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Visual analysis method for cultural heritage site risk assessment

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Abstract Many significant cultural heritage sites are at risk caused by natural environment. A unique type of natural risk to heritage sites is deterioration risk. Conservators and managers of heritage sites are attempting to develop a risk management approach to reduce this type of risk. Risk assessment is the essential component part of risk management process. However, it is hindered by several challenges resulting from the complexity of deterioration risk. We propose the use of visual analysis method for deterioration risk assessment focusing on matching the major needs and objectives of deterioration risk analysis. Our purpose is to facilitate risk analysis which consists of perceiving risk as basis, risk level estimate, and risk cause analysis. A spatial view of deterioration risk is designed for the discovery of distribution patterns. Based on clustering technique, we propose a visual analytics method for risk level analysis. Lastly, the proposed multidimensional data analysis technique is used to detect the causes of deterioration risks.

Keywords Visual analysis · Cultural heritage · Deterioration risk · Risk assessment

1 Introduction

For cultural heritage sites, risk refers to the possibility of causing damage to the value and integrity of these cultural properties. Many noteworthy cultural heritage sites all over the world are exposed to various natural threats. According to the effect of these natural threats, risks to cultural heritage sites may be divided into two categories: disaster risk and deterioration risk. Disaster risks are a common subject in many fields of study, whereas deterioration risks are unique to cultural heritage sites. This article focuses on this special type of risk.

Degradation of cultural heritage sites is inevitable and, in some cases, could even be accelerated by environmental factors. Accelerated degradation is considered a kind of risk because it would probably lead to advanced damage to cultural heritage sites. To reduce deterioration risks to cultural heritage sites,

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conservators and site managers are attempting to develop measures based on the results of risk assessment. Risk assessment is an overall procedure of risk identification, risk analysis, and risk evaluation. Of them, the most important step is risk analysis, which determines the level of risk and identifies the nature of risk, particularly the source and cause of risk.

However, conservators and site managers are often confronted with problems resulting from the complexity of deterioration risk analysis. First, heritage sites have abundant deterioration risks, and each risk involves several properties, such as name, spatial information, possibility, and loss. These properties, which comprise the risk list, are not easily identified at first glance, especially the spatial information. Second, the data used in analyzing deterioration risks are high-dimensional, multivariate, and heterogeneous. They include numerical data from monitoring instrument, text data from archive, and image data. Third, analyzing the cause of deterioration is a complex endeavor because many of the possible causes remain unknown even though domain experts have exerted great efforts to study deterioration mechanism. Finally, stakeholders involved in risk analysis are pluralistic, which results in various perspectives of analysis. The differences in the specialty, experience, position, and task of conservators and managers lead to different demands of analysis. Therefore, an efficient way of reducing the difficulty of deterioration risk analysis must be established. For this purpose, we introduce visualization and visual analytics as technical assistance techniques for risk assessment.

To our knowledge, no study has reported on this topic, although a number of related works can be found in the fields of cultural heritage and visualization. Recent studies have focused on two perspectives. One is the large-scale visualization of deterioration distribution and environmental data. This perspective focuses on risk presentation but not analysis. The other is the analysis of environmental monitoring data in heritage field. However, this perspective does not consider risk but only the environmental factors.

This article proposes the use of spatial information based on visual analysis approach to match the major needs and objectives of deterioration risk analysis of cultural heritage sites. The main objective of our work is to facilitate this task, which consists of perceiving risk as basis, risk level estimate, and risk cause analysis.

Our main contributions are summarized as follows: (1) design a view for spatial distribution of deterioration risks; (2) propose a space-associated visual analytics method for analyzing deterioration risk level; (3) propose a visual method for multidimensional data analysis to detect the correlation between degradation and some factors.

2 Related work

2.1 Risk management of cultural heritage sites

The risk management of cultural heritage sites is divided into two categories, namely relics, which are movable in museums, and cultural heritage sites, which are outdoor and immovable. Several methods have been developed for the risk management of museum relics. Michalski (1990) proposed an overall framework of preventive conservation as the main basis of risk management in museums, as well as five measures for avoiding or slowing down relic deterioration. Waller (1994) developed a four-step procedure of risk management in museums; in this approach, risks are divided into three types according to the features of risk possibility and the consequences. The majority of studies on the risk management of cultural heritage sites have focused on disaster risks, such as fire, flooding, and earthquakes. Several methods have been proposed for managing disaster risks (UNESCO 2010). A case study of the Petra World Heritage Site was organized to develop a risk management methodology (Vafadari et al. 2012).

2.2 Cultural heritage date visualization

Methods for the collection, analysis, and visualization of cultural heritage information have been improving in recent years. GIS-based information visualization, which utilizes geographic location information, has been widely used in this field. Petrescu (2007) described the status of the use of GIS in the preservation of cultural heritage sites. Huisman et al. (2009) developed geovisual analytics functions for archeological investigation. Blaise and Dudek (2008) introduced a methodology framework that integrated legacies from the fields of architectural modeling and information visualization. Deufemia (2012) presented an interactive visualization system that supported archeologists in examining large repositories of documents and drawings. Ma et al. (2012) proposed the Living Liquid as a visualization tool that museum visitors can use to explore the time-varying global distribution of simulated marine microbes.

2.3 Cultural heritage deterioration cause study

Many research works have revealed that the possible causes of deterioration of cultural heritage sites include hydrogeological factors (Piao et al. 2003), microbiological factors (Garg et al. 1995), air factors (De la Fuente et al. 2011), and environmental factors (Wang et al. 2006). Using field investigation and laboratory analysis, He et al. (2014) identified four main deterioration modes of an earthen architectural heritage, namely wind-related, water-related, temperature-related, and chemical-related deteriorations. Chiappini et al. (2004) applied multidimensional data visualization techniques to study the decay events of ancient buildings. Various researchers applied photorealistic computer graphics techniques to simulate the weathering of stones (Chen 2005) and metals (Petrescu 2007). Inkpen et al. (2008) integrated a database with GIS to record and monitor stone degradation. Salonia (2003) set up an Information System as an auxiliary tool for the organization, representation, and utilization of data in the recovery of historical buildings. Zhang et al. (2013) proposed a visual analytics framework and a set of tools for multiscale analytic support to discover degradation patterns.

In summary, although related studies have investigated cultural heritage risks and the data analysis of deterioration, no study has developed visualization or visual analytics techniques for deterioration risk analysis, which is the primary motivation of our work.

3 Our method

3.1 Overview

Our method is designed in a framework of risk assessment that involves risk identification, risk analysis, and risk evaluation. The identification step is the basic part of assessment. The analysis step is the most essential one which is based on the result of risk identification and provides basis for risk evaluation. Risk analysis comprises two integral parts: (1) to analyze the level of the identified risks and (2) to understand the nature of these risks, including their causes. The first part is the basis for deciding the priority of risk response, and the second one provides basis for risk response. The objective of our method is to assist conservators and site managers with risk analysis.

According to the objective of risk analysis, the analytic task list includes: (1) to comprehend the result of risk identification, (2) to estimate the risk level, and (3) to explore the relationship between deterioration and some specific factors. With the analytic task list as the guide, the proposed method consists of three interrelated parts: a spatial view of deterioration risks, a visual analytics method for risk level analysis, and a visual multidimensional data analysis method for exploring deterioration causes (Fig. 1). First, risk analysis is based on the risk identification results, which include description of risk elements usually with structured data. Analysts must comprehend these results before any further risk analysis is performed. We design a spatial view of deterioration risks to address the deficiency of currently existing method. With the proposed method, the deterioration risks, particularly the spatial information and the distribution patterns, can be perceived more intuitively. Second, we propose a visual analytics method based on clustering technique for

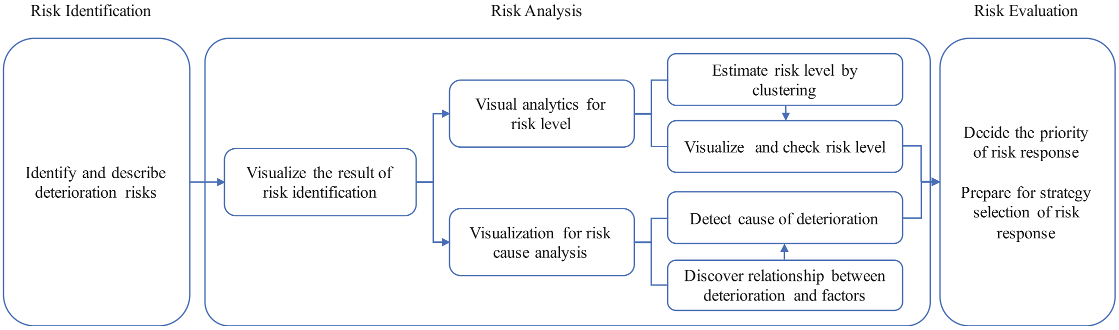

Fig. 1 Visual analysis method for deterioration risk assessment of cultural heritage sites

risk level analysis, which is one of the main purposes of risk analysis. Finally, for the analysis of risk causes, which is the other purpose of risk analysis, we propose a visual multidimensional data analysis method for users to detect the relationship between deterioration and different factors through the use of commonly used statistical plots.

The Mogao Grottoes site, which is a famous World Cultural Heritage Site in China, is used as an example in this study to explain our method. This site encompasses 492 caves containing artwork. These caves were constructed along the cliff facing east, extending from the north to the south at different levels of height. The wall paintings in these caves are suffering from various types of deterioration. The analysis will be based on the data of wall-painting deterioration.

3.2 Spatial view of deterioration risk

Deterioration risk is a type of risk that is unique to cultural heritage sites. The deterioration of heritage sites could be ongoing for hundreds of years, and the extent of the damage varies. Some varieties of deterioration continually worsen over time, and the deterioration process could be accelerated by the disturbance of environmental factors, whereas other cases are in relatively stable condition. Active degradation is considered a deterioration risk to cultural heritage sites.

Conservators and site managers identify deterioration risks on the basis of monitoring, documents, and expert advice. A list of deterioration risk involves the risk details, which generally includes the risk object, the risk event, and its position. The cause and the consequence are also the outputs of risk identification. In general, cultural heritage sites are generally too large to be assessed as a whole. For this reason, conservators divide it into parts so that assessments could be conducted in sections. We regard each part of the cultural heritage site as an object of deterioration risk and as the analysis area of deterioration risk. A risk event refers to the accelerated degradation caused by environmental factors disturbance. In Mogao, each cave is regarded as an object of deterioration risk.

Often, more than one type of deterioration can be found in a cave, such as disruption, flaking, blister, and detachment. As such, the risk list of Mogao will involve thousands of information to describe all of the deterioration risks to Mogao, suggesting that using the conventional method to perceive these deterioration risks would be difficult. Therefore, we design a spatial view of all deterioration risks of Mogao to provide conservators and site managers with a method that can comprehend deterioration risks explicitly at the very beginning of the risk analysis process.

First, we identify the coordinates of each cave on the basis of their actual location. The value of the x and y coordinates, respectively, mirror the relative position of each cave in the horizontal and vertical directions. In the real world, caves are not aligned with one another in either the horizontal or vertical direction. We slightly adjust the coordinate values so that the adjacent caves are in a horizontal or vertical line, thus making our design better for finding the patterns of risk distribution.

In our design, caves are divided into four layers according to their y coordinates. They are arranged in four rows from left to right corresponding to the caves in the site from the south to the north. The top row is coded as layer 4, followed by layer 3, layer 2, and layer 1. However, caves on the cliff are irregular. Some caves are located at the bottom of the cliff but have a higher y coordinate, while some caves are at the medium of the cliff but have a lower y coordinate. To present the visual positions of the caves on the cliff, we code each cave with different shapes. An inverted triangle represents a cave at the top of the cliff, which means that there are no caves above it. A triangle represents a cave at the bottom of the cliff, which indicates that there are no caves below it. A square represents a cave between a top and bottom caves. In addition, conservators are interested in a particular kind of cave that has a very thin peak. This kind of cave is represented by a diamond. On this basis, a spatial view of each cave as a basic map is developed.

Second, some elements of deterioration risks can be presented on the basic map. The condition of degradation is an important element of deterioration risks. The amount and degree of degradation can be obtained from the document of cave condition assessment. The amount of degradation refers to the number of places where a specific type of degradation is present in a cave, whereas the degree of degradation is the severity in one place. We take their product as the deterioration condition of a cave. We then categorize the values of the product into five groups to represent the degradation condition of a cave. The first group is the zero, which represents the absence of degradation in the cave. The others are divided into four groups. The split points are 25, 50, and 75 % of the maximum value of the degradation condition. Those <25 % of the maximum and more than zero represent slight degradation; between 25 and 50 % represent moderate degradation; between 50 and 75 % represent serious degradation; and more than 75 % represent very serious degradation. We use different colors to represent different deterioration risks, and the opaqueness of the color indicates the degradation condition. Transparent zero means no degradation. Transparent 25, 50, 75, and 100 % correspond to slight, moderate, serious, and very serious degradation, respectively. Similarly, the change rate of degradation, which is another important element of deterioration risk, can be presented on the basic map. The color represents the type of risk, and the opaqueness indicates the degree of the change rate. A faster degradation change corresponds to a higher transparency. In addition, the construction dynasty of a cave is an important factor for risk cause. Conservators and site managers intend to perceive the dynasty distribution. Thus, we also provide a filtering function to present the view of the different dynasty and the relative deterioration with the basic map.

Finally, we design a spatial view to present all deterioration risks to Mogao. One characteristic of all deteriorations can be presented simultaneously. In this view, each cave is represented by the same four symbols in a vertical row with different colors and opaqueness. Thus, the distribution of multideterioration can be perceived easily. In addition, the differences in the distribution between each risk can also be determined (Fig. 2). One type of deterioration risk can be filtered to observe the distribution pattern more clearly (Fig. 3).

3.3 Visual analytics of risk level

Risk magnitude (MR) is crucial in determining priorities for responding to risks. The MR is typically represented as a function of risk consequence and possibility. For cultural heritage sites, the consequence of the deterioration risk is the loss of integrity and value of a site, and the possibility is the probability or frequency that the risk event happens. The loss of integrity is tangible, whereas the loss of value is intangible. MR analysis starts with the tangible loss without considering the loss of value. We define it as a risk level (LR) and propose a visual analysis method.

Data on possibility and consequence (physical loss) can be determined from previous investigations and statistics. We believe that an analysis area of heritage sites is more vulnerable to some types of deterioration than others if a higher degree of such deterioration exists in this area. In other words, a higher degree of certain deterioration corresponds to a greater possibility of such deterioration risk in the area. By contrast, those analysis areas wherein deterioration worsens faster (i.e., more active) are expected to suffer more physical damage than others in unit time regardless of the factors that influence them. Thus, the level of

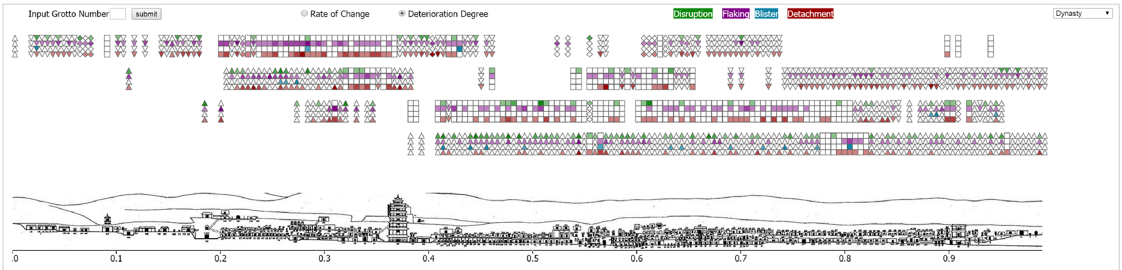

Fig. 2 Spatial view of deterioration risks

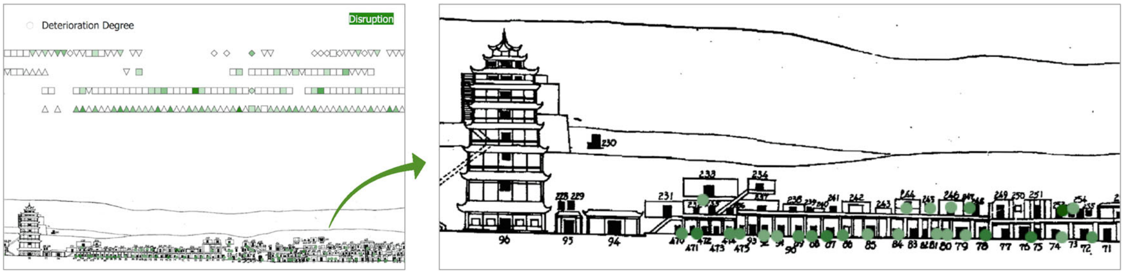

Fig. 3 Spatial view for one type of deterioration risk

deterioration risk can be estimated from the data of the current condition of the deterioration and its rate of change.

We provide an analysis method that can estimate the LR of each analysis area considering a single type of deterioration risk, such as disruption. We divide the LR into four degrees represented by numbers 1, 2, 3, and 4, where 4 is the highest risk level and 1 is the lowest risk level.

For an analysis area, such as a cave, LR is relative and is determined by comparison between different areas. We assume that areas sharing similar characteristics should be at the same LR. Thus, the clustering technique could be used to distribute caves into subsets that stand for each group of areas at the same LR. *k*-medoids algorithm is used. Each cave is an object of clustering, and the risk possibility and consequence are the attributes of the object.

The process is described as follows. For many caves, both the values of possibility and consequence are zero. These caves are directly distributed into the group of LR $= 1$ without clustering. Then, the other caves are clustered and $k = 3$. To determine the magnitude of each cluster, the values of possibility and consequence of each medoid are multiplied. The result is ordered to determine the level of each cluster and is visualized in two ways. First, different LRs are represented by four colors: red for the highest one and orange, yellow, and blue for the rest. Second, a scatterplot is used to check the result. Two dimensions of the scatterplot are the possibility and the consequence of a specific deterioration risk. Each point represents a specific cave. Third, the LR distribution is presented by the spatial view proposed in Sect. 3.2 (Fig. 4).

3.4 Visual analysis of risk cause

The other important task of risk analysis is to explore the cause of deterioration risk. This task provides a decision basis for selecting strategies to mitigate or eliminate existing deterioration risks. What confuses conservators and site managers is that the causes of deterioration risk are complex, and many of them have not been confirmed. Nevertheless, domain experts have conducted substantial research so that the analysis of the deterioration risk cause is feasible. Deterioration factors can be divided into two categories that are defined as exogenous factor and endogenous factor.

The exogenous factors refer to the environmental factors of deterioration. They include temperature, relative humidity, light, wind, dust and sand, microbes, water, fire, and other elements. Based on our references and the experience of domain experts, a network graph is drawn to present these exogenous factors and their relation with deterioration in Mogao (Fig. 5). The graph comprises three categories of elements, namely natural phenomena, exogenous factor of deterioration, and appearance of deterioration. The natural phenomena include rain and wind, and natural hazards such as floods and earthquakes. The appearance of deterioration is the form of deterioration that could be observed by the naked eye and is also

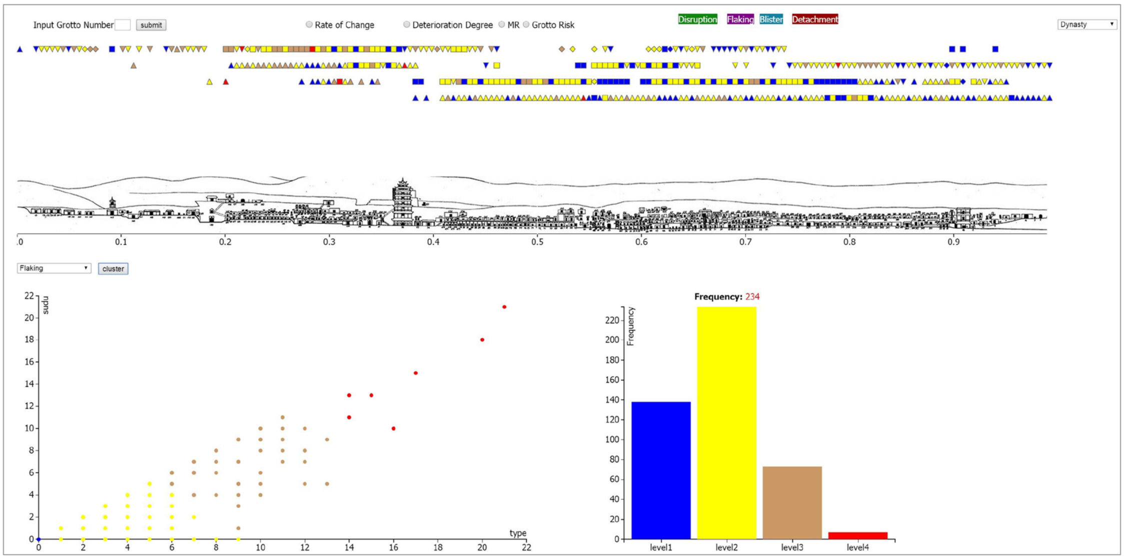

Fig. 4 Visual analytics of risk level

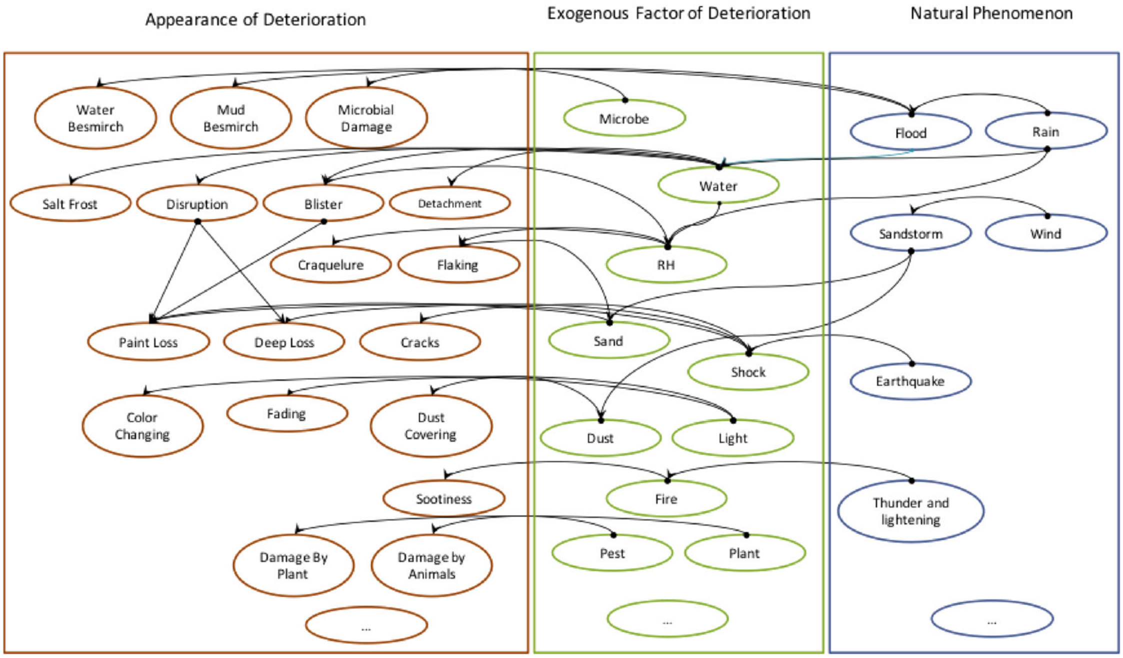

Fig. 5 Network graph of deteriorations and their exogenous factors

used to identify relative deterioration risks. Using Fig. 5, we can understand the possible exogenous factors that are likely to cause deterioration.

The endogenous factor is related to the heritage site itself. This kind of factor plays an important part in determining the vulnerability of a cultural heritage site. The vulnerability refers to the probability that the site is likely to suffer a certain degradation or damage, and it depends on the physical characteristic of a cultural heritage site such as construction material, technique, size, and structure. These are the main endogenous factors of heritage deterioration. Construction material and technique are too complicated to describe, but they are usually associated with the period of construction. Thus, the construction period is sometimes considered as an endogenous factor instead of material and technique. In Mogao, possible endogenous factors of deterioration include construction period, the cave position on a cliff, the area of the cave, and the character of the cliff where the cave is located.

It is a challenging task to find the relationship between the possible endogenous factors and deterioration. Conservators often make judgement according to field observations. However, this method is only applicable to experienced experts. Thus, we develop a visual method to assist conservators in detecting this kind of relation through commonly used statistical analysis graphs such as bar, boxplot, and scatter. Also, the discovery can be used to test the experimental result conducted under simulated conditions or to assist in finding clues for further mechanism study.

The goal of analysis is to associate one kind of deterioration with one single or a few different endogenous factors. First, conservators need to know the frequency distribution of caves with certain features such as constructional dynasty or with particular risk characteristic such as deterioration degree at the beginning of analysis. The bar chart is used to meet this demand. The x coordinate represents the risk characteristic or cave features which also are the endogenous factors. The y coordinate represents the frequency of caves. The height of the bar indicates the frequency of caves with the same x value (Fig. 6). Second, conservators expect to detect the association between one single endogenous factor and a specific kind of deterioration risk. A set of boxplot is used to analyze whether the risk characteristic such as the deterioration degree or the rate of deterioration change is associated with some endogenous factors (Fig. 7). The y coordinate represents the degradation degree or the rate of change. Each boxplot represents the subclass of one kind of endogenous factor. Then the data distribution of risk characteristic can be identified. Analysts can determine whether an association exists between the endogenous factors and the risk characteristic. Finally, conservators often request to explore the relationship between several endogenous factors and deterioration risk characteristic. The scatterplot is used to show multivariate endogenous factors of deterioration risks (Fig. 8). In Fig. 8, three endogenous factors are selected. They are the constructional

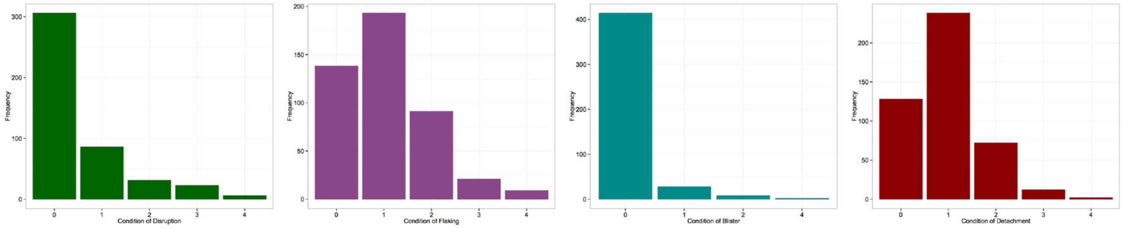

Fig. 6 Frequency of caves with different deterioration conditions

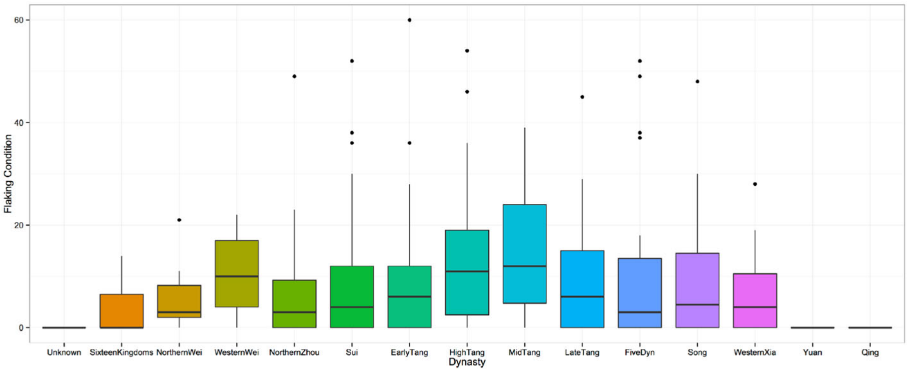

Fig. 7 *Boxplot* to analyze the relationship between deterioration and constructional dynasty

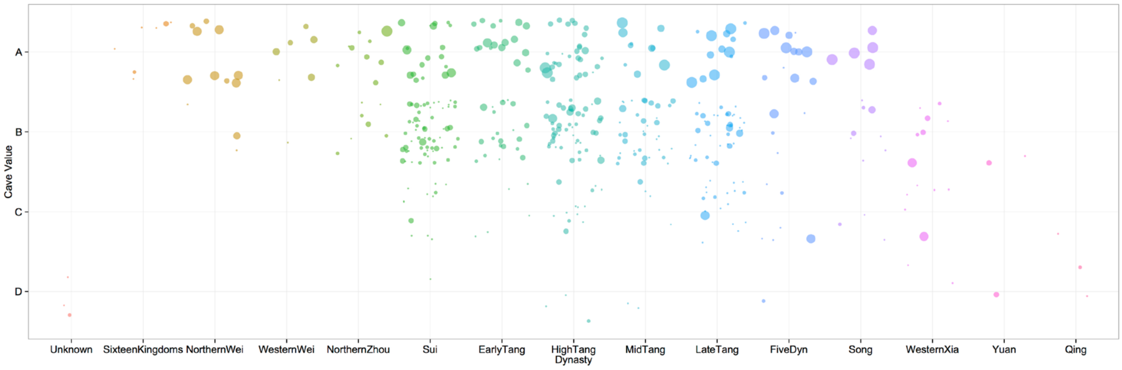

Fig. 8 Relations between value, constructional dynasty, and area of cave

dynasty (x coordinate), the cave value (y coordinate), and the cave area. The color is used to represent the constructional dynasty, and the size of point is used to represent the cave area. In addition, the faceted scatterplot is used to analyze the relationship between the endogenous factors and the risk characteristic (Fig. 9). From this visual analysis, some clues are expected to be found.

4 Evaluation

4.1 Case study

Our method is used for risk analysis in Mogao. We choose four categories of deterioration risks as study objects, namely disruption, flaking, blisters, and detachment (Fig. 10). These four types of degradation are common in Mogao and have relatively high activity.

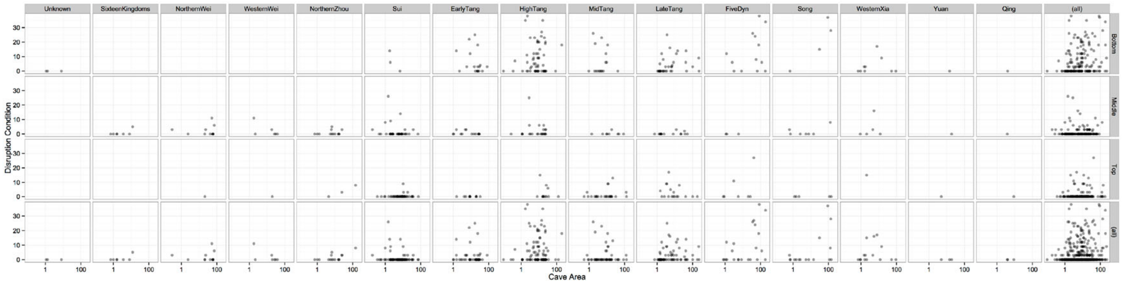

Fig. 9 Faceted scatterplot to analyze the relationship between deterioration and three endogenous factors

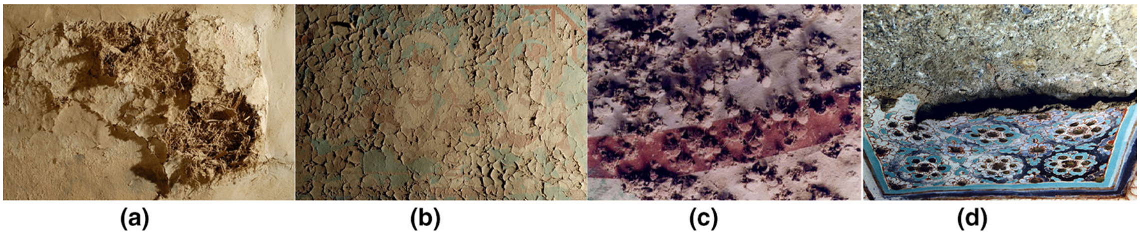

Fig. 10 Deterioration of wall painting. **a** Disruption, **b** flaking, **c** blisters, **d** detachment

Table 1 Cave constructional dynasties

Dynasty	Period (AC)	Dynasty	Period (AC)
Sixteen Kingdoms	366–439	Middle Tang	781–847
Northern Wei	439–534	Late Tang	848–906
Western Wei	535–556	Five Dynasties	907–959
Northern Zhou	557–580	Song	960–1035
Sui	581–618	Western Xia	1036–1226
Early Tang	618–906	Yuan	1227–1368
High Tang	705–780	Qing	1636–1912

The goals of the case study are the following: (1) to perceive the risk attribute from multiple angles, (2) to estimate the risk magnitude of deterioration risk, and (3) to analyze the possible cause of the deterioration.

First, the deterioration risk involves two important sides of the attribute that analysts have to understand before further analysis. They are the risk object and risk characteristics. What analysts need to know about the risk object is that each cave in Mogao has its own spatial distribution, constructional dynasty, area, and value. The deterioration risk characteristic generally includes the extent of deterioration and rate change. They are an important basis for estimating the level of risk and for conducting risk cause analysis. The preceding information is presented by the spatial view (Fig. 2) along with a set of four bar charts (Fig. 6) and a scatterplot (Fig. 8). Furthermore, each type of deterioration can be filtered separately to show the distribution more clearly (Fig. 3).

The spatial view shows that most of the disruption occurs at the bottom caves, while the other three types of deterioration have few obvious distribution patterns. The cave features, which are dynasty (*x* and represented by different colors), value (*y*), and area (size of point) in Mogao, are shown in Fig. 8. The figure shows that (1) all caves constructed before the Northern Zhou dynasty are highly valuable and (2) most of the large caves are highly valuable.

Second, in the case of flaking risk, the risk level of each cave is estimated with a clustering technique and the results are presented by the special view, a scatterplot, and a bar plot (Fig. 4). The results show that most of the caves are at risk level 2, and the caves at risk level 4 are the fewest. As regards the spatial distribution of risk level, no obvious pattern is observed.

Finally, we choose three endogenous factors, which are constructional dynasty, cave position, and cave area, to analyze their impact on deterioration. A total of 14 dynasties are recognized in Mogao (Table 1). More caves were constructed between the Sui and High Tang dynasties than during other periods (Fig. 11).

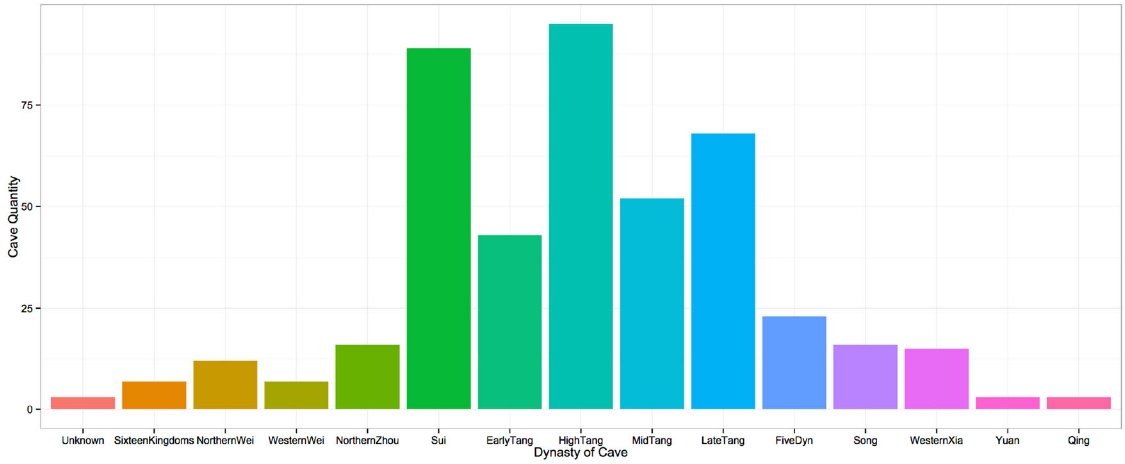

Fig. 11 Frequency of caves constructed in different dynasties

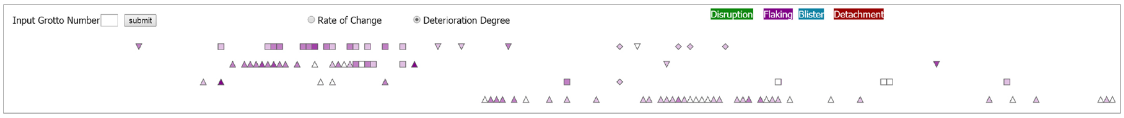

Fig. 12 Flaking distribution of High Tang caves

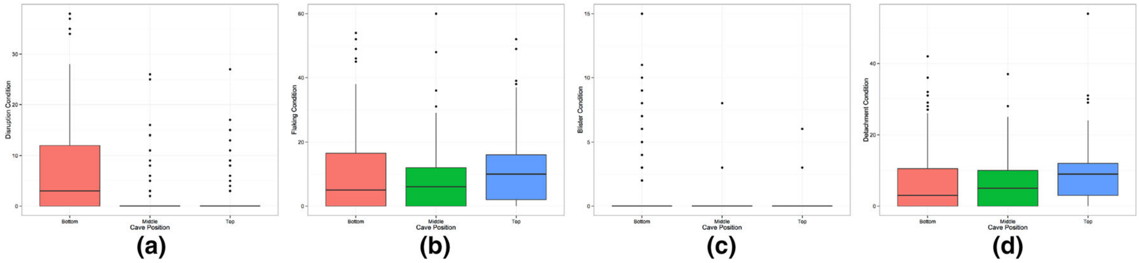

Fig. 13 *Boxplots* to analyze the relationship between deterioration and cave position. **a** Disruption, **b** flaking, **c** blisters, **d** detachment

As mentioned, dynasty is considered as an endogenous factor of deterioration instead of construction material and technique. We analyze the relationship between the dynasty and four types of deterioration using the boxplot method (Fig. 8). We find a certain association between the dynasty and flaking. With regard to the other three types of deterioration, no such association is discovered. The caves constructed during Western Wei (the fourth dynasty shown in Fig. 11) are fewer but have more serious flaking than those constructed during an earlier period. From the Northern Zhou to the Early Tang dynasties, the severity of flaking is at a lower level. Then, the level of severity increases again from the High Tang to the Middle Tang dynasties. The constructional dynasty has an effect on the vulnerability of caves in terms of flaking. Experts suppose that the paintings during the early period were different from those during the Tang dynasty. Rendering between the wall and paint layer is observed in the Tang caves but not in the early-period caves. Flaking is likely to be observed on the paintings with rendering. The flaking distribution of High Tang caves is presented in Fig. 12.

As defined in Sect. 3.2, the cave position includes three types, namely bottom, medium, and top. We aim to determine whether a relationship exists between the deterioration and the cave position. The spatial view and a set of four boxplots are simultaneously used in our analysis (Fig. 13). The caves at the bottom are most vulnerable to disruption. Caves that suffer from blisters are few, but most of them are at the bottom because both disruption and blisters are caused by water and salt. The cave at the bottom is likely to suffer from the effect of water, which leads to salt dissolution and swelling or precipitation.

A faceted view of the scatterplot (Fig. 9) is used to determine whether the deterioration is affected by multiendogenous factors. For example, in the case of disruption, the constructional dynasty, area, and position of the cave are analyzed simultaneously. The x coordinate is the base-10 logarithm of the cave area, which makes the difference more obvious. The y coordinate is the degree of disruption. Caves are grouped according to constructional dynasty and position. The disruption degree and cave area seem to have a weak positive correlation.

4.2 Expert review

The expert review is performed to evaluate our method from usability, visual design, and knowledge discovery. The evaluation experts, who are conservators and managers, are from Dunhuang Academy, an institute responsible for the Mogao conservation. All experts consider our work valuable. They believe that our method proposes a tool for conservators to perceive the documentary data effectively and to analyze the deterioration from overview to parts. The method enables intuitive observation of the distribution of various types of deterioration and other cave attributes such as the constructional dynasty. The method also provides a basis for preventive conservation. The visual design meets the working demand of conservators because it is highly intuitive in positioning the deterioration without "translation." The knowledge discovered by the method is also proven by experts. In summary, all of the evaluation experts agree that our method is useful for deterioration risk management. The experts have provided advice on visualization, such as color and glyph, to help us revise our work in the future. Finally, the experts hope that our method could be used in Mogao along with the monitoring system.

5 Conclusion

This paper has proposed a visual method for deterioration risk analysis in the framework of risk assessment. A spatial view is designed to help conservators and site managers perceive all deterioration risks and their spatial distribution explicitly from an overview before further analysis. Then, two visual analysis methods are proposed for the two main purposes of risk analysis. One is the visual analytics method for risk magnitude analysis based on clustering technique. The other is a visual method to determine the cause of deterioration risks.

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