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Digital Conservation of Tang Dynasty Military Attire for Sustainable Museums and Tourism

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Abstract
This research aims to consider the methods of preserving Tang Dynasty-era military uniforms that are emblematic of culture and authority but are challenging to maintain because of their scarcity and degradation. This research proposes novel restorative and exhibition methods for these historical pieces using 3D modelling, Virtual Reality (VR), and Augmented Reality (AR) technologies. Such technological integration allows them to engage the public in an immersive manner, arousing appreciation and deep understanding of culture. Digital technologies confirm the efficient, sustainable development of culture and facilitate access to an audience worldwide.

Keywords: Tang Dynasty, digital preservation, 3D modelling, cultural heritage

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1.0 Introduction

Between 618 and 907 AD, China underwent rapid advancements in political, military, economic, and cultural domains. This period, known as the Tang Dynasty, is regarded as one of the golden eras in Chinese history. Military uniforms from this era held meaning beyond mere protective wear—they symbolized social class, political authority, and artistic expression. These uniforms featured ornate designs, vivid colours, and intricate patterns, reflecting both the richness of Tang culture and the technological sophistication of the time (Liu, 2013).

The historical significance of Tang military attire is documented through various artifacts such as murals, burial goods, poetry, and inscriptions (Hua, 2018; Wei, 2011). These materials provide a robust foundation for examining the Tang military system, craftsmanship, and cultural interconnections. However, the physical preservation of such historical relics presents substantial challenges. Most surviving fragments are rare, decayed, and incomplete, making full physical restoration difficult. Furthermore, issues like material degradation, outdated conservation techniques, and inadequate environmental controls hinder their long-term preservation and exhibition.

As a result, museums often rely on modern replicas to showcase Tang military attire. This reliance limits both public understanding and academic exploration of the garments' functional and symbolic roles. The scarcity and degradation of the original uniforms, combined with the challenges posed by traditional restoration techniques, underscore the urgent need for innovative digital preservation methods. These methods can bridge the gap between the deterioration of physical artifacts and their cultural and historical significance. Fortunately, advancements in digital technology now offer alternative means of conservation and interpretation. Three-dimensional (3D)

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modeling, CLO3D (a garment simulation software), virtual reality (VR), and augmented reality (AR) have emerged as transformative tools in restoring, researching, and exhibiting cultural heritage (Rand, 2025; Liu et al., 2022).

The aim of this study is to explore how digital preservation techniques—such as 3D modelling, CLO3D, VR, and AR—can be applied to Tang military uniforms for museum exhibits and cultural tourism. Two main objectives guide this research: first, to assess how 3D modelling and CLO3D can aid in the digital reconstruction and restoration of Tang military uniforms; second, to investigate how digital restoration methods—such as 3D modelling and CLO3D—can alter scholars' views on the artistic craftsmanship, functional design, and wearing techniques of Tang military attire, enriching their understanding of the garments' historical and cultural significance.

These objectives aim to explore the role of digital preservation techniques in both restoring historical artifacts and providing immersive, interactive experiences for the public. These digital tools enable the creation of vivid and interactive museum displays, making heritage more accessible and engaging. By integrating such technologies, institutions can foster public appreciation and understanding on a broader scale. This research contributes to heritage conservation discourse by highlighting digital methods as vital to preserving and understanding world history in contemporary society.

2.0 Literature Review

Examining Tang military uniforms provides the Tang Dynasty's remarkable military, cultural, and technological achievements. These uniforms were not simply pieces of armour but represented social class, military power, and artistic skill within the context of the Tang Dynasty. This review aims to elaborate on the complex details and significance of Tang military garments by studying their construct features, relevant domains, and preservation issues. Appreciating such factors allows us to understand how military power, governance, and identity intertwined during that era and how aesthetics and functionality were integrated into the state's rule.

2.1 Characteristics of Tang Military Uniforms

The Tang Dynasty (618-907 AD) is celebrated not only for its military and cultural dominance but also for its highly sophisticated military uniforms. These uniforms were more than just protective clothing—they symbolized sovereignty, military power, and the rich cultural heritage of the Tang Empire. According to *Tang Liudian*, historical texts describe 13 distinct varieties of armour, including Mingguang, Guangyao, Xilin, and others, each designed for specific ranks and roles within the military structure (Lu et al., 2014). These garments were crafted with elaborate materials, vibrant colours, and intricate patterns, reflecting the social hierarchy and aesthetic sophistication of the Tang Dynasty. The uniforms were designed not only for protection but also for mobility, allowing soldiers to perform effectively in battle while showcasing their rank and affiliation. This consideration of movement aligns with modern military uniform design, where functionality is prioritized alongside comfort (Kametani et al., 2023). The visual impact of these uniforms was further enhanced by the use of mythical motifs, such as dragons and tigers, which symbolized strength and courage, integrating traditional Chinese folklore and religion into the military attire (Wei, 2011).

Fig. 1: Structural Analysis of Tang Dynasty Warrior Figurine Armor

The design of the Tang military uniforms also served a symbolic function, indicating the wearer's rank and role within the empire. Similar to the later Qing Dynasty uniforms, which utilized insignia and colour-coded elements to denote military positions (Liu et al., 2024), the Tang military attire featured distinctive decorative insignia and patterns that reflected both the military and cultural status of the wearer. These elements were not just functional but also culturally significant, reflecting the broader artistic exchange that defined the Tang era (Xue & Liu, 2023). The cultural symbolism embedded in these uniforms served as a means of asserting the Tang Empire's authority, with richly adorned and intricately designed garments helping to project power and superiority on the battlefield. Moreover, the technological design of the Tang military uniforms, especially the use of lamellar armour, enabled soldiers to achieve a balance between protection and mobility, crucial for their effectiveness in various environmental conditions. This innovation in military attire is comparable to modern military uniforms, which are tested for climate adaptability and mobility (Seeley et al., 2024). The Tang uniforms embodied a fusion of functionality and symbolism, reinforcing both the military's operational effectiveness and the broader cultural identity of the empire. This duality in purpose—practical and symbolic—also highlights a broader trend in military attire across various dynasties, where artistic elements were intricately woven into functional designs to signify rank and reflect the empire's cultural values.

2.2 The Culture of Tang Military Uniforms

Beyond their practical use in battle, Tang military uniforms played a vital role in the cultural and ceremonial life of the Tang Dynasty. These uniforms were more than just functional attire; they were symbols of sovereignty, rank, and political status. Rooted in an elaborate system of rites and ceremonies inherited from the Western Zhou Dynasty, military attire in the Tang period was integral to state rituals and political expression (Ji et al., 1999). The role of the Tang military uniform was elevated to a ceremonial level, as seen in the grand deification ceremonies led by Emperor Xuanzong at Mount Tai, where soldiers adorned in elaborate uniforms not only participated in religious rituals but also displayed the empire's political strength. As Wang (2006) describes, these uniforms symbolized dual identities: on one hand, they marked soldiers as subjects of the Tang state, while on the other, they reinforced the personal identity of the warrior. These garments, adorned with mythical symbols like dragons and tigers, were more than just decorative—they were meant to represent strength, bravery, and the moral values of the Tang Empire, with the visual impact of the uniforms adding grandeur and solemnity to the state events, reinforcing the Tang Empire's authority.

The cultural significance of Tang military uniforms is closely tied to the technological and artistic advancements of the period. These uniforms were not only practical but also embedded in the broader cultural richness and artistic diversity of the Tang Dynasty (Wang et al., 2023). The military attire was intricately designed to signify rank and role within the military hierarchy, using specific insignia, colours, and patterns that indicated the wearer's position. The symbolism in these designs went beyond aesthetics, linking soldiers to their roles within the empire's political and cultural framework. The integration of AI-driven systems has recently expanded our understanding of these historical garments, allowing for the digital exploration of their design and cultural context. By using AI-driven interaction systems, researchers can create immersive experiences that bring Tang military uniforms to life, bridging the gap between historical knowledge and modern appreciation (Du, 2023). These tools not only enhance cultural engagement but also contribute to the preservation and education of Tang Dynasty heritage. Through digital tools and AI, the exploration of these uniforms has become more accessible to global audiences, facilitating the transmission of traditional knowledge and ensuring the preservation of China's intangible cultural heritage for future generations (Du, 2023). Moreover, comparing the Tang uniforms with later military attire, such as the Qing Dynasty uniforms, reveals a broader tradition in Chinese military dress, where both symbolism and functionality are intertwined, reflecting evolving trends in artistic expression and military culture (Park, 2022).

2.3 Digital Technologies in Cultural Heritage Preservation

The use of 3D and CLO3D technologies plays a significant role in the preservation of cultural heritage by enabling the digital documentation, replication, and innovative presentation of both tangible and intangible cultural assets. These technologies provide a non-invasive means to capture and recreate cultural artifacts, ensuring their longevity and accessibility for future generations. 3D scanning allows for the creation of detailed digital models of cultural heritage sites and objects, facilitating research, restoration, and virtual display, while also enabling the production of physical replicas through 3D printing, enhancing public engagement in educational and exhibition contexts (Kantaros, Ganetsos, & Petrescu, 2023). CLO3D is applied in the preservation of intangible cultural heritage, such as traditional clothing designs, by digitizing and innovating techniques like Wenzhou blue clamp-resist dyeing, making these practices more accessible and appealing to contemporary audiences (You, 2022). Additionally, digital auralisation and virtual reality applications offer an immersive way to experience cultural heritage sites, preserving them and enhancing visitor engagement (Schauer et al., 2023). Despite these advancements, challenges such as copyright issues and the need for specialized equipment and expertise remain barriers to widespread adoption, but the potential of these technologies to transform cultural heritage preservation remains significant, offering new ways to document, share, and experience cultural legacies (Oruc, 2022; Kantaros, Ganetsos, & Petrescu, 2023).

2.4 Issues Concerning Conservation of the Tang Military Uniforms

Preserving military uniforms from the Tang Dynasty is challenging for several reasons, the most significant being the lack of available relics and their deteriorated conditions. The Tang government's historical control over the military's procurement of equipment meant that the construction and storage of armour were strictly controlled, resulting in very few complete sets of armour available in modern times (Bai & Zhong, 2008). The situation is worsened by regional excavation trends showing disassembled armour in border regions like Liaoning and Tibet instead of central areas like Chang'an and Luoyang (Chinese Archaeological Society, 1984-2022).

Table 1. Excavation of Tang Dynasty Military Uniforms and Armor Relics from 1983 to 2023

Title	Cultural Relic Category	Province
Luobei County Tuanjie Brick Factory Mohe Tomb Site	Armor	Heilongjiang
Gaoshan Mountain Fortress Site, Fushun City	Iron Armor Plate	Liaoning
Gaogulian Mountain Fortress Site, Fushun	Armor Plate	Liaoning
Punu Valley Ancient Tombs, Naitong County	Iron Armor Plate	Tibet
Gaoshan City, Fushun City	Helmet, Chest Armor, Military Equipment	Liaoning
Yushan Goguryeo Tombs, Ji'an County	Iron Horse Gear, Gilded Horse Gear, Iron Armor Plate	Liaoning
Guge Kingdom Ruins, Zhada County	Iron Armor, Helmet	Tibet
Duoxiang Village Guge Dynasty Castle Ruins, Zhada County	Iron Armor Plate, Helmet Plate	Tibet
Mianzhichang Sui and Tang Martyrs' Tombs, Fengxiang County	Copper Armlet	Shaanxi
Hushan Goguryeo Site, Dandong	Iron Armor Plate, Ceramic Water Bottle for Soldiers	Liaoning
Hushan Goguryeo Bozhu Fortress Site, Kuandian	Iron Armor Plate	Liaoning
Kaoxiaotugou Tibetan Period Site, Dulan County	Lacquered Armor	Qinghai
Wunv Mountain Fortress Site	Iron Armor Tunic	Liaoning
Piyang·Dongga Site, Zhada County	Fragments of Armor Tunic	Tibet
North Gate Site of Longquanfu Outer City, Shangjing, Bohai Kingdom	Armor Plate	Heilongjiang
Suoyangcheng Ruins, Anxi County	Iron Armor Plate	Gansu
Qionglong Ancient City Ruins, Ga'er County	Iron Armor Plate	Tibet
Donggou Ancient Tombs and Lower Fortress Tomb Area, Ji'an City	Iron Armor Plate	Jilin
Sumi City Ruins, Huadian City	Iron Armor Plate	Jilin
Liu Dynasty Goguryeo Mountain Fortress, Ji'an City	Armor Plate	Jilin
Chengshan Neolithic to Sui-Tang Period Site, Xifeng County	Iron Armor Plate	Liaoning
Yanzhou Goguryeo Mountain Fortress, Liaoyang City	Armor Plate	Liaoning
Tang Dynasty Tomb, Chashan Village, Tianzhu County	Iron Armor	Gansu
Qingshiling Mountain Fortress, Gaizhou City	Iron Armor	Liaoning
Chengzi Mountain Fortress, Xifeng County, Tieling City	Armor Plate	Liaoning
Re Shui Tombs 2018 Xuewei No.1 Tomb, Dulan County, Qinghai	Iron Armor, Iron Armor Plate	Qinghai
Tang Dynasty Tuyuhun Royal Tombs, Wuwei, Gansu	Iron Armor	Gansu
Dongxing Site, Tumen City	Armor Plate	Jilin
Keyakekuduke Beacon Tower Site, Weili, Xinjiang	Armor, Military Documents	Xinjiang

(Source: Annual Report of Chinese Archaeology)

The challenges are outlined below:

1. Lack of Armor Artifacts: In the Annual Report of Chinese Archaeology, the author researched the Tang Dynasty armour relics unearthed in China between the years 1983 and 2023 and stated that the unearthed Tang armour remains are astonishingly nominal (Chen, 2021).

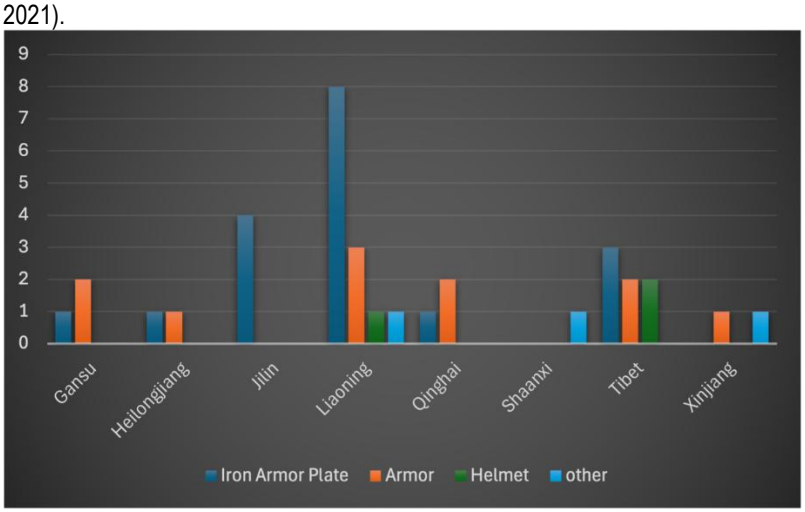

Fig 2: Distribution of Tang Dynasty Military Relics Excavated by Type and Region (1983-2022)

2. Phenomenon of Excavation by Region: From the statistics of the excavation sites, Tang Dynasty armour was primarily found in borders such as Liaoning, Qinghai, and Tibet. On the other hand, even though many objects have been excavated from the capital cities of Xi'an and Luoyang, there has been no record of any complete Tang Dynasty armour relics.

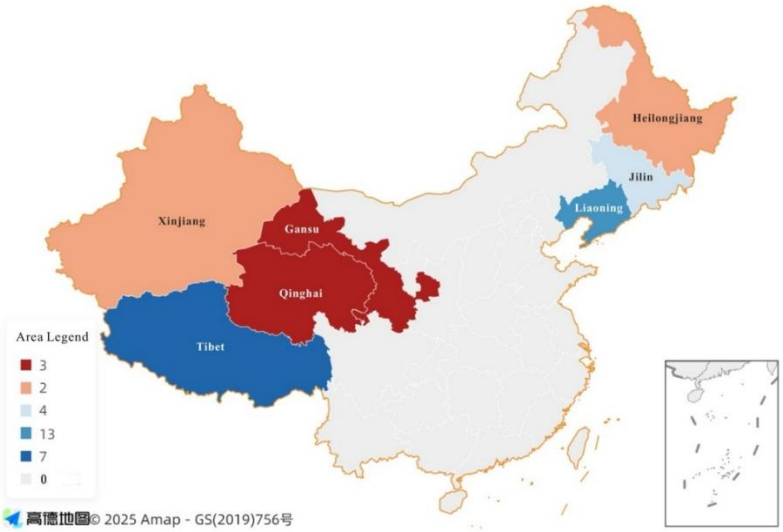

Fig. 3: Distribution Map of Tang Dynasty Military Relic Excavation Locations

3. Impacts of Negative Control: The Tang armoured and controlled the production and distribution of armour to such a severe extent that private ownership was not allowed, and even funerary practices, wherein armour could be used during the Tangs, were prohibited. This policy eventually resulted in the majority of armour not being passed down to the present day.
4. Material and Preservation Issues: Numerous textiles, leather, and iron were used to produce Tang military uniforms and armour. A considerable portion of armour is made of metal, which is much more resistant to corrosion; however, due to the Tang Dynasty tomb's conditions, which consisted of the armour being buried underground for extensive periods, underwent temperature and humidity shifts, acidic and alkaline salt exposure, and microbial erosion, preservation of the armour components becomes rather challenging. Most of the recently discovered armour manifests in incomplete clusters, dispersed fragments. Hence, considerable time is required to clean and document the site, photograph it, and transport the items using boxes and boards to cart them to the research laboratory (Bai, 2000).

Additionally, the compound degradation of the armour's materials—iron, leather, and textiles—for each doing so at different times makes these efforts even more challenging (Ma et al., 2020). The ferocious environments already roughly buried in Tang Dynasty tombs accelerate further destruction and make recovering artifacts much more difficult. As a result, items are even in incredibly restored states; they face problematic environmental sensitivity displays, and even well-restored items face problems and challenges. Such is the gap in traditional approaches that makes it clear why new approaches to the preservation of artifacts aimed towards preservation for research of Tang military uniforms and garments of the uniform should be adopted.

3.0 Methodology

This research on digitally conserving Tang Dynasty military garments adopts a multidisciplinary approach, combining historical, technological, archaeological, and museological methods. The goal is to design usable conservation methodologies for the artifacts and assess their potential for display in museums and cultural tourism. The study integrates modern digital technologies with historical research to explore innovative ways of preserving and presenting Tang military attire.

3.1 Historical and Archaeological Research Analysis

This research begins with a comprehensive review of textual sources, visual materials, and archaeological data relevant to Tang military attire. The aim is to capture the design, materials, and cultural significance of the garments through historical records (e.g., poetry, murals, inscriptions) and archaeological artifacts. These sources provide foundational information for the digital restoration process. Key archaeological data include Tang tomb murals, ceremonial objects, and inscriptions that depict military attire, helping identify the structure, design, and symbolism of these uniforms. For example, Tang tomb murals from Luoyang reveal armor designs, while burial goods and stone inscriptions offer details on the military's dress (Wei, 2011).

3.2 Digital Restoration Techniques

The study utilizes advanced digital technologies such as 3D modelling and CLO3D garment simulation for the digital restoration of Tang military uniforms. These methods enable virtual reconstruction by extracting measurements and visuals from available artifacts and documented history. The 3D modelling approach allows for the detailed digital replication of Tang military garments, preserving their intricate designs and materials. CLO3D is particularly advantageous for simulating the functionality, comfort, and fit of garments, addressing structural inadequacies that traditional methods cannot resolve. The choice of CLO3D is *justified* by its superior ability to accurately model garment construction and fabric behavior, which is crucial for faithfully restoring the historical attire (Liu et al., 2022).

3.3 Usage of Virtual and Augmented Reality Technologies

Virtual Reality (VR) and Augmented Reality (AR) are assessed for their potential in enhancing museum displays. These technologies allow for interactive and immersive experiences, enabling museum visitors to engage more deeply with the Tang military attire. The research investigates how VR and AR can translate historical environments and create dynamic, multi-sensory experiences that promote greater public appreciation of the uniforms. VR, for example, enables the recreation of the Tang military context, offering a 360-degree virtual tour of ancient military settings. AR, on the other hand, enhances physical exhibits by overlaying digital information, enabling visitors to explore the symbolism and construction of the garments interactively.

3.4 Analysis of Museums as Digital Preservation Case Studies

This study includes an analysis of museum case studies where digital technologies like VR and AR have been successfully integrated into cultural heritage preservation strategies. Museums such as the Palace Museum and the Louvre have used VR and AR to transform the exhibition of cultural artifacts, offering dynamic and educational experiences for visitors. These case studies provide insights into how Tang military uniforms could be similarly integrated into museum settings, contributing to interactive learning and enhanced engagement with cultural heritage.

3.5 Limitations of the Research

While the use of digital technologies in this study offers valuable insights, there are several limitations. The accuracy of digital reconstructions depends heavily on the availability of high-quality archaeological data and historical records, which can sometimes be incomplete or unclear. Additionally, the technology used in this research, such as VR and AR, requires specialized equipment and expertise, which may limit the accessibility and adoption of these methods in some settings. Furthermore, digital preservation tools like CLO3D may not fully replicate the texture and intricacies of physical artifacts, leading to potential discrepancies between the virtual and real-world garments. Lastly, the study's scope is restricted by the availability of Tang military artifacts, as not all historical pieces have been preserved or are accessible for analysis.

4.0 Findings

This research demonstrates the transformative role that digital technologies, particularly 3D modelling, CLO3D, and VR/AR, play in preserving and presenting Tang Dynasty military uniforms. These technologies have provided solutions to the challenges of artifact degradation, allowing for more accurate restoration, interactive displays, and global accessibility to cultural heritage.

4.1 Application of 3D Technology

The findings reveal that 3D modelling is crucial in the digital conservation of Tang military uniforms, especially for fragmented or incomplete artifacts. This technology has enabled the accurate reconstruction of garments by capturing their measurements and visual materials, such as murals and warrior figurines. By integrating 3D scanning with historical data, the study successfully bridges gaps in the physical restoration process, ensuring that the uniforms are reconstructed with historical fidelity.

4.2 Restoring Using CLO3D Technology

CLO3D has been identified as an essential tool for the digital restoration of Tang military attire. Unlike traditional restoration methods, CLO3D allows for virtual garment construction, which includes pattern making, sewing, and fitting tests. The software's ability to simulate fabric behavior and the wearability of military attire makes it a powerful tool for restoring garments while also addressing issues like structural inadequacies that are often overlooked by other 3D technologies. This digital approach allows for a more precise and detailed restoration, refining the historical accuracy of the uniforms.

4.3 Application of Virtual and Augmented Reality

The findings also emphasize the impact of VR and AR technologies in museum exhibitions. These technologies allow for interactive experiences, enabling visitors to explore the history and cultural significance of the Tang military uniforms in a more engaging way. For instance, VR provides a 360-degree experience of the Tang military context, allowing users to virtually experience the environment in which these garments were worn, while AR enhances physical exhibitions by overlaying historical data and visual elements. This results in a more immersive and informative museum visit.

4.4 The Effect on Conservation and Exhibition

Digital preservation techniques have significantly reduced costs and restoration time for Tang military uniforms while maintaining the integrity of their original features. These digital methods not only allow for the virtual display of severely damaged artifacts but also make them globally accessible, facilitating wider engagement. Through these digital platforms, museums can continue to display fragile artifacts, ensuring that they are preserved for future generations while fostering an international understanding of Tang Dynasty heritage.

5.0 Discussion

The findings of this study highlight the transformative potential of digital technologies in the preservation and exhibition of Tang military uniforms, directly addressing the challenges posed by the scarcity and degradation of physical artifacts. The use of 3D modelling and CLO3D has allowed for the digital reconstruction of uniforms, ensuring that missing or damaged elements are accurately restored. By

leveraging historical data from archaeological sources and textual records, these technologies have enabled a more authentic recreation of the uniforms' design, materials, and functionality.

CLO3D, in particular, stands out for its ability to simulate garment construction and fabric behavior, offering a level of precision that traditional methods cannot achieve (Liu et al., 2022). This technology provides invaluable insights into the historical craftsmanship of the Tang military attire, shedding light on tailoring techniques and wearability. The integration of VR and AR technologies into museum displays has further enhanced visitor engagement, offering a multi-sensory experience that brings the historical context of the uniforms to life. By using VR to recreate ancient military environments and AR to overlay digital information onto physical exhibits, these technologies have expanded the boundaries of traditional museum experiences, enabling a deeper connection between visitors and the artifacts.

Moreover, these digital methods contribute to sustainable preservation, reducing the reliance on fragile physical objects that are vulnerable to environmental damage. Digital replicas created through 3D modelling can be exhibited globally, allowing people who cannot physically visit museums to engage with Tang Dynasty culture. The use of digital preservation tools has also made it possible to restore and display culturally significant artifacts that would otherwise be too fragile to exhibit in their original form. This represents a paradigm shift in the way cultural heritage is preserved, studied, and presented to the public, offering a model that could be replicated across other fields of cultural heritage conservation.

In conclusion, the digital preservation techniques explored in this study not only provide a solution for the physical preservation of Tang military uniforms but also offer new avenues for cultural engagement, education, and global access. The combination of 3D modelling, CLO3D, VR, and AR represents a pioneering approach to preserving, showcasing, and understanding cultural heritage, ensuring the continuity of this invaluable part of Chinese history for future generations.

6.0 Conclusion

This research has demonstrated the effective use of digital technologies like 3D modelling, CLO3D, VR, and AR in preserving and restoring Tang Dynasty military uniforms, addressing significant challenges posed by the scarcity and deterioration of these artifacts. The study contributes to the field of digital heritage preservation by showcasing how these technologies enable accurate reconstructions and offer immersive experiences for public engagement, advancing both museum practices and cultural tourism. However, further improvements can be made by enhancing data accuracy through broader archaeological collaboration and integrating new digital tools to ensure more precise restorations. Future research could explore the application of AI-driven tools for more complex garment simulations and expanding the use of VR/AR to enhance educational outreach and global access to cultural heritage.

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Paper Contribution to Related Field of Study

This paper is relevant to the cultural heritage conservation domain by showcasing the effective use of digital technologies such as 3D modelling and VR/AR in tackling the preservation issues about severely lacking and deteriorating Tang Dynasty military uniforms. It underscores the ability of these technologies to increase public participation and academic interest by providing novel and engaging interactions beyond what is offered in the conventional approach. Digital technologies help in the precise reconstruction of historical objects and pave the way towards eco-friendly approaches to museum exhibitions and cultural tourism.

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