Research Status and Development Trend of Virtual Restoration of Cultural Relics in China—Based on the Visualization and Analysis of Literature Knowledge Mapping in the Past Twenty Years

Linglong Wang[a], Ziying Zhang*

Department of History and Literature, Beijing Union University, 197 West Beitucheng Road, Beijing, China
[a]1044892307@qq.com
*Corresponding author

Abstract: In order to deeply understand the development status quo and future trends in the field of virtual restoration of cultural relics in China, and to promote the application of virtual restoration technology in the field of cultural relics protection, this paper, with the help of CiteSpace visualization and analysis tools, takes the Chinese literature database of China National Knowledge Infrastructure (CKNI) as the source of data, and conducts a knowledge mapping analysis of the relevant literature on virtual restoration of Chinese cultural relics in the last twenty years. The results show that from 2002 to 2024, the research on virtual restoration of cultural relics in China can be roughly divided into the preliminary exploration stage, the rapid development stage and the integration and innovation stage; high-frequency keywords such as "mural restoration" and "deep learning" represent the research hotspots of virtual restoration of cultural relics, and the application of artificial intelligence technology is the main application of virtual restoration of cultural relics. Research hotspots, the application of artificial intelligence technology is the hot topic of future research in the field of virtual restoration.

1. Introduction

Virtual restoration of cultural relics refers to the use of digital image processing, computer visualization, virtual reality and other technologies for digital restoration of cultural relics missing part of the information, and in the support of professional research information, and strive to restore the original appearance of cultural relics, in order to facilitate the better protection of cultural relics, preservation and dissemination of display[1].On October 28, 2021, the General Office of the State

Council issued the "14th Five-Year Plan" for cultural relics protection and scientific and technological innovation, emphasizing the comprehensive strengthening of cultural relics protection and scientific and technological innovation[2].On October 26, 2023, the Central Propaganda Department, the Ministry of Culture and Tourism, the State Administration of Cultural Heritage and other issuance of the "on the strengthening of scientific and technological innovation of cultural relics Opinions" notice, around the work of cultural relics protection, 'Opinions' pointed out that we should optimize the layout of scientific and technological innovation of cultural relics, and encourage scientific and technological innovation and transformation of achievements[3].Proposed restoration technology as relying on computers, the Internet, digitization and other areas of the emergence of new technology of cultural relics science and technology, the protection and restoration of cultural relics has a leading significance, the cause of cultural relics in the new century and the scientific and technological revolution of the trend to stand out in the cultural heritage and cultural heritage protection and inheritance is also of great significance to the current cultural relics community research hot spot.

Restoration of cultural relics is of great significance for the protection of cultural heritage, the inheritance of history and culture, the promotion of cultural exchanges and academic research, the enhancement of national cultural soft power and the promotion of the development of cultural tourism. China has a huge number of cultural relics, as of the end of 2021, China has 108 million pieces (sets) of movable cultural relics, 767,000 immovable cultural relics, a large number of cultural relics to be restored deep in storage, the imbalance between supply and demand of cultural relics restoration is more prominent[4].In recent years, virtual reality, three-dimensional laser scanning, close-up photogrammetry, 3D printing, three-dimensional reconstruction and visualization and other new technologies have been rapidly developed and applied to the virtual restoration of cultural relics, showing a unique form of expression in the protection of heritage heritage historical, scientific and cultural values, restoration of cultural relics in their original state and public awareness and education.Compared with the traditional restoration process, the virtual restoration technology makes the protection of cultural relics more efficient and non-destructive, and can also informatize the restoration data.

This paper collects the research literature on virtual restoration of cultural relics in China Knowledge Network Literature Database (hereinafter referred to as "CNKI") in the past two decades, and carries out the analysis of the current status of virtual restoration of cultural relics by means of the knowledge graph visualization and analysis software CiteSpace on the development of the phases of the current status of virtual restoration of cultural relics, the research team, the hotspots of the research and the cutting-edge trends and other aspects. Analysis, the 21st century in China's virtual restoration of the development trend and the future direction of a clear, intuitive display for China's cultural relics virtual restoration of the innovative development of the field of research and material culture heritage protection to provide reference.

2. Data sources and research methodology

2.1 Data sources

This article sets the literature retrieval time range from January 2000 to December 2024. It conducts a search in the CNKI database with "virtual restoration" and "digital restoration" as the

themes and "cultural relics" as the precise keyword. To ensure the quality of the literature, each retrieved document was carefully screened to eliminate those not related to the theme of "virtual restoration", duplicate documents, editorial materials, etc. Eventually, 488 valid documents were obtained.

2.2 Research methodology

The study used the visual bibliometric analysis software CiteSpace (V5.7.R5) to map and analyze the literature knowledge map with 488 documents retrieved and selected from China Knowledge Network. Scientific knowledge mapping of literature is an emerging measurement and visualization method based on information science, combining statistics, graphics and other disciplines, after clustering, analysis, and revealing the various origins and veins of knowledge with concise and vivid diagrams, which can visually and imaginatively represent the relationship between related knowledge domains[5].CiteSpace is a literature visualization and analysis tool based on computer java language developed by Dr. Chaomei Chen of Drexel University. CiteSpace has powerful visualization capabilities to generate multiple types of graphs, including co-occurrence graphs and collaboration graphs; it can group similar literature or concepts through clustering view, as well as dynamically display the evolution of the research field using time zone view; it can dynamically identify co-citation clusters and key nodes; and it can also help researchers to quickly capture the current research hotspots and cutting-edge trends to provide a powerful navigation for academic exploration by providing powerful navigation[6].

After converting the format of the literature to be analyzed, it was imported into the CiteSpace software. The time span (Time Slicing) was set from 2002 to 2024, with the default time slice being one year. In the visualization analysis of the keyword co-occurrence network, "keyword" was selected as the node type (node type), and the top 50 items (the top 50 items ranked by frequency of occurrence) were analyzed within each time slice. The connection strength was set to cosine.

3. Development history and research status

Figure 1 shows the annual statistical chart of the number of retrieved literature on virtual restoration of cultural relics. From the figure, it can be seen that the development of the field of virtual restoration of cultural relics in China has shown a trend of steady growth year by year since 2002. In terms of the number of literature, the research paper on virtual restoration of cultural relics appeared for the first time in 2002, and the number of papers issued reached a peak in 2024.

Through the specific analysis of literature data and literature keywords, the research history of virtual restoration of cultural relics in China can be roughly divided into three stages. The first stage, i.e. 2002-2009, is the starting stage of the research on virtual restoration of cultural relics. Dunhuang Grottoes Virtual Reproduction and Mural Restoration Simulation, published in 2002[7], is the first exploratory research document that combines computer technology with traditional cultural relics protection work. The annual average number of articles published in this phase is less than 4. Due to the fact that fewer scholars are engaged in this area of research in this period and in the era of 3G network, the development of digital technology in this period also limits the professional integration of information technology and the field of cultural relics restoration. The second stage, i.e., 2010-2019, is the stage of rapid development of virtual restoration technology for cultural relics. Since the 18th Party Congress, cultural self-confidence has been deeply rooted in people's hearts,

and in the context of multidisciplinary integration, the humanities and social sciences and natural sciences have been more closely combined, and virtual restoration has shown an unprecedented new momentum. The third stage, i.e., 2020-present, is the stage of integration and innovative development of virtual restoration of cultural relics. Virtual restoration of cultural relics is gradually becoming a hot topic, cultural relics workers continue to better shoulder the new era of the new cultural mission, in the inheritance of the excellent traditional Chinese culture while promoting cultural innovation, culture for development, science and technology to lead innovation.

Keywords are a condensation of the content of the document, which can show the topic of the document in a concise manner. In the following, with the help of CiteSpace software, the keywords of the documents in these three time periods are analyzed in an independent knowledge map to explore the general development of virtual restoration of cultural relics in China. The frequency of keyword occurrences is linearly correlated with the heat level, and mapping keyword co-occurrences also helps to understand the hotspots and future trends in the field[8]. In keyword co-occurrence time zone mapping, nodes represent keywords, the size of the node represents the frequency of keyword occurrence, the connecting line represents that the keyword has appeared in the same document, and the thicker the connecting line represents the more times the keyword has co-occurred[9].
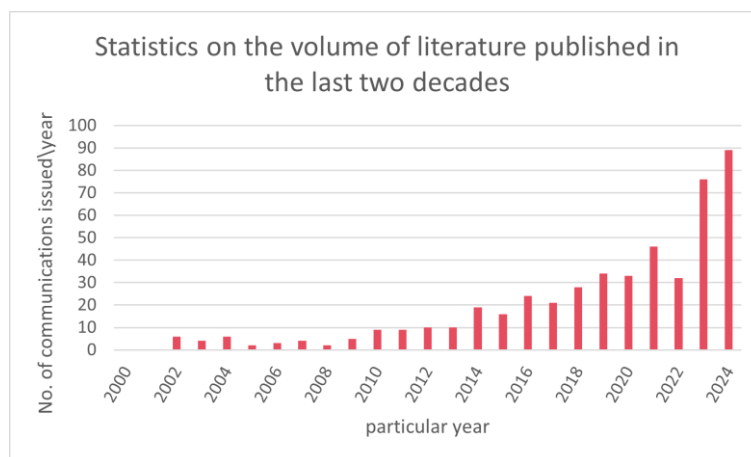
Fig.1 Annual statistical chart of the number of virtual restoration documents of cultural relics in the last two decades

3.1 Initial Exploratory Phase of Combining Cultural Heritage Restoration and Digital Technology

The retrieved 37 literatures in the field of virtual restoration of cultural relics from 2002 to 2009 were imported into CiteSpace software for visualization and analysis, and the keyword co-occurrence time zone mapping of the literatures from 2000 to 2009 was obtained as shown in Figure 2.

Fig.2 Mapping of keyword co-occurrence time zones in the literature, 2000-2009

The most frequent keywords in Figure 2 are "mural restoration" and "deep learning". 2002 retrieved only six pieces of literature, but at this time, scholars have paid attention to the technical combination of computer technology and cultural relics restoration, and deep learning technology was firstly applied to the work of mural restoration. Deep learning technology was first applied to mural painting restoration. For example, Huazhong et al. explored the virtual restoration of Dunhuang wall paintings and the evolution of simulation modeling[10], and Lv Ke et al. investigated the fast matching method of 3D contour curves in the restoration of cultural relics[11], and so on.The keyword "virtual restoration" as a CNKI search criterion appeared in 2003, when virtual restoration began to be discussed and recognized as an emerging cross-cutting field. Subsequent keywords from 2004-2009 show that although the amount of literature is still small, the scope of research on virtual restoration of artifacts is gradually expanding." Virtual restoration" in the previous frescoes on the basis of virtual restoration research continues to deepen at the same time, there are 'cultural relics restoration', 'virtual cultural relics', "painting and calligraphy heritage conservation", '3D virtual reconstruction' and other key words,For example, Li Chunlong et al. proposed a virtual restoration method for axisymmetric broken artifacts[12], Liu Songzhong discussed the research of analog brush type system for digital restoration of Chinese painting and calligraphy cultural relics[13], Su Yunqiao in the master's thesis to do three-dimensional technology digital restoration of Qingzhou Buddha comprehensive research[14], etc.2000-2009 virtual restoration of cultural relics technology is still in its infancy, the relevant scholars in different areas of application groping test, dedicated to the study of cultural relics and science and technology of the new combination of the future virtual restoration of cultural relics for the development of the technology has laid a broad and solid foundation.

3.2 Rapid Development Phase Mainly in Image Processing and 3D Technology

Applying the same method described above, Figure 3 shows the keyword co-occurrence time zone mapping of 190 documents about virtual restoration of artifacts retrieved in CNKI from 2010-2019.From Figure 3, we can see that the keyword with the highest frequency is "virtual restoration", indicating that at this stage, a cross-disciplinary research centered on virtual restoration of cultural relics has been formed, and the scope of its research is constantly expanding, and virtual restoration has begun to be combined with a variety of disciplines, such as ancient architecture, VR

technology, ancient paintings and calligraphy, machine learning, three-dimensional laser technology and so on. The concept of "virtual restoration of cultural relics" is gradually recognized by the public.
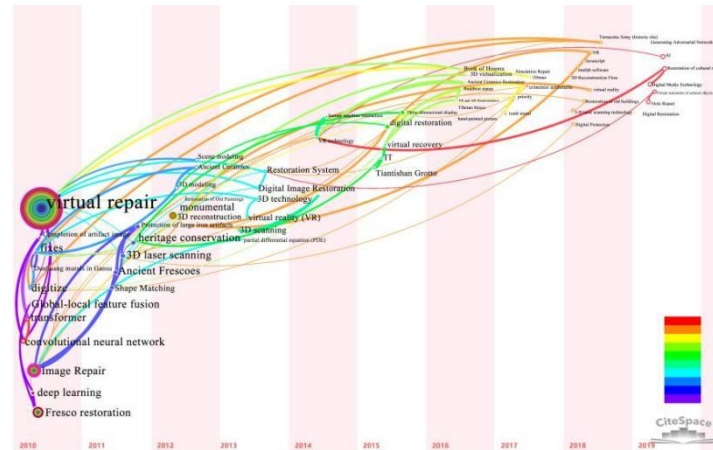

Fig.3 Mapping of keyword co-occurrence time zones in the literature, 2010-2019

In addition to the keyword "virtual restoration", the most frequently occurring terms are "mural restoration" and "image restoration". Continuing the research hotspot of the previous phase, to 2010, the cultural relics image virtual restoration technology has achieved a lot, such as generating adversarial network[15], criminisi algorithm[16], D-S evidence theory[17] and other digital image restoration technology, which can be carrying broken, contaminated, cracked, and other diseases such as cultural relics image restoration of the grottoes, ancient buildings, and other immovable cultural relics on the mural paintings, color paintings of cultural relics As well as ancient books and paintings of cultural relics protection and preservation, display and dissemination have important value and significance. This stage of virtual restoration of cultural relics wide range, from the plane repair extended to multi-scale space digital restoration, "three-dimensional laser scanning", "fragment splicing", "ancient architecture" and so on. Keywords appear more frequently, three-dimensional cultural relics of the virtual restoration technology continues to progress, virtual technology in the restoration of ancient architecture restoration, there is a strong operability.

3.3 Convergence Development Phase Focusing on AI Applications and Virtual Innovations

There has been a significant increase in the publication of articles related to virtual restoration of cultural artifacts in the last few years compared to the previous decade. Figure 4 shows the keyword co-occurrence time zone mapping of 276 documents about virtual restoration of artifacts from 2020-2024, and comparing with Figures 2 and 3, the number of nodes in the keyword co-occurrence time zone mapping at this stage is significantly higher and the connectivity between nodes is more complex. It can be seen that there are a large number of scholars from different research fields intersected in the study of virtual restoration of cultural relics and formed a certain scale, and the relationship between the various fields of virtual restoration of cultural relics has become closer, and the viscosity between the disciplines has increased. Ignoring the search condition "virtual restoration" and the high-frequency keywords that have already appeared in Fig. 3 and Fig. 4, it is found that in the literature published in 2020-2024, keywords such as "virtual reality technology" and "generative adversarial network" increase. The keywords "virtual reality technology" and

"generative adversarial network" increase, and the research on virtual restoration of cultural relics tends to be diversified, and after a rapid development stage, it enters a fusion development stage mainly based on the application of artificial intelligence and virtual innovation.
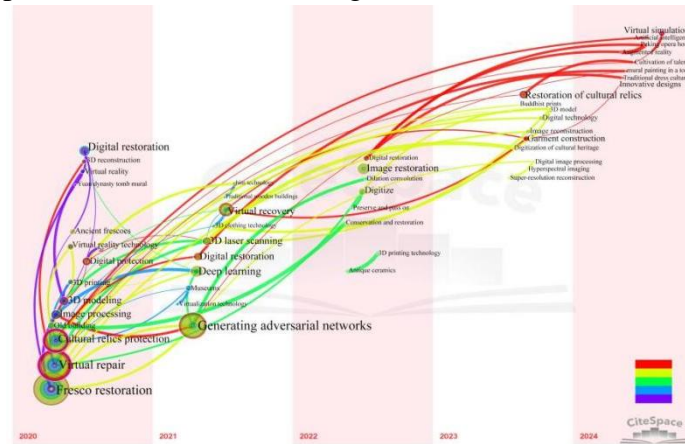

Fig.4 Mapping of keyword co-occurrence time zones in the literature, 2020-2024

So far, the virtual restoration research has covered clothing, ancient books and paintings, ancient architecture, ceramics, stone inscriptions and many other fields, and closely integrated with artificial intelligence technology, deriving more cultural relics virtual restoration of innovative technologies, such as cultural relics orthopedic and pieces of virtual splicing, AI automatic identification algorithms, VR virtual reality reconstruction technology, such as the recent samsungdui bronze bronze riding beasts pack kneeling people sitting on the top of the Zun bronze statue, the terracotta warriors and horses fragments of the restoration of the terracotta warriors and horses are all virtual restoration, etc. are excellent application cases.In terms of talent training, the number of master's and doctoral dissertations in this time period has also increased significantly, such as Tong Yongdong in his doctoral dissertation studied the color and texture virtual restoration of colorful plastic artifacts[18], Cao Ning in his master's dissertation explored the recovery of information on the smoked area of the temple mural paintings based on spectral imaging[19], etc., the virtual restoration of cultural relics as a new field of cultural relics conservation and restoration has attracted a large number of young scholars, from various disciplines, they integrate cutting-edge science and technology at home and abroad to protect our cultural heritage is a new star. From various disciplines, they integrate cutting-edge science and technology at home and abroad to protect China's cultural heritage, which is a new star in the research of conservation and restoration of cultural relics.

4. Research hotspots

Research hotspots are problems or topics that appear relatively frequently in a field during a certain period of time and are widely explored and researched by experts and scholars, and evolve with the maturity of research technology, social development, and changes in human needs[20].Research hotspots are closely related to keywords, and the higher the frequency of keywords, the more they can reflect the current research trends and priorities in the field. In the above paper, the development lineage of virtual restoration of domestic cultural relics since this century was analyzed through the keyword co-occurrence time zone mapping, and then the

retrieved literature was imported into CiteSpace for keyword clustering to get the keyword co-occurrence mapping from 2002 to 2024, see Figure 5.
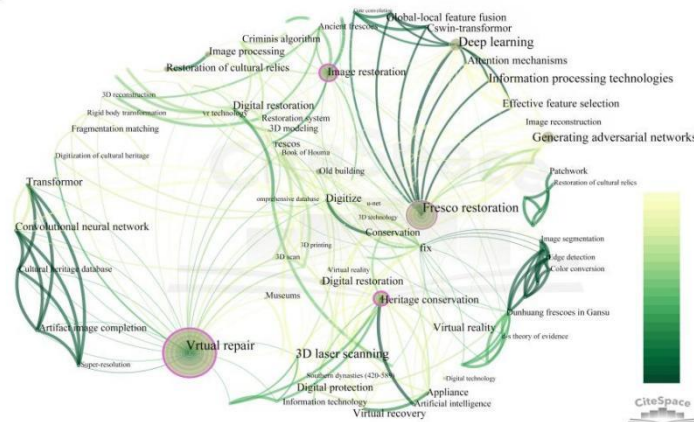

Fig.5 Keyword co-occurrence mapping, 2002-2024

There are some near synonyms in the keyword co-occurrence mapping, which will affect the accuracy of the data and need to be screened for the keyword's. Two keywords with a high degree of repetition, namely the search terms "virtual restoration" and "digital restoration", were first combined; Secondly, since deep learning is a kind of machine learning, and its technical methods also include convolutional neural networks, DBN and stacked self-coding network models[21], the terms "deep learning", "transformer", "cswin-transformer", 'convolutional neural network', 'global-local feature fusion', 'generative adversarial network', and so on. networks" and other keywords are merged; Finally, the frequency and centrality of intermediaries are counted to obtain 10 keywords in order of frequency, such as "mural restoration", "deep learning", "image restoration", "cultural relics protection", and so on. "and 10 keywords in order of frequency, as shown in Table 1.Combined with Figure 5 and Table 1, we can see that "mural restoration" and "deep learning" have the highest frequency, with centrality of 0.08 and 0.02 respectively, which are the two aspects of the domestic virtual restoration research topics, and we will analyze the two high-frequency keywords in detail below. The following is a detailed analysis of these two high-frequency keywords.

Tab.1 Top 10 high frequency keywords 2002-2024

Frequency	Centrality	Keywords
74	0.08	Fresco restoration
52	0.02	Deep learning
28	0.22	Image Restoration
24	0.12	Heritage conservation
17	0.13	Digitize
14	0.06	Old building
10	0.04	Frescos
10	0.12	3D laser scanning
9	0.07	Restoration of cultural relics
7	0.02	virtual reality technology

4.1 Fresco restoration

In the CNKI database, the keyword "mural restoration" appeared 72 times in the literature related to virtual restoration of cultural relics published in the past two decades, ranking the first. The term "mural restoration" appeared as early as 2002, the use of virtual technology to restore digital murals, is the first attempt of virtual restoration technology in the restoration of cultural relics. The research on mural restoration has a large time span, and the virtual restoration research of mural artifacts has continued to overcome difficulties in the last two decades of research, and the team engaged in the virtual restoration of mural paintings has gradually expanded. For the restoration of digital images, there are generally four kinds of image restoration methods based on partial differential equations, image restoration methods based on texture synthesis, image restoration methods based on sparse representation and image restoration methods based on deep learning[22].With the advancement of digital scanning technology, image restoration methods and technology in the field of computer vision, as well as the addition of advanced instruments such as spectral detection and three-dimensional laser scanning, the types of virtually repairable diseases of murals, color paintings, ancient books and paintings and cultural relics objects are becoming more and more extensive and the technology is becoming more and more practical. Mural restoration has always been a hot research direction of virtual restoration, in recent years, such as Shanxi Wutai Mountain, Dunhuang and other cultural heritage units of the virtual restoration of murals have achieved fruitful results, which carries the historical, artistic and cultural value of the public in front of the public again, to achieve the sustainability of the cultural heritage of the development and protection. Fresco restoration mainly image restoration is a very important research direction for virtual restoration of cultural relics in the past two decades, due to the complexity of the research object, the diversity of the research content, the research methodology of the intersection, but also promotes the virtual restoration of paintings and drawings, antique books, paintings and other two-dimensional cultural relics, it can be assumed that the fresco restoration is still a hotspot in the virtual restoration technology research.

4.2 Deep learning

"Deep learning" is the second most frequent keyword for 'virtual restoration of cultural relics'. Deep learning, which automatically learns and extracts complex features from data by building multi-level neural network models, is an important branch in the field of machine learning. Deep learning has made notable achievements in related areas of the computer science discipline since 2000 and especially since 2010.The wide application of deep learning in the field of virtual restoration of cultural relics also shows that deep learning and the emerging artificial intelligence technology in recent years can be applied to the virtual restoration of cultural relics, and the application in this field is gradually showing great potential and value. With the development of deep learning, virtual reality and other artificial intelligence technologies, it can be predicted that the virtual restoration of artifacts will achieve a higher level of automation and intelligence. For example, AI can more accurately identify and analyze broken areas of cultural relics, automatically propose restoration solutions, and even predict potential risks and damages. The future virtual restoration technology will pay more attention to the details and be able to restore the original color and texture of cultural relics, making the restored relics more realistic. This not only helps to

enhance the audience's viewing experience, but also provides more authentic and reliable information for education and research on cultural relics. Therefore, the application of artificial intelligence represented by deep learning in the field of virtual restoration of cultural relics has a broad prospect and will bring revolutionary changes to the protection and inheritance of cultural relics.

5. Frontier trend analysis

Cutting-edge trend analysis can promote the innovation and application of virtual restoration technology of cultural relics, and promote the development of cultural relics protection and cultural inheritance. Keyword emergence refers to the demonstration of a significant increase in the frequency of a keyword within a certain period of time, so its analysis can reflect the research hotspot of a certain field in a certain period of time, and reveal the future research trends and development direction[23]. Figure 6 shows the top ten emergent keywords in the literature of virtual restoration of cultural relics in CNKI database from 2002 to 2024.

Keywords	Year	Strength	Begin	End	2002 - 2024
Cultural heritage database	2002	3.94	2002	2011	
Artifact image completion	2002	3.64	2002	2011	
Attention mechanism	2002	3.31	2002	2009	
Frescos	2002	3.35	2009	2017	
Old building	2002	3.44	2016	2018	
Digital Restoration	2002	4.76	2019	2021	
Generating adversarial network	2002	5.44	2021	2024	

Figure 6 Keywords for virtual restoration of cultural heritage highlights, 2002-2024

As can be seen in Figure 6, the emergent keywords during the period of 2002-2011 are "cultural relics database", "cultural relics image complementation" and "attention mechanism". This period is an important period in the construction of cultural relics digitization, in the starting stage of virtual restoration of cultural relics, but also the starting stage of cultural relics information digitization, scholars will be the latest deep learning algorithms at that time - the attention mechanism is applied in the study of virtual restoration of cultural relics, the main study of cultural relics image information is missing. 2009- During the period of 2018, the emergent keywords are "fresco" and "ancient architecture". This period is a stage of rapid development of virtual restoration research of cultural relics, the object of restoration is no longer limited to flat cultural relics, but also began to explore the virtual restoration of immovable cultural relics of three-dimensional model research. 2019-2024 the emergence of keywords are "digital restoration" and "generative adversarial network" and "digital restoration". The keywords for emergence in 2019-2024 are "digital restoration" and "generative adversarial network". The virtual restoration of cultural relics in this period is closely related to the latest information technology, and the latest deep learning algorithms of the last few years are applied to the virtual restoration of cultural relics, such as generative adversarial network.

From the above analysis, it can be foreseen that with the rapid development of the field of artificial intelligence, the application of the latest artificial intelligence technology, such as ChatGPT and other natural language processing models, to cultural relics restoration and the realization of intelligent restoration of cultural relics will bring greater changes and progress in the

field of cultural relics restoration and protection.

6. Conclusion

With the help of CiteSpace visual bibliometric analysis software on the knowledge network database retrieved from 2002-2024 heritage virtual restoration literature for the visual analysis of the knowledge graph, and combined with the literature, China's cultural relics virtual restoration development history is roughly divided into the 2000-2009 heritage restoration and digital technology combined with the initial exploration stage , the rapid development stage of image processing and three-dimensional technology in 2010-2019, and the integration development stage of artificial intelligence application and virtual innovation in 2020-present.Through the analysis of literature keyword co-occurrence knowledge map and keyword emergence map, it can be understood that in the past two decades, the research direction of virtual restoration of cultural relics, represented by mural painting restoration, has been continuously exploring and developing in research breadth and research depth, and combining with the latest AI technology, it has made efforts to improve the efficiency and precision of cultural relics restoration, which has played a positive role in promoting the protection and preservation of cultural relics, as well as their display and dissemination.

In summary, from the development history, research hotspots and cutting-edge trends of virtual restoration of cultural relics in China in the past two decades, the research on virtual restoration of cultural relics in China is in the stage of rapid development. Under the support of national policy, social encouragement and public promotion, the virtual restoration of cultural relics and information technology innovation continue to integrate and develop innovatively, which will become the core issue of cultural relics protection, and contribute to the inheritance and protection of the outstanding traditional Chinese culture with new strength.

Acknowledgements

References

[1] Wu Yuhua and Hu Yungang, "Experiment on the Application of Data Acquisition and Virtual Restoration in the Restoration of Dazu Stone Carvings" [J], Scientific Research on Chinese Cultural Relics, No. 3, 2013, pp. 33-36.
[2] "Circular of the General Office of the State Council on the Issuance of the 14th Five-Year Plan for Cultural Relics Protection and Scientific and Technological Innovation" [J], Bulletin of the State Council of the People's Republic of China, No. 33, 2021, pp. 21-36.
[3] Du Peng: "Strengthening Technological Weaknesses to Empower High-Quality Development of Cultural Relics" [N], Science and Technology Daily, November 22, 2023, Page 1.
[4] Cui Yan: "Immovable Cultural Relics Can Be 'Looked at' or 'Immediately'" [N], Qingdao Daily, February 20, 2024, p.5
[5] Wu Mei, "A Bibliometric Analysis of 20 Years of <Language and Literature Application> Based on CiteSpace" [D], Nanjing: Nanjing Normal University, 2021, p. 56.
[6] Xiao Ming, Chen Jiayong, and Li Guojun, "Visualization and Analysis of Scientific Knowledge Graph Based on CiteSpace Research" [J], Library and Intelligence Work, Vol. 6, 2011, pp. 91-95.
[7] Lu Dongming, Pan Yunhe, Chen Ren: "Virtual Reproduction and Mural Restoration Simulation of Dunhuang Grottoes" [J], Journal of Surveying and Mapping, No. 1, 2002, pp. 12-16.
[8] Jue Wu, Jia-Nan Yu, and Su-Fei Chen, "Analysis of Research Status and Hot Spots of Immersive Virtual

Technology in Cultural Heritage" [J], Creativity and Design, Vol. 3, No. 3, 2022, pp. 71-80.

[9] Jianbo Hu and Anxin Cui, "Visualization and Analysis of Carbon Peak Carbon Neutral Research Based on CiteSpace" [J], Ecological Economy, Vol. 2, No. 2, 2023, pp. 223-229.

[10] Hua Zhong, Lu Dongming, Pan Yunhe: "Research on Virtual Restoration and Evolutionary Simulation Model of Dunhuang Mural Paintings" [J], Chinese Journal of Image Graphics, No. 2, 2002, pp. 79-84.

[11] Lv Ke, Geng Guohua, and Zhou Mingquan, "Spatial Curve Matching Based on Hash Method" [J], Electronics Letters, Vol. 2, No. 2, 2003, pp. 294-296.

[12] LI Chunlong, ZHOU Mingquan, CHENG Xin,et al. A virtual restoration method for axisymmetric broken artifacts[J]. Journal of Computer-Aided Design and Graphics, 2006,(05):620-624.

[13] LIU Song, DING Haiyan, ZHAI Lianchun,et al. Research on analog pen system for digital restoration of Chinese painting and calligraphy artifacts[J]. Journal of Yunnan University (Natural Science Edition), 2007,(S2):295-300.

[14] Su Yunqiao. A Comprehensive Study on the Digital Restoration of Qingzhou Buddha Statues by Three-dimensional Technology [D]. Yantai University,2008.

[15] Zhang Mingfei. Research on computer-aided mural painting restoration based on generative adversarial network[D]. Northwest University,2019.

[16] Liang Long,Wang Kai. Research on fresco image restoration algorithm[J]. Computer CD-ROM Software and Applications,2013,16(07):114+116.

[17] PI Bingkun,WANG Shuwen,ZHANG Hongqiang.D-S evidence theory in mural painting image restoration algorithm[J]. Journal of Changchun Engineering College(Natural Science Edition),2015,16(04):89-92+107.

[18] Tong Yongdong, Research on Virtual Restoration of Color and Texture of Colored Plastic Relics [D], Beijing: University of Science and Technology Beijing, 2022, p. 86.

[19] Cao Ning, "Information Recovery of Smoked Areas of Monastery Murals Based on Spectral Imaging" [D], Beijing: Beijing Architecture University, 2021, p. 69.

[20] YANG Ying, XIAO Tan, NAN Jingfu, HUANG Qin, "Bibliometric Analysis of the Development Trend of Virtual Simulation Experimental Teaching in Colleges and Universities" [J], Experimental Technology and Management, Vol. 12, 2020, pp. 24-28.

[21] Haonan Wang, Boehmer Liu, and Yiyun Zhang, "A Review of Deep Reinforcement Learning (in English)" [J] Frontiers of Information Technology & Electronic Engineering, Vol. 12, No. 2020, pp. 1726-1745.

[22] Chen Yong and Tao Meifeng, "An overview of digital restoration methods for Dunhuang wall paintings" [J], Software Guide, Vol. 5, 2021, pp. 237-242.

[23] Longxue Hua and Yingliang Wu, "Review and Prospect of Process Mining Research Based on CNKI Bibliometric Analysis"[J], Journal of Management, Vol. 6, 2021, pp. 938-948.