

# The Analysis of Evolutionary Path of Research Topics on the Field of Visualization of International Cultural Heritage Information Since the 21st Century

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**ABSTRACT.** This paper has retrieved 979 literatures in the field of visualization of cultural heritage information between 2000 and 2020 from Web Of Science core collection. With the keys words as the unit of analysis, cluster analysis and co-word analysis as the research methods and SciMAT as the tool, it has identified research highlights and evolution paths in different periods. The research has found that research topics vary a lot in different periods. Part of the thematic studies are strongly related in sequence, the evolutionary relations between topics gradually become complex in the middle and latter period, and 5 evolution paths are presented in general. System is the main research interests and will continue to be the research highlights. Museum becomes a fundamental topic with great potential in the field after continuous integration and regeneration. 3-D visualization, with the largest time span and various research contents, is the fundamental topic in the field.

## 1 Introduction

In 2015 and 2016, the State Council of the PRC has successively issued Action Outline on Promoting the Development of Big Data, and Directive Opinion of the State Council Concerning the Further Strengthening of the Work Related to Cultural Relics, which point out that “China will make full use of information technology to vigorously implement “Internet + Chinese Civilization” Action Plan, and build an integrated big data service platform for cultural transmission to spread Chinese traditional culture”, indicating the emerging research on digital preservation, transmission and innovation of culture and cultural heritage in the future. Cultural heritage information refers to all information related to cultural heritage, which include various content forms such as cultural relics, sites, digital archives, digital collections and inheritors. It is of great significance for preserving the memory of civilization, and inheriting the cultural gene as well as knowledge services in the Internet era.

The research on the field of visualization of international cultural heritage information started early and was abundant. In contrast, China started the information construction of Wenbo system resources since 1980s, which developed slowly. The research results were scarce in the early period. After 2000, the research entered a period of growth with the increase in exchange and learning. Domestic and foreign studies integrated theories and methods of many disciplines such as scientific

visualization, human-computer interaction, data mining, image technology, graphics, archaeology and cognitive science, and covered various aspects of visualization of cultural heritage information, including archaeology, ontology, 3-D visualization, cultural relics restoration, virtual reconstruction, virtual museums, cultural heritage management, cultural ecology, etc. There were also domestic and foreign scholars who paid attention to the research highlights and frontiers of information visualization, and wrote review articles on information visualization, document visualization, visualization principles and technologies. But they have not paid special attention to the field of visualization of cultural heritage information so far. The evolution of research trends, highlights and frontiers, and research topics in this field has not been discussed. In this regard, this article, taking key words of literatures concerning the research on the field of visualization of cultural heritage information as research subjects, has identified the rule of development within by tracking the research topics, and analyzed the research topics in different periods and their dynamic evolution process in detail, so as to provide references for scholars to follow frontier information and academic development.

## 2 Research Methods and Data Processing

### 2.1 Research Methods

This article conducts visualization analysis based on

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SciMat software. With author's words and source's words as the unit of analysis, it draws strategic diagram graph and theme evolution graph of four time periods and identifies the dynamic evolution path of research topics in the field of visualization of cultural heritage information by means of literature knowledge graphs.

## 2.2 Data Retrieval and Preprocessing

Based on SCI - E, SSCI, and A&HCI of Web of Science Core Collection, the author retrieved literatures with titles like "cultural heritage information visualization" or extended d terms including "cultural heritage visualization", "cultural heritage visibility", "cultural heritage info graphics", "cultural heritage digital presentation", and "DIPP digital presentation and presentation of cultural and scientific heritage". Of the retrieval, the time period ranges from 2000 to 2020, all languages are covered, and literature type is limited to research literatures like article or review. On May 11, 2020, a total of 979 data records were obtained through retrieval.

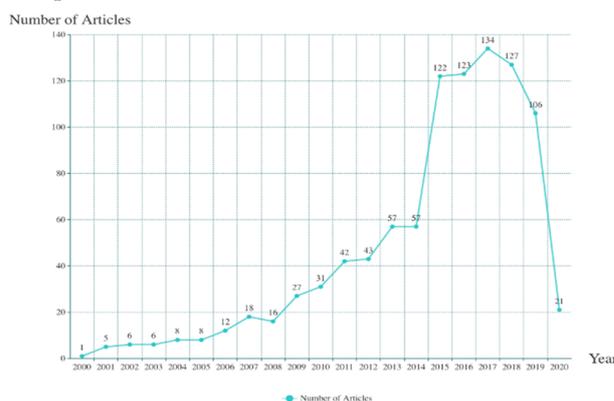
With the function of "finding similar words by plurals automatic" of SciMat software, the singular and plural of keywords could be automatically merged. Key words that are not automatically merged due to different writing and abbreviations need to be merged manually. Such key words include "3D-MODEL-3D-SCANNER-3D-TECHNOLOGIES", "VISUALISATION-VISUALIZATION-TECHNIQUE", and "WATER-REPELLENTS-WIRELESS-SENSOR-WOVEN-FABRIC". Key words that are synonyms could be merged through Word-word group manual set. Such key words include "SHAPE-GRAMMAR-SHIPWRECK" and "USER-USER-STUDIES". Meaningless key words that appear frequently but are irrelevant to the topics are deleted. Such key words include "TOOL", "RTF", etc.

## 2.3 Time Periods Division and Parameter Selection of the Research

With the time line as the horizontal axis and number of articles in publication list as the vertical axis, the scatter diagram of research on visualization of international cultural heritage information between 2000 and 2020 can be drawn. (See Figure 1) Due to the small amount of literatures in the early period and concentrated growth in certain years, this article combines the two division methods of literature quantity and fixed time window to avoid the smoothness of the data. The period from 2000 to 2010 is equidistantly divided into two time periods by adopting the method of fixed time window. In 2015, there was an explosive growth in the amount of literatures and the research reached a new plateau. Therefore, the period from 2011 to 2014 is divided into the third time period of research and the year 2015 falls into the fourth time period of research.

After the division of time periods, then the parameters are set in terms of research time periods and indicators. Author's words and source's words are set as the unit of analysis. Data reduction thresholds for the four time periods are 2, 4, 3, and 6 respectively and network

reduction thresholds are 3, 2, 3 and 6. The clustering algorithm is a simple centers algorithm. Key words are clustered according to their similarities and the core key words are selected and labeled the class name. The maximum network size is set as 20 and the minimum network size is set as 2, so as to maintain a reasonable size of clustering network. The quality measures of clustering include the total citation and average citation of the literature. More citations means greater impact on topics in the later period. The similarity measures for the evolution graph select salton's cosine coefficient to construct semantic association strength and evolution path of topics.

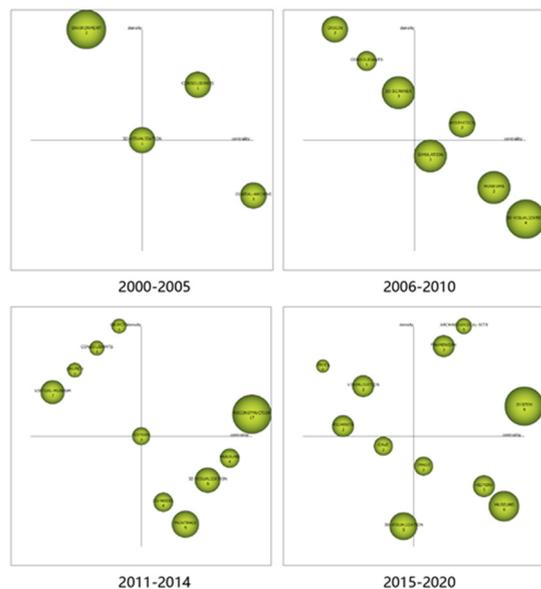


**Figure 1:** Scatter diagram of annual amount of literatures concerning research on visualization of international cultural heritage information between 2000 and 2020

## 3 Evolution Analysis of Research Topics on the Field of Visualization of International Cultural Heritage Information from the Perspective of Strategy Map

### 3.1 The analysis of evolution states of research topics

The strategy map drawn by SciMAT visually displayed the evolution of clustering topics of four time periods. (See Figure 2) In the strategy map, the horizontal axis is Centrality, which represents strength of association between a certain topic with other topics. A larger value means that the topic is at the center of research in the period and has a great influence. The vertical axis is Density, which represents the strength of association between key words within a topic. The larger the value, the more mature the topic is and the greater the potential for evolution. In the map, each node represents a clustering topic, and the figure represents the amount of related records. The larger the node, the more attention the topic attracts.



**Figure 2:** The strategy map of clustering of research topics in the four periods

After a comprehensive analysis of the strategy map of clustering, the evolution of research topics in the four periods is analyzed as follows:

1) From 2001 to 2005, there were only 34 research literatures and a few topic words. The research was in its early stage of development. From the strategic diagram graph, it can be seen that the keyword clustering in this research period falls into four topics, namely Consolidants, 3D-Visualization, Digital Archive and Environment. The topic Consolidants in the right upper quadrant is a relatively mature key topic word in this period. It is clustered by the key words of Consolidants and Water-repellents, with relatively high density and centrality, having a strong ability of evolution in the early and middle stage. The topic Environment in the left upper quadrant is clustered by the key words of Panoramic-Images, 3D-Model and Museum. Articles in publication were fewer and barely relevant in this period. Digital Archive in the lower right quadrant, with higher centrality but lower density, is strongly associated with other topics and is the fundamental topic of this field. 3D-Visualization at the center of the graph ranked the second in the number of articles in publication and had balanced performances in various aspects during this research period.

2) From 2006 to 2010, research on the field of visualization of international cultural heritage information developed rapidly with a surge in the amount of literatures (104 articles) and topics. Seven topics were formed including Origin, Consolidants, 3D-Scanner, Simulation, Museum, Aesthetics and 3D-Visualization. Aesthetics is independent from the topic 3D Visualization of the previous time period and is in the right upper quadrant. It has a few literatures which are closely relevant but attracts less attention. Topics in the left upper quadrant include Origin, Consolidants and 3D-Scanner. The topic words have a high density and internal key words are closely related. For instance, the topic 3D-Scanner clustered by

key words of virtual museum and laser scanner has large quantity of articles in publication and enjoys relatively high popularity. Another two topic words of Origin and Consolidants, which are well developed but have low centrality, are mature professional topics in the field. In the right lower quadrant are three topics including Simulation, Museum and 3D Visualization. Among them, 3D Visualization is evolved from the time period between 2001 and 2005, and has higher centrality than the other two topics with the utmost attention and great influences in this research period.

The literatures most cited mainly focused on the field 3D Visualization in this research period. The article *The role of saline solution properties on porous limestone salt weathering by magnesium and sodium sulfates* written by RUIZAGUDO et al published in 2007 proposed to use different techniques to realize the visualization of the crystallization process and discussed new ways of dealing with salt weathering in the field of conservation for cultural heritage <sup>[1]</sup>. *Photon-Based Techniques for Nondestructive Subsurface Analysis of Painted Cultural Heritage Artifacts* written by JANSSENS et al published in 2010 used infrared reflection imagery and X-ray radiography to conduct imaging analysis on underpainting and other complex three-dimensional substructures <sup>[2]</sup>.

3) From 2011 to 2014, research on the field of visualization of international cultural heritage information stepped into a stage of steady development. Compared with the previous time period, the number of articles rose exponentially, and the number of topics continued to increase. 10 topics were clustered including Reconstruction, Virtual-Museum, Church, Consolidants, Objects, Museum, 3D-Visualization, 3D-Model and Paintings. The topic Reconstruction is in the right upper quadrant and is clustered by key words such as point cloud, standard, facade, city, model and perspective. With high centrality and relatively high density, it is the well-developed core topic in this time period. The performance of four topic words in the right lower quadrant differ greatly in the amount of literatures, density and centrality. The topics of 3D-Model and Paintings have average centrality, less articles in publication, loose internal relations and immature development. The topic of 3D Visualization evolved from the last two time periods enjoys a constantly rising popularity. The topic clustered by key words including cultural landscape, technical control and 3D browser has become the fundamental topic in the field. *Contributions of Cultural Services to the Ecosystem Services Agenda* written by Daniel et al published in 2012, which was frequently cited (544 times), proposed to build a cultural ecosystem concerning cultural landscape. It links ecological structures and functions with cultural values and benefits, and integrates more extensive cultural services besides cultural heritage. <sup>[3]</sup>In 2013, two articles frequently cited focused on the topic of Reconstruction, and discussed the application of relevant techniques to archaeological sites, that is, *Texture attribute analysis of GPR data for archaeological prospection* published by ZHAO et al, and *Archeological excavation monitoring using dense stereo matching techniques* published by Dellepiane et al.

4) From 2015 to 2020, the year 2015 witnessed a

significant rise in the amount of literatures of research on the field of visualization of international cultural heritage information (rising from 57 articles in 2014 to 122 articles in 2015). Since then, the research stepped into a stage of rapid development. There were 634 literatures in this research period. Compared with the previous time period, the number of topics grows exponentially and new topics account for half of the sum. Eleven topics were formed including Archaeology Site, Framework, System, Image, History, Museum, Cave, 3D-Visualization, pigment, Visualization and Trees.

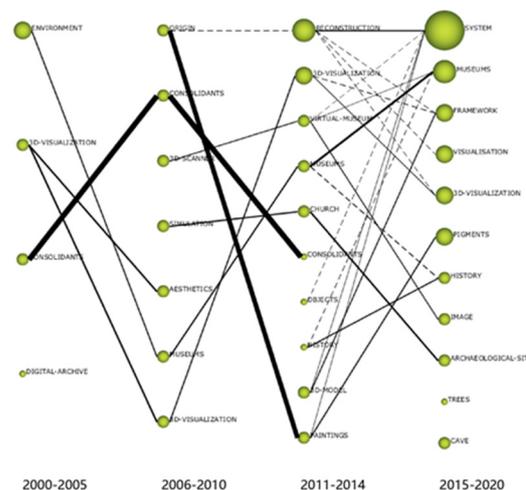
The topics clustered in the right upper quadrant are Archaeology Site, Framework and System. The topic of System assimilated the dominant topics of Reconstruction and 3D-Model in the previous time period. Besides, it clustered 17 key words such as taxonomy, ontology, model, mobile applications, interactive interface, map, landscape and drones, which were closely related. It was the core topic in this research period. The topics clustered in the right lower quadrant are Museum, History and Image. The topic of Museum was evolved from the last two time periods and continuously attracted the attention of the researchers. It had the highest centrality and clustered key words like smart phone, virtual museum, digital library, information system and memory. The topic of History was evolved from the last research period but has rising centrality and research attention. The topic words in the left upper quadrant are Visualization, Pigment and Trees. The topic of pigment is differentiated from the topic of Painting in the last time period and becomes a well-developed professional topic in the field. The topic of trees clustered two key words, namely trees and visual interface. With high density but low centrality, it received little attention and was the professional topic of the research center. The topics in the left lower quadrant are Cave and 3D Visualization. The topic of Cave, as a new topic, was marginalized in the research with less key words and low centrality. 3D Visualization was the only key word that ran through the four research periods. From 2015 to 2020, some key words in the previous research period assimilated many new topics (ie: point cloud, computational ontology) while evolving into the framework topic. Its research contents have changed.

The topic of System, which was the core research topic in the field, clustered a bunch of highlights and frontier research. For example, in terms of ontology research, papers frequently cited include *Conceptual knowledge-based modeling of interactive 3D content* written by FLOTYNSKI et al published in 2015 and *knowledge graph for TCM health preservation: Design, construction, and applications* written by YU et al published in 2017. In terms of 3D model and reconstruction research, the paper frequently cited includes *4d reconstruction and visualization of cultural heritage: analyzing our legacy through time* written by RODRIGEZ et al published in 2017<sup>[4]</sup>. In terms of drone's research, *Improving archaeological prospection using localized uavs assisted photogrammetry: an example from the roman gold district of the eria river valley (nw spain)* written by FERNANDEZ-LOZANO et al published in 2016 reported the application of identification, description and explanation of goldmine positions in ancient Rome, the

northwestern part of Spain based on integrated geographical application of radar data and drone-assisted photogrammetry<sup>[5]</sup>.

### 3.2 The analysis of dynamic evolution path of research topics

The dynamic evolution graph of topics (Figure 3) displayed the dynamic evolution trends of the development, variation and disappearance of various topics in the four research periods. For example, from the figure we can clearly recognize the topic running through all time periods (3D Visualization), the topic that disappeared (Aesthetics) and the latest topic (Trees and Cave). In the figure, each column represents a time period, and the node represents the cluster topic. The size of the nodes is proportional to the amount of literatures on this topic. The connection between two nodes in adjacent time periods represents the continuity of the topic research. The deeper or thicker the connection, the higher degree of relevance between topics. From the figure, it can be seen that the evolution graph of topics shows a trend of more and larger topic nodes over time. Especially in the later period, as its research popularity significantly increased, there were more new nodes, the nodes grew in size distinctly and the data flow between nodes were rising and became more complex. In general, there were a few research topics which received little attention in the early stage but the evolution relationship between topics is clear. Till the third and fourth time periods, there were more newly emerging topics which had obvious differentiation, integration and regeneration. The evolution of topics became more complex.



**Figure 3:** Evolution path graph of research highlights in the visualization of international cultural heritage information since the 21st century

According to the topic evolution graph, by observing and studying the size of topic nodes and data flow between topics, we could recognize 5 clear topic evolution paths in the field of visualization of international cultural heritage information.

(1) System

The topic of System focused on the aspects such as

reconstruction, virtual reconstruction, ontology, taxonomies, model, unmanned-aerial-vehicle, wireless sensor, interface and mobile-application. With close internal relations and high research popularity, it was currently the main research field in the visualization of international cultural heritage information. In the evolution path of the topic of System, two evolution sub-paths could be recognized, namely the sub-path of Origin-Reconstruction-System and the sub-path of Origin-Paintings-System. The first sub-path of evolution developed rapidly. In the second time period after emerging as a stable professional topic, it became a mature topic in the third time period and stabilized in the right upper quadrant becoming the research center of the field. The evolution process of the second sub-path was more complex. During the process, new topics with great potential were constantly integrated (such as Objects, 3D Model). The evolution of topics experienced dynamic changes from left upper, right lower to right upper and the influence of topics gradually increased.

#### (2) Museum

Museum consists of two sub-paths. The first sub-path is Environment-Museums-Museums-Museums and the second sub-path is 3D Scanner-Virtual Museum-Museums. The topic of Museum focused on aspects such as Virtual Museum, Digital Libraries, Information-Systems, Technology, 3D Model and Digital Archive. It had a clear thread of knowledge and a long history of development. Especially in the final period, it integrated two topics in the last two time periods (Museum and Virtual Museum), assimilated some new research directions (such as Information System, Smart phone, Digital Library and Memory) and continuously explored the combination of technology and applications, developing into a fundamental topic with great potential in the field. The positions of Museum and Virtual Museum in the strategy map of different time periods shifted from left upper quadrant to right lower quadrant with the research popularity constantly rising and impact on other topics increasing. These topics were promising research directions.

#### (3) 3D Visualization

3D Visualization is an evolution path with the strongest continuity and has run through 4 time periods. But the research contents changed a lot with the development and iteration of modern technologies. Core key words of each time period were closely linked with technology, devices and applications. In the previous three time periods, this topic developed steadily and shifted from the left upper quadrant in the early stage to the right lower quadrant. With the constant rise in research popularity and impact, it developed into the fundamental topic in the field. In the final research period, some research contents were retained and meanwhile some new topics were assimilated. The amount of literatures showed a significant increase. However, the topic is in the left lower quadrant now and has loose internal relations. And its development is immature after regeneration of the topic. Some other key words were split and formed a new topic-Framework after being integrated with the contents of topics of Reconstruction and 3D Model, becoming the core research direction in the field currently.

#### (4) Archaeology Site

The topic of Archaeology Site has a clear evolution path and data flow, which is recognized as Simulation-Church-Archaeology Site. Relevant topics which shifted from right lower, left upper to right upper gradually developed and matured, and were hot topics of small areas in growth. The topic contents were monotonous and had close internal relations. But it had weak connection with other topics in the same research period, without obvious integration or division. It was a relatively independent and professional research direction in the field of visualization of international cultural heritage information.

#### (5) Consolidants

The topic of Consolidants is relatively stable and well-developed. In terms of evolution state and evolution path, it was in the right upper quadrant in the early stage and received high attention. When the research content is focused in the field, it has a greater impact. Till the second and third time period, the topic shifted to left upper quadrant and became a professional topic with steady development. The data flow of topic evolution is clear and monotonous. There is no clear sign of differentiation, integration and regeneration. And the topic disappeared after the third time period.

## 4 Conclusion

By dividing the research literatures into four time periods, this paper studies and analyzed evolution dynamics and evolution path of topics in the four periods concerning literatures studying visualization of international cultural heritage information since the 21st century. It has found that the topic evolution is increasingly stable and there is strong continuity of research, which proves that the development of research in this field tends to mature and more new research topics need to be explored in the later period. By tracking the dynamic evolution path of topics in different periods with the topic evolution graph, the author has recognized 5 knowledge evolution paths. Among them, System is the main research field of the visualization of international cultural heritage information and will continue to be the research highlights. Research directions of 3D reconstruction, ontology and taxonomy within the topic are worthy of attention. After continuous integration and regeneration, Museum became a fundamental topic with great potential in the field. 3-D visualization, with the largest time span and various research contents, is the fundamental topic in the field after some of the key words split during the evolution process. The topic of Archaeology Site was a relatively independent and professional research direction with relatively monotonous contents. However, Consolidants as a professional research direction had less momentum in evolution and disappeared in the fourth time period. In addition, some professional topics, such as aesthetics and simulation, appeared briefly during the evolution process and did not attract continuous attention.

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