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The Research Overview of Rockwork Hills in Chinese Classical Gardens Based on Digital Technology Applications

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Abstract: Classical Chinese gardens are an integral part of the world's garden system, with rockwork hills being a fundamental element in their construction. In recent years, digital technology has been widely applied. This study employs four different methods for two-dimensional and three-dimensional information recording of rockwork hills, and compares their advantages and disadvantages. It summarizes and outlines the digital documentation methods, demonstrating that digital documentation of rockwork hills in gardens is a relatively cutting-edge research direction, necessitating the comprehensive application of BIM and GIS technologies.

1. Introduction

The term " duo shan " first appeared in the book "Yuany è,"[1] referring to the art of constructing artificial hills using natural stones as the primary landscaping element[2]. It involves the artistic process of stacking and building these hills while integrating the unique characteristics of the stones with artistic techniques, aiming to achieve a result that appears as if created by nature. Classical garden construction originated in the Qin and Han dynasties, with rockwork hills evolving alongside it. In diverse environments and spaces, they created various forms of natural artistic spaces, establishing a unique artistry of rockwork hill construction with a history spanning over two thousand years in the world of garden history. [3]

1.1. Historical Development of Rockwork Hills

The creation of artificial hills can be traced back to the Qin and Han dynasties, where the prototype was a "platform." These platforms had a simple "eight" shape, with a larger base and a smaller top, ensuring the stability of the stacked earth.[4] Platform-style rockwork hills sought to convey symbolism and mythical elements rather than imitate natural landscapes, representing a pursuit of divine enlightenment and immortality. Written records indicate that artificial rockwork hills first appeared during the Han dynasty [5], primarily focusing on mimicking natural landscapes, emphasizing large-scale mountain forms, and striving for realistic proportions.

During the Wei and Jin periods, the popularity of landscape poetry and landscape painting led to a greater exploration of the objective natural landscape world and stimulated subjective spiritual insights [4]. It was from this period onwards that deliberate imitation and reproduction of natural

mountain forms began. Artistic techniques gradually shifted from realism towards expressionism, marking the inception of naturalistic rockwork hills.

The Tang and Song dynasties marked a flourishing period in the construction of artificial hills, with palace gardens still employing the grand-scale approach reminiscent of the Qin and Han periods, but with a newfound emphasis on achieving intricacy within expansiveness [5]. This period established the traditional courtyard rockwork hill model, aiming to depict diverse mountainous features using the smallest possible space and minimal soil and stones.

The Ming and Qing dynasties witnessed the pinnacle of rockwork hill development. In the late Ming dynasty, J ìCh éng made significant contributions to both the practical and theoretical aspects of rockwork hill construction. The book "Yuany è" provided comprehensive, systematic, and theoretical summaries of rockwork hill techniques, offering insightful discussions on stone selection, layout, engineering structures, and construction techniques [5]. The previous approach of using actual mountains as the scale reference was no longer prevalent. Instead, inspiration was drawn directly from natural landscapes, subject to highly abstracted and refined representations, combined with localized exaggerations, merging the realistic and expressive techniques to recreate natural landscapes. Additionally, the theories of landscape painting and landscape poetry were seamlessly integrated with rockwork hill theory, mutually influencing and complementing each other, culminating in the peak of Chinese garden rockwork hill artistry [3].

In modern times, rockwork hills in gardens not only embody a sense of spirituality but also emphasize realistic techniques in specific details. In addition to traditional stone materials, new types of stones have been researched, developed, and utilized. As gardens continue to evolve, rockwork hills have been integrated into various aspects of people's lives.

1.2. Current Status of Rockwork Hill Research

Domestically, research on rockwork hills in classical Chinese gardens is thorough and comprehensive. For example, "The Theory and Techniques of Piling Stones to Create Mountains" [6] (written by Fang Hui, published by China Architecture & Building Press) provides detailed discussions on the history, styles, techniques, and forms of rockwork hills. Additionally, works like Du Wan's "Yunlin Shipu" and Lin Youlin's "Suyuan Shipu" classify and elaborate on stone materials, accompanied by illustrative diagrams, offering valuable reference material. Research on rockwork hills in classical gardens is less extensive internationally, with limited studies primarily focusing on Japan and a few Western countries. The renowned Japanese garden classic "Sakuteiki" from the Fujiwara era [7], revered in both Eastern and Western garden traditions, provides detailed descriptions of rock placement in Japanese gardens, particularly in dry landscape gardens.Okada Tadashi's "The Theory of Chinese Gardens" delves into traditional Chinese courtyard gardens, offering various perspectives on the development of Japanese gardens, including a study on rock placement in traditional courtyard gardens [8].

Upon reviewing literature on rockwork hills, it is evident that scholars consider the exploration of rock placement as a pivotal aspect of classical garden research. As depicted in Figure 1, the relationship between classical gardens and rockwork hills is closely intertwined. Research encompasses not only specialized aspects such as the historical evolution, construction techniques, and artistic achievements of rock placement, but also extends to studies on stone materials, traditional methods of rock placement, and theoretical frameworks for rock placement. The scope of research is broad, thorough, and comprehensive.

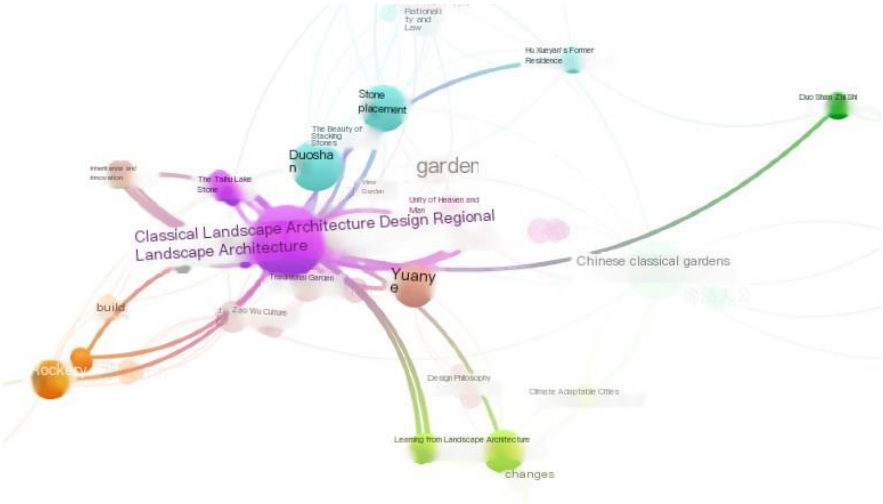

Figure 1: Clustered view of classical gardens

In recent years, various academic journals, as well as master's and doctoral theses, both domestically and internationally, have conducted research on rockwork hills in royal gardens from different perspectives. By using advanced search functions on CNKI (China National Knowledge Infrastructure) with the query "Classical Garden Rockwork Hills ", literature from the past decade was retrieved, yielding a total of 89 papers. Employing VOSviewer for visualized analysis of the relevant literature, as shown in Figure 2- 4. It is evident that the research hotspots in classical garden rockwork hill studies can be broadly categorized into classical gardens, private gardens, royal gardens, and rockwork hills. Research density is notably high in the areas of classical gardens and rockwork hills. Furthermore, literature focusing on spatial layout and theoretical frameworks are considered relatively cutting-edge in this field.

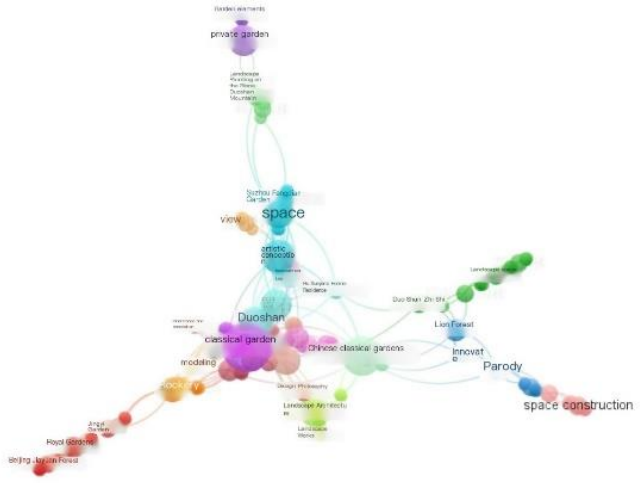

Figure 2: Cluster view of literature on " Classical Garden Rockwork Hills " in the past ten years

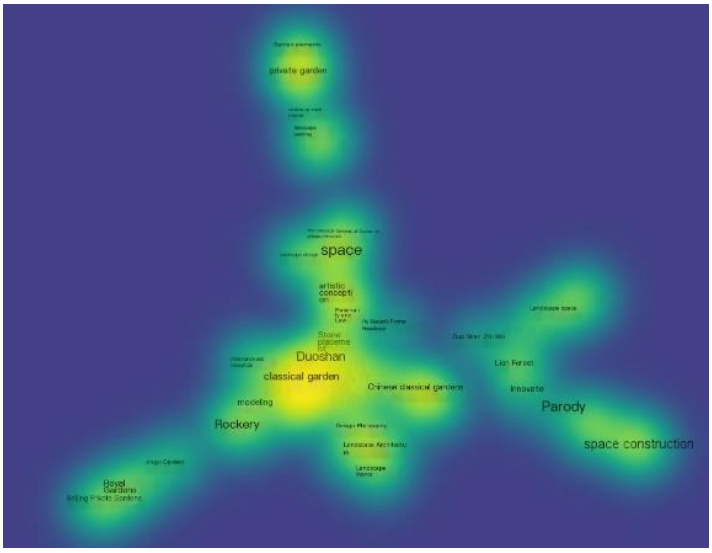

Figure 3: View of the density of literature on "Classical Garden Rockwork Hills" in the past ten years

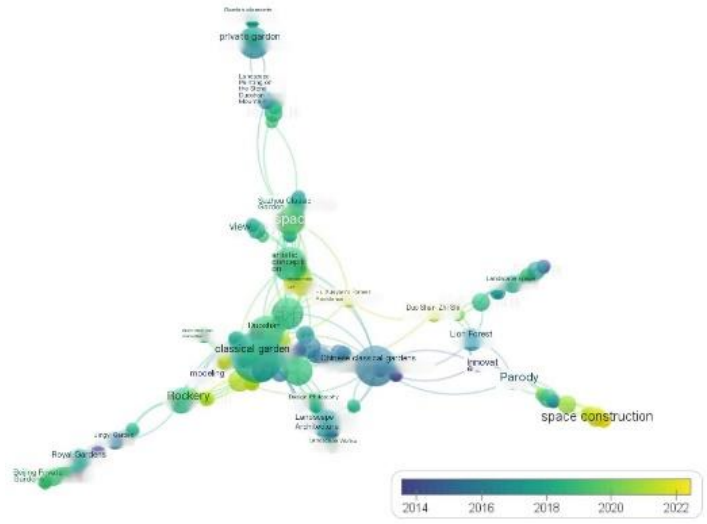

Figure 4: Labeled view of literature on "Classical Garden Rockwork Hills" in the past ten years

In terms of stone material research[3,9,10], some scholars have conducted comparative analyses on rockwork hills in gardens with regards to factors such as regional influences, historical and cultural contexts, stylistic layouts, material applications, artistic techniques, and stacking methods, effectively combining theory with practical examples.

In the realm of traditional methods for rock placement, Wei Feiyu has summarized the functional uses, design techniques, and artistic achievements of placing stones in rockwork hills. This includes elucidating the sequence of design principles for placing stones in rockwork hills and exploring how this practice can be applied in modern garden design [4]. Zhu Lingyi, drawing from typical examples, has analyzed the layout techniques of rockwork hills, the combination of typical rock formations, and the integration of rocks with other elements in the garden. [11].

In the theoretical study of rock placement in rockwork hills, scholars such as [12, 13, 14] have individually conducted research on the thematic intentions of classical garden rockwork hills, the combination of pavilions with artificial hills, and the color schemes of rockwork hill landscapes. These studies emphasize that the mountainous terrain is a crucial and indispensable element in garden

construction.

Hu Wenhai compared the cultural connotations of Chinese rockwork hills with Japanese dry landscape gardens (kare-sansui). Japanese kare-sansui creates a desolate world, reflecting the Japanese reverence for nature and their relatively pessimistic view of impermanence in the face of nature. It also embodies the Japanese aesthetic of pursuing simplicity and understated beauty [15]. In medieval Europe, gardens with rockwork hills were constructed within the castles of feudal lords and monasteries of churches [16]. Scholars such as Stuart [17] and Maggie K [18] in Britain have conducted in-depth explorations of traditional rock placement in rockwork hills, yielding richer results. In modern times, foreign gardens have developed along two main lines: public parks and private gardens. They have gradually integrated with urban greening, ecological balance, and environmental protection, thus expanding the scope of traditional garden rockwork hill studies and proposing new garden design theories.

The history of Chinese garden development is long and rich, with rockwork hills being inseparable from gardens. However, most research focuses on specific gardens, emphasizing on-site investigations and summaries of individual gardens, lacking a comprehensive and systematic classification. With the continuous improvement of 3D information acquisition technology, the integration of classical garden rockwork hills with digital technology has allowed for the creation of rockwork hill models using more scientific digital techniques. This has facilitated the establishment of a systematic digital rockwork hill stone database for classical gardens. It provides crucial technical support for the more systematic collection, analysis, and research of rockwork hill examples.

2. Research on Digital Modeling of Rockwork Hills

In contemporary landscape architecture, the scale of rockwork hill application is increasing, with a substantial number of projects requiring theoretical guidance [19]. Applying modern digital technology overcomes traditional surveying limits. Transitioning from 2D to 3D representation enhances accuracy and research efficiency. This offers a fresh perspective on preserving ancient garden techniques and traditional Chinese culture in the era of 3D technology.

In ancient times, the drawing techniques for placing stones in rockwork hills were akin to an art form in itself, characterized by an emphasis on expressive rather than realistic depiction, with a focus on capturing the essence of the artificial hill [20]. Utilizing modern advanced digital surveying technology not only allows for the accurate acquisition of the appearance data of cultural heritage, but also enables the digital recording and visual representation of the surveyed object. Moreover, this process does not require direct contact with the object, thereby avoiding any potential damage [21].

In recent years, the continuous development of digital surveying technology has brought about advancements in the field of cultural heritage. For example, as early as 2001, Robson Brown utilized three-dimensional reality models to conduct high-precision measurements, representation, management, and analysis of aspects such as the shape and scale of the research object. This has fundamentally transformed the measurement and recording work of heritage related to rock art [22].

Currently, modern digital surveying technology applied to cultural heritage primarily consists of two types: optical-based and distance-based. In terms of methodology, it mainly includes close-range photogrammetry [23,24] and three-dimensional laser scanning measurement techniques[25,26], which can also be combined for different applications[27,28]. Each surveying method has its strengths and weaknesses, and the choice of surveying technology and method should be determined after conducting a multi-element analysis of the specific cultural heritage object. For modeling rockwork hills, various methods are employed, including computer-based two-dimensional drawing, manual construction of three-dimensional models, reverse modeling from photo information, and three-dimensional laser scanning technology. These approaches are utilized to record both the two-

dimensional and three-dimensional information of the rock formations [19].

2.1. Two-Dimensional Software Modeling

There is no standardized method for rockwork hill surveying. In AutoCAD, lines are categorized by thickness hierarchy (contour, perforation, structural, texture). As shown in Figure 5. However, accurately representing variations in protrusions in complex rock forms proves to be challenging (Tabel 1). [19].

Table 1: AutoCAD Modeling Advantages and Disadvantages

Advantages	disadvantages
CAD can be directly inserted into the picture and directly depicted on it, more convenient, faster, and better depicted and modified than ordinary hand-drawn.	Photographs have a perspective effect and cannot be used for flat projection drawing.
Expressed in lines can highlight the outline and structure of the mountain.	It is impossible to express the texture, color and other details of the gyozan with lines. Line depiction is rigid and unable to express godliness.

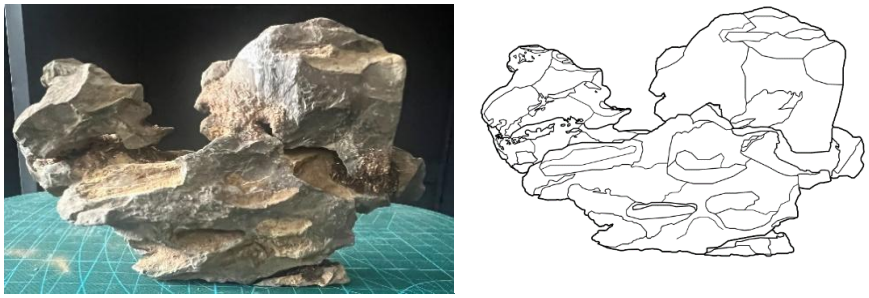

Figure 5: AutoCAD depiction

2.2 3D Software Modeling

Three-dimensional modeling software is more commonly used is 3DsMAX, Sketch up, Rhino, etc.Using 3D software to model different stones, it was found that the found that the models made by 3DsMAX were not detailed enough and the texture expression was not clear. The Sketch up can only make the relationship between the position and size of the stone; The Rhino model effect is too smooth. (Tabel 2.)

Table 2: Advantages and disadvantages of 3D modeling and sculpting techniques

Advantages	disadvantages
Wide range of 3D modeling applications	Time-consuming and cannot be batch operated
Model regulation aspects are comprehensive	Difficulty in controlling the morphology of complex models and lack of morphological accuracy

2.3 Photo modeling

Photo modeling is the process of reconstructing a 3D model of a photographed object by taking dozens to hundreds of photos, using mathematical methods, and relying on related software processing systems.[29] As shown in Figure 6, some scholars[30,31,32] have used different software and techniques to refine the modeling and design. The photo modeling technology is applied to the rockery, and the assistance of 3D software is needed when the interior of the mountain is found to be hollow. (Table 3.)

Table 3: Advantages and disadvantages of photo modeling

Advantages	disadvantages
Short time consuming and can be batch operated	Poor restitution of combined groups
High model accuracy	Have restrictions on objects (be non-regular, non-transparent)
Low cost of photo modeling	

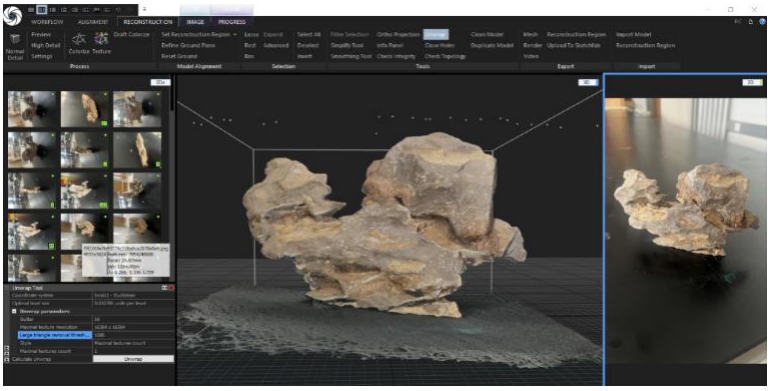

Figure 6: Reality Capture modeling

2.4. Three-Dimensional Modeling Based on Laser Scanning

3D laser scanning, or "reality capture tech," akin to radio wave and ultrasound scanning, measures distance, angle, scans, and positions objects. It captures data on distance, shape, and appearance, then analyzes to create a 3D model. Measurement platforms can be categorized into four types: ground-based three-dimensional laser scanners, vehicle-mounted three-dimensional laser scanners, handheld three-dimensional laser scanners, and airborne three-dimensional laser scanners, each designed for specific applications[33].Zhang Daochun applied three-dimensional laser scanning and Building Information Modeling (BIM) technology to the facade measurement of an old building. He developed a feasible facade measurement technical process, successfully obtaining both two-dimensional and three-dimensional data of the building[34].

Currently, the establishment of rockwork hill models using three-dimensional laser scanning technology can be divided into two approaches. One is to create models of small-scale rock formations using handheld three-dimensional laser scanners. As shown in Figure 7, while the other involves using ground-based three-dimensional laser scanners for large-volume and complex-shaped rockwork hills.

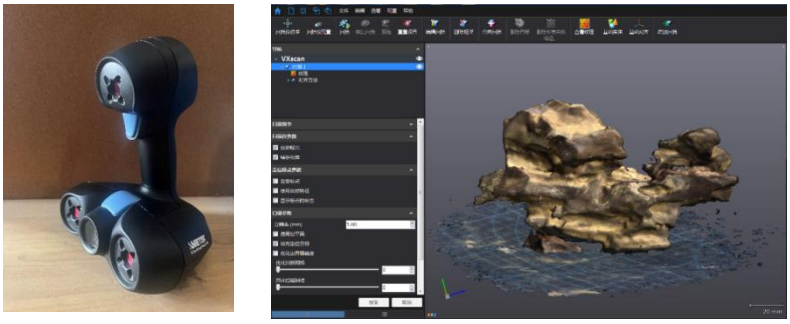

Figure 7: Handheld scanner modeling

The terrestrial 3D laser scanners is divided into three steps, observing the object to be scanned, placing the phase ball and finally arranging the scanning site to be scanned. The first is to observe the object to be scanned. Second is the arrangement of the phase ball. The 3D scanner must be able to scan three phase spheres before they can be flattened together during software processing. Finally, when scanning, the field scanner can basically scan anywhere as long as the human eye can see [19]. (Table 4.)

Table 4: Advantages and disadvantages of terrestrial 3D laser scanners

Advantages	disadvantages
High modeling accuracy	Conflicting relationship between accuracy and scan rate
Wide range of applications	Machine software incompatibility
No need for excessive manual intervention	Expensive machines

Currently for the digital modeling of the Rockwork Hills has two-dimensional software modeling, three-dimensional software modeling, photo modeling, three-dimensional laser scanning modeling of these four. two-dimensional and three-dimensional software modeling time-consuming, cannot be operated in batch, there are errors on the model, the degree of restoration is not high, and with the line cannot be expressed in the details of the texture of the Rockwork Hills, the color, the demeanor, and so on. Photo modeling method is time-consuming and low cost,the model exhibits high precision, but there is a lower level of fidelity in reproducing grouped formations. Three-dimensional laser modeling boasts high accuracy and a wide range of applicability, requiring minimal manual intervention. However, it may be less convenient for post-processing due to software incompatibility among scanning tools.

To enhance modeling efficiency for rockwork hills, different modeling methods can be applied based on the specific characteristics of the rock formation. For small individual rock formations, a combination of photo modeling and handheld laser scanning can be used. This approach ensures model accuracy while significantly reducing time consumption. For larger, composite rock formations, ground-based laser scanning is recommended due to its wide scanning range, high precision, and efficiency. Regardless of the scanning method, post-processing and refinement of the model can be conducted using three-dimensional software, ultimately improving both accuracy and efficiency.

3. Research on Digital Documentation of Rockwork Hills

Currently, the most advanced and effective information management technologies in the field of cultural heritage information management are Geographic Information Systems (GIS) and Building Information Modeling (BIM). BIM technology demonstrates strong advantages in managing

information related to individual buildings and architectural components, allowing for the breakdown of internal structures and the labeling of attributes such as materials and dimensions. However, for spatial and geographical elements outside of the building, as well as the relationships between various other elements, GIS platforms are needed for information management[35]. Researchers like Fai [36] and Campanaro have utilized GIS and BIM technologies for three-dimensional surveys of buildings, significantly enhancing the effectiveness of conservation strategies for historical architecture. With the development of BIM technology in the field of architecture[37], Professor ERVIN from Harvard University first introduced the theory of Landscape Information Modeling (LIM) in 2009[38]. LIM is closely related in nature and concept to BIM, constituting a comprehensive large-scale database containing all information related to the entire life cycle of landscape construction projects, including planning, design, construction, operation, and maintenance. In 2019, Murphy introduced the concept of HBIM for the first time. HBIM has the functionality of parametric processing for building components, showcasing outstanding advantages in unified information management, multi-party cooperation, and the whole-life-cycle management of architectural heritage [39].

A search on the China National Knowledge Infrastructure (CNKI) yielded a total of 41 relevant studies on "digital documentation" in the past decade. Using VOSviewer for analysis, it was determined that the majority of research focused on intangible cultural heritage and historical buildings. Additionally, research on historical building documentation is considered a relatively cutting-edge research direction, as shown in Figure 8 and 9.

In China, research on garden modeling and documentation currently involves the combination of various technologies, including BIM and GIS. For instance, [40, 35, 21]and others emphasize the necessity of digital documentation and explore digital methods using a combination of BIM and GIS technologies.

Currently, there is limited research on the documentation of rockwork hills, and most literature related to the digital documentation of rockwork hills focuses on entire gardens or architectural complexes. For the digital documentation of rockwork hills, BIM can be employed for information model construction. The Revit software can be used for information model construction using the method of rock stacking to analyze, deduce, and replicate typical rock stacking techniques. Additionally, GIS software such as the SkylineGIobe series can be used for the management, editing, and analysis of three-dimensional data. By integrating BIM and GIS technologies, comprehensive digital construction of rockwork hills can be achieved, leading to a better understanding, planning, and maintenance of these features.

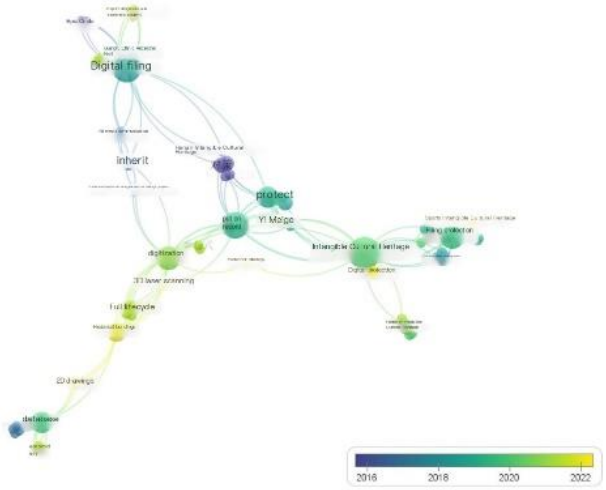

Figure 8: Cluster view of literature on "digital archiving" in the last decade

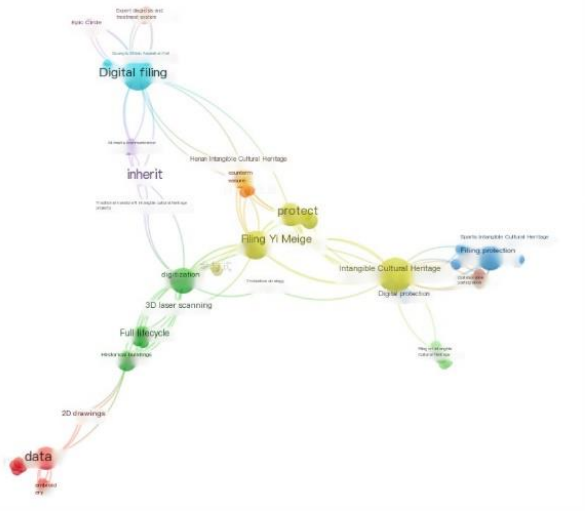

Figure 9: View of the labels of the literature on "digital archiving" in the last ten years.

4. Conclusion and Outlook

In today's world, the development of digitization and intelligence is continuously advancing, and science and technology have become the primary driving force for the progress of various industries and countries. In this context, there have been some research achievements in the digitization of rockwork hills. For instance, technologies like digital close-range photogrammetry, laser scanning, and point cloud visualization have been employed to gather spatial information of rockwork hills. Additionally, techniques such as BIM and GIS have been utilized for documentation work. However, there is still a scarcity of systematic research results regarding the digitization and documentation of rockwork hills.

Rockwork hills play a crucial role in classical gardens, and the application of three-dimensional digital information technology in the field of rockwork hills in Chinese classical gardens holds significant prospects and necessity. Through digital technology, it is possible to comprehensively and accurately record and preserve the spatial information of rockwork hills, including data on their shape, structure, and material, which is crucial for the conservation and restoration of gardens. Research on the digitization and documentation of rockwork hills not only provides powerful tools for garden preservation and restoration but also contributes to the inheritance and promotion of cultural heritage. Therefore, strengthening the research and application of digital technology for rockwork hills holds inevitable significance and value for the study and preservation of Chinese classical gardens.

Acknowledgements

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