AI-Empowered Ancient Chinese Book Collection and Reading Culture: Material Forms, Spatial Narratives, and Cutting-Edge Applications

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Abstract

Abstract: This paper takes ancient Chinese book collection and reading culture as its research object, innovatively integrating perspectives of material culture, spatial narrative, and cutting-edge technology to explore the underlying cultural thoughts, social impacts, and contemporary values. The article employs cutting-edge technologies such as artificial intelligence, blockchain, quantum computing, biotechnology, and extended reality to conduct an in-depth analysis of the material forms, binding formats, and storage spaces of books, as well as individual reading histories, revealing the interactive relationship with ancient cultural inheritance. The research focuses on the digitization of ancient books, semantic analysis, construction of immersive experiences, and cultural relic protection under technology empowerment, as well as micro-narratives, ethical reflection, and cross-cultural comparison. This paper aims to provide new theoretical perspectives and practical pathways for the protection, inheritance, and innovation of cultural heritage.

Full Text

AI-Powered Ancient Chinese Book Collection and Reading Culture: Material Form, Spatial Narrative, and Frontier Applications

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Abstract

This study examines ancient Chinese book collection and reading culture through an innovative integration of material culture, spatial narrative, and cutting-edge technological perspectives to explore underlying cultural

ideologies, societal impacts, and contemporary value. Employing frontier technologies including artificial intelligence, blockchain, quantum computing, biotechnology, and extended reality, the paper conducts in-depth analysis of the physical forms, binding styles, and storage spaces of books, as well as individual reading histories, revealing their interactive relationships with ancient cultural transmission. The research emphasizes technology-enabled digitization of ancient texts, semantic analysis, immersive experience construction, artifact preservation, alongside micro-narrative analysis, ethical reflection, and cross-cultural comparison. This paper aims to provide new theoretical perspectives and practical pathways for the protection, transmission, and innovation of cultural heritage.

Keywords: Ancient China; Book Collection; Artificial Intelligence; Material Culture; Cultural Heritage

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Books serve as the continuous lifeblood of human civilization, bearing wisdom and cultural memory passed down through generations. In ancient China, book collection and reading were far more than mere knowledge transmission—they were vital engines driving societal and cultural development. From early bamboo slips and silk manuscripts to later paper books, from humble study rooms to magnificent library towers, the material forms, binding arts, and storage spaces of books all bore deep imprints of their eras' cultural marks, embodying rich cultural connotations and social significance. However, for a long time, research on ancient book collection culture has focused primarily on textual criticism and historical narration, inevitably constrained in data scale, analytical methods, and technical means. These limitations have made it difficult to fully reconstruct individual reading experiences, conduct cross-cultural and multi-dimensional comparative analyses, or deeply explore the tremendous potential of frontier technologies in cultural heritage protection. Facing the wave of the information age and opportunities from technological revolutions, how to harness the power of cutting-edge technology to inject new vitality into ancient book collection culture research is undoubtedly an important subject worthy of serious consideration. This study seeks to emphasize the unique and indispensable value of frontier technologies in ancient cultural research by introducing artificial intelligence (AI), blockchain, quantum computing, and other advanced technologies into the study of ancient Chinese book collection culture, hoping to break through traditional research limitations, expand the boundaries of cultural studies, and open new pathways for the protection and transmission of ancient culture.

The core objective of this research is to explore how frontier technologies can more deeply excavate the rich connotations and important values of ancient book collection culture, and further examine how these technologies can empower the protection, transmission, and innovation of cultural heritage to effectively solve current problems. Through meticulous analysis of ancient books' material forms, binding styles, storage spaces, and individual reading histories, this study

aims to explore their complex interactions with ancient cultural transmission, reveal the cultural ideologies and social meanings hidden beneath material surfaces, and provide new ideas and methods for the digitization, restoration, and protection of cultural heritage. The author sincerely hopes that through the power of technology, we can reconstruct the authentic appearance of ancient book collections as much as possible, re-examine ancients' cherishing of knowledge, pursuit of culture, and persistent exploration of the spiritual world, and enable these precious cultural heritages to re-enter public view in more vivid and attractive ways.

The core question this study attempts to answer is: How can frontier technologies empower the protection, transmission, and innovation of ancient book collection and reading culture? To more concretely explore this question, this paper further examines several aspects: How can AI assist in the digitization and semantic analysis of ancient books to improve research efficiency and quality? How can Extended Reality (XR) technology build immersive cultural experiences to promote cultural transmission and education? How can frontier technologies such as biotechnology and quantum computing be applied to artifact protection and provide understanding of artifact deterioration mechanisms from micro and macro perspectives? How can reflections on AI ethics be integrated into cultural heritage transmission and innovation to ensure technological applications align with common human interests? And how can we more comprehensively understand cultural diversity and complexity from perspectives of micro-narrative and cross-cultural comparison?

To better answer these questions, this paper constructs a research framework centered on "AI-Powered Ancient Chinese Book Collection and Reading Culture" with "Material Form, Spatial Narrative, and Frontier Applications" as its core, divided into several parts: First, the paper analyzes specific applications of AI in ancient book digitization and semantic analysis, focusing on AI's positive role in improving digitization efficiency and achieving semantic understanding. Second, it explores book format analysis and immersive experience construction under the integration of AI and XR technologies, emphasizing these technologies' tremendous potential in cultural transmission and education. Third, it investigates intelligent analysis of collection spaces based on spatial narrative and discusses related technologies' applications in artifact protection and intelligent management. Fourth, it examines applications of biotechnology and quantum computing in artifact protection and analyzes their important value in understanding artifact deterioration mechanisms from micro perspectives. Fifth, it explores the relationship between AI ethics and cultural heritage transmission to ensure technological applications always serve common human interests. Finally, through micro-narrative and cross-cultural comparison, it reveals unique characteristics of book collection culture under different cultural backgrounds to promote intercultural exchange and mutual learning. In the concluding section, the author summarizes main findings, proposes future research prospects, and reflects on ethical issues that may arise in frontier technology applications.

2 Literature Review

Research on ancient Chinese book collection and reading culture represents a continuous academic tradition, gathering wisdom and efforts of numerous scholars to form considerable academic achievements. In traditional research fields, scholars have conducted in-depth explorations mainly from the following aspects:

First, in studies of ancient book collection and reading culture, scholars have devoted substantial efforts to the evolution of book collections, changes in reading methods, and the key roles played by bibliophiles and academies in knowledge transmission. For example, early research often focused on textual criticism, conducting meticulous examinations of ancient bibliographic works such as *Qi Lue* and *Bie Lu*, and deeply investigating the lives and collection activities of famous bibliophiles like Liu Xiang and Fan Qin [2]. Additionally, some scholars have taken unique approaches from social history perspectives, examining reading cultures across different social strata and analyzing their profound impacts on societal development. These studies have undoubtedly laid a solid foundation for outlining the overall contours of ancient book collection culture. However, we must also recognize that these studies have paid relatively insufficient attention to material culture, rarely integrated with frontier technologies, employed relatively singular research methods, and struggled to handle large-scale data analysis.

Second, in material culture research, scholars have mainly discussed book materials, binding forms, and production techniques. For instance, scholars have conducted detailed analyses of characteristics and evolution of different material books including bamboo slips, wooden tablets, silk, and paper, and explored potential impacts of book materials on reading methods [3]. Moreover, scholars have conducted fascinating investigations into characteristics, evolution, and cultural connotations of different binding forms such as scroll binding, butterfly binding, and thread binding, striving to reveal cultural meanings hidden behind book binding forms [4]. However, these studies have mostly focused on books themselves, rarely examined their deeper significance from macro cultural and social perspectives, and even more rarely engaged in interdisciplinary dialogue with modern technology. Consequently, they have limitations in research methods and analytical depth, making it difficult to fully present deep connections between book forms and culture.

Third, in spatial narrative research, scholars have focused on architectural characteristics, functional layouts, and cultural symbolic meanings of ancient collection spaces such as studies, library towers, academies, and temples [5]. For example, some scholars have conducted detailed examinations of architectural features, collection systems, and cultural transmission functions of private library towers in Jiangnan during the Ming and Qing dynasties [6]. Other scholars have deeply explored unique attributes of academy collection institutions and their important roles in cultural transmission and academic exchange. These studies

have undoubtedly revealed the diversity and complexity of collection culture from spatial perspectives. Unfortunately, these studies have mostly remained within traditional humanities analysis paradigms, lacking powerful intervention from modern technology, making it difficult to achieve precise modeling and intelligent management of collection spaces.

In recent years, with the rapid development of frontier technologies, some scholars have keenly seized this historical opportunity and begun creatively applying artificial intelligence, blockchain, quantum computing, and other frontier technologies to cultural heritage protection and document research. For example, in cultural heritage protection, scholars have actively explored using remote sensing technology and 3D modeling for digital preservation of ancient architectural sites, and attempted to build intelligent artifact monitoring systems using IoT and AI technologies [7]. In document research, scholars have tried to use image recognition and natural language processing technologies for efficient digital processing and deep content analysis of vast ancient books [8]. However, we must clearly recognize that these studies have mostly remained at the exploratory level of single technologies or specific application scenarios, lacking systematic research that organically integrates frontier technologies with material forms and spatial narratives of book collection culture. Even fewer have focused on reconstructing individual reading histories from micro perspectives or conducting cross-cultural comparative research based on quantum computing.

In summary, existing research has undoubtedly provided valuable academic resources and diverse perspectives for deeply understanding ancient Chinese book collection culture. However, we must also acknowledge that traditional research still largely emphasizes historical narration and humanities analysis, with obvious deficiencies in research methods, data analysis, and technical means, and clear limitations in research on the integration of material culture and technology. Meanwhile, existing frontier technology research has mostly focused on single technology applications, lacking holistic and systematic consideration of book collection culture.

Therefore, this study hopes to fill these research gaps by innovatively integrating frontier technologies like AI with ancient Chinese book collection culture research. It deeply explores how material forms, spatial narratives, and frontier technologies can collectively empower the protection, transmission, and innovation of cultural heritage, and strives to inject new perspectives and methods into cultural studies, truly transforming technology into a powerful tool for understanding, transmitting, and promoting cultural innovation.

3.2 AI-Powered Ancient Book Digitization and Semantic Analysis

Ancient books are the continuous lifeblood of Chinese civilization, bearing vast amounts of historical, cultural, and scientific information. However, erosion by time, fragile preservation environments, and human-caused damage have left

large quantities of ancient books facing severe challenges of deterioration, dispersal, and ineffective utilization. How to efficiently complete the digitization of ancient books and deeply excavate their cultural treasures has become a core issue urgently needing resolution in the field of cultural heritage protection and transmission [9][10][11]. The sudden emergence of artificial intelligence (AI) technology not only provides new ideas and methods for solving this difficult problem but also creates unprecedented historical opportunities for deep integration of technology and cultural heritage protection, elevating ancient book digitization from mere mechanical technical operations to noble respect and careful transmission of cultural heritage.

AI-Driven Ancient Book Digitization: Traditional ancient book digitization processes mainly rely on manual image scanning, text entry, and repeated proofreading. This approach is not only time-consuming and labor-intensive with low efficiency and high costs but also prone to human error, clearly unable to meet the urgent needs of cultural heritage protection. The introduction of AI technology can not only greatly improve the efficiency and quality of ancient book digitization but, more importantly, can inject the soul of cultural protection into the digitization process through intelligent means, doing its utmost to restore the historical original appearance of ancient books and enabling their transmission in more vivid forms [12].

AI Image Recognition and OCR: AI image recognition technology, particularly advanced models based on deep learning such as Convolutional Neural Networks (CNN), demonstrates remarkable capabilities in image processing. It can not only quickly and accurately identify complex elements like text, images, and layouts in ancient book images and convert text into editable electronic text (i.e., Optical Character Recognition, OCR), but more admirably, it can also to some extent understand the cultural meanings contained within this visual information. For example, in text recognition, AI models can learn unique font styles and exquisite stroke characteristics from massive amounts of ancient book text to achieve automatic recognition of texts from different periods and different writers, and can even intelligently repair blurred or damaged portions of text. Taking the digitization of damaged text from Dunhuang manuscripts as an example, deep learning-based OCR models such as Google's Tesseract-OCR and Baidu's PaddleOCR can learn from large quantities of Dunhuang manuscript text images and cleverly employ Recurrent Neural Networks (RNN), Long Short-Term Memory networks (LSTM), and other models to automatically infer and complete damaged text, making it as close as possible to its original state. Additionally, AI can automatically detect flaws such as stains, damage, and watermarks in ancient book images and skillfully employ image processing algorithms, such as image restoration technology based on Generative Adversarial Networks (GAN), to perform fine repairs and optimization. This restoration process is far more than simple technical operation; it represents deep respect and careful restoration of the cultural value borne by ancient books, also laying a solid foundation for subsequent semantic analysis [13].

Blockchain Technology Empowerment: Copyright protection and authenticity verification of digitized ancient books are undoubtedly major challenges in the cultural heritage digitization process. Blockchain technology, with its unique advantages of decentralization and immutability, provides new solutions for these problems. Blockchain is essentially a distributed ledger technology that uses sophisticated cryptography to link transaction records into an immutable chain. Using blockchain technology, we can generate a unique hash value for each digitized ancient book as its digital identity symbol and record key information such as copyright ownership, author information, and circulation history, forming an unbreakable chain of evidence. This can both ensure the legality and integrity of cultural heritage and fully demonstrate respect for and protection of intellectual property rights, thereby encouraging more people to actively participate in the great cause of ancient book digitization and cultural transmission [14]. For example, when a digitized ancient book is successfully uploaded to a blockchain platform, all operations are permanently recorded on the blockchain, and no one can arbitrarily change this information, providing strong guarantees for the authenticity and copyright ownership of digitized ancient books. Additionally, blockchain technology supports the use of smart contracts that can automatically execute copyright licensing and transaction rules, making the dissemination process of ancient books more open and transparent and opening new avenues for the sharing and utilization of cultural heritage. For example, we can use blockchain technology to build a digital copyright trading platform for ancient books, enabling copyright owners to independently manage and trade digitized ancient books [15].

Quantum Computing Acceleration: When facing the massive undertaking of digitizing huge quantities of ancient books, traditional computing capabilities may prove inadequate. Quantum computing brings new hope with its unparalleled powerful parallel computing capabilities. Quantum computing cleverly utilizes fundamental principles of quantum mechanics, such as superposition and entanglement, to achieve parallel computing, thereby easily solving complex problems beyond the reach of traditional computers [16]. Quantum computing can significantly accelerate key processes such as ancient book image processing, data analysis, and pattern recognition, greatly shortening digitization processing time and significantly improving digitization efficiency. For example, using the famous quantum annealing algorithm in quantum computing, we can accelerate the noise reduction and restoration processes of ancient book images, greatly shortening the time required for originally extremely complex image processing, enabling massive quantities of ancient book images to be processed in extremely short time. Additionally, quantum computing shows great potential in pattern recognition, enabling faster and more accurate identification of complex elements such as text, images, and layouts in ancient books, comprehensively improving the precision and efficiency of ancient book digitization [17]. For instance, when digitizing millions of pages of ancient books, quantum computing can significantly reduce processing time, shortening tasks that originally took days to just a few hours, thereby greatly improving digitization efficiency

and making cultural heritage digitization and protection work more efficient, allowing more people the opportunity to personally appreciate these brilliant cultural treasures.

3.2 Semantic Analysis and Knowledge Mining Based on NLP

Digitization is only the starting point of ancient book research; how to deeply excavate the rich knowledge and unique cultural value contained in ancient books is the more core and important task. Natural Language Processing (NLP) technology demonstrates exceptional capabilities in understanding and analyzing text semantics, injecting new vitality into ancient book research. Simultaneously, the semantic analysis process is far more than cold technical operation; it represents profound interpretation and careful transmission of ancient cultural thought.

Natural Language Processing (NLP): NLP technologies such as Recurrent Neural Networks (RNN) and Transformer models can effectively help researchers deeply understand the rich connotations of ancient books through comprehensive analysis of grammatical structures, semantic relationships, contextual information, and profound historical and cultural backgrounds. They can not only automatically perform keyword extraction, topic mining, and sentiment analysis to help researchers quickly grasp core content and emotional tendencies of ancient books but also meticulously analyze rhetorical devices, language styles, and logical structures to achieve deeper understanding of cultural connotations and ideological expressions borne by ancient books, providing more efficient tools for cultural transmission [18]. For example, when analyzing an ancient poem, NLP technology can precisely analyze semantics and contexts of key words in the poem through word vector technologies (such as Word2Vec, GloVe, BERT, etc.), accurately identifying the poem's themes, emotional tendencies, and employed rhetorical devices, thereby helping researchers more deeply appreciate the poem's artistic conception. For instance, using sentiment analysis technology, we can accurately identify positive or negative emotions contained in poetry, thereby revealing the poet's state of mind and thoughts during creation. Additionally, we can use Named Entity Recognition (NER) technology to identify important people, places, and events mentioned in poetry, providing richer information for poetry interpretation.

Knowledge Graph Construction: Ancient books contain vast amounts of knowledge; however, this knowledge often exists in scattered, isolated forms that are difficult to organize and utilize systematically. Knowledge graphs are not just a method for cleverly organizing and effectively managing knowledge in graphical form but also a powerful tool for transmitting excellent traditional Chinese culture. Using AI technology, we can organically connect scattered knowledge points such as people, places, events, and ideas in ancient books to form a vast and precise knowledge network, achieving effective organization, intuitive visualization, and intelligent reasoning of knowledge, thereby greatly

facilitating researchers' in-depth knowledge mining. For example, we can construct a knowledge graph about ancient bibliophiles, cleverly connecting information such as bibliophiles' life experiences, architectural characteristics of their library towers, unique features of their collections, and their outstanding academic achievements to form a rich and three-dimensional knowledge network. This greatly facilitates researchers' deep understanding of bibliophiles' unique contributions to Chinese culture and promotes holistic understanding of ancient book collection culture. Such knowledge graphs can also be vividly presented using advanced visualization technology, enabling researchers to more intuitively perceive inherent connections between knowledge points [19].

Data Mining and Pattern Recognition: Through in-depth data mining and sophisticated pattern recognition of massive ancient book data, we can not only analyze macro phenomena such as evolution patterns of language styles and temporal changes of themes in ancient books to explore developmental trajectories of ancient social culture but, more excitingly, can also keenly capture hidden patterns and connections from vast cultural data. For example, we can cleverly employ association rule mining technology to deeply analyze word usage habits and grammatical characteristics of ancient books from different historical periods, providing important basis for judging creation dates and cultural backgrounds of ancient books. We can also use clustering analysis technology to accurately analyze frequently occurring themes and keywords in ancient books, thereby profoundly revealing mainstream thoughts and cultural changes in ancient society. This analysis is far more than interpretation of cold data; it represents profound perception of ancient cultural pulses and deep understanding of historical changes. For instance, through in-depth data analysis of the voluminous cultural masterpiece *Siku Quanshu*, we can clearly discern hot fields and key directions of Qing dynasty academic research.

4.1 AI-Driven Precision Identification and Intelligent Modeling of Book Forms

Book format is far more than cold physical shells; they are vivid carriers bearing heavy historical and cultural information. The binding forms, exquisite layout designs, and diverse illustrations of ancient books all vividly demonstrate unique aesthetic tastes, profound cultural concepts, and excellent technical levels of different historical periods. However, traditional book format research mainly relies on detailed textual criticism and direct observation of physical objects, a research method that inevitably has certain limitations and cannot comprehensively and deeply reveal rich cultural connotations hidden behind book formats. Creatively combining frontier artificial intelligence (AI) technology with highly promising Extended Reality (XR) technology can not only inject new perspectives and research methods into book format analysis but also greatly promote deep integration between technology and culture, thereby achieving deeper understanding and more vivid presentation of ancient books. This fusion is far more than simple superposition at the technical level; it is more profoundly

embodied in deep interpretation and innovative presentation of cultural connotations.

Traditional manual book classification and modeling methods are not only inefficient but also highly susceptible to interference from researchers' subjective factors, making it difficult to guarantee objectivity and accuracy of research results. The introduction of AI technology can achieve automatic precision identification and intelligent modeling of book forms, providing researchers with more accurate and reliable data support and more intuitive and vivid presentation methods. More importantly, the application of AI technology is far more than cold stacking of technical tools; it serves the noble goal of cultural research through deep learning and profound understanding of human cultural expression methods.

Cultural Interpretation Through Deep Learning Image Recognition: Deep learning technology, particularly high-performance Convolutional Neural Network (CNN) models, can not only automatically and accurately identify various morphological features of books such as precise page dimensions, exquisite binding methods (like antique scroll binding, elegant sutra folding, unique butterfly binding, and simple and practical thread binding) [FIGURE:1] and

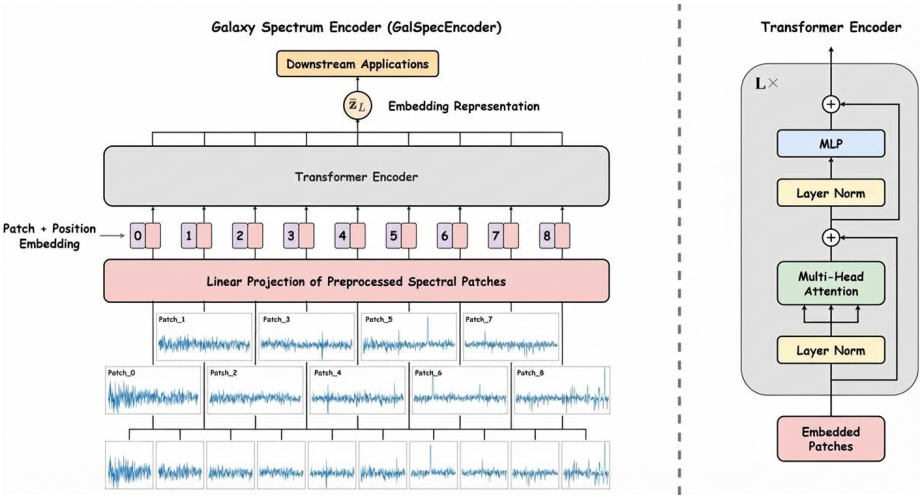

Figure 1: Figure 2

, distinctive cover designs, ingenious layout structures, and diverse illustrations but also deeply learn and understand rich cultural meanings contained behind these morphological features. For example, through meticulous analysis of binding style differences across different historical periods, AI can automatically and accurately identify unique characteristics of different periods through deep learning of massive data, such as the simple and elegant beauty of Song dynasty books, the exquisite and gorgeous style of Ming dynasty books, and the

complex and delicate charm of Qing dynasty books, thereby powerfully helping researchers deeply understand unique aesthetic tastes and profound cultural concepts of different eras. Thus, AI's image recognition process is far more than simple technical operation; it simultaneously interprets rich cultural information carried by images, which is undoubtedly a vivid embodiment of deep integration between technology and culture. For instance, through in-depth analysis of book layout designs across different historical periods, AI can accurately identify layout specifications, font choices, and illustration positions of different eras, thereby profoundly revealing unique aesthetic standards and cultural preferences of different times [20].

Three-Dimensional Modeling and Cultural Presentation Through Visualization: Based on AI image recognition technology and advanced 3D reconstruction technologies such as Structure from Motion (SfM) and Multi-View Stereo (MVS), constructing lifelike 3D models of ancient books is far more than technical innovation; it is a highly infectious medium for cultural transmission. These fine 3D models can clearly and intuitively present the three-dimensional structure of books, greatly facilitating researchers' deep understanding of exquisite production techniques and profound cultural connotations. For example, using 3D models, we can clearly display complex binding methods of thread-bound books such as ingenious page folding methods and sophisticated thread stitching techniques. We can also clearly display unique layout characteristics of butterfly-bound books such as perfect symmetry of pages and exquisite treatment of central seams, enabling users to not only appreciate the external beauty of books but also deeply understand the exquisite production techniques and profound cultural meanings behind them. Meanwhile, cleverly combining data visualization technology to present abstract data such as book dimensions, proportions, and materials in vivid and intuitive charts and graphs can more intuitively demonstrate cultural characteristics and unique artistic values contained in books. This is far more than simple data listing and presentation; it represents deep excavation and artistic presentation of cultural connotations. For instance, through meticulous analysis of dimensional changes of books across different periods, researchers can deeply reveal the uses and cultural status of books in different eras, providing new perspectives for cultural research.

4.2 XR Technology Building Immersive Cultural Experiences

Extended Reality (XR) technology, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), provides users with unprecedented new interactive experiences. Creatively combining XR technology with book format analysis can not only build captivating immersive cultural experiences that enable users to personally experience the unique charm of ancient books but also greatly promote the transmission and popularization of excellent traditional Chinese culture, truly achieving deep integration between technology and culture and enabling precious cultural heritages to enter public daily life in more vivid

and lively ways [21].

Cultural Edification Through VR/AR Immersive Experiences: Cleverly utilizing VR technology, we can construct lifelike virtual ancient collection spaces such as elegant ancient studies, solemn library towers, or ancient academies filled with scholarly atmosphere, completely immersing users in specific historical and cultural scenes to experience unique ancient reading atmospheres. This is far more than simple technical experience; it represents profound edification and spiritual baptism of excellent traditional Chinese culture. Users can wear VR devices to achieve a wonderful "time-space travel," browsing those virtual books bearing historical memory, truly experiencing the unique material beauty of ancient books, and engaging in rich and colorful interactions with virtual environments as if truly returning to that distant era filled with scholarly atmosphere. For example, users can enter a virtual Ming dynasty library tower to freely browse various editions of exquisite thread-bound books and engage in lively exchanges with virtual ancient figures to deeply understand book production techniques and rich cultural customs of that time. Cleverly utilizing AR technology can overlay lifelike virtual books onto the real world, enabling users to meticulously observe virtual book models in real environments, deeply understand book structures and characteristics, and thereby cleverly connect vivid real life with profound ancient culture. For instance, users can see a virtual thread-bound book on their real desk and use finger gestures to perform actions like page-turning and zooming, or overlay virtual ancient books onto their hands to truly experience their dimensions and weight, obtaining more intuitive and authentic cultural experiences. This experience is far more than simple technical demonstration; it is an innovative attempt to cleverly bring ancient culture and wisdom into modern life, making precious cultural heritages more accessible and deeply rooted in people's hearts.

Mixed Reality (MR) Interaction: Mixed Reality (MR) technology integrates lifelike virtual ancient books with rich and colorful real worlds to achieve unprecedented deep interaction between people and books, bringing users unforgettable unique cultural experiences [22]. Users can engage in rich and colorful interactions with virtual books through natural gestures, concise voice commands, and other interaction methods, such as freely turning pages, zooming images at will, easily extracting text information, and listening to pleasant reading voices. This not only enables users to acquire rich knowledge but also allows them to deeply appreciate profound cultural heritage and delicate emotions contained in ancient books. For example, when users flip through a virtual ancient book in the real world using MR technology, they can not only hear beautiful ancient book reading voices (thanks to advanced speech synthesis technology) but also clearly see detailed annotations on pages (thanks to powerful AI text recognition technology) and even engage in lively conversations with virtual ancient figures (thanks to increasingly mature AI dialogue technology), thereby widely disseminating excellent traditional Chinese culture through interactive experiences. Such interaction methods are far more than simple technology applications; they represent deep interpretation and innovative transmission

of ancient cultural connotations, making cultural learning more active, more interesting, and better able to stimulate people's strong interest in excellent traditional Chinese culture.

[FIGURE:5]

5 Intelligent Deep Analysis of Collection Spaces Based on Spatial Narrative

Collection spaces are far more than cold physical locations for books; they are important carriers bearing heavy cultural memory and conducting cultural transmission, silently telling rich historical memories, unique social customs, and precious cultural values. From humble studies to magnificent library towers, different types of collection spaces such as private studies, official library towers, academic collection pavilions, and sacred temple sutra repositories all profoundly reflect ancient society's degree of emphasis on knowledge, diverse cultural concepts, strict power structures, and unique aesthetic tastes.

Traditional research methods often rely on document descriptions and field investigations, approaches that inevitably have limitations and cannot comprehensively and deeply present the complexity and dynamics of collection spaces. Creatively combining frontier artificial intelligence (AI) technology, promising blockchain technology, and humanistic spatial narrative can achieve deeper and more comprehensive understanding of collection spaces and endow them with new cultural significance. This combination can not only significantly improve research efficiency at the technical level but also deeply excavate deeper meanings contained in spaces at the cultural level.

5.1 AI-Driven Precision Modeling and Intelligent Analysis of Collection Spaces

Traditional spatial research methods mainly rely on cumbersome field measurements, lengthy document descriptions, and time-consuming manual drawing, suffering from many problems such as low precision, inefficiency, difficulty in visualization, and inability to conduct large-scale spatial data analysis, which severely restricts in-depth spatial research. The introduction of AI technology can not only achieve more precise modeling and more intelligent analysis of collection spaces but also profoundly reveal rich cultural information and complex power relationships hidden behind spaces, making spatial research more profound and extensive.

Perfect Combination of GIS and Spatial Analysis: Geographic Information System (GIS) technology can precisely record geographical locations, complex terrain features, and important surrounding environments of ancient collection spaces and cleverly utilize AI algorithms for in-depth spatial analysis. For example, through GIS analysis of distribution patterns of collection spaces of different periods and types, we can clearly reveal changes in ancient cultural cen-

ters and clear paths of cultural transmission. For instance, through GIS analysis of academies in the Tang and Song dynasties, we can discover that academy locations often comprehensively considered geographical convenience and beautiful natural environments, vividly reflecting contemporary literati's high emphasis on cultural transmission and academic research. Through GIS analysis of private library towers in the Ming and Qing dynasties, we can discover close associations between library tower distribution and economic-cultural development levels, profoundly revealing intrinsic connections between collection culture and socio-economic development. Through in-depth analysis of library tower location characteristics, we can further understand ancient society's unique cultural interpretation of geographical environments. For example, ancient library tower locations often tended toward higher terrain, good ventilation, and areas away from humidity to ensure safe preservation of precious books, reflecting contemporary people's respect for and reverence of knowledge. We can even further analyze transportation conditions and population distribution around library towers to more comprehensively reveal profound relationships between collection spaces and complex social environments. Meanwhile, cleverly utilizing AI technology such as deep learning-based spatial clustering algorithms and spatial autocorrelation analysis, we can conduct deep mining of vast GIS data to discover potential patterns and intrinsic connections hidden behind spatial distributions, thereby more deeply understanding the important roles played by collection spaces in cultural transmission [23]. For example, AI can accurately predict potential risks such as floods and fires that a library tower might face based on rich historical data, providing scientific and effective decision-making support for cultural heritage protection work. This spatial analysis has long transcended simple presentation of physical space; it closely combines abstract geographical space with rich cultural meaning, profoundly revealing the cultural logic hidden behind space and making spatial research more powerfully explanatory [23].

Intelligent Integration of Environmental Simulation and Analysis: Environmental factors such as temperature, humidity, lighting, and ventilation in collection spaces directly and profoundly affect book preservation conditions. Cleverly utilizing AI technology, we can conduct fine simulation and in-depth analysis of environmental factors in collection spaces. For example, by using AI to simulate temperature changes, humidity variations, lighting intensity fluctuations, and air circulation conditions inside library towers across different seasons and climate conditions, combined with suitable environmental data required for ancient book preservation, we can effectively help researchers comprehensively understand complex impacts of environmental factors on book preservation, providing scientific and reliable basis for cultural heritage protection work. This simulation can not only help researchers understand subtle changes in ancient books under different environments but also accurately predict various potential damages precious artifacts might suffer under future environmental changes, enabling timely preventive measures to address problems before they occur. Meanwhile, cleverly utilizing AI technology, we can also deeply analyze

architectural designs of ancient library towers such as clever window layouts, scientific ventilation settings, and careful selection of wall materials, and finely simulate complex impacts of these designs on environmental factors, thereby profoundly revealing ancient craftsmen's excellent wisdom in book preservation and providing valuable reference for modern artifact protection [24]. For example, through AI analysis, we can clearly discover that ancient library tower designs fully considered the importance of ventilation and moisture prevention, undoubtedly reflecting contemporary people's high emphasis and extraordinary wisdom on book preservation. This environmental analysis is far more than objective analysis of environmental factors; it represents profound interpretation and innovative transmission of ancient craftsmen's excellent wisdom, also providing extremely valuable experience for our modern artifact protection work.

5.2 Blockchain Technology Injecting Powerful Momentum into Cultural Heritage Protection

Cultural heritage protection is undoubtedly a crucial component of cultural transmission. The introduction of blockchain technology not only provides new technical means for artifact traceability and management but also injects unprecedented powerful vitality into cultural heritage protection and transmission. This innovative technology application not only significantly improves efficiency of cultural heritage protection but also greatly enhances transparency and credibility of cultural heritage protection work [25][26].

Solid Guarantee for Artifact Traceability: Using blockchain technology, we can detailedly record historical information and circulation processes of library towers and precious cultural relics, forming an unbreakable and tamper-proof evidence chain to achieve effective artifact traceability. Through blockchain technology, we can completely record construction dates, careful designers, maintenance records across generations, and detailed circulation information of precious artifacts inside library towers (including book titles, editions, successive collectors, etc.), enabling each artifact to have a clear and unique "identity" and detailed "resume." This effectively prevents illegal artifact smuggling and trading, ensuring safety and integrity of cultural heritage. For example, if a precious ancient book is stolen or illegally traded, we can use blockchain technology to quickly and accurately trace its source and detailed circulation process, effectively helping relevant institutions recover artifacts in time and severely punish illegal activities. This artifact traceability process is far more than simple recording of artifact information; it represents full respect for and effective protection of historical and cultural values borne by artifacts, providing reliable and powerful guarantees for cultural heritage protection and transmission work.

Comprehensive Protection Through Intelligent Monitoring: Using advanced IoT technology and powerful AI algorithms, we can conduct real-time and comprehensive monitoring of collection spaces to timely discover and effectively solve various potential safety hazards. We can deploy various high-

precision sensors inside library towers to monitor important environmental factors such as temperature, humidity, lighting intensity, air quality, and pest conditions in real time and upload this data to secure and reliable cloud platforms in real time. Then, using AI algorithms, we can conduct in-depth analysis of massive monitoring data, accurately judge whether potential safety hazards such as fire, flood, or insect damage exist, and issue timely alerts to achieve intelligent and comprehensive protection of cultural heritage, truly preventing problems before they occur. For example, AI can accurately predict fire or flood risks that might occur inside library towers based on detailed data collected by sensors and issue timely alerts to notify relevant management personnel, enabling them to quickly take effective protective measures. This intelligent monitoring is far more than simple manifestation of advanced technology; it represents careful protection and comprehensive guardianship of precious cultural heritage, making cultural heritage protection work more proactive, more efficient, and more scientific.

Type	Representative	Functional Use	Architecture	Colal Symbolism
Private Study	Tuisiyuan Study	Reading, Taking Noties, Writing	Small, By Window, Heavily Decorated	Ind. Self-Clgivation, Literati Elegance
Academy Pavilion	Bailudong Academy	Education, Lecturing, Storing Books	Orderly Shelving, Central Hall	Desemination, Academic Inheritance
Official Library Teilding	Wenyuange	Official Classic Storage	High and Transunt, With Railings	Authority of Institutional Regulations
Temple Secripture Pavilion	Famensi Secripture Pavilion	Classic Copying, Offering	Vertical Structure, Sealed Preservation	Sanctity, Continuation of Religious Culture

Figure 2: Figure 7

5.3 The Interplay of Spatial Narrative and Cultural Meaning

Spatial narrative refers to effectively expressing specific thoughts and rich cultural values through clever construction and in-depth interpretation of particular spaces. In the field of collection culture research, collection spaces are far more than cold physical existences; they are profound embodiments of vivid social relationships and unique expressions of cultural meaning. For example, through in-depth research on elegant literati studies, we can deeply understand ancient literati's unique lifestyles, elegant aesthetic tastes, and persistent spiritual pursuits. Through detailed research on ancient library towers, we can comprehensively understand ancient society's high degree of emphasis on knowledge, complete cultural institutions, and strict hierarchical concepts. Through research on ancient academies, we can clearly understand ancient education systems, strong academic atmospheres, and unique cultural transmission models.

Integrating spatial narrative into our research is far more than objective analysis of space; it represents profound interpretation of cultural connotations. Through spatial narrative, we can more deeply understand the rich culture of ancient soci-

ety and more profoundly appreciate the excellent wisdom of ancient civilization, making our spatial research more humanistic and culturally profound.

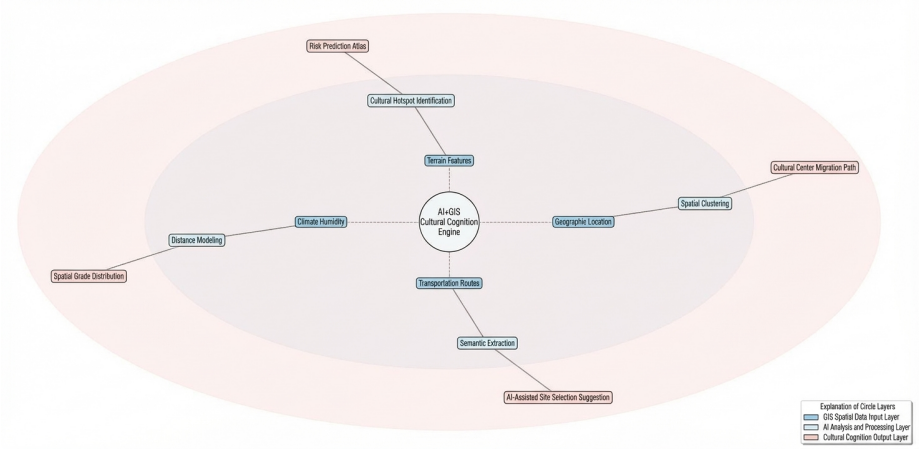

Figure 3: Figure 8

6 Biotechnology and Quantum Computing: Injecting New Life into Cultural Treasures

Paper artifacts such as ancient books bearing millennium-old wisdom, documents recording historical moments, and calligraphy and paintings full of artistic value are precious remains of human civilization, containing vast amounts of historical, cultural, and scientific information. However, due to the inherent fragility of paper artifacts, they are highly susceptible to biological erosion (such as mold, bacteria, and other microorganisms), chemical corrosion (such as damage from acidic substances), and external environmental factors (such as unstable temperature and humidity, excessive lighting, etc.), leading to irreversible deterioration and serious damage. Traditional artifact restoration methods such as mechanical repair and chemical cleaning often suffer from low efficiency, unsatisfactory results, and difficulty avoiding secondary damage to artifacts. Today, the innovative introduction of biotechnology and quantum computing not only provides unprecedented advanced technical means for artifact protection but, more importantly, can profoundly reveal the intrinsic nature of artifact deterioration from microscopic levels, providing new ideas and methods for scientific, efficient, and sustainable artifact restoration and protection, making artifact protection work more refined, intelligent, and humanized.

6.1 Biotechnology: A Green Engine for Paper Artifact Restoration

The vigorous rise of biotechnology has brought revolutionary changes to the field of artifact protection. Biotechnology can not only effectively solve many difficult problems that traditional restoration methods cannot overcome but also restore and protect precious artifacts in a more environmentally friendly and sustainable manner, achieving a major transformation of artifact protection concepts from traditional passive restoration to proactive preventive protection [27][28].

Biodegradation Detection: Biological degradation of ancient book paper is an important factor causing their decay. Microbial activity ruthlessly decomposes important components such as cellulose in paper, leading to significantly decreased paper strength and making it fragile and brittle. Traditional detection methods such as microscopic observation and chemical analysis are often time-consuming and labor-intensive and cannot precisely quantify degradation degrees. Today, cleverly utilizing biosensing technologies such as Enzyme-Linked Immunosorbent Assay (ELISA) and Polymerase Chain Reaction (PCR)-based biosensors, we can quickly and sensitively detect quantities and types of microorganisms in paper (such as mold, bacteria, etc.) and paper biodegradation products (such as cellulase, hemicellulase, etc.), thereby accurately assessing preservation conditions of ancient books. This advanced detection method can not only help artifact restorers timely discover deterioration signs of paper but, more importantly, can customize personalized protection plans for each artifact based on specific degradation degrees. For example, we can select the most suitable biological enzymes for restoration based on detected microorganism types and quantities, making artifact protection work more precise and scientific. For instance, through biosensors, we can precisely detect cellulase activity in paper to quantitatively analyze cellulose degradation degrees and accurately determine which parts need more focused restoration and protection.

Bioenzyme Restoration: Traditional restoration methods such as using corrosive chemical reagents (like strong acids or bases) or destructive mechanical methods (like scraping or grinding) often cause irreparable secondary damage to precious paper artifacts, such as accelerating paper aging processes or changing original paper colors. Today, cleverly utilizing bioenzyme technologies such as cellulase, amylase, and protease, we can conduct gentle and effective biological restoration of ancient book paper, thoroughly removing mold, stubborn stains, and harmful acidic substances from paper surfaces while maximizing avoidance of any form of secondary damage. Bioenzymes have high specificity, enabling them to precisely remove specific pollutants without causing any damage to paper structure itself. For example, using cellulase, we can effectively remove mold and cellulose degradation products from paper, restoring original paper strength and toughness and significantly reducing paper acidity. Using lipase, we can gently remove oil stains and fingerprints from paper, avoiding adverse effects of these stains on long-term paper preservation and restoring paper to

healthy condition. This biological restoration method is not only efficient and safe but also more environmentally friendly, fully conforming to sustainable development concepts and better demonstrating our deep respect and humanistic care for artifact protection.

Application of Biomaterials: Traditional restoration materials such as chemically synthesized materials often suffer from poor durability, easy aging, and environmental unfriendliness. Today, cleverly utilizing biomaterial technology, we can develop various new types of ancient book protection materials such as biodegradable restoration materials (like natural plant cellulose and abundant chitin) and protective coatings with insect-proof and mold-proof functions (like excellent chitosan and natural plant extracts). These advanced biomaterials not only have good restoration effects but also possess excellent biocompatibility and environmental friendliness, enabling better protection of precious artifacts while minimizing environmental pollution, better demonstrating our active pursuit of sustainable development concepts. For example, using natural biomaterials like plant cellulose and chitosan, we can produce paper restoration materials with good strength and breathability that can effectively repair damaged paper while having good biodegradability that causes no environmental pollution, fully demonstrating our high sense of environmental responsibility. Additionally, using natural plant extracts, we can produce protective coatings with excellent insect-proof and mold-proof effects, effectively extending the preservation lifespan of ancient books and significantly reducing excessive dependence on chemical materials.

Environmental Factors	Impact Level	Typical Risks	Recommended Threshold Range
Temperature	High	Paper become brittle, ink fades	16–22°C
Humidity	Very High	Mold, insect damage, deforiation	45–60% RH
Light	Medium	Handwrite fades, cover discoloration	<50lux (Cultural Relic Standard)
Pests	High	Pages perfurated, pevere damage	Insect sealing + AI monitoring
Ventilation	Important	Moisture-proof/temperation failure failure	Micro-venilation + direcnal airflow design

Figure 4: Figure 9

6.2 Quantum Computing: Injecting Powerful Momentum into Artifact Protection

Artifact protection work requires not only fine restoration means at microscopic levels but also deep understanding of artifact deterioration mechanisms from macro perspectives. The introduction of quantum computing provides us with powerful tools for understanding extremely complex systems, helping us reveal intrinsic laws of artifact corrosion and deterioration from deeper levels and providing more scientific basis for artifact protection work. Quantum computing

technology is mainly introduced through the following approaches:

Scientific Research Cooperation and Project Support: Research and application of quantum computing technology require substantial research investment and close interdisciplinary cooperation. To successfully introduce frontier quantum computing technology into artifact protection, cooperation among government agencies, research institutes, universities, and cultural heritage protection institutions is usually needed to jointly promote innovative applications of quantum computing technology in artifact protection through joint research projects and co-established research centers. For example, some countries have established specialized quantum information technology research centers that actively support wide applications of quantum computing technology in various fields, including protection of precious cultural heritage. These research cooperation projects usually bring together top experts in physics, chemistry, materials science, computer science, and artifact protection to jointly tackle various complex problems in artifact protection.

Technology Transfer and Application Transformation: Research results of quantum computing technology need effective technology transfer and application transformation to truly be applied in artifact protection practice. Usually, research institutions transform research results of quantum computing technology into professional software, hardware, or innovative services applicable to artifact protection fields, then provide these advanced technologies to artifact protection institutions and professional artifact restorers through technology licensing, transfer, and consulting. For example, some research institutions are actively developing quantum computing simulation software that can effectively help artifact restorers deeply analyze chemical compositions, microstructures, and complex deterioration mechanisms of artifacts and provide scientific and reliable decision-making support for artifact restoration work.

Personnel Training and Academic Exchange: To better apply frontier quantum computing technology, we need to actively cultivate interdisciplinary talents proficient in both quantum computing technology and deep artifact protection knowledge. Through establishing relevant professional courses, regularly holding high-level academic seminars, and actively conducting talent exchange activities, we can effectively promote wide application of quantum computing technology in artifact protection. For example, some famous universities are offering frontier courses in the interdisciplinary field of quantum computing and artifact protection, striving to cultivate compound talents with dual skills in quantum computing and artifact protection. Meanwhile, we also build bridges between quantum computing experts and artifact protection experts through various academic exchange activities, thereby vigorously promoting flourishing development of quantum computing technology in artifact protection.

Simulating Chemical Reactions: Paper corrosion is an extremely complex process involving various chemical reactions such as hydrolysis, oxidation, and acid-base reactions. Cleverly utilizing quantum computing technology, we can precisely simulate complex chemical reaction processes between important

macromolecular compounds like cellulose and lignin in paper and various environmental factors such as oxygen, water vapor, and acid-base substances, thereby profoundly revealing paper deterioration mechanisms and deeply understanding intrinsic laws and unique characteristics of paper corrosion under different environments. For example, through simulation analysis of complex reaction processes, we can accurately assess paper corrosion degrees and speeds under different environments, providing scientific and reliable basis for artifact protection work. Using advanced Density Functional Theory in quantum computing, we can precisely simulate complex hydrolysis processes of paper in acidic environments, accurately calculate reaction rates and final products, thereby finding effective methods to slow down acid corrosion and maximizing the lifespan of precious paper artifacts, providing more scientific and precise solutions for artifact protection work.

Analyzing Complex Data: Artifact protection work generates extremely complex data such as detailed environmental monitoring data (temperature, humidity, lighting, air quality, etc.), precise artifact composition data (cellulose, lignin content, etc.), and large amounts of artifact image data. Traditional computational methods often struggle to effectively process such huge and complex data. Today, cleverly utilizing quantum computing technology, we can quickly and efficiently process and analyze these complex artifact data to discover hidden patterns and intrinsic connections behind artifacts that are difficult to reveal through traditional methods. For example, using powerful Principal Component Analysis algorithms in quantum computing, we can quickly and accurately analyze compositions, microstructures, and physicochemical characteristics of different artifact materials to effectively identify different artifact types and origins and deeply analyze comprehensive impacts of various environmental factors on artifacts, thereby revealing artifact deterioration mechanisms and intrinsic laws and providing scientific and reliable basis for artifact protection work, making artifact protection more scientific and targeted. For example, quantum computing can also help researchers keenly analyze extremely subtle changes inside artifacts to discover various potential safety hazards in advance and timely propose corresponding protection suggestions, truly preventing problems before they occur.

The application of biotechnology and quantum computing is far more than simple improvement of technical means; it represents a profound transformation of artifact protection concepts. It elevates artifact protection work from passive restoration at macro levels to proactive understanding at micro levels, from passive rescue to active prevention and protection, making artifact protection work more refined and intelligent. Through biotechnology, we can more deeply understand microstructures, intrinsic characteristics, and complex interactions between artifact materials and surrounding environments, enabling more targeted restoration and protection while minimizing secondary damage to artifacts during restoration, making artifact restoration work more focused on sustainability and high respect for culture. Through quantum computing, we can more deeply understand artifact deterioration mechanisms, thereby pre-

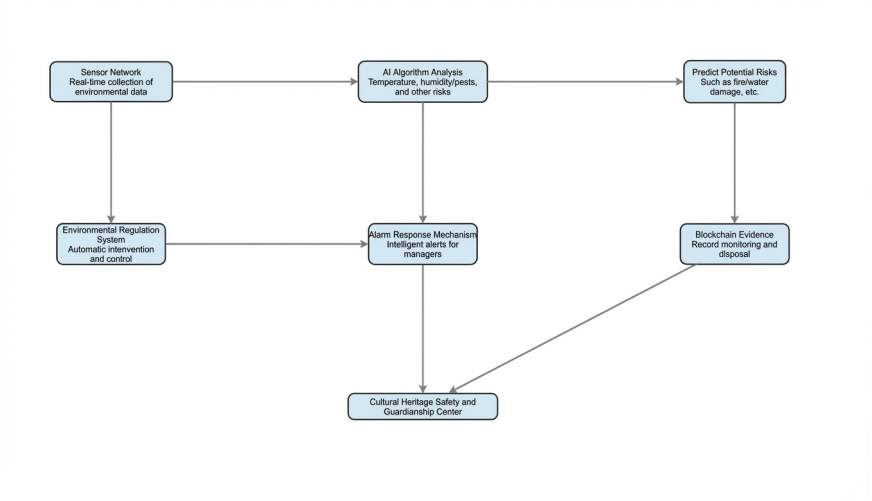

Figure 5: Figure 10

venting and effectively controlling artifact deterioration in advance, providing more scientific basis and more efficient solutions for artifact protection work. These advanced technologies are not only important means of artifact protection but also our deep respect and innovative transmission for ancient culture and ancestors' wisdom, as well as important manifestations of our responsibility to history and the future [29].

7 AI Ethics and Cultural Heritage Transmission

The application of Artificial Intelligence (AI) technology in the cultural heritage field is increasingly widespread, bringing unprecedented opportunities for cultural heritage protection, research, and transmission, such as more efficient digitization, more precise analysis, and more vivid presentation. However, while fully enjoying technological dividends, we must also face squarely the ethical challenges it may bring, ensuring technological applications conform to ethical principles of cultural heritage protection and ultimately serve the sustainable development of human culture, making technology an aid rather than a hindrance to cultural transmission. This section will discuss algorithm transparency, fairness, and AI-driven cultural transmission and communication, emphasizing humanistic care and responsibility behind technology applications [30][31].

7.1 Transparency and Fairness of AI Algorithms

The transparency and fairness of AI algorithms are ethical issues that cannot be ignored in cultural heritage research. Due to the complexity of AI algorithms, especially the "black box" effect of deep learning models, without necessary

supervision and constraints, they may lead to bias and discrimination, thereby damaging the authenticity and fairness of cultural heritage. Such bias and discrimination may not only manifest at technical levels but may also reflect social and cultural biases, leading to misinterpretation of cultural heritage.

Explainable AI: Complex AI models such as deep learning, like Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN), are often considered "black boxes" with decision-making processes that are difficult to understand, making it hard for researchers to trust AI analysis results and correct and improve them. To avoid algorithm black box effects, researchers should utilize Explainable AI (XAI) models as much as possible. XAI models can not only provide prediction results but also explain their decision-making basis, allowing researchers to understand AI reasoning processes and thereby enhancing trust in and control over AI systems. For example, in ancient book text recognition, XAI models can not only recognize text but also explain recognition reasons, such as which strokes and features lead to identification of certain characters, helping researchers judge AI recognition accuracy and manually correct misrecognized parts. For instance, using methods like LIME (Local Interpretable Model-agnostic Explanations) can explain AI model decision-making processes in ancient book text recognition, thereby improving researcher trust and control. This transparent approach not only helps correct AI algorithm defects and improve AI accuracy and reliability but also demonstrates pursuit of rigorous and transparent research processes, representing respect for and responsibility toward cultural heritage.

Data Bias Analysis: AI models rely on large amounts of data for training, and training data quality directly affects model performance and fairness. If training data itself contains bias—for example, certain types of books or certain cultural groups have more related data while others have less—then trained models will also contain bias, leading to erroneous conclusions and making research results selective and biased. Therefore, using AI technology for bias analysis of datasets is a very important part of cultural heritage research. For example, in ancient book image recognition, if the training dataset contains more images of Ming dynasty books but fewer images of Tang dynasty books, then the trained AI model may have bias when recognizing Tang dynasty books. Therefore, researchers should use AI technology to analyze dataset bias, such as using fairness metrics like differential impact and equal opportunity to assess model bias levels, and take corresponding measures like increasing few-sample data, conducting data augmentation, and using fair learning algorithms to avoid research conclusion distortion caused by data bias and ensure objectivity and fairness of research results. This rigorous data analysis is not only responsible for research conclusions but also represents respect for the authenticity and integrity of cultural heritage, avoiding misinterpretation and distortion of cultural heritage caused by improper technology use.

7.2 AI-Driven Cultural Transmission and Communication

AI technology not only provides new means for cultural heritage research and protection but also brings new opportunities for cultural heritage transmission and communication. How to use AI technology to enable more people to understand and love cultural heritage and allow cultural heritage to enter people's lives in more vivid and interesting ways is an important current topic in cultural communication [32][33].

Personalized Content Recommendation: Everyone has different interests and needs regarding cultural heritage. Using AI technology, based on users' interests, preferences, and knowledge backgrounds, and employing collaborative filtering and content-based recommendation algorithms, we can recommend cultural heritage content suitable for their personalized needs, improving user experience and making cultural transmission more precise and effective. For example, by analyzing users' browsing history, search records, and interactive behaviors, AI can recommend ancient books, artifacts, historical stories, and cultural activities that users might be interested in, allowing users to learn cultural knowledge in relaxed and pleasant atmospheres and stimulating their love for cultural heritage. This personalized recommendation mechanism not only improves cultural transmission efficiency but also brings culture closer to users, promoting popularization of cultural heritage.

Interactive Cultural Experience: Traditional cultural transmission methods such as exhibitions and lectures are often relatively one-way and difficult to arouse user interest and participation. Using AI technology, we can develop interactive cultural experience projects such as virtual tours, cultural games, intelligent Q&A, and AR/VR interactive experiences, allowing users to understand ancient book collection culture in more vivid and interesting ways. For example, using AI technology, we can develop virtual tour systems allowing users to explore ancient books in virtual environments and understand their historical and cultural backgrounds; develop cultural games allowing users to learn cultural knowledge while experiencing cultural charm through interaction; and develop intelligent Q&A systems allowing users to ask questions through voice or text to learn about cultural heritage information. This interactive experience not only improves user participation but also makes cultural transmission more lively and vibrant, making cultural learning more interesting and attractive.

Multimodal Cultural Transmission: To better meet different user needs, using AI technology, we can present cultural heritage content in multimodal forms such as text, images, video, and audio, thereby expanding coverage of cultural transmission and making it more inclusive and accessible. For example, we can convert ancient book content into audiobooks (using speech synthesis technology) enabling visually impaired people to easily access cultural knowledge; we can produce short videos of artifact information (using AI video generation technology) making it easier for young people to accept cultural transmission; and we can create animations from illustrations in ancient books (using AI image

processing technology) making cultural transmission more lively and interesting. This multimodal presentation can not only meet different user needs but also make cultural transmission more extensive and profound, bringing cultural heritage to the public in richer and more colorful forms.

AI ethics is not merely a technical issue but also an embodiment of cultural values. When using AI technology for cultural heritage research and transmission, we must adhere to ethical principles of cultural heritage protection, ensure technology applications serve common human interests, and avoid technology causing damage to cultural heritage or becoming a tool for commercial profit. We should serve not only technological progress but also technological ethics, ensuring technology serves sustainable development of human culture and better serves human welfare in the process of cultural transmission. Only in this way can we enable cultural heritage to radiate new vitality with the help of technology and make greater contributions to the progress of human civilization.

8 Micro-Narrative and Cross-Cultural Comparison

Traditional cultural research often prefers "grand narrative" approaches, focusing on major historical events, important cultural trends, and elite figures. While this approach has its benefits in helping us grasp mainstream threads of cultural development, it can easily make us overlook the richness and diversity of culture itself. Cultural heritage exists not only in grand historical narratives but is also deeply rooted in details of our daily lives and in the reading and cultural practices of ordinary people. Therefore, if we can introduce "micro-narrative" methods into cultural heritage research, we can observe and understand the true face of culture from more detailed perspectives and reveal the diversity and complexity of cultural transmission. Meanwhile, through cross-cultural comparison, we can better understand book collection and reading cultures among different civilizations, promote exchange and mutual learning between cultures, and make our cultural research more comprehensive and in-depth.

8.1 AI-Enabled Individual Reading History Research

"Individual reading history research" simply means focusing on ordinary people's reading practices and the impacts of reading behavior on their lives, thoughts, and values. It emphasizes the individuality, regionality, and sociality of reading. If we can use AI technology, we can reconstruct ancient individuals' real reading experiences from micro perspectives as much as possible, thereby more comprehensively understanding the true face of ancient reading culture and breaking previous limitations that only focused on elite reading histories, presenting more diversified cultural landscapes [34][35].

Personal Annotation Analysis: When ancient people read books, they often left various annotations such as circles, dots, reading notes, or reflections. These annotations not only reflect readers' personal reading comprehension, thoughts, and emotions but also contain rich cultural information. By analyzing

annotation content, we can understand readers' comprehension levels, reading preferences, and ideological tendencies regarding specific texts, and even learn about readers' personal lives and social interactions. Using Natural Language Processing (NLP) technologies such as sentiment analysis, topic modeling, and named entity recognition, we can conduct in-depth analysis of these personal annotations to reconstruct individuals' reading experiences in ancient times as much as possible. For example, through annotation content analysis, we can know whether readers' understanding of a book is deep or shallow, what types of books they prefer, and what their ideological tendencies are. Through analysis of frequently occurring words in annotations, we can know readers' focus points. Through analysis of emotions expressed in annotations, we can understand readers' attitudes and feelings toward texts. Through analysis of citations of other books and comments made in annotations, we can understand connections between readers and other texts. Additionally, through analysis of annotation styles, fonts, and word usage habits, we can understand readers' cultural backgrounds, social status, education levels, and their cultural environments. This analysis is far more than reconstruction of personal reading behavior; it represents in-depth excavation of individual thoughts and cultural concepts, helping us more deeply understand impacts of reading on individual lives and thoughts.

Collection Seal Analysis: Ancient bibliophiles usually stamped their own collection seals on books they collected. These collection seals not only function as ownership markers but also record circulation processes of books, reflecting cultural transmission stories behind them. Using AI image recognition technology, particularly deep learning models, we can automatically identify collection seals on ancient books and connect these seals with related bibliophiles, library towers, and collection catalogs to trace circulation processes of ancient books, reconstruct cultural transmission networks behind them, and reveal fates and values of books in different historical periods. For example, by analyzing multiple collection seals appearing on one ancient book, we can learn who owned the book in different historical periods and how it was passed down. By analyzing times and places where collection seals appear, we can understand dissemination and influence of books in different regions and cultural groups. This analysis is far more than tracing book circulation history; it represents understanding of cultural transmission and knowledge inheritance, helping us reconstruct the diversity and complexity of cultural transmission.

Manuscript Analysis: In addition to formally published printed books, ancient times also saw large quantities of manuscripts including reading notes, letters, diaries, and private copies. These manuscripts were often not publicly issued and reflect reading culture of the "silent majority." Using AI technology, particularly Natural Language Processing (NLP), we can analyze these ancient manuscripts to reveal reading habits, preferences, cultural understanding, and attitudes of ordinary ancient people. For example, by analyzing language styles, font characteristics, content selection, and theme preferences of manuscripts, we can understand cultural levels, ideological states, living conditions, and social interactions of ordinary ancient people and reveal impacts of social culture on

individuals. This analysis is far more than reconstruction of micro reading histories; it represents respect for diversity of social culture, giving us opportunities to see more diversified reading landscapes.

8.2 Quantum Computing-Driven Cross-Cultural Comparative Research

Through cross-cultural comparison, we can better understand book collection and reading cultures among different civilizations and promote cultural exchange and mutual learning. Quantum computing, with its powerful parallel computing capabilities and ability to process complex data, provides a new tool for cross-cultural comparative research, enabling us to process more data in shorter time and thereby draw more scientific conclusions.

Cross-Civilization Analysis: Different civilizations have significant differences in book collection and reading. Using quantum computing technologies such as quantum clustering algorithms and quantum principal component analysis algorithms, we can conduct large-scale quantitative analysis of collection systems, reading habits, and book forms of different civilizations to explore their cultural characteristics and reveal intrinsic reasons for cultural diversity. For example, we can compare Chinese ancient book collection culture (such as architectural characteristics of library towers, classification methods of collections, etc.) with ancient Greek book collection culture (such as organizational structure of the Library of Alexandria, book circulation methods, etc.), analyzing their similarities and differences in collection concepts, reading methods, and book forms to explore characteristics of different civilizations in knowledge transmission and cultural development, providing some reference for today's cultural exchange and mutual learning. This analysis is far more than comparison between different cultures; it represents exploration of common cultural heritage of humanity.

Complex Socio-Cultural Comparison: Even within the same civilization, different societies have significant differences in book collection culture. For example, different social strata, regions, and historical periods all have different book collection cultures. Using quantum computing technology, we can analyze characteristics of book collection cultures in different societies, such as social stratum distribution of collections (like royal collections, private collections, academy collections, etc.), social significance of reading, and cultural power relationships (like control over knowledge and cultural transmission), thereby exploring impacts of social culture on book collection culture and revealing power structures and cultural mechanisms behind book collection culture. For example, we can compare different types of collections in ancient China, such as royal collections, private collections, academy collections, and temple collections, to reveal roles played by different social strata in knowledge acquisition and cultural transmission and impacts of social culture on book collection culture. This socio-cultural comparison helps us more comprehensively understand complexity and diversity of book collection culture and reveals interactions between

culture and society.

Micro-narrative and cross-cultural comparison are not only methods of cultural research but also unique perspectives for understanding culture. Micro-narrative emphasizes interpreting culture from individual perspectives, focusing on cultural details and diversity. Cross-cultural comparison emphasizes understanding culture from different cultural perspectives, promoting exchange and mutual learning between civilizations. In this process, frontier technologies are not only research tools but also bridges connecting different cultures and individuals, helping us better understand cultural heritage, promote cultural exchange and mutual learning, and making us respect cultural diversity more and cherish humanity's common cultural heritage.

9 Conclusion and Outlook

This study takes ancient Chinese book collection and reading culture as its research object, innovatively combining material culture, spatial narrative, and frontier technologies to construct an interdisciplinary analytical framework. Through in-depth analysis of books' material forms, binding styles, storage spaces, and individual reading histories, we reveal the tremendous potential of frontier technologies in cultural heritage protection, transmission, and innovation and propose a series of practically meaningful recommendations, providing new ideas for future cultural heritage research.

The core argument of this study is: Frontier technologies are not only tools for cultural research but also driving forces for cultural transmission. Through applications of technologies such as Artificial Intelligence (AI), blockchain, quantum computing, biotechnology, and Extended Reality (XR), we can more deeply understand the connotations and values of ancient book collection culture and enable cultural heritage to enter public view in more vivid and attractive ways [36].

AI-Powered Ancient Book Digitization and Semantic Analysis: AI technologies such as deep learning models and OCR technology can efficiently complete digitization processing of ancient books including image recognition, text recognition, and layout analysis, transforming ancient books into editable digital texts and greatly improving digitization efficiency and precision. Simultaneously, using Natural Language Processing (NLP) technologies such as word vector technology and topic modeling technology to deeply mine semantic information and knowledge structures of ancient books helps researchers understand cultural connotations and ideological expressions, enabling cultural heritage to be better preserved, interpreted, and transmitted in digital form and providing powerful data support for cultural research. For example, using AI technology, voluminous works like *Yongle Encyclopedia* can be quickly digitized, and knowledge graph technology can be used to construct their knowledge networks, facilitating researchers' access and study.

Book Format Analysis Under AI and XR Technology Integration: AI

technology can automatically identify morphological features, binding forms, and layout characteristics of books, conduct precise classification using deep learning image recognition models, construct 3D models of ancient books using 3D modeling technology to present their three-dimensional forms, and combine XR technologies like VR/AR/MR to build immersive experiences. This allows users to personally experience the charm of ancient books, understand their production techniques, artistic values, and cultural connotations, thereby promoting cultural transmission and knowledge popularization. For example, through VR technology, users can enter virtual ancient library towers, personally flip through ancient books, and feel their charm, thereby enhancing the attractiveness of cultural heritage.

Intelligent Analysis of Collection Spaces Based on Spatial Narrative: AI technology can combine with Geographic Information System (GIS) technology to analyze geographical locations, architectural structures, and spatial layouts of collection spaces and reveal their connections with social culture and historical changes, helping us understand cultural meanings and historical values of collection spaces. Blockchain technology provides safe and reliable guarantees for artifact traceability and intelligent monitoring, making cultural heritage protection more open, transparent, and efficient. For example, through GIS analysis of ancient academy distributions, we can reveal transmission paths of ancient education and changes in cultural centers.

Application of Biotechnology and Quantum Computing in Artifact Protection: Biotechnology such as biosensing technology, bioenzyme restoration technology, and biomaterial technology analyzes artifact deterioration mechanisms from microscopic levels and uses bioenzyme technology for restoration, achieving more precise and sustainable artifact protection. Quantum computing provides more scientific theoretical basis for artifact protection through simulating chemical reaction processes and analyzing complex artifact data, thereby promoting transformation of artifact protection from passive rescue to active protection and extending artifact lifespans. For example, through quantum computing, we can precisely simulate complex chemical reactions involved in paper corrosion processes to find methods for slowing down corrosion.

Micro-Narrative and Cross-Cultural Comparison: AI technology helps us reconstruct individual reading histories by analyzing personal annotations, collection seals, and manuscripts, revealing reading culture of the "silent majority" and compensating for limitations of grand narrative research. Quantum computing can promote comparative research between different civilizations by analyzing collection systems, book forms, and reading habits of different civilizations to reveal cultural diversity and complexity and promote intercultural exchange and mutual learning. For example, using quantum computing technology for comparative research on Chinese and ancient Greek book collection cultures can reveal characteristics of different civilizations and enhance mutual understanding.

Theoretical Contributions:

The theoretical contributions of this study are: **Constructing an interdisciplinary theoretical framework:** This study innovatively combines material culture, spatial narrative, frontier technologies, and cultural heritage research to construct an interdisciplinary theoretical framework that breaks traditional research barriers, provides new perspectives and methods for cultural heritage research, and offers new theoretical support for subsequent research. **Proposing a new research paradigm:** This study emphasizes the role of frontier technologies in cultural research and uses technology as an important means to interpret, transmit, and promote cultural innovation, providing a new paradigm for cultural heritage research. This new paradigm not only helps expand boundaries of cultural research but also promotes modernization of cultural heritage research. **Enriching connotations of cultural research:** This study deepens understanding of cultural diversity and complexity from micro-narrative and cross-cultural comparison perspectives, expands horizons of cultural research, pays more attention to humanistic and social aspects of cultural research, and makes cultural heritage research more comprehensive and in-depth.

Practical Significance:

The practical significance of this study lies in: **Promoting cultural heritage protection and transmission:** Through frontier technology applications, it provides new solutions for digitization, restoration, and protection of cultural heritage, such as using AI technology for ancient book digitization and bioenzyme restoration technology for paper artifact restoration, enabling precious cultural heritage to be better preserved and transmitted and providing new ideas and methods for cultural heritage protection. **Promoting cultural transmission and education:** Using XR technology to build immersive cultural experiences such as virtual museums and cultural games transforms abstract cultural knowledge into vivid stories, enabling more people to understand and love cultural heritage and stimulating public cultural consciousness, thereby allowing cultural heritage to better integrate into modern life and play its proper social value. **Promoting cultural industry innovation:** Using AI technology to develop culturally creative products with cultural connotations such as cultural and creative derivatives and cultural tourism projects promotes commercial transformation of cultural heritage and achieves sustainable development of cultural heritage, injecting new vitality into cultural industries. **Promoting cross-cultural exchange and mutual learning:** Through cross-cultural comparative research, it enhances mutual understanding and respect between different civilizations, thereby promoting cultural exchange and mutual learning and contributing cultural strength to building a community with a shared future for mankind.

Ethical Reflection: While using frontier technologies for cultural research, we must also face squarely the ethical issues technology may bring, ensuring technology applications conform to ethical principles of cultural heritage protection and focusing on common human interests and sustainable development while

pursuing technological progress:

- **Ensuring AI algorithm transparency and fairness:** We need to use Explainable AI (XAI) models to explain decision-making processes, avoid algorithm black boxes, and increase research credibility. We need to use AI technology to analyze dataset bias to avoid erroneous conclusions caused by data bias and ensure objectivity and fairness of research results.
- **Respecting cultural heritage autonomy and integrity:** When using frontier technologies for cultural heritage digitization and transmission, we must fully respect cultural heritage autonomy and integrity, avoid distorting and misusing cultural heritage, and ensure technology applications do not damage authenticity of cultural heritage.
- **Focusing on fairness and inclusiveness in technology application:** When using AI technology to promote cultural heritage, we must pay attention to needs of different social groups, especially cultural rights of vulnerable groups, ensure cultural heritage can be shared by all, achieve fairness and inclusiveness of cultural heritage, and make cultural development more balanced and healthy.

Future Prospects: Future cultural heritage research should continue focusing on: **Deepening interdisciplinary research:** Further strengthening cooperation between humanities, social sciences, and natural sciences to build more complete interdisciplinary research systems, providing more comprehensive theoretical support and technical support for cultural heritage research and broader cooperation platforms for scholars in different fields. **Expanding technology application scenarios:** Further exploring applications of frontier technologies in more fields such as cultural heritage protection, research, and transmission, making technology better serve cultural development, solve practical problems, and play greater roles in cultural heritage protection. **Strengthening ethical reflection:** Strengthening reflection on and discussion of ethical issues in frontier technology applications, ensuring technology can truly serve human cultural welfare, and enabling humans to better control technology to avoid technology misuse and loss of control. **Focusing on micro-narrative:** Paying attention to cultural memory and practices of ordinary people, enriching cultural understanding from micro levels, making cultural research closer to life and more humanistic. **Promoting cross-cultural exchange:** Strengthening dialogue and exchange between different civilizations, promoting cultural exchange and mutual learning, enabling different cultures to understand and respect each other, and jointly building a community with a shared future for mankind.

This study aims to provide new ideas for the protection, transmission, and innovation of ancient book collection culture. The author believes that through deep integration of frontier technologies and cultural heritage, we can enable cultural heritage to radiate new vitality and make greater contributions to the progress of human civilization, allowing cultural heritage to be better transmitted and developed with the help of technology.

(This conclusion involves key technical methods and theoretical support, refer-

ring to authoritative research including AI application to ancient book recognition (Wang et al., 2023), XR fusion for cultural display (Baltrušaitis et al., 2019), bioenzyme artifact restoration (Cappitelli et al., 2020), quantum computing simulation of cultural data (Cerezo et al., 2021), etc. Specific literature please see full footnotes or reference list.)

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Figures

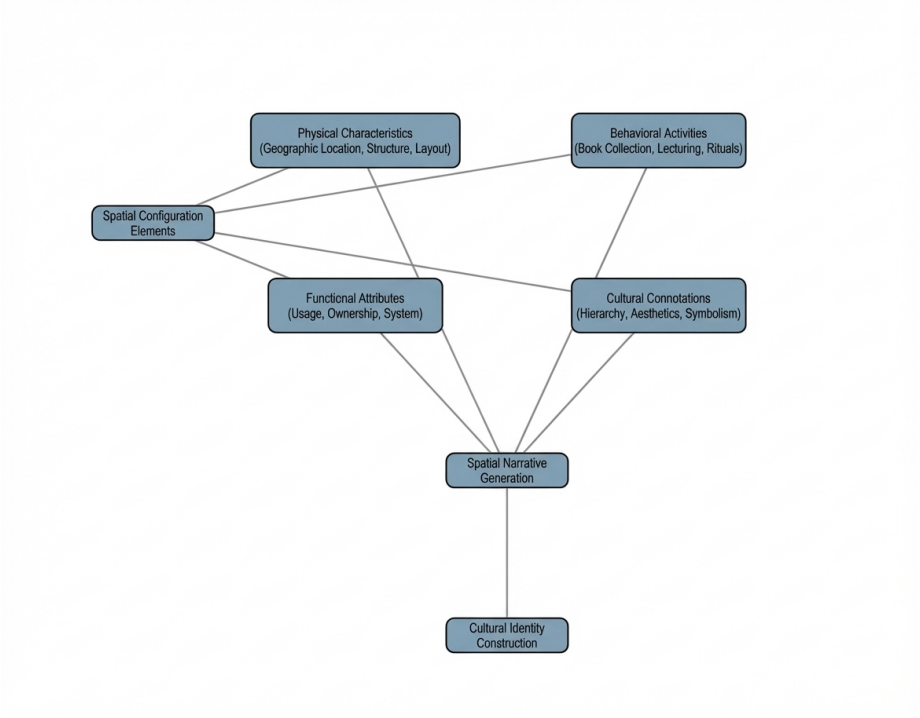

Figure 6: Figure 11

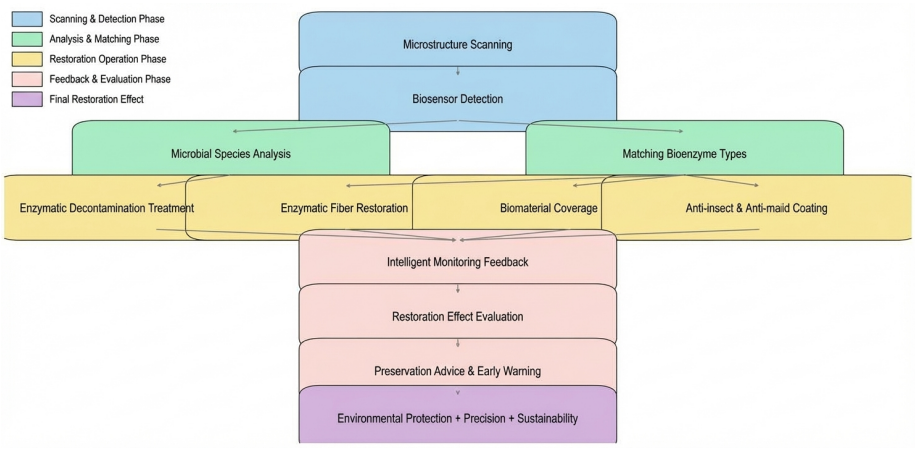

Figure 7: Figure 12

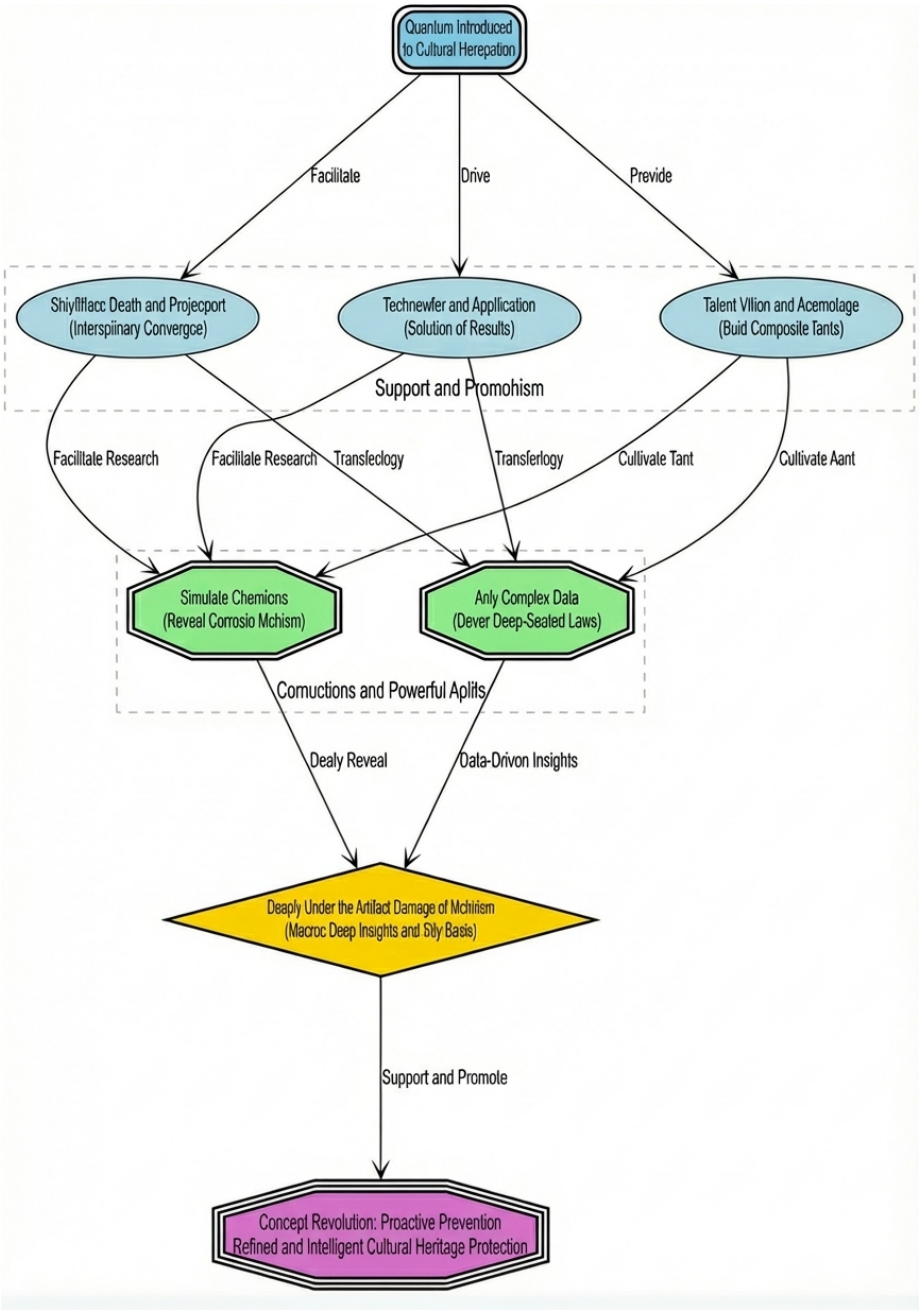

Figure 8: Figure 13