duoliya
Beijing University of Technology, China

Branislav Antonić
University of Belgrade, Serbia

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1. Introduction

1.1. Background and significance

The Grand Canal and the Danube are renowned waterways worldwide, symbolizing the cultural heritages of the East and the West, respectively. China's Grand Canal is the world's longest existing canal and the largest in scale, representing a significant cultural gene pool of the Chinese nation. The Danube, on the other hand, stands as Europe's second-longest river, distinguished as the river flowing through the most countries globally. It has cultivated a diverse culture in the Danube basin, such as the establishment of Lepenski Vir, the oldest permanent settlement far from the Mediterranean in Europe. As two waterways with profound histories, both harbor rich and varied cultural legacies, playing an indelible role in civilizational interactions and societal evolution. In the modern era, methods of cultural heritage preservation and utilization are undergoing profound changes alongside technological advancements. New preservation and inheritance methods characterized by digitization, informatization, and intelligence have garnered much attention. The integration of artificial intelligence and other novel technologies and methodologies has become a vital force and determinant in rejuvenating cultural heritage. Against this backdrop, this article aims to examine the current state of digital revitalization designs for cultural heritages along the ancient waterway basins in China and Europe, taking China's Grand Canal and Europe's Danube as examples. The Grand Canal and the Danube Basin not only possess unique cultural features but also confront their respective challenges, including urban development, threats from natural environments, and societal transformations. Therefore, by contrasting the digital revitalization status of cultural heritages between the two waterways, we can draw valuable lessons, enhancing the effectiveness of cultural heritage protection, hoping that these legacies continue to thrive and flourish in the future. This research will deepen people's understanding of cultural heritages in the Sino-European regions, promote international cultural exchanges, and offer opportunities for communities in both areas. Using digital design as a tool encourages cultural inheritance, the growth of the tourism sector, and societal engagement. It places cultural heritage preservation within a global context, providing a theoretical foundation for its sustainable development.

*Corresponding author: hyhlu163@126.com

1.2. Research content

This study begins with an investigation and analysis of the digital design definitions, scope, technical methods, and revitalization forms of the cultural heritage of both the Grand Canal and the Danube. It further delves into a detailed comparison of the status of digital design for cultural heritage in both waterway basins. In-depth analyses are carried out from perspectives such as sustainable design, digital scanning technology, experience design, and social management service design. Through this, the study seeks to uncover similarities and differences between the two waterways in terms of history, culture, economy, ecology, and more. This provides valuable insights and lessons for cultural heritage preservation and revitalization, optimizing the preservation efforts for both parties. Simultaneously, the study explores the potential and opportunities of both waterways in terms of the revitalization and protection of cultural heritage. It advocates for international cooperation between the two sides in aspects like technological synchronization and experience sharing, jointly promoting the rejuvenation of human cultural heritage in the digital age.

2. The current state of digitalization of the cultural heritage of the Grand Canal

2.1. Definition and scope

The Grand Canal is the longest ancient artificial waterway in the world, stretching from the north to the south of China, connecting numerous historically and culturally significant cities. Its cultural heritage is rich and unique.Every segment of the Grand Canal nurtures distinct cultural landscapes and legacies. The cultural heritage of the Grand Canal spans multiple eras, from the pre-Qin Dynasty to modern times, reflecting the shifts and development of Chinese history and culture, and is abundant with cultural relics. These not only demonstrate ancient Chinese hydraulic engineering techniques but also blend seamlessly with the economy, culture, and arts. Although the modern significance of the Grand Canal has diminished over time, many of its historical and cultural heritages continue to be preserved and researched.

2.1.1. Cultural heritage of the Grand Canal

The cultural heritage of the Grand Canal generally refers to cultural relics distributed along its course that inevitably relate to the canal's formation and development, intertwined with the unique production, lifestyle, and regional cultural ecology of the canal and its vicinity. Together, they form a colorful and historically rich cultural system. The cultural heritage of the Grand Canal encompasses a vast array of tangible and intangible assets [1]. Figure 1 shows the Beijing Tongzhou Canal Cultural Park and its representative cultural heritage. According to the 'Regulations on the Preservation of the Grand Canal Heritage,' tangible heritage includes ancient buildings, bridges, sluice gates, docks, artifacts, ancient texts, inscriptions, hydraulic structures, historical remains, and associated environmental landscapes along the waterway. Moreover, the Grand Canal region boasts 837 intangible cultural heritage items, integrating six cultural forms, spanning artifacts, landscapes, historical sites, traditional literature, performing arts, handicrafts, traditional festivals, and production and living experiences. This includes traditional crafts, music, dances, dramas, rituals, festivals, as well as lifestyles, customs, folktales, and legends from the regions along the waterway.

Figure 1. Grand Canal Park and Grand Canal Cultural Heritage. a) Beijing Tongzhou Canal Park; b) tangible heritage of the Grand Canal: Tongzhou Lighthouse; c) intangible heritage of the Grand Canal: shadow puppets. (Source: www.bjdyhsy.com, https://www.bjtzh.gov.cn, www.baike.so.com [Accessed on 5/552025])

2.1.2. Digital design of the Grand Canal cultural heritage

Digital design is the close integration of digital technology and design. Through the application of artificial intelligence, virtual reality, computer-aided design, etc., new methods of digital design are formed. This enables rapid generation, modification, and optimization of design proposals and digital product representation. By revolutionizing exhibition methods and integrating design thinking and processes, innovative design methods are formed, offering optimized digital experiences and bridging the gap between cultural heritage and its audience. Figure 2 shows the digital design of the Grand Canal intangible cultural heritage shadow puppetry. Users can control the shadow puppetry performance through motion capture technology. The evolution of digital technology has matured and refined the digital ecosystem. The digitalization process has significantly enhanced efforts to preserve and transmit cultural heritage, enabling more efficient documentation, storage, and dissemination of historical artifacts and knowledge [2]. Digital design of the Grand Canal's cultural heritage has made considerable progress. Many universities, research institutions, and cultural preservation departments have begun digitally scanning ancient buildings, bridges, inscriptions, and texts along the Grand Canal, establishing relevant databases. Meanwhile, several tech companies and research institutions are venturing into 3D scanning and modeling techniques to reconstruct some of the Grand Canal's cultural relics. Furthermore, some cit-

ies along the Grand Canal are using digital technology to showcase its cultural heritage, offering the public first-hand experiences of its historical and contemporary prosperity through museums and exhibition halls. Beyond offline experiences, several online platforms and mobile apps provide information, photos, videos, and educational resources on the Grand Canal's cultural heritage.

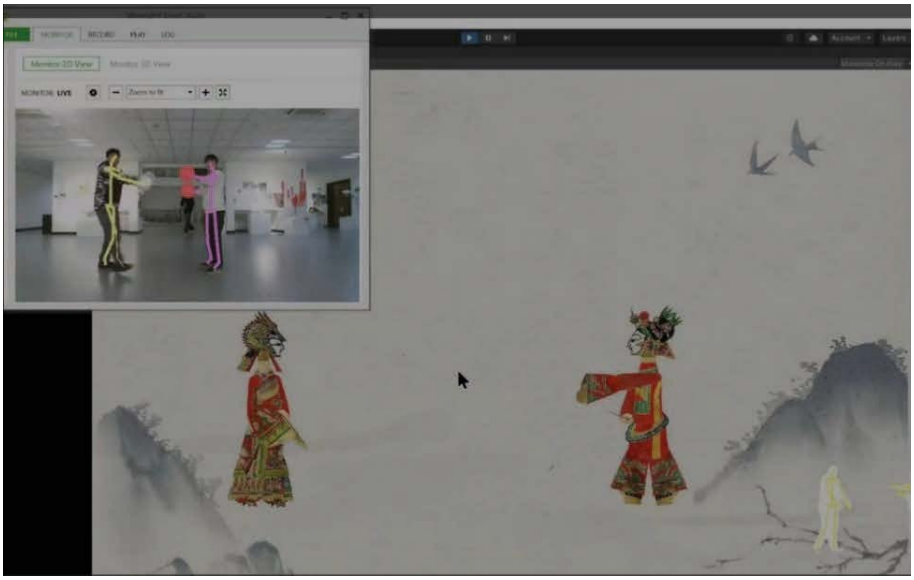

Figure 2. Digital design of shadow puppets.

2.2. Technological classification

In preserving, showcasing and promoting cultural heritage like the Grand Canal, advanced digital technologies have given rise to new content carriers, production methods, cultural experiences, and interactive scenarios, serving as a potent means for its transformation and propagation [3].

1) 3D Scanning and photogrammetry

This allows for the precise digital replication of historical sites and relics. Such documentation acts as a backup, ensuring a digital record of its original state, even if the physical site undergoes damage or degradation. For instance, the intangible cultural heritage of Tianjin, "Tian's Boat Model", was recreated based on the Lu River supervisor map, providing a vivid representation of the transport boat [4].

2) Virtual Reality (VR) and Augmented Reality (AR):

VR technology offers immersive experience, making individuals feel as though they are amidst the ancient Grand Canal, while AR overlays digital information onto the real world, superimposing information, narratives, and historical reconstructions onto the visitor's actual

site view. For instance, the "Millennium Long River — Cultural Landmarks on the Beijing-Hangzhou Grand Canal VR" project vividly presents the cultural landmarks of cities along the waterway using VR technology [5]. With the aid of digital tools like VR, the project comprehensively and systematically showcases the Grand Canal cultural heritage, meeting users' essential cultural and entertainment needs.

3) 3D modeling and rendering technologies

These are used for high-precision 3D data collection of architectures, artifacts, and historical sites. This enhances user experience and allows planners to visualize potential outcomes with digital design tools before undertaking physical restoration, minimizing wear on fragile sites. For example, the Grand Canal (Hangzhou section) Protection Center collaborated with Zhejiang University on an archaeological study and restoration display project for Gongchen Bridge. Utilizing comprehensive 3D digitization, they provided accurate 3D models and scientific data for archaeological research, educational development, and public display, aiming to rejuvenate this World Cultural Heritage and better showcase its historical and cultural value.

4) Digital audio processing and Geographic Information System (GIS) technologies

Digital audio processing allows for the digitization of ancient music, songs, oral tales, or background music and narration for exhibitions. GIS can be used to analyze and display geographical, historical, and cultural information about the Grand Canal and can also aid in planning and management. For instance, Shen Peishan and others utilized GIS to analyze land use changes along the Yangzhou section of the Grand Canal, proposing planning and management suggestions for its geographical environment [6].

5) Multimodal technologies

This encompasses various modes of information, including text, images, videos, audio, etc. Using multimodal technologies offers users a multi-sensory experience, evoking pleasure and emotional resonance, thus having a stronger communicative impact. In the South Wang Junction Museum of the Grand Canal in Wenshang County, Jining City, light, sound, and touch are integrated, immersing visitors in simulated scenarios [7].

In summary, the digital design of the Grand Canal cultural heritage necessitates the integrated application of various technologies. While these technologies can offer the public enhanced experiences, they also aid in the preservation and research of cultural heritages. Despite the digital efforts for the Grand Canal cultural heritage achieving certain results, challenges remain, such as insufficient funding, technological limitations, and striking a balance between preservation and display.

2.3. Revitalization methods

The Grand Canal is an important cultural heritage of China, boasting rich historical and cultural values. In recent years, in order to better protect and pass on this cultural heritage while meeting the needs of modern society and economic development, various methods to revitalize the Grand Canal cultural heritage have been explored.

1) Cultural tourism industry

Old warehouses and factories along the waterway have been transformed into cultural and creative parks, attracting artists and creative enterprises. The historic industrial architecture of the Grand Canal (Zhenjiang section) in the Zhongxi Jindu area, after a series of protective and transformation measures, successfully preserved historical legacies like the printing factory, the city's pesticide factory, and the filter factory. Today, the transformed Xijindu historic district has evolved into a multifunctional tourist destination, integrating venue displays, cultural exchanges, and leisurely sightseeing. This area has become a highlight of Zhenjiang city, adding significant charm [8].

2) Education and research

Research centers related to waterway culture have been established, conducting various research, training, and educational activities. For example, Gao Weiying and others, based on their research on 'The Heritage and Innovation of Grand Canal Culture', explored integrating and promoting Grand Canal culture in higher education. Integrating the diverse culture of the Grand Canal into higher education is crucial, aiding in both its preservation and innovation of the Grand Canal culture by utilizing advanced digital tools, as well as contributing to fostering educational reforms in universities [9].

3) Ecological restoration and green development

Ecological restoration of the environment along the waterway has been undertaken to create a green and ecological cultural belt. In Yuxiang Village in Hangzhou, utilizing the abundant local natural ecological and cultural resources, a Grand Canal Ecological Health Resort has been established. This resort combines traditional health culture with ecological culture. Relying on its profound cultural heritage, it aims to create a vacation area centered on ecological health, integrating health, tourism, and leisure [10].

4) Community participation

Communities and residents along the waterway are encouraged to participate in the protection and revitalization of waterway culture, establishing community museums, art studios, etc. The 'Three Treasures' of the Grand Canal culture nurtured in the Changzhou region (Changzhou combs, random needle embroidery, and green bamboo carving) are recognized as national intangible cultural heritages and are valuable treasures of local culture. In 2016, the Changzhou 'Three Treasures' community education project base was officially established and offers a variety of learning and display activities for local residents, achieving significant social impact [11].

3. Digital status of the Danube cultural heritage

3.1. Definition and scope

The Danube is the second-longest river in Europe, with a total length of about 2,850 kilometers. Originating in the Black Forest region of Germany, it eventually flows into the Black Sea, marking the borders of several countries along its course. The Danube plays a pivotal role in cultural and economic exchanges and holds an exceptionally significant place in European history, culture, and geography.The Danube basin spans multiple countries,

including Germany, Austria, Slovakia, Hungary, Croatia, Serbia, Bulgaria, Romania, and Ukraine. Key cities like Vienna, Budapest, and Belgrade represent the rich diversity of European culture. Cultural festivals, like the Busó festival in Mohács, Hungary, are cross-ethnic, multicultural events in regions along the Danube. The waterway is a vital natural resource for the countries it flows through and a spatial framework that carries a wealth of shared heritage.

3.1.1. Danube cultural heritage

UNESCO defines cultural heritage as "the legacy, in both tangible and intangible forms, that embodies natural, cultural, historical, and humanistic values. It is the legacy we inherit from the past, live within the present, and pass on to future generations" [12]. The cultural heritage of the Danube in this article refers to the vast geographic area from the river's source to its mouth, encompassing ancient architecture, historical landmarks, artistic works, literary legacies, lifestyles of residents, and traditions and customs related to the waterway. This heritage represents the convergence of numerous countries and cultures with a profound historical and cultural backdrop. The scope of this heritage is extensive, reflecting the diversity and cultural richness of the Danube region and its coastal settlements, and its significance in European culture and history. Each country or region the Danube flows through has its unique cultural heritage, creating a diversified cultural system.

3.1.2. Digital design of the Danube cultural heritage

In contemporary society, rapid advancements in digital technology offer unprecedented opportunities for the preservation, promotion, and reinvention of the Danube's cultural heritage. Merging digital design with the Danube's cultural heritage offers a fresh perspective, revitalizing this ancient land. The European 2020 strategic framework has cultivated a new vision for the Danube region. The backdrop of digital transformation provides the necessary semiotic conditions for executing this strategy [13]. Digital technology serves as an advanced mechanism for the preservation of monuments, artworks, and manuscripts from the Danube region. This not only offers a digital backup for tangible relics, minimizing losses from natural disasters or human actions but also facilitates an immersive experience for the public through virtual reality (VR) and augmented reality (AR) technologies.

3.2. Technology classification

The integration of digital technology with cultural heritage, especially in a historically rich area like the Danube, has brought about many advancements. These technologies aim to enhance understanding, preservation, accessibility, and appreciation of cultural heritage. The following classifications, set against the backdrop of the Danube region, delve into the digital technologies commonly used in the field of cultural heritage:

1) Virtual Reality (VR) and Augmented Reality (AR)

This not only offers an efficient way of protecting these assets but also enables the public to experience them in a novel manner, thereby heightening their conservation awareness. Taking Budapest as an example, its history can be traced back to ancient Roman times.Using VR technology, researchers and designers have crafted an interactive 3D

model that allows audiences to immerse themselves in the Budapest of ancient Roman times, gaining insights into the city's architecture, culture, and way of life. The Iron Age Danube project encompasses various themes and sites traceable to the Iron Age along the Danube. Researchers are exploring the feasibility of using completed VR and AR models in computer-generated site reconstructions, which are not only valuable tools for recreating historical environments but also highly applicable in promotional museums and exhibitions [14]. At significant historical sites in Vienna, like the Hofburg Palace, visitors can use AR technology via mobile phones or special glasses to view overlays of ancient and contemporary scenes, thus deepening their historical understanding.

2) Digital scanning

Museums and libraries along the Danube utilize high-precision digital scanning techniques to digitize their collection of artworks and ancient manuscripts. This not only provides a backup for these treasured relics but also facilitates online access for scholars and the public worldwide. Within the DANUrB+ INTERREG project, team members have introduced a new collection of city maps - a digital atlas of heritage towns along the Danube - which stands as one of the main deliverables of the project [15].

3) Internet of Things (IoT)

Certain historic structures along the Danube, such as churches and castles, have installed sensors to monitor vital parameters like humidity and temperature. This data is transmitted in real-time using IoT technology, aiding administrators in ensuring the safety and integrity of the cultural heritage.

4) Digital narratives

Leveraging digital technologies, such as animations, videos, and interactive websites, the history, traditions, and tales of the Danube are presented innovatively, drawing younger generations to delve deeper into the rich culture of the land. Within the Art Nouveau Movement Danube project, a digital repository for the Art Nouveau Movement was developed and executed, which contains information about various forms of movable, immovable, and intangible Art Nouveau heritage across the entire Danube region (3D objects, videos, texts, photos, descriptions). The metadata sources are repurposing and enrichment of European metadata and the new digitization and documentation of Art Nouveau heritage in the area [16].

3.3. Activation forms

The cultural heritage of the Danube, as a significant carrier of European history and culture, holds paramount importance in terms of revival and protection. To ensure that these invaluable cultural assets do not just remain confined to museums and history books, but become vibrant components of modern society, countries and regions along the Danube have adopted various activation forms.

1) Digital preservation and exhibition

Advanced technologies, such as 3D modeling, VR, and AR, are employed to digitally document and display the cultural heritage of the Danube basin. This not only provides an

efficient means of protecting these heritages but also lets the public experience them in an entirely fresh manner, hence boosting their conservation awareness. The goal of the ArchaeoGates project is to identify cultural sites submerged beneath the Danube, and to gather and process data to develop a database (Danube Submerged Heritage D.A.R.S.H.) with a possibility of expanding it to cover other waterway basins and/or lakes. To have a tangible grasp of the underwater cultural heritage found at the waterway bottom, 3D models and projections will be created. The reconstruction of these submerged sites will add immeasurable value to the region and the entire Danube area [17].

2) Eco-tourism and cultural experiences

By integrating the natural ecology of the Danube, eco-tourism is promoted, incorporating cultural heritage into the experience. For instance, hiking routes can be established along the waterway, allowing tourists to enjoy natural landscapes while learning about historical and cultural stories along the way. The DANUrB project, led by Kristianova K., has developed a set of green space assessment criteria. It's designed to select green spaces and incorporate them into theme-based location audio tours offered by mobile applications, discovering unused and concealed cultural and natural heritage resources, aiming to enhance sustainable tourism in Danube settlements [18].

3) Sustainable energy strategies

In cultural heritage preservation zones, there's a push for using renewable energy sources like solar and wind power, ensuring that site maintenance and management are environmentally friendly, while also catering to the basic needs of visitors.

4) Ecological restoration and cultural heritage

Cultural heritage can play a pivotal role in the formulation of cultural and tourism development policies in the downstream regions of the Danube. However, attention should be given to the manner of managing cultural values and the possibility of coordinating them with other forms of tourism [19]. For those cultural heritage areas damaged due to historical or natural reasons, ecological restoration, such as afforestation and wetland protection, can be undertaken. Integrating local cultural traditions with these ecological restoration projects and encouraging community participation is pivotal.

5) Smart cultural heritage management

Using Internet of Things (IoT) technology, sensors, AI, and other tools, the cultural heritage of the Danube basin is managed intelligently. This facilitates real-time monitoring of the heritage's condition, the prediction of potential risks, and offers visitors a more personalized and comfortable visiting experience.

4. Comparison

Based on the content above, we have carried out a deep analysis and comparison. It is evident that while both the Grand Canal and the Danube River are ancient waterways with deep historical roots and rich cultural heritage, they exhibit distinct characteristics, especially in their digital design and revitalization efforts.

1) Different emphasis on sustainable concepts

The regions along the Danube River possess a stronger ecological mindset, prioritizing sustainable development. China, on the other hand, is still in a preliminary phase in this regard, lacking formal attention and serious discussion. Regions of the Danube River basin emphasize sustainability. The European Union has introduced various policies and measures related to the ecology and environmental protection of the Danube, such as the "Birds Directive" and the "Habitats Directive," to ensure the waterway's ecological diversity and health. In terms of form, the digital design of Danube cultural heritage not only emphasizes heritage conservation but also focuses on the protection of ecological and natural assets (see Figure 3). For instance, they promote integrated tourism methods that incorporate cultural heritage into natural landscapes (Figure 3); they encourage tourists to engage closely with nature while learning about local history and culture; they actively promote the use of renewable energy sources, such as solar and wind power, to reduce carbon emissions; and implement ecological restoration measures. In contrast, the Grand Canal focuses more on cultural heritage itself, with less emphasis on sustainability [10]. This suggests a weaker alignment between ecological and cultural policies, and a lack of integration between digital revitalization design and ecological sustainability.

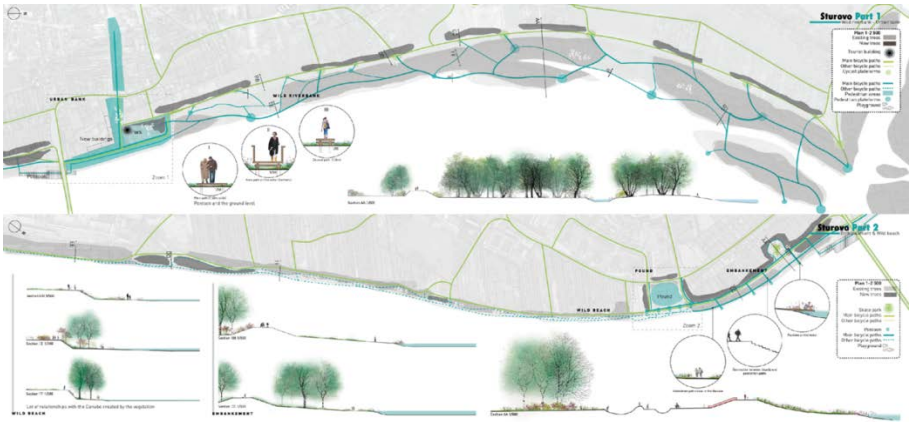

Figure 3. Green infrastructure and landscape design cases under the DANUrB+ project framework [18].

2) Technological applications

In China, the technology is relatively advanced, with a stronger focus on artificial intelligence and interactive technology. In contrast, the Danube region still lingers in the era of big data, heavily relying on database technologies and emphasizing data collection, storage, and information visualization (for example see Figure 4). During the digitalization process of the Grand Canal's cultural heritage, a variety of cutting-edge technologies were employed, including 3D scanning, virtual and augmented reality, multi-modal interactive technology, digital sound processing, and Geographic Information System (GIS) technology. China's lead in the digital technology sector may be attributed to significant investments in talent, research, and funding. For instance, projects like "Millennium Long River - Cultural Landmarks of the Beijing-Hangzhou Grand Canal in VR" effectively showcase landmarks and culture using VR technology [5]. Conversely, the Danube region appears to be lagging in

this domain, possibly due to limited resources and a weaker technological foundation. Furthermore, in China, there is a tendency to adopt interdisciplinary collaboration, integrating digital technology with cultural heritage, tourism, and ecological conservation. In contrast, the Danube region lacks the same level of interdisciplinary efforts, resulting in a more singular application of digital technologies. Lastly, in terms of cultural and educational backgrounds, China boasts more cultural and educational institutions, collaborating with higher education and research institutions to foster digital technology innovation. The Danube region similarly exhibits collaborative efforts but at a less extensive level, which has led to relative setbacks in technological innovation.

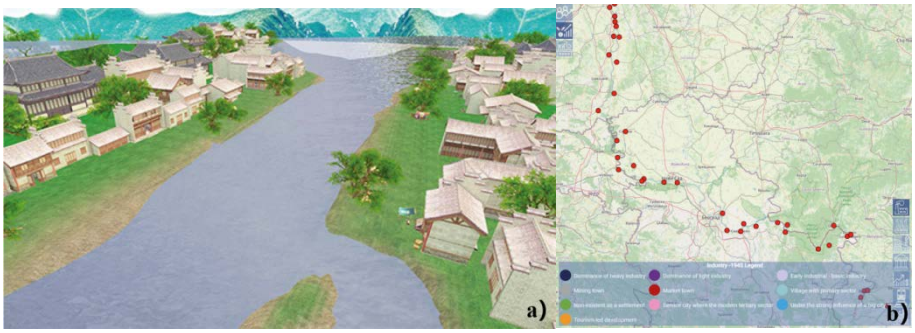

Figure 4. Comparison of the application of digital design technology for the cultural heritage of the Grand Canal and the Danube River. a) The Grand Canal: "Millennium River -Cultural Landmark VR on the Beijing-Hangzhou Grand Canal" project; b) Danube: Digital Atlas. (Source: www.hongsedibiao.com [Accessed on 5/552025]).

3) Experience design

The design philosophies of the East and West differ. Western design emphasizes practicality, functionality, and simplicity, while Eastern design places more value on emotion, aesthetics, and overall experience. Consequently, in practical application, the Grand Canal focuses more on the interactional experience between people and cultural heritage, offering users an immersive experience, while the Danube places greater emphasis on integration with specific practices (for example see Figure 5). The Grand Canal is not just a river in a geographical sense; it carries a wealth of historical memories, folk emotions, and cultural traditions. For Chinese users, any content related to the Grand Canal can evoke profound cultural sentiments and pride. Therefore, emphasizing interactive and immersive experiences can help users feel this connection more deeply, engaging them further. Conversely, the Danube's situation differs. It traverses the European continent, flowing through multiple countries and encompassing diverse cultural backgrounds.

Unlike the deep emotional connection associated with the Grand Canal, the Danube represents a sense of diversity, shared spirit, and unity, leading to a cohesive and systematic approach to management and planning. Thus, the digital design of Danube cultural heritage places more emphasis on practicality and application, catering to the varied needs of a multicultural background.

Differences between the two are also evident in terms of technology and resources. The digitization of the Danube's cultural heritage leans more towards utility, while the Grand Canal receives more support from the cultural, tourism, and educational sectors, directing its

design more towards an immersive experience. User expectations and cultural backgrounds also contribute to this distinction. European users anticipate tangible value from the Danube's cultural heritage, such as leveraging these resources to bring economic benefits or cultural exchanges to local communities. In contrast, Chinese users are more concerned about how digital technology can better enable them to perceive, understand, and experience their own culture and history.

The immersive experience of the digitalization of the Grand Canal's cultural heritage and the practical approach of the Danube in experience design reflect their respective cultural and historical backgrounds, resource allocation, and user expectations. Both have their unique value and significance, offering users invaluable cultural experiences.

Figure 5. Comparison of digital experience design for cultural heritage of the Grand Canal and Danube. a) The Grand Canal: Naked-eye 3D Gongchen Bridge performance at the opening ceremony of the Hangzhou Aslan Games; b) The Grand Canal: Information visualization display of DANUrB project platform.
(Image source website: www.news.cctv.com, www.platform.danurb.eu).

4) Social management service design

Both China's Grand Canal and Europe's Danube River treasure a wealth of cultural heritage. However, when considering their revitalization strategies and social management service design, they exhibit distinct differences. The revitalization of the Grand Canal's cultural heritage lacks a systematic social management service design; related research and social management are fragmented among governments, enterprises, and multiple research teams. In contrast, under the framework of the European Union, the Danube has a well-established project support system. With the coordination and cooperation of multiple countries, the Danube cultural heritage framework presents a systematic and organized overview, like the DANUrB+ initiative (see Figure 6). In terms of international collaboration, the digitization of the Danube's cultural heritage far surpasses China's Grand Canal. International scholars have reached a broad consensus on the Danube cultural heritage digitization project regarding collaboration motivations, management, and strategic directions, while China's research on the relationship between the Grand Canal's cultural heritage digitization and cross-border tourism cooperation is still in its infancy, indicating a certain gap compared to the international standard [20]. In 2010, the European Union introduced the "EU Strategy for the Danube Region (EUSDR)." This aims to enhance cooperation between the riparian countries, promote economic, social, and cultural development, while ensuring the environmental sustainability of the Danube. As a result, under the unified management of the EU, the Danube has established a complete framework with primary goals including the protection of the Danube's ecological environment, the promotion of regional economic development, and the strengthening of cooperation and exchanges between riparian countries.

Figure 6. DANUrB+ transnational program project.

DANUrB+ is a transnational program developed under the Interreg framework. It aims to reactivate the underutilized cultural heritage and resources in diminishing settlements around the Danube and border areas, creating new possibilities to make their towns and regions attractive again. The project is dedicated to researching urban development, cultural heritage, and sustainability issues in the Danube region and offers a method to promote the Danube's urban and cultural heritage. Major goals of the DANUrB+ project include studying the urban and cultural heritage of the Danube basin to promote sustainable urban development; undertaking interdisciplinary research to foster cooperation and exchange in the Danube region; and promoting the development and tourism of the Danube region by enhancing the visibility of its cities and cultural heritage. The EU provides unified resources, strategies, and directions for countries along the Danube. Under such a framework, transnational and interdisciplinary collaboration becomes possible, integrating resources and knowledge from all parties to strongly support the revitalization of cultural heritage. The EU framework encourages public participation, ensuring that the revitalization of cultural heritage meets the needs and expectations of the public. The project involves research institutions, universities, and partners from several countries, with projects like the "Monumental Early Iron Age Landscapes in the Danube Basin" receiving favorable support and guidance. This project examines monumental archaeological landscapes from the Early Iron Age, approximately from the 9th to the 4th centuries BC, developing a digital research database for hilltop settlements and large grave cemeteries, reviving archaeological parks and educational trails, and creating new museum

projects for tourists. In contrast, the Grand Canal's cultural heritage lacks unified management and policy support. Its overall structure is relatively loose, without systematic research or management projects under a unified framework. This disparity primarily stems from a lack of unified management and policy support. Cultural heritage management in the Grand Canal region is typically handled by different local governments, historical conservation institutions, and cultural organizations. Due to the lack of a unified management framework, collaboration and coordination among these agencies can be challenging, resulting in fragmented and disjointed management systems. Moreover, due to the decentralized nature of cultural heritage management, resources might be unevenly distributed. Some heritage sites might receive more resources and support, while others may lack necessary funding and manpower, potentially leading to imbalanced preservation. In general, due to the absence of an overall plan, research on the preservation and utilization of the Grand Canal's cultural heritage is typically scattered, lacking a unified vision and long-term strategy. This has impeded the overall preservation and orderly development of cultural heritage.

5. Common features and challenges

5.1. Common features

The Grand Canal and the Danube River are both vital waterways in their respective regions, playing pivotal roles in the advancement of economic and trade developments throughout history. They have connected major economic centers, flowing through significant cities, facilitating the exchange of goods and culture. Both waterways are essential freshwater sources, supplying drinking water and irrigation for agriculture. Their presence allows for a diverse ecosystem in their basins, playing a critical role in maintaining local biodiversity. As they meander through diverse regions, they bridge different cultures, ethnicities, and traditions.

1) Broad scope: extensive historical, geographical, and cultural reach

Historically, the Grand Canal dates back to the Spring and Autumn period, spanning over 2500 years. From its early beginnings during the Warring States to its significant expansions during the Sui Dynasty and further maintenance and growth in the Song, Yuan, Ming, and Qing dynasties, the Grand Canal has been a witness to China's prosperity and transformation, bearing the weight of its rich history. The Danube, in contrast, serves as a testament to European history, flowing through many of the continent's ancient civilizations and empires. From the Celtic and Dacian cultures to the Roman and Austro-Hungarian empires and the modern European nations, the Danube's history intertwines with the regions it passes through, spanning thousands of years. Spatially, the Grand Canal starts from Beijing and extends south to Hangzhou, bridging the gap between North and South China and connecting the Yellow, Huai, and Yangtze River basins. This extensive spatial reach has cultivated unique geographical, cultural, and economic zones along its path, promoting cultural exchange and amalgamation. The Danube, originating from Germany's Black Forest, flows through ten countries before draining into the Black Sea. Its vast trajectory from Central to Eastern Europe encapsulates a plethora of languages, religions, and cultures, establishing itself as a pivotal medium for multicultural exchanges in Europe. In summary, both the Grand Canal and the Danube span millennia, rich with culture and history. They flow through various countries or regions, acting as connectors of different cultures and economies. Their significance in bridging diverse areas and cultures is paramount, making them vital heritages of human civilization.

2) Tourism promoting the preservation and propagation of cultural heritage

Both the Grand Canal and the Danube serve as symbols of cultural history. With the rise of tourism, cities along the Grand Canal, such as Hangzhou and Suzhou, benefit from tourism revenues and investments, which in turn fund the preservation and restoration of their cultural heritage and ancient architecture. Tourism also amplifies the focus on waterway ecology. Furthermore, tourism revives traditional crafts, dances, theater, and music. Tourists' interest prompts local governments and businesses to invest in the cultural sector, rejuvenating endangered traditions. Similarly, countries along the Danube, like Austria and Hungary, profit from cruise liners and cultural festivals, which fuel the resurgence and transmission of local heritage. Catering tourists, the ten nations through which the Danube flows have strengthened their collaboration and formulated strategies for cultural preservation. Be it the Grand Canal of the East or the Danube of the West, tourism has been instrumental in championing the preservation of cultural heritage. It not only funds restoration and maintenance but also creates conducive conditions for the transmission and propagation of traditional culture. This ensures the flame of heritage continues to burn bright for both waterways in contemporary times.

3) Emphasis on the digital preservation of cultural heritage

For the Grand Canal and the Danube, rich in cultural heritage, digital preservation emerged as a response to potential risks to their treasures. Ancient structures, bridges, and cultural landmarks along the Grand Canal have undergone 3D scanning and modeling, offering visitors an immersive virtual experience and serving as a reference for heritage restoration. Similarly, the Danube's historic castles, churches, and other sites have also been digitized, enhancing public historical experiences and providing precision in restoration efforts. Comprehensive digital archives of the Grand Canal amalgamate varied resources, becoming pivotal for research and understanding. Digitized documents from the ten Danube countries facilitate research and dissemination. Modern innovations, such as virtual reality and augmented reality, have found applications in both waterways. Virtual tourism minimizes physical wear and tear on the sites, and digital museums offer at-home experiences of cultural heritage. Coupled with gaming and simulation, education on cultural heritage becomes interactive and vivid. Overall, with the advent of digital technology, both waterways' cultural heritage has been safeguarded more comprehensively and profoundly. Digitization ensures lasting, stable preservation while enhancing accessibility and shareability. This digital approach has allowed the cultural legacies of these waterways to be better inherited and propagated in the modern era, setting a benchmark for global heritage conservation.

4) Adoption of visualization techniques like 3D modeling

In the digital designs of cultural heritage for both the Grand Canal and the Danube, 3D modeling and data visualization emerged as two pivotal techniques. 3D modeling allows high-precision replication and digitization of the waterways and their adjoining cultural landmarks. These models provide an immersive virtual touring experience for the public and are invaluable for restoration, protection, and research. Additionally, they store detailed information for future researchers. Data visualization offers a more intuitive method to present the plethora of data and information related to these waterways. Whether mapping the course, transportation routes, or showcasing population, cultural, and economic data along their banks, various formats vividly capture and convey the essence. This not only enhances public engagement and experience but also aids decision-makers and researchers in rapid and accurate data extraction and analysis. Digital designs have fortified the preserva-

tion and promotion of the cultural heritage of the Grand Canal and the Danube, revitalizing these precious cultural resources in the digital age.

5.2. Common issues

1) Lack of a systematic, comprehensive platform for cultural heritage

Given the current state of digitalization of the Grand Canal and the Danube River cultural heritage, there is a conspicuous absence of a systematic and holistic platform dedicated to cultural heritage, such as a comprehensive digital cultural heritage display platform or a digital cultural heritage journey. In the case of the Grand Canal, although some digital design work has been done, these resources are scattered among government agencies, enterprises, and multiple research teams. There is a lack of unified guidance and collaboration framework, making it challenging for users to access comprehensive information on a single platform. Similarly, in the Danube River basin, while some digital efforts exist, there is no holistic digital platform to systematically present the cultural heritage along the Danube. This might lead to users struggling to obtain comprehensive information about the cultural heritage. The absence of such a systematic platform restricts the public's deep understanding and experience of these significant cultural heritages, also impacting the full utilization and dissemination of digital resources. Therefore, establishing a unified digital cultural heritage platform to present these rich cultural heritages in a comprehensive and integrated manner will aid in enhancing public cultural literacy and promoting cultural transmission and exchange.

2) While interaction technologies are mature, their integration with the waterways feels forced

From the digital perspective of the Grand Canal and the Danube River, "interaction technology has relatively matured, but its integration with the waterways feels somewhat rigid." In the current tech environment, we have many advanced interactive technologies, such as Augmented Reality (AR), Virtual Reality (VR), and the Internet of Things (IoT). These technologies have been widely used in many fields, bringing about revolutionary changes. However, when trying to integrate these interactive technologies with the historically rich and structurally complex Grand Canal and Danube River, several challenges arise. Firstly, the history and cultural background of these two waterways are very rich, and we need to ensure that the digitalization process does not lose or distort this invaluable information. Secondly, integrating these technologies without harming the waterways' natural environment and ecological balance is both a technical and strategic challenge. More importantly, we need to contemplate how to combine these technologies with the actual use and management of the waterways. For instance, how to ensure the safe passage of ships while providing an interactive tourist experience, or how to use IoT to monitor the water quality, flow rate, and other vital parameters in real-time. In summary, while interactive technologies are quite advanced, perfectly integrating them with the Grand Canal and Danube River still requires further innovation and effort.

3) Focus on basic information, limited immersive user experience, and mobile-suited information presentation

In the current technological environment, we have many advanced interactive technologies, such as Augmented Reality (AR), Virtual Reality (VR), and the Internet of Things (IoT).

These technologies have been widely adopted in various fields, bringing transformative changes. However, when attempting to integrate these interactive technologies with the historically significant and structurally intricate Grand Canal and Danube River, challenges emerge. Firstly, the history and cultural background of these waterways are incredibly rich, necessitating that the digitalization process does not compromise or distort these treasures. Secondly, merging these technologies without disrupting the waterways' natural environment and ecological balance poses both a technical and strategic challenge. Of utmost importance is considering how to tie these technologies into the real-world use and management of the waterways, such as ensuring safe navigation for vessels while providing an interactive experience for tourists, or using IoT for real-time monitoring of water quality, flow rates, and other crucial metrics. Overall, although interactive technologies are highly developed, seamlessly merging them with the Grand Canal and Danube River demands more innovation and diligence.

6. Conclusion and recommendations

The cultural heritages of the Grand Canal and the Danube River both manifest the rich and varied history and cultural legacies of their respective regions. The Grand Canal, as a masterpiece of ancient Chinese canal engineering, epitomizes China's illustrious history of waterway transportation and agricultural progression. Presently, research on the cultural heritage of the Grand Canal is primarily centered on archaeological excavations, historical document studies, and cultural continuities, harnessing digital tools like virtual and augmented reality to enhance user experience. Conversely, the Danube River, being one of Europe's principal waterways, holds a crucial role in interlinking the culture and history of multiple countries. Currently, there is a broad focus on the Danube's ecological heritage, especially in the realms of ecological conservation, historic architecture, and archaeological sites. Technologically, there is an inclination towards digital narratives combined with sustainable development, using digital scanning among other techniques for data storage and database creation.

The cultural treasures of these waterways represent invaluable wealth for their regions, offering a profound depth of historical and cultural significance. Although both waterway regions have ventured into the digitalization of their cultural heritage to some extent, there is yet to be a unified and comprehensive platform offering a complete and systematic digital heritage experience for the public. In terms of the Grand Canal's cultural heritage, despite its immense cultural importance, certain areas continue to grapple with conflicts between development and conservation. Additionally, striking a balance between modern development and the perpetuation of traditional culture poses challenges. For the Danube, environmental contamination, over-development, and the pressures of tourism pose threats to its ecology and cultural heritage. Concurrently, international collaboration and resource sharing remain significant challenges. To efficaciously digitize the heritages of both the Danube and the Grand Canal, several measures are proposed below:

- Encourage collaboration across all parties to jointly establish a comprehensive digital platform covering the cultural heritages of both waterway basins, offering functionalities like digital heritage tours.
- Achieve resource consolidation and standardization by laying down uniform digital standards and formats, ensuring the high quality and usability of digital assets.
- Enhance user experience design, incorporating principles of experiential design to deepen users' digital engagement, such as by introducing interactive elements and immersive experiences while safeguarding information accuracy and relevance.

- For the Danube, given its transnational character, strengthen international cooperation and resource sharing to jointly accelerate the digitalization of its cultural heritage. Elevate interaction and immersive experiences by fully integrating these technologies into digital designs, thereby enhancing user participation and the overall quality of the experience.
- Lastly, augment information visualization by refining its technology, ensuring a more vivid and lucid conveyance of the cultural heritage's essence and values.

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Biographical notes

Jing Zhao is an assistant professor at the college of art and design at Beijing University of Technology. She has an interdisciplinary background in information technology, systems engineering and design, and has experience in both the information technology industry and university design research. She received her doctorate from the Polytechnic University of Milan in 2016. Her research directions are cultural heritage, digital design, and emotional quantification.She has participated in or presided over several projects on the digitization of cultural heritage.

Yiming Ma is a master student in Industrial Design Engineering in Beijing University of Technology. Her research directions are intelligent interactive design, intangible cultural heritage digital design, and emotional interactive design. During her undergraduate and graduate studies, she worked on many traditional cultural digital designs and smart product designs.

Yuhong Han is a professor and doctoral supervisor at the college of art and design in Beijing University of Technology. She is currently the head of the Industrial Design Engineering major and director of the Institute of Sustainable Development and Low-Carbon Design of the School of Art and Design of Beijing University of Technology. She has presided over and participated in more than 20 projects and published more than 30 academic papers. Her research directions are the interactive landscape design of the Grand Canal, the design of public facilities in smart cities, and environmental design.

Duoliya is a master student in Design Studies in Beijing University of Technology. Her research directions are Intelligent interactive design, intangible cultural heritage digital design, and emotional interactive design. Her graduation project is Design of Traditional Mongolian Milk Tea Appliances Based on Experience Design.

Branislav Antonic' is a teaching assistant at the University of Belgrade, Faculty of Architecture, where he graduated (2008) and received his PhD status (2018). Prior to his assistant position, he worked as a scientific researcher fellow at the faculty (2012-17). His professional engagement is connected to the field of urbanism, with a focus on urban planning, the urban dimension of housing and the development of towns and small cities. As an external assistant of the Research-Business Centre of the Faculty, he has been a member of the working team of urban plans, spatial plans, urban studies, urban and architectural design projects. He has also participated in the organisation of several scientific and professional conferences, workshops and professional exhibitions and is a member of several international and national professional associations in the field of urbanism.

Summary

This paper conducts a comparative analysis of the digital design status of cultural heritage in two historically significant waterways: the Grand Canal in China and the Danube River in Central Europe. It investigates the current state of digitalization, the technological methods employed in digital design, and the forms of revitalization. Through a comprehensive comparative analysis, the study emphasizes key distinctions in sustainable concepts, technological applications, experience design, and social management service design. Furthermore, it identifies common features and shared challenges faced in both waterway regions. This research offers valuable insights into the digital preservation and activation of cultural heritage in these vital waterways, promoting cultural exchange between China and Europe and enhancing the global renewal of cultural heritage in ancient river basins.

Riassunto

Questo articolo conduce un'analisi comparativa dello stato della progettazione digitale del patrimonio culturale in due corsi d'acqua storicamente significativi: il Canal Grande in Cina e il Danubio nell'Europa centrale. Analizza lo stato attuale della digitalizzazione, i metodi tecnologici impiegati nella progettazione digitale e le forme di rivitalizzazione. Attraverso un'analisi comparativa completa, lo studio enfatizza le principali distinzioni nei concetti di sostenibilità, nelle applicazioni tecnologiche, nella progettazione dell'esperienza e nella progettazione dei servizi di gestione sociale. Inoltre,

identifica caratteristiche comuni e sfide condivise in entrambe le regioni fluviali. Questa ricerca offre preziosi spunti sulla conservazione e la riattivazione digitale del patrimonio culturale in questi importanti corsi d'acqua, promuovendo lo scambio culturale tra Cina ed Europa e rafforzando il rinnovamento globale del patrimonio culturale negli antichi bacini fluviali.