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METHODS FOR THE PRESERVATION AND RESTORATION OF DUNHUANG WALL PAINTINGS: FOREIGN EXPERIENCE

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Abstract

This article examines the genesis of planning solutions and ceiling designs of Dunhuang cave shrines. Based on the methods of defining features, graphic-and-analytical and system-and-structural analysis, the spread of types of plans and ceilings from dynasty to dynasty has been traced. Using auxiliary methods of historical, mathematical, and comparative analysis, a general picture of the development of the planning structure and constructive schemes of Dunhuang shrines from the Northern Lian period to the Yuan period has been created. By counting the types of plans and ceilings in each period, a group of the most common types of plans was determined: with a combination of larger and smaller rectangles (where the smaller is the altar part of a square or rectangular shape), a plan in the form of a square with a protruding trapezoidal altar, an altar in outline close to a rectangle or trapezoids with rounded corners, a horizontally elongated plan rectangle, based on squares with protrusions. The most common type of ceiling is fu-dou-ding with modifications.

Keywords*: China; Dunhuang; Cave plan; Ceiling; Genesis*

Introduction

The uniqueness of the Dunhuang cave complex lies not only in its status as the largest Buddhist cult object in the world, which was formed over one thousand years but also as a museum of Buddhist art in an authentic environment. Its main value is the wall paintings, dating from the 4th to the 14th century. Unfortunately, those ancient wall paintings were affected by negative natural factors, resulting in the peeling of the paint layer, its crumbling, pollution, loss of fragments, and the problem of their reproduction.

The issue of the state of ancient architectural and artistic monuments is important for many countries around the world. Therefore, in this study, the recommendations of D. Giaccone, P. Fanelli and U. Santamaria [1] were analyzed in the field of monitoring the condition of an object

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over time using modern methods, in particular Geometric Modelling, which significantly reduces the time required to calculate the results obtained. According to the proposed options for fixing the state of monuments, which have different damages, degrees of deformation, as well as complex shapes and decorations, their modeling method also allows for the fixation of internal deformations and the specificity of the design schemes of objects, which also have their own features.

Their approach is based on the method of structural analysis, which distinguishes it from traditional approaches and provides the following advantages:

– taking into account hidden damages during the examination of the object;

– combining visual inspections and instrumental investigations with modeling in various ways (static, longitudinal, modal, and dynamic with a spectrum);

– using modeling methods to fix hidden internal damages, including cracks.

In the presented study, attention is focused on the problems of the emergency state of Dunhuang murals, and foreign restoration experience is analyzed, which can be used for China as well, however, with the correction of local techniques of authentic frescoes and natural and climatic conditions.

The main group consisted of sources dedicated to the restoration technologies and research of the Dunhuang complex itself. In particular, the article by D. Giaccone *et al.* [1], is devoted to the topic of restoration technologies. Y. Ding, I.G. Sandu [2], M. Orlenko *et al.* [3], I. Sandu *et al.* [4]. The group of publications devoted to the history and descriptions of Dunhuang and its artifacts is represented by the works of K. Li [5], T. Yan [6], S. Wang [7], W. Duan [8-10], Z. Shi [11].

The second group consisted of publications that helped to more broadly analyze aspects of the restoration of the Dunhuang wall paintings. They covered various aspects:

– general aspects of protection of the historical environment, memory of the place, museology – articles by V. Petrušonis [12], L. Pujia [13], I. Sandu *et.al.* [14], P. Spiridon and I. Sandu [15], P. Spiridon *et al.* [16];

– mutual influences of the historical object and the environment – the publication of Y. Ivashko *et al.* [17];

– the concept of a work of art and art in restoration – articles by P. Gryglewski *et al.* [18], M. Orlenko and Y. Ivashko [19];

– religious and worldview aspects of Chinese architecture and art – articles by M. Krupa *et al.* [20], Y. Ding *et al.* [21], Y. Hong [22];

– general aspects of Chinese architecture and art – publications by Y. Ivashko *et al*. [23-26], Z. Li [27], M. Orlenko *et al.* [28], M. Żychowska *et al.* [29-30];

– foreign restoration experience – articles by S. Baiandin *et al.* [31], Y. Ivashko *et al.* [32], M. Orlenko *et al.* [33].

The purpose of the article is to characterize the wall painting of Dunhuang sanctuaries from the point of view of the peculiarities of its execution techniques in different periods, to analyze the existing Chinese experience of restoration of Dunhuang frescoes, and to compare it with foreign methods.

Materials and methods

General scientific research methods were used in the study of the practical block, including field inspections, photography, modeling, experimental, and graphic-and-analytical methods. Theoretical block methods such as historical, cultural, art, and comparative analysis were used as auxiliary methods.

The dominance of practical research methods is because the conclusions of the research are aimed directly at practical activities, namely the protection and restoration of Dunhuang murals. Part of the methods of the theoretical block is aimed at evaluating the specifics of the

Dunhuang wall painting as a whole and at different historical periods, and the method of comparative analysis allows comparing Chinese and foreign approaches to the restoration of wall paintings.

Results and discussion

Figurative and technological characteristics of Dunhuang wall paintings

The analysis of the pictorial concept of the interiors of the shrines of the Dunhuang complex includes the systematization of the plans of the caves, as this precedes the study of the specifics of the location of the works of art on the planes and in the space of the sanctuaries.

The main problem of the destruction of the wall paintings of the Dunhuang caves is related to jamming due to the aggressive influence of water sources – rivers, underground water, precipitation, as well as the influence of irrigation of agricultural lands. Together, the action of these aggressive factors leads to an increase in the humidity of the surfaces of sanctuaries.

One of the options for solving the problem of excessive moisture is the replacement of the land irrigation system, the replacement of tree species in the area, and the protection of stone surfaces with a special protective system against precipitation.

Studies of the Dunhuang murals have proven that the paints are based on natural mineral pigments, which explains their brightness. Chemical analysis of pigments proved the use of more than thirty types of pigments based on natural minerals (mainly) and synthetic chemical dyes (in small quantities). Azurite, malachite, cinnabar, vermilion, clam powder, gold, silver, and mica were used as mineral pigments. The frescoes of the archaic period had mostly dark colours, and paints based on malachite and ultramarine pigments were used to paint the background (Figs. 1 and 2).

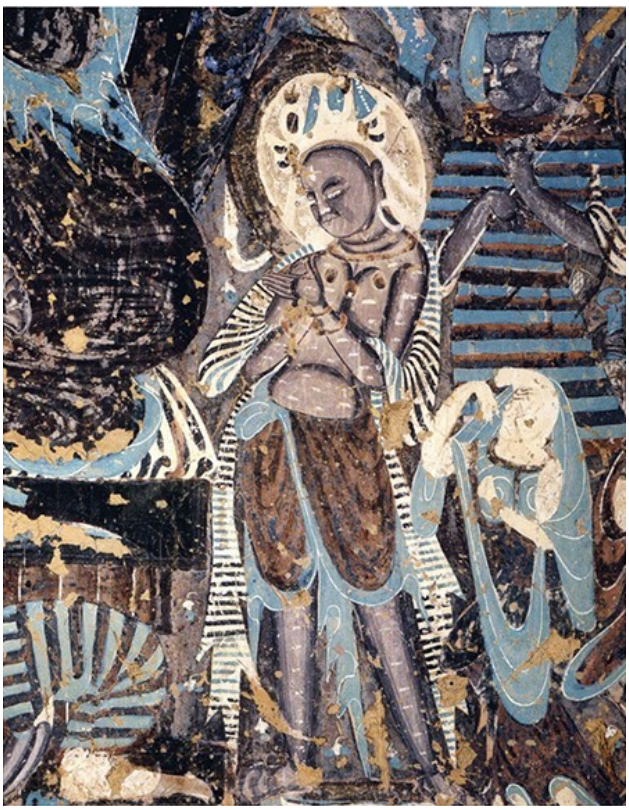

Fig. 1. Cave 254, Northern Wei period (439 – 534). The plot with the Buddha

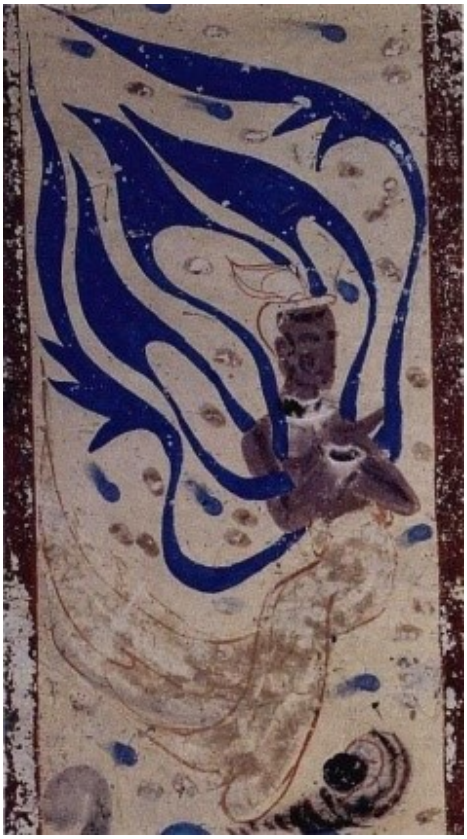

Fig. 2. Cave 248, Western Wei period (535 – 556). Deva (Heavenly Being)

The periodization of the mural paint colours differs somewhat from the three periods of thematic mural painting (depictions of the Buddha, portrait, and landscape genres): the early period – from the Wei dynasty to the Sui dynasty, the middle – the Sui and Tang dynasties and the Five Dynasties and the Late – the Song and Yuan dynasties. It was established that the colour scheme of the wall paintings corresponds to the traditional concept of colour in Buddhist art.

The pigments of the frescoes of the Wei Dynasty are based on laterite, cinnabar, lapis lazuli, azurite, verdigris, malachite, and kaolin. The selection of pigments corresponded to the common concept of a limited number of bright saturated colours. This corresponded to the mural concept of the Xiyu (Western China) style. Dunhuang frescoes of the Wei period are based on the use of white powder with the colour of laterite as the main tone and use pigments based on azurite and malachite. Such a colour scheme based on natural pigments was supposed to contribute to the creation of a festive mood.

The middle period of wall painting of the Sui and Tang times (Figs. 3 and 4) was marked by a gradual departure from the Xiyu style towards the local style of the Central Plains, the colour scheme becomes more complex with the use of artificial red colour, a combination of monochrome and polychrome techniques with a high level of execution. The innovation was not only in imagery, but also in the chemical composition of paints, where, in addition to pigments based on laterite and azurite, grass-green pigments are used, fragments of frescoes are covered with gold leaf to emphasize the grandeur of the subjects and depicted figures.

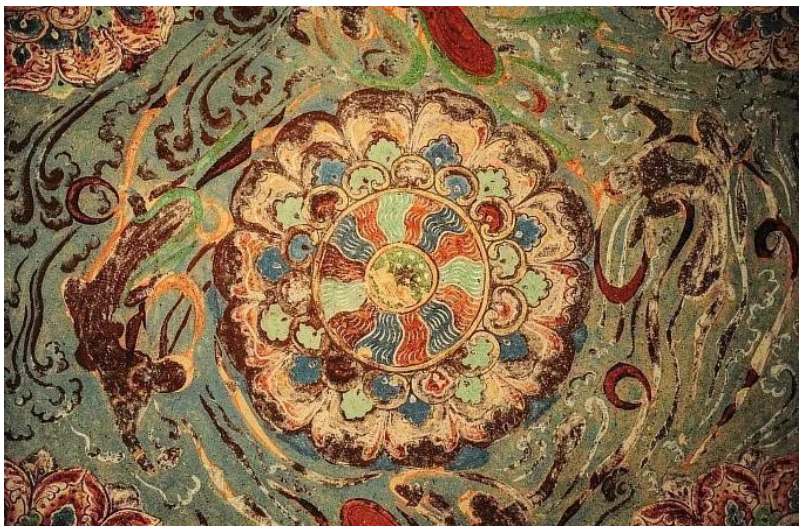

Fig. 3. Cave 329, Early Tang period (618 – 704). Image of Feitian (Flying lotus caisson)

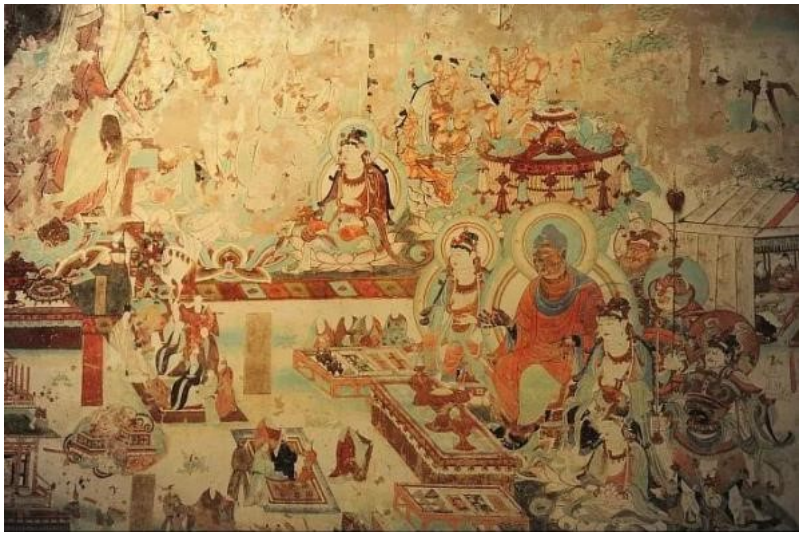

Fig. 4. Cave 25, Middle Tang period (705 – 848). Maitreya's Sutra

The maximum flourishing of frescoes fell during the Tang period (Fig. 5). When the frescoes were executed by the Western Region Concave-convex Method with simultaneous visual effects, detailing of the decor, gradations of colour brightness, and contrast between cold and warm colours. In addition to previously known pigments based on natural minerals, their pigments are used, such as lead minium, verdigris, and soot.

All colours are extremely bright, and the frescoes are distinguished by the richness of polychromy. The later period of polychromy is characterized by subdued colours influenced by Tibetan tantrism (Fig. 6). The main focus is on linear drawing, complemented by colour.

Thus, an important aspect, along with the analysis of the stylistics of the wall painting, is the analysis of the chemical composition of paints.

Fig. 5. Yulin Cave 25, Middle Tang period (705 – 848). "Dance and Music"

Fig. 6. Cave 465, Yuan period (1271 – 1368). The plot with the Buddha

The use of paints based on mineral pigments was because mineral pigments have saturated colors and do not change their colour over time. This genre of painting based on mineral pigments with bright colours was called "Zhòngcǎi hua" ("saturated colour paintings"). After the Yuan dynasty, paints of this composition were almost not used.

Based on mineral pigments, the painting derived from ancient rock painting in the technique of "Gōngbǐ zhòngcǎi" ("Meticulous and colorful") is performed, where such mineral pigments as cinnabar, azurite, malachite, gold, and white powder are used.

Although this genre lost its importance after the Yuan Dynasty, the principles of using paints based on mineral pigments were used until the appearance of Western painting techniques in the Qing period.

The tradition of mineral pigment-based paints was rediscovered in the early 20th century with the discovery of the Dunhuang Murals, which led to a revival of the "Gōngbǐ zhòngcǎi" genre, from the 1930s until today, artists have been researching and copying Dunhuang murals to modernize their paintings traditions of this technique.

During the Wei dynasty, frescoes typically had a flat background without any expression of spatial planes, and the dominant color was laterite. Initially, a white color was applied, followed by other colours. During the Tang dynasty, to achieve a three-dimensional effect of Buddha and bodhisattva figures, a special effect was used called "drainage powder" (Lì fěn), to which metal foil was attached "leaking powder and gilding" (Lì fěn tiē jīn). The colours based on natural mineral pigments were bright and pure to attract visitors' attention.

The second special method that was used in the Dunhuang murals is the “Yūn rǎn” method (smudge – the technique of retouching or applying a shadow) in combination with the line drawing method (Xiàn miáofǎ), which made the image more flexible and brighter and thus influenced the imagery of modern variant of painting "Gōngbǐ zhòngcǎi". The technique of "Méi gǔ huà fǎ" (Boneless painting method) in modern "Gōngbǐ zhòngcǎi" imitates the combination of bright colour spots on Dunhuang murals, where the fine lines that outline the forms have been lost over time.

Thus, despite its age, the Dunhuang frescoes demonstrate high achievements in the technique of paints, for the production of which dozens of mineral pigments (minerals and materials from the Xiyu regions), as well as gold powder and gold leaf, were used.

Modern painting "Gōngbǐ zhòngcǎi" is also based on the use of mineral pigments, but artificial ones, which are characterized by the expressiveness of color, as well as on the use of metal foil to enrich the effect.

Dunhuang's frescoes with the so-called "thick background color" (Thick background color) also influenced similar techniques of modern "Gōngbǐ zhòngcǎi".

China's restoration experience and analysis of foreign experience

In recent decades, China has been actively involved in the process of exchanging experiences with restorers from other countries. One of the latest examples is the Third Qujiang Mural Painting Forum – an international scientific conference dedicated to research in the field of mural art history and conservation and restoration technologies", which took place in 2017. Sixty restorers from different countries of the world took part, and several reports were related to the preservation and restoration of Dunhuang frescoes, as well as wall paintings of ancient burials.

As experts, employees of the Institute of Archeology of the Academy of Social Sciences, the Dunhuang Research Institute, and the Chinese Academy of Cultural Heritage shared their practical experience of restoring ancient Chinese frescoes. Xi'an Qujiang Art Museum is known since 2012, it specializes in the preservation and exhibition of Chinese murals and demonstrates the genesis process of ancient Chinese wall painting.

Ge Chengyong, a professor at the Chinese Academy of Cultural Heritage, gave an important presentation characterizing the presence of secular themes in the frescoes of the Tang Dynasty, noting that a number of the plots were created under the influence of Tang poetry.

A report by Hou Shixin, director of the Xinjiang Museum, confirmed the influence of Indian art on early Chinese frescoes. Ken Okada, director of the Tokyo Institute of Cultural Properties, spoke on the importance of copying and restoring ancient frescoes, emphasizing the need to analyze current copying techniques. Okada acknowledged the contributions of his predecessors in the field of copying frescoes but stressed the importance of updating techniques to ensure the preservation of these ancient artworks.

Italian restorer Maria Perla introduced modern Italian tools and methods that reveal the technology of using gold foil on medieval frescoes, as well as methods of applying glycerin-based glues and adding inorganic pigments (mainly white) and ochre. Professor Tonia Eckfield from the University of Melbourne, a participant in the collaborative program between scientists in Australia and China in the field of research on Tang and Yuan era murals, introduced the characteristics of low-concentration adhesives that can be found in the dry layer of wall paintings.

He Ping, director of the British Central Asian Archaeological Society, gave a talk related to the topic of the dissertation. He made a comparison between Indian Gandhara Buddhist art and Dunhuang frescoes.

A report by Wang Zhengyi from Dunhuang Research Academy was devoted to the study of Mogao caves. Caves 138, 344 and 454 are mentioned in his report.

The specifics of the wall painting style of the Tibetan version of Buddhism and its influence on the wall painting of China have been researched by Zhu Lei of the Fuxin City Museum.

Restorers discussed the main problems of wall paintings, methods of diagnosing damage and technologies for restoring wall paintings. For example, Ma Yirong from the Shaanxi History Museum analyzed the techniques and materials of the Tang era frescoes on the example of the Tomb of Concubine Wu Hui wall painting of this period. In particular, the methods of stereomicroscopy, microscopy with ultra-deep sharpness, X-ray diffraction, scanning electron microscopy, and spectroscopy were used to analyze and study the state of preservation, types of damage and degree of damage, wall painting techniques, and materials used. The mural restoration process was developed by preliminary modeling of all restoration stages.

The Frontier method is used to protect wall coatings in China. In particular, researchers Chen Guoke and Wei Yanfei from the Gansu Provincial Institute of Cultural Relics and Archeology highlighted the results of their practical research on the use of polyacrylic acid-functional graphene $Ca(OH)_2$ Nanocomposites to protect ancient frescoes. They examined a polychrome wall painting of a Tang Dynasty tomb in Gansu province, made mainly with ink lines. The conducted examinations proved that the reverse side of the frescoes is dirty, there are places of loss and cracks, the front part of the mural is deformed from the centre and there is mold on it. The condition of the frescoes was determined as an emergency.

In China, organic (acrylic polymers Parrot B-72 and AC33) and inorganic materials (lime water, barium hydroxide, alkaline earth silicate) are most widely used as reinforcing materials for the protection and restoration of fresco murals.

The disadvantages of these materials are as follows:

– Parrot B-72 and AC33 acrylic polymers after thermal oxidation and light irradiation have signs of aging of the material, and therefore a decrease in mechanical strength and shedding of the mural layer;

– lime water, barium hydroxide, and alkaline earth silicate have poor permeability and their crystallization of soluble salts during use limits their scope of application for reinforcing wall paintings.

Chen Guoke and Wei Yanfei give an example of a new effective, but rather expensive inorganic nanomaterial nano $Ca(OH)_2$. The disadvantages of this material include the following:

– high production cost;

– large particle size;

– slow process of carbonization;

– insufficient reinforcement strength.

Taking into account the shortcomings of these reinforcement techniques, Chen Guoke and Wei Yanfei proposed their method of strengthening and protecting murals with graphene-based nanomaterials. The technology assumes that functional graphene materials based on polyacrylic acid graphene / nano $Ca(OH)_2$ are synthesized by the aqueous solution method. The properties of the $PAAG_@Ca(OH)_2$ material were investigated using transmission electron microscopy, X-ray diffraction, and X-ray photoelectron spectroscopy, and the following parameters were determined:

– high porosity;

– strong adsorption;

– hydrophilicity is required;

– good level of vapor permeability;

– strong adhesion to wall pigments;

– combination of characteristics of inorganic and organic materials for the synthesis of a new type of composite material based on calcium hydroxide and polyacrylic acid resin.

The research procedure involved comparing the reinforcing effect, bond strength, hydrophilicity, and permeability of AC33 and $PAAG_@Ca(OH)_2$ nanocomposites on the surface of a fragment imitating a fresco in laboratory conditions. The obtained results proved the superiority of $PAAG_@Ca(OH)_2$ in terms of porosity, adsorption, hydrophilicity, and permeability, in addition, its effect on the surface of the sample was not so noticeable, which proved its superiority as a material for reinforcing frescoes.

This research was funded by the National Social Science Foundation, the State Administration of Cultural Relics, the Scientific and Technical Research Project for the Protection of Cultural Relics of Gansu Province (Research on the application of functional graphene polyacrylic acid/nano Ca $(OH)_2$ in the reinforcement of murals).

The next aspect of mural restoration is the elimination of excessive moisture. A separate problem is associated with excessive salinity. Salt removal involves the use of the following water desalination tools:

– three-part desalination layer: mural protective layer, desalination material layer, buffer layer. A soft pad protects the mural by absorbing salt. The protective layer (made of cotton fabric) comes into contact with the fresco and protects it from damage, the desalination layer is a material with high water absorption, high salt absorption, the buffer layer (two centimeters thick sponge) prevents damage to the surface of the painting under the influence of external forces;

– desalination board – a support plate with a ventilation hole, filled with a desalinated gasket.

Water desalination works are carried out at a temperature of 15 – 35ºC and a humidity level of less than 75%.

The desalination process is carried out when soluble salt accumulates after grouting the seams and reinforcing the drum cavities. The vacuum box is a box with a desalination plate, so its size is adapted to the dimensions of the desalination plate. The desalination equipment consists of a vacuum chamber, a desalination plate, and a vacuum pump, and the pressure of the vacuum pump is adjustable at the level of 0.0 –15.0kPa.

The process of laying plates for desalination happens in several stages:

– the desalinating plate is placed into a vacuum box, and a support rod is attached to the construction scaffolding to secure the vacuum box with the desalinating plate on the fresco.

– the tightness of the support for the desalinating plate is chosen according to the location of the fresco.

– the desalination zone should not be too large, and the edge of the desalinating plate should be 20–30cm higher than the grout zone to reduce moisture diffusion from the grout material to the edges of the reinforced area.

– the suction nozzle is connected to the vacuum pump, and the suction volume is adjusted so that the negative pressure value of the vacuum pump is within the range of 5–7kPa.

If the relative humidity of the air on the surface of the mural exceeds 60%, it is necessary to replace the desalination (desalination) material. on the other hand, when the relative humidity of the air on the surface of the mural is less than 60%, the desalination material should not be replaced, but one should wait until the relative humidity on the surface of the mural does not break with the relative humidity of the surrounding environment. If the relative humidity of the air exceeds 60%, the relative humidity of the air on the surface of the mural corresponds to the relative humidity of the indoor air, the desalination (desalination) material should be replaced every two days, and the desalination plate should be removed after its replacement four times.

In the process, the relative humidity of the air in the desalination plate is monitored: a card with a humidity indicator is placed behind the vacuum desalination plate and the value of the humidity level is recorded when it changes.

The next operation is the secondary desalination (desalination) of water, which is carried out because after desalination of the fresco with the help of a desalination plate, soluble salts remain in uneven depressions, for secondary desalination an ultrasonic sprayer of water vapor is used, and the operation itself takes place in several stages:

– with the help of steam generated by an ultrasonic water vapor sprayer (steam temperature 200°C, the amount is regulated depending on the area of the surface of the mural to be treated), soak absorbent cotton paper measuring 5 x 5cm and apply it to the surface of the mural, then press it with a soft a sponge for close contact with the mural, and when the paper dries, it is removed;

– after 7 – 8 times of organized adsorption, the result is the removal of crystalline precipitates from the surface of the mural.

These issues are particularly relevant in the case of the unique Dunhuang Wall Painting, the world's largest collection of unique Buddhist artifacts, chief among which is a wall painting that span 1,500 summers of multiple dynasties.

Li Yunhe became the first professional restorer of the frescoes in 1956, but due to the lack of a sufficient number of local restorers, Czech restorers were invited to remove contamination, desalination and restoration of the upper layer. Li Yunhe has been involved in the restoration of Dunhuang murals for 63 years, contributing to the restoration of more than four thousand square meters of murals.

The difficulty of these works in those years was that he had to sleep in the dusty sanctuaries during the restoration works, it was cold inside the caves in winter and hot in summer. He is considered the progenitor of the restoration of the Dunhuang caves because based on familiarization with the practical restoration experience of Czech specialists, as well as his improved wall painting restoration technique, he made other enthusiasts interested in the Dunhuang wall painting and contributed to the recognition of Dunhuang in the world.

The technologies developed by Mr. Li were as follows:

i) the first method – the restorer from the scaffolding inserts a tamponade tube into the gap between the mural and the wall, takes the prepared cement mortar into a syringe, fills the empty part of the mural through the tamponade tube, and then uses the siding to support the wall from above and glues the mural to the wall;

ii) the second method – is used in the event of a threat of excessive moisture to the wall of the base for the mural, in this case, the restorer first fixes the mural in front, then exposes the wall and installs a metal frame on the reverse side of the mural, thus leaving a distance of 8 –10 cm between the mural and the wall and the risk of damage to the fresco both from excessive moisture on the wall and from an earthquake is reduced;

iii) the third method involves gluing the mural to the base using modern diagnostic methods, such as X-ray fluorescence, X-ray diffraction, scanning electron microscopy, cross-sectional microscopy, laser microscopy, and confocal spectroscopy, which determine the characteristics of the original materials and technologies of mural painting. Subsequently, the process of "transferring" the mural to the base, which corresponds to the characteristics of the

original base for the mural, takes place. In this way, a large part of the murals was preserved and restored, such as the mural with the image of the Buddha, where part of the image was peeled off. First, the planes of the wall painting of the lower tier were restored, and then the lost fragment was recreated using analogs. The work continued during 2012-2014.

In the presented study, an analysis of the Ukrainian experience of restoring frescoes of the pre-Mongol period was carried out to compare them with Dunhuang frescoes and methods of their preservation and restoration. The main difference is where these murals are located. In Ukraine, ancient frescoes cover planes in temples, while in China, wall paintings have been used in tombs and cave sanctuaries since ancient times. In contrast to China, the caves in Kyiv, in the Kyiv Pechersk Lavra, and Chernihiv on the Boldyn Mountains are not covered with wall paintings, there was no such tradition, and the caves were used as cave churches and burial places of saints and a few laymen.

The preparatory stage in the restoration of monumental painting, one of the varieties of which is a fresco, is the compilation of cartograms of the paintings' state, which was first introduced as a method of cartographic fixation by the artist-restorer L.P. Kalinichenko in 1947-1952 [5, p. 549].

In the field of restoration, making cartograms of the state of the painting is not the same as copying frescoes, which was carried out by Dunhuang research artists, although such copying is part of the cartograms. When drawing up cartograms of the state of the painting, a systematic holistic picture of the presence of the painting (in our case – a fresco mural) is presented with the measurement of the entire room and the drawing of sweeps of walls, ceilings, and vaults, on which linear images of all frescoes are applied (actually, what was done for each fresco research artists of Dunhuang) [5, p. 549]. Architects' measurements (plans and sections), if available, are also used.

Developments of all surfaces with the application of murals' linear images are performed on millimeter-squared paper at a scale of 1:10 or 1:20, and the scale for all planes with images must be the same [5, p. 549]. In the case of a large size of plane with a mural, its development is divided into several parts, and the division is usually taken according to architectural details.

In the case of fresco wall painting on curved surfaces, there is a problem of image distortion. To solve this issue, the surface is conventionally divided into several planes, with the sequential creation of the surface development for each of them. Their totality will be a conventional surface development along such curved surfaces as a dome, sails, and vault [5, p. 549]. The same method can be applied to the complex surfaces of the Dunhuang sanctuaries.

In the case when there are openings in the plane, door and window reveals and available niches are scanned from the side at this place.

A certain difficulty lies in the construction of a conditional scan of a hemisphere (dome) or a quarter of a sphere (conch), as a rule, in this case, the method of auxiliary cylinders is used. This method consists in the fact that with the help of vertical planes that pass through the center of the hemisphere, its surface is divided into several equal compartments with the sequential construction of the sweep of these compartments, and the number of such compartments can vary depending on the specific task [5, pp. 549 – 550]. Most often, for the conditional sweep of the dome, these are four compartments, conches – three.

When performing conventional surface development, the painting on the surfaces is considered. As an example, we can cite the scanning of images in the dome of Sophia Cathedral in Kyiv (Pantokrator and four archangels), where the planes were divided into a conditional circle and four conditional compartments, each of which contained one image of an archangel [5, p.550]. The example of the wall painting of the Armenian Church in Yalta shows that in some cases there may be a need to divide the surface even into twelve conventional sectors, based on the number of twelve symmetrical elements.

The second method of performing architectural surface development is photogrammetric, more accurate. In this case, the linear contours of all wall paintings are also drawn.

Further, after carrying out architectural surface development of the planes with the wall painting, comprehensive studies of the condition of the plaster and the mural itself are carried out and all types of damage to the plaster and mural, traces of previous restorations or repairs, the presence of plaster layers from an earlier period, wall painting under later images are applied in the form of conventional markings with hatching or colour, etc. [5, p. 550]. This cartogram is a document before the actual restoration work begins. It is used to calculate the volumes and types of projected restoration and restoration works, and based on this, a defect report and cost calculation are drawn up [5, p. 550].

Based on this cartogram of the wall painting state, other cartograms are made (probes with the indication of their locations and sizes, project proposals for the restoration of the wall painting, etc.). For this purpose, the types and locations of the predicted restoration measures are applied to the architectural surface development using conventional markings.

The final stage is a cartogram of the completed restoration works, on which, with the help of conventional markings, contours that differ in thickness, hatching, and colour, all the performed types of measures are indicated with the corresponding locations.

On each sheet of the cartogram of the completed works, there is a heading with the name of the object of restoration, place, orientation, and scale. They can also add other information – dimensions, area, etc. [5, p. 551]. The cartogram is supplemented with a table of conventional designations with an explanation of their meanings. In the right part of the sheet, a stamp is placed with the name of the organization performing the works, the names of the leaders of the restoration work, and the name of the cartogram maker [5, p. 551].

Thanks to the introduction of cartograms into the restoration process, it became possible to have complete control over it, especially since all information about a specific restoration process in a particular location is fixed in the cartogram. After the completion of the mural restoration process, the cartogram is reproduced in the required number of copies and is part of the scientific and technical report on the scope of work performed.

The restoration of frescoes from the pre-Mongol era in Ukraine has faced challenges since the science of restoration and understanding of the differences between restoration and repair only emerged in the 20th century. Therefore, a systematic approach to restoration could only be applied after World War II, with the establishment of the "Budmonument" group, which later transformed into the powerful corporation "Ukrrestoration". Before the mid-20th century, restoration was interpreted as simple repair work, which led to significant damage to wall paintings.

After drawing up the cartograms of the wall painting, the stage of field and laboratory research begins, when the history of the wall painting is analyzed, its fate in different periods and the changes that took place during these periods, technical and technological indicators (the specificity of masonry materials, the chemical composition of plaster, masonry mortar, layers of later times, wall paint layer, mechanical characteristics of masonry). Fixation of layers is carried out by the method of probing, mechanically using a scalpel, or chemically using chemical reagents [5, p. 552].

Places of exfoliation are fixed by tapping the surface with the wall painting with fingers or a rubber medical mallet [5, p. 552]. The places of detachment are determined by sound and marked on the map, based on this data, the places for injection with a strengthening solution are then determined.

After determining the locations of the wall painting peeling from the base, soundings of 3 x 4 cm or, if necessary, larger, are made in the problem area.

Based on analytical, natural, and laboratory studies (which indicate the history and periods of creation of the wall painting, the state of preservation with an indication of the reasons for the state of emergency, places of excessive moisture, fixation of areas of exfoliation), maps-maps of soundings and photo-fixation. The Scientific and Restoration Council is developing a program for carrying out restoration works [5, p. 552]. Separately, after uncovering the whitewash or lime

plastering, cartograms are drawn on a scale of 1:5, 1:10 and 1:20 with the fixation of the state of the wall painting, using conventional designations [5, p. 552].

Just as in the case of Dunhuang's frescoes, the main reason for the unsatisfactory condition of the wall painting, the foundations under it, is a violation of the temperature and humidity regime. That is why the study of the temperature and humidity condition of the room and its parts begins, and in case of violation of the indicators, the causes of the accident.

Sometimes there is an early wall painting under a later layer that needs to be revealed. If the upper layer is chalk, lime, or plaster, it is removed mechanically using a scalpel and a slightly moistened tampon, the upper layer of an oil mural is removed with organic solvents, such as alcohol, pinene, acetone) [5, p. 553]. After removing the upper layer, the lower layer of the mural is washed with an alcohol-water solution consisting of ethyl alcohol and distilled water in equal proportions. A cotton gauze swab soaked in this solution is used to remove contamination from the surface, and a scalpel is used to remove the remnants.

If the upper layer of the wall painting is also valuable, a layering operation is carried out and the removed upper layer is transferred to a new base with the possibility of further exposure.

Another problem with fresco wall painting is the appearance of cracks in the walls and, accordingly, in the wall painting. In this case, injection of cracks is carried out. The design engineer and the restoration artist provide their recommendations in advance. The difficulty of injection work is not to damage the fresco. The procedure for injecting shallow cracks is as follows [5, p. 553]:

– they are used as a solution for sealing plaster or alabaster;

– in the thickness of the masonry, a hole is made to supply the cement-lime solution in a ratio of 1:2, and the distance between the holes is 40-50cm, then the solution is pumped in until it appears in the upper hole;

– the appearance of the solution in the upper hole indicates that the void between the detached mural and masonry is filled;

– close the lower hole with cotton wool and watch so that the solution does not start pouring out directly onto the fresco through the upper hole;

– in some cases, the edge of the crack with the fresco is sealed with mica or cigarette paper on a 5% solution of sturgeon glue;

– during the entire injection process, to prevent the solution from spilling out through hairline cracks, they are previously sealed with tracing paper, which is removed after the solution dries.

In the case of the Dunhuang frescoes, cases of the fresco being transferred to a new base have been described. The "Ukrrestavratsiya" corporation also developed the technology of layering and transferring the fresco to a new base, which consists of the following stages [5, pp. 561 – 563]:

– surface cleaning from contamination;
– gluing the surface with mica paper;
– preliminary marking of fragments;
– dissection with a medical saw of the upper layer of the mural;
– detachment of the fresco or its part;
– treatment of the reverse side of the removed mural;
– preparation of a new base for transferring and securing the removed mural;
– puttying of joints of cuts and cracks;
– fixation of mural pigments;
– puttying of small fragments of wall painting.

Now, let's analyze each stage of transferring the fresco onto a new base in more detail.

The first stage of cleaning the surface from contamination occurs in the following sequence [5, p.561]:

– prepare an alcohol-water solution or an alcohol-pinene emulsion in a 1:1 ratio;

– clean the planes of the mural with a cotton-gauze swab soaked in the prepared solution;

– these measures are carried out for better gluing of paper, gauze, and reinforcing frame.

The second stage of gluing the mica paper surface is carried out as follows [5, p. 561]:

– pre-cut mica paper into pieces, prepare gauze, 10% solution of sturgeon glue with honey in a 1:1 ratio, sodium pentachlorophenol antiseptic at the rate of 0.1% by weight of dry sturgeon glue;

– the surface of the fresco cleaned of surface contamination is sealed with several layers of mica paper, gauze on a 10% solution of sturgeon glue with honey, sodium pentachlorophenol is used;

– when the mural or its fragment, which is to be transferred to a new base, dries after gluing, to preserve the integrity of the mural in the process of its removal, a frame reinforcement is glued to it, which is made of wooden rails with a cross-section of 25 x 30mm, pasted with strips of gauze 5–10cm wide.

The third stage is the preliminary marking of the fragments, which takes place in advance and involves marking for further joining of the parts of the mural that are removed, most often marking parts of figures and other responsible elements [5, p. 561].

The fourth stage of the procedure involves cutting the top layer of the wall with a medical saw. This is a very crucial step and involves the following stages:

– using a pre-prepared medical saw with small teeth, cut to a depth of 8–10mm.

– do not cut the corners during the incision to avoid further cutting with a scalpel or sharp knife.

These steps should be carried out with utmost care and precision.

The fifth stage of exfoliation of the fresco or its part is the most dangerous and responsible, since it is at this stage that the fresco is most likely to be damaged [5, pp. 561–562]. These actions take place in the following sequence:

– a saw, spatula, or other tool is inserted into the slot with the blunt side and the plaster is pressed around the perimeter at an angle;

– then identify the place where the fragment of the fresco falls behind more easily and insert a metal plate in this place to protect the lower layer of the painting in the process of carrying out the peeling operation with the help of an elongated chisel, since this operation is the most risky from the point of view of preserving the integrity of the fresco, under the fragment that is peeling off, additionally put plywood on the subframe as a protective shield.

The sixth stage – processing of the gate side of the removed mural painting transfers to the next stages [5, p. 562]:

– visible frescoes from this place;

– cutting out irregularities from the front side of the fresco;

– securing the tinted ball and sides of the fresco with 15% Polybutyl methacrylate (PBMA) in xylol;

– first prepare 15% of PBMA in acetone;

– place the gate side, which may be clogged, and fill it with putty on PBMA with glue in a base on top (15% of PBMA in acetone);

– after preparing the surface, stick on it a thin paste of 20% PBMA in acetone with added cream and two or three balls of glass fibre fabric.

The seventh stage of the process involves preparing a new base for transferring and fixing the removed fresco. The sequence of steps is as follows [5, p. 562]:

– first, a wooden parquet board is prepared according to the dimensions of the removed fresco;

– a layer of fiberglass is pasted on the board base to carry out the transfer of the mural to a new base;

– the fresco is attached to the new base with a 20% PBMA solution in acetone;

– after the completion of the transfer to a new base, the fresco is opened from the

reinforcement and pasted with gauze and paper, using warm water and mechanical means for this.

The eighth stage – puttying the joints of cuts and cracks – takes place in the following sequence [5, p. 562]:

– pre-prepare a 15% solution of PBMA in acetone with chalk;

– fill the places of styles and deep cracks with the prepared solution;

– after waiting for the treated areas to completely dry, they are puttied with casein-oil putty;

– remove the remains of putty with a moistened cotton wool;

– if necessary, the places of loss and joints are tinted with dry pigments with a 3-4% solution of PVC in tetrahydrofuran, with the help of watercolor paints or with an 8-10% solution of PBMA in acetone with dry pigments.

The ninth stage of fixing pigments in a fresco is associated with a specific type of damage that can occur, known as "dispersion". This happens when the pigments become scattered due to rapid changes in temperature and humidity, causing the wet wall to freeze. In emergencies where oil coatings are damaged, silicon-organic polymers are used to solve this problem. However, these polymers can lead to darkening of the fresco over time. [5, pp. 562 – 563].

The tenth stage – filling small losses of the fresco – takes place in the following sequence [5, p. 563]:

– putty is prepared using a 5% PVC solution with a filler – chalk and dry pigments to match the colour of the plaster;

– apply the prepared putty on places of small losses;

– when the putty dries, its remains are removed with a swab soaked in acetone;

– fragmented areas of losses are tinted with dry pigments on a 3% PVC solution in tetrahydrofuran;

– losses, which occupy a significant part of the fresco, are covered with a neutral tone;

– in the case of multi-temporal wall painting in one room (Sophia of Kyiv, Saviour Cathedral in Chernihiv, St. Cyril's Church in Kyiv), the rules of separating multi-temporal wall painting with a thin (5 – 6 mm) line-edge of a light tone are followed (composition: putty on PVC resin with filler – 5 % PVC solution in dichloroethane or 15% in tetrahydrofuran). If necessary, the border strip is additionally tinted with the same PVC solution with dry pigments.

Conclusions

During the research, the plans of 309 main caves were analyzed to characterize the wall paintings. The specific polychromy of the Dunhuang wall painting and its symbolism should be emphasized. The ancient palette of the Chinese painting "Dānqīng" included blue, red, white, and black colours. Buddhism made its correction in the symbolism of colors, in particular, good deeds were associated with white, and evil deeds with black. Accordingly, the white colour of purity became the colour for images of the Buddha, bodhisattvas, and the goddess of Mercy Guanyin. The colour enhanced the content of the fresco, depicting holiness or solemnity (the golden or red colour of the clothes of Buddhas and bodhisattvas), and the dark side of evil forces (black or dark tones of the demons' figures).

However, the polychromy of Dunhuang's frescoes developed in several stages. In early frescoes, this is the "Xīyù āotú fǎ" (Western Region Concave-convex Method) method from ancient India, when the same colour in tone and saturation expressed the three-dimensionality of the depicted face. Under the influence of negative factors – both external – stone erosion, jamming, and internal – chemical changes in the pigment – the colours of the frescoes changed, the lines became poorly defined, and the faces of the figures darkened.

The fresco restoration methods used in China were defined and characterized:

– Frontier method for protection of wall coatings in China using poly acrylic acid-functional graphene $Ca(OH)_2$ Nanocomposites;

– the use of organic (acrylic polymers Parrot B-72 and AC33) and inorganic materials (lime water, barium hydroxide, alkaline earth silicate) as reinforcing materials for the protection and restoration of fresco wall paintings;

– a method of strengthening and protecting frescoes with nanomaterials based on graphene materials based on polyacrylic acid graphene / nano $Ca(OH)_2$, which are synthesized by the aqueous solution method;

– desalination and elimination of excessive moisture using a three-layer desalination pad and desalination plates with secondary desalination;

– the use of Li Yunhe's method concerning the elimination of peeling of the mural using a tamponage tube, syringe, cement mortar, and siding;

– the use of Li Yunhe's method regarding the elimination of excessive moisture, when the restorer first fixes the mural in front, then exposes the wall and installs a metal frame on the back side of the mural, thus there is a distance of 8-10 cm between the mural and the wall and the risk of damage to the mural as a result of excessive moisture is reduced walls and earthquakes;

– the use of Li Yunhe's method regarding the removal of fresco detachment using modern diagnostic methods, such as X-ray fluorescence, X-ray diffraction, scanning electron microscopy, cross-section microscopy, laser microscopy, confocal spectroscopy, which determine the characteristics of the original materials and technologies of mural painting. Subsequently, the process of "transferring" the fresco to the base, which corresponds to the characteristics of the original base for the mural, takes place.

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