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RATIONAL AND AESTHETIC PRINCIPLES OF FORM-MAKING IN TRADITIONAL CHINESE ARCHITECTURE AS THE BASIS OF RESTORATION ACTIVITIES

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Abstract

Chinese architecture is characterized by an original structural scheme, a specific volumetric and spatial composition, and expressive silhouette, the tone of which is set by the roofs of an unusual concave end-up shape, emphasized bright polychrome with open colours and decor. All these components were not random and were not caused only by the whim of the architect or customer, but for thousands of years have been regulated by the principles of Feng Shui, the canons of Taoism, Confucianism and Buddhism. That is why every detail of the structure was provided with a particular hidden meaning. However, the spread of wood construction over time led to the emergency state of many small pavilions and gazebos. Chinese researchers pay attention to the poor state of many historical pavilions and gazebos and negative examples of their reconstruction, which distorted the primary structure of the object. Since the authenticity of the architecture is completely lost as a result of such "reconstructions", the experience of the Ukrainian special research and restoration-design-production corporation Ukrrestavratsiia, obtained on numerous wooden churches and wooden structural elements of buildings for other purposes, can be useful in conservation and restoration of China wooden objects.

Keywords*: Chinese pavilions; Building structures; Conservation; Restoration; Authenticity*

Introduction

The Chinese pavilion has come a long way from simple strategic structures at the borders to graceful buildings that fit well into an artificially created or natural landscape and accented by bizarre roof shapes, decor and flowers. Chinese design schemes have spread along with Buddhism outside the country, and have become virtually universal for various climatic conditions, which indicates their perfection and functionality.

The analysis of the Chinese pavilions proved that at the same time, there were several schemes of the proportional and metro-rhythmic composition of pavilions based on the local modules and canons.

The loadbearing structures of the pavilions were wooden, as in most ancient buildings in China, especially considering the availability of the appropriate amount of timber suitable for construction (Fig. 1). The stone was used for laying foundation and bases, while building superstructures were made of wood, and roofs were tiled. The use of a system of inclined

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coatings becomes a distinctive feature of Chinese and Japanese architecture, and it is the design variation of Chinese roofs under the conditions of a large amount of precipitation from Persian, Asian and Indian roofs in the hot dry climate.

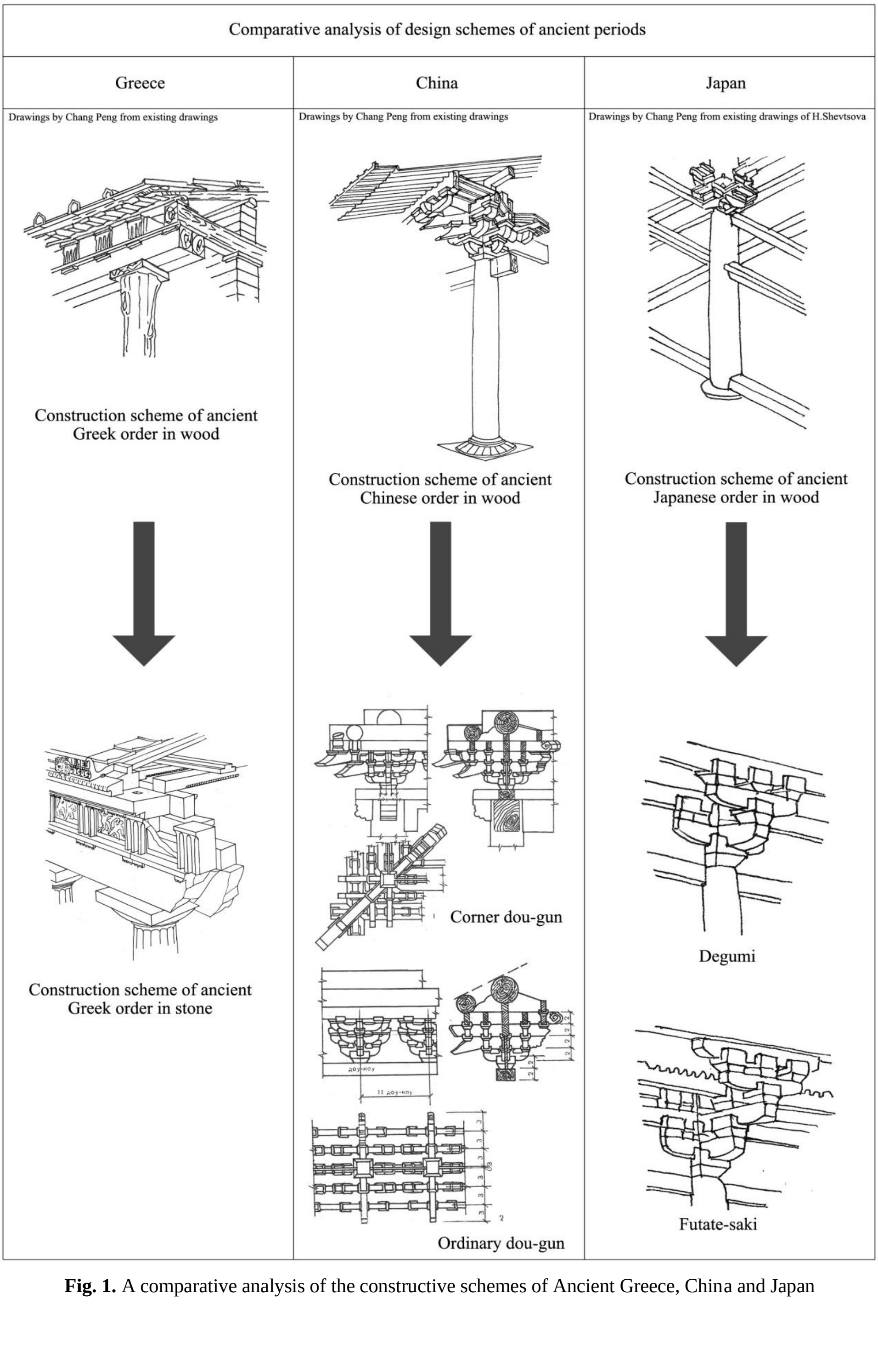

Fig. 1. A comparative analysis of the constructive schemes of Ancient Greece, China and Japan

Chinese researcher Zhang Guanying recalls the example of replacing approximately 1949 authentic wooden structures of the gazebo at the Huaisheng Mosque in Guangzhou with reinforced concrete, two other wooden gazebos underwent similar changes [1]. This led to the loss of authenticity of the gazebo image, its materials and structures and should be considered as a negative example of interference in the historical object primary structure, as in this case were not complied with the main rules of the restoration work.

For a long time, an international team of restorers studied the causes of the emergency condition of wooden monuments of different countries and analysed the most effective methods for overcoming it. The result was a series of scientific publications dedicated to the monuments of Ukraine, Poland and China. Based on the accumulated Ukrainian experience, they determined the restoration techniques. Taking into consideration local climatic conditions and qualities of wood, they can be used for China as well.

Materials and Methods

The basis for the study was Chinese publications, which analyzed both general aspects related to Chinese architecture and art [2], and aspects directly related to landscape gardening and pavilions [3, 4, 5].

Traditional Chinese architecture has been researched by many scientists such as Zhang Guanyin [1], Zhou Weiquan [3], Lu Ren [4], Zhong Huanan [5], and others. Innovative in the presented study is the analysis of possibilities of applying the Ukrainian restoration experience to preserve the historical pavilions of China authentic appearance, in order to avoid the loss of their original appearance and designs and errors during their updating, which were mentioned in the introduction.

There are several versions concerning the primary sources of ancient Chinese architecture; modern scholars consider this architecture to be autochthonous, which arose precisely on this territory of the indigenous population. These conclusions were proved by archaeological findings, which are dated back to the third millennium BC, among which painted ceramics were found.

Chinese architecture was formed against the background of constant contacts and mutual influences of China with the outside world. For example, in the 3rd century BC – the 3rdcentury AD, those were the contacts with the countries of Central Asia, Persia and India. China had a noticeable impact on the formation and development of Japanese architecture; it is especially noticeable in the design schemes and outlines of some roofs.

Taking into consideration the multi-dimension structure of the small traditional Chinese architecture, the methods of historical analysis, comparative analysis and the graph-analytical method were used to study its architectural and construction features and to develop reasonable proposals for the restoration of such objects.

The application of the method of system-structural analysis enabled analysing pavilions in various aspects. As well the iconographic sources were used.

Given the widespread use of wood in the constructions of historic Chinese pavilions, additional scientific sources related to the latest technologies in the study of wooden fragments [6], with the cause of the emergency condition of wooden parts [7], the restoration of wooden elements and structures in architectural monuments [8], as well as sources that argued for the reuse of quality timber [9], were involved.

Results and Discussions

The historically functional and aesthetic component in Chinese pavilions have been inextricably linked. In fact, a pavilion in a Chinese garden, park or mountain landscape has become an accent object with properties not only of architecture but also of sculpture, given the outline of the roof and the presence of sculptural decoration in the form of fantastic creatures, animals and birds, so it may be even the term "architecture-sculpture" was used. In modern parks, these properties have in many cases been taken over by modern monumental sculpture, in particular, as Liu Junnan writes, noting that "in China there was an ancient tradition of landscape gardening, whose history far exceeds by age any similar examples in other countries" [10, p.361]. The author actually indirectly draws analogies between the traditional "sculpturesqueness" of historic gazebos in parks and the sculpture that replaced them in modern parks, the incorporation of which into the surrounding natural landscape is based on similar principles.

In historic Chinese pavilions and gazebos it is advisable to simultaneously analyze the constructive and artistic component, since each constructive element here is essentially a work of art, and this proves the specific meaningful content of the term "work of art" in the restoration field [11].

Visual information for analysis was supplemented by publications devoted to historical Chinese pavilions and gazebos, especially those where dimensional drawings, photographs and historical information on specific objects were given, since in some cases such buildings are difficult to access (pavilions in villages or mountains) or difficult to obtain permission for their measurements (pavilions in imperial residences and monasteries, at temples) [3, 4, 5]. In small buildings, the examples of which are pavilions, the roof structure was created by hip rafters, a horizontal tie and a roof boarding of poles, which rested at one end into the foot of a rafter, and the other one into the tie. The horizontal tie was joined by a rope and it was not in the same plane with the rafters, as a result, there was a bowed outline of the roof boarding, with raised corners. It explains the origin of the initial deflected shape of roofs with raised corners, which spread in China and then in Japan (Fig. 2).

If hewn timber was used instead of tree trunks, the impact of bamboo structures was also observed. The load-bearing structure of round wood consisted of wooden pylons joined by tenons with horizontal purlins, and in this case, there were no raking anti-deformation struts, and static was ensured exclusively by tenons.

As can be seen in the examples of historical pavilions for various purposes, in some cases, the height of the roof exceeded half the height of the entire building, while remaining visually light and artful. This impression was increased by the raised edges of the roof with deep projecting eaves. Despite the similarity of historical architectural and construction legislation, some regions have their most popular types of roofs, which include paired roofs – in the pavilions of the northeast, expressive curved up roofs – in the east and less often in the centre and southwest.

By types, these were traditional four-pitched roofs (one- and two-tier), which could have raised ends (one-, two- and three-tier), tented roofs with concave planes, in the form of a truncated tent with raised ends; half-gable and conical roofs; several types of roofs could be arranged at once in one pavilion, which gave additional expressiveness to the construction. The frame of the traditional Chinese roof with a combination of vertical and horizontal parts consisted of round struts and horizontal purlins of rectangular cross-section, which transferred loads from the roof to the span piece, and the weight of the span piece was transmitted by two struts that formed a connecting element. In the framework of the Chinese roof, there is no component analogue of the rafter's foot and the tie itself performs a radically different function: in the Ukrainian house it is a fastening element; in the Chinese pavilion it is the bear loading part of the structure, which works on bending. It is not adapted for very long spans, and this fact imposed some restrictions on the measurements of structures.

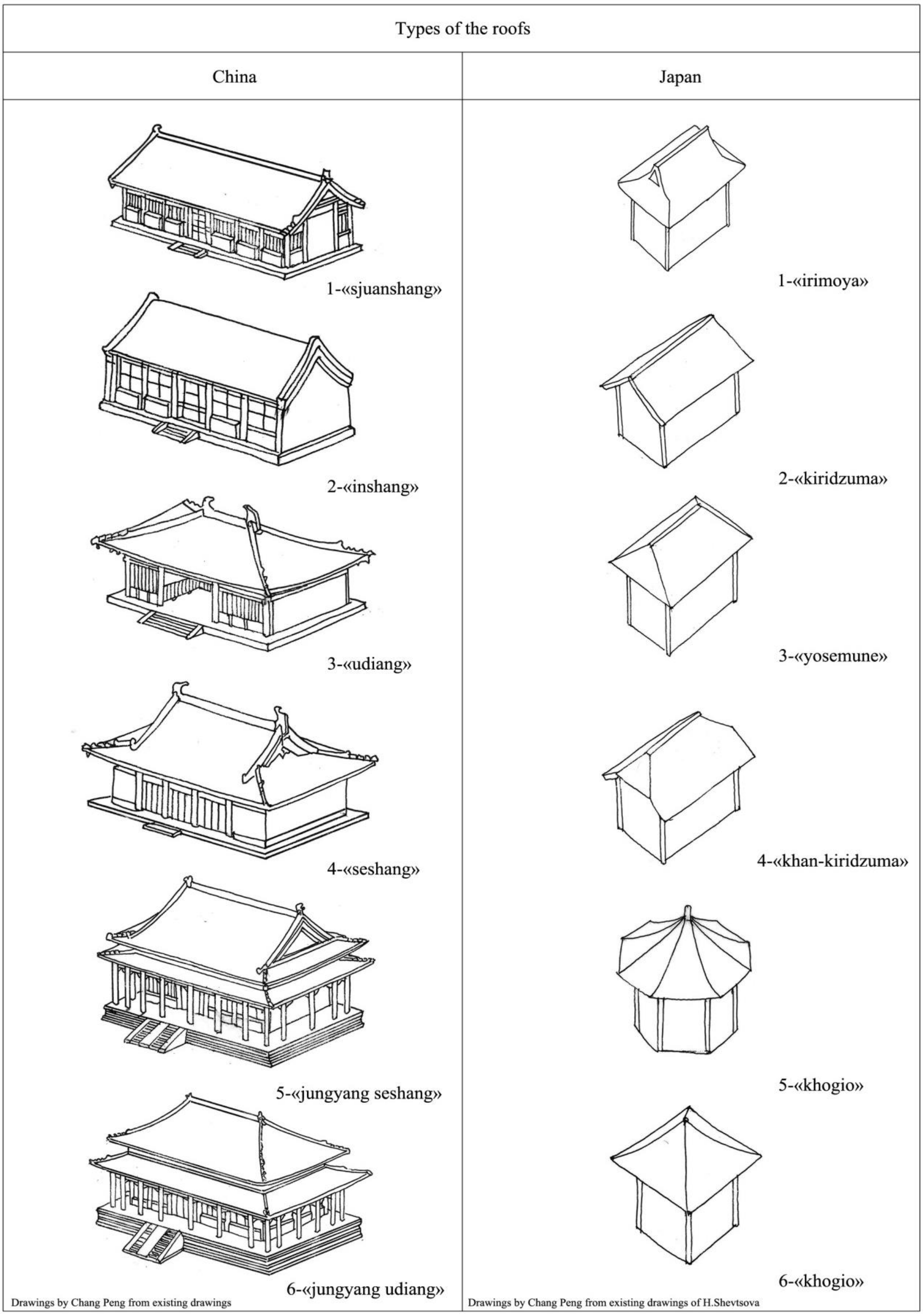

Fig. 2. Roof types of China and Japan in ancient times

The timber structures were covered with convenient in laying S-shaped roof tile with the use of mortar for protection against wind. The external joints were also coated with mortar for greater resistibility. The lathwork was of varying inclination for maintaining a heavy roof. Otherwise, the roofs were covered with simpler and cheaper straw or shingles. Very often it was used split bamboo trunks which resembled the tiling. The lathwork in the constructions of

China and Japan were similar: for this purpose, they used (most often) either tree trunks that had a fibrous structure, or trees with the empty stem (bamboo).

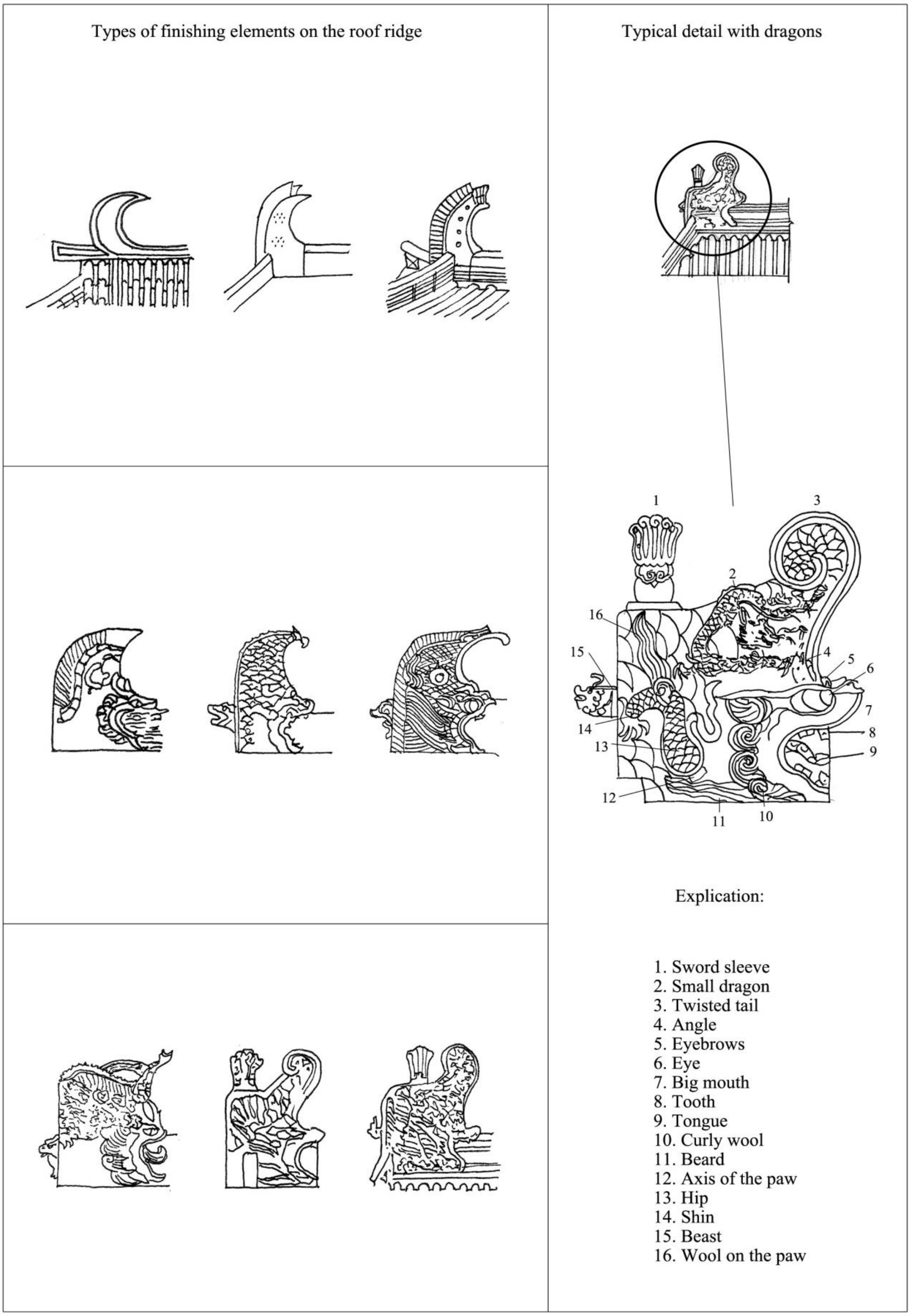

Fig. 3. Ceramic roof elements with symbolic meaning

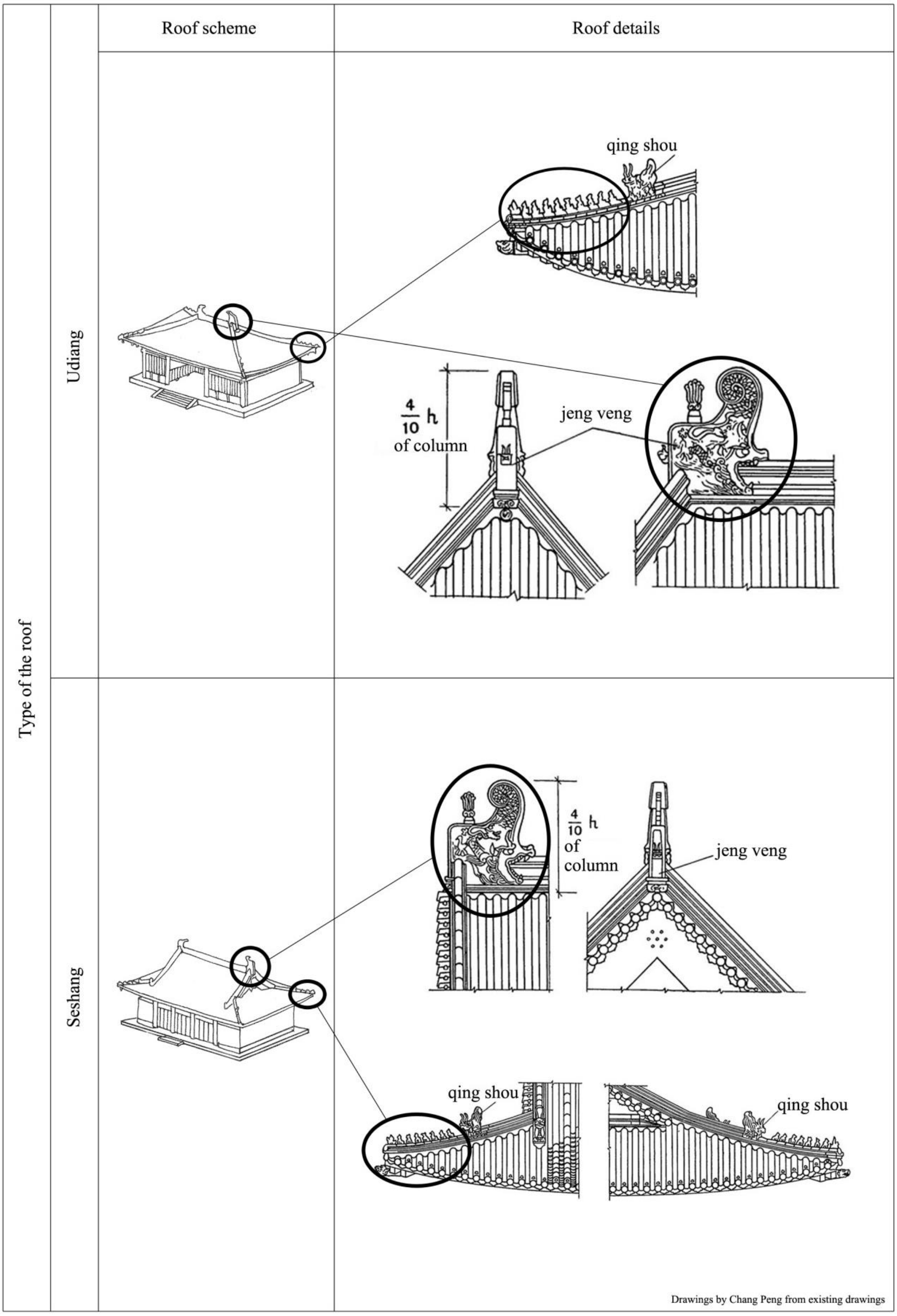

Fig. 4. The modularity of the roof decorative elements

The main structural elements of the roof – longitudinal purlins – were located at regular intervals and their number in the roof with a ridge was always odd, from three to nine. The distance between purlins depended upon the thickness of struts and was equal to its four diameters. The increase in height of one purlin over the second is the function of the distance between purlins X and is traditionally expressed as 0.5 X – 0.7 X – 0.8 X – 0.9 X in the case of the nine-purlin roof. These rules provide a characteristic curvature of the roof slopes that characterize the architecture of the Qing period.

Traditionally, a roof was made of ceramic cylindrical tiles with drips at the edge of the roof. The ridge and the edges of the roof slopes were made from particular parts of a complex outline for a tight fit of the roof elements and closing the cracks. The edges of the slopes were decorated with an odd number of cult figures of animals, birds and fantastic creatures, the ridge ended with the image of a dragon (Fig. 3, 4).

A Chinese, unique structural element is the dougong – a column cap, a bracket system, – formed by placing a large wooden block (dou) on a column to provide a solid base for the bow-shaped brackets (gong) that support the beam or another gong above it. It provides increased support for the weight of the horizontal beams that span the vertical pillars by transferring the weight on horizontal beams over a larger area to the vertical columns. Each Dougong is a complex structure with the connection of elements by notches. "Dou" is a square element with a groove in the upper part, in which brackets – "gongs" (elongated bars in the form of a bracket with cutouts) – are inserted. All dous are the same size, while the higher gongs are longer than the lower ones. Additional beams lying cornerwise ("ans") can increase the number of mounted "gongs" and thus contribute to a more even distribution of the load from the roof to the columns. The main constituent elements of the Dougong system included zao hu dou, ne dao gong and huang gong, which had fixed parameters.

Dougongs rely on beams between the columns of the outer rows (a kind of Chinese analogue of the ancient Greek architrave), and the transition from them to the forming gallery columns is carried out using brackets 1/3 – 1/4 of the width of the span. At first, these brackets were a functional structural element, but later they were transformed into the decorative completion of the support column.

Sometimes there were additional dougongs that rested only on the transverse bars. They were used to even the load from the heavy, due to the weight of the ceramic tiles and the roof. As a result, a structure is formed, significantly expanding upwards from the support, which can withstand high loads and creates the possibility of increasing the area of the roof supports and its overhanging eaves. Like most other elements of Chinese architecture, the Dougong system also showed the significance of the building: the number of tiers of the consoles testified to the rank of the building. The Chinese roofs were especially graceful due to the multi-tiered cornice which supported the roof. It was formed of Dougongs on the beams between the columns of the outer rows and over the columns.

So, Dougong brackets acted as a connecting element between the upper structures, beams and columns, as well as the uniform distribution of loads. It was already mentioned the appearance of a new module of the entire building structure in the Qing era – Doukou (width of the groove of the dou), which determined the diameter of the columns, the dimensions of the beams, the distance between the axes of the dougongs, which was fixed and unchanged (11 doukous).

That particular raising of the corners of the roofs, which became the defining trait of the Chinese pavilions as well, was created in the Song era by increasing the height of the outer columns, and in the Qing era – due to Dougongs. The number of Dougongs between the columns determined the width of the purlin along the facade, the central span was the widest and had 6 – 8 Dougongs. In some cases, the Dougongs formed a diminishing row – 6, 5, 4. The narrowest, connected with the gallery span, contained 1 Dougong.

Such a design scheme made it possible to erect buildings of varying complexity, including multi-purlin ones. The far overhanging eaves of the roof were equal to 1/3 of the height of the loadbearing column, and the external row of columns supporting the eaves created an open gallery from one, two or four sides of the building. The height of the supporting column was most often ten diameters, that is, it was measured by the diameter of the cross-section.

In this case, the walls performed only the enclosing function and could be erected as wooden collapsible structures from door and window blocks with frames. It was introduced the concept of the "jian" design module, which was formed by two transverse rows of columns connected by a system of beams, and then the length of the building was determined by the number of purlins on the facade, that is, the number of "jian" cells placed in a row, and the depth, in its turn, depended on the size of "jian" and the number of supporting columns in the transverse row.

Guidelines and technologies for restoration of wooden structures

The problem of wood conservation in architectural monuments is very acute and is associated with the preservation of historical and cultural values of the monument. Prior to the restoration of wood in the architectural monuments, the degree of preservation and the causes of the emergency are recorded, including the activities of biodegraders. As noted by P.V. Alfieri, R. García, V. Rosato, M.V. Correa "Wood from heritage is usually attacked by wood-decay fungi generating mainly loss of dimensional and structural stability. The study of wood biodegradation process and its mechanism allow the obtaining of tools for wood conservation" [7, p. 607].

Today, experts from different countries offer their methods of restoration of wooden elements of architectural monuments. For example, J. Abbasi, K. Samanian, M. Afsharpor from Iran propose to use the following tried and tested method: "One of the most frequently used consolidate for wooden material is polyvinyl butyral (PVB). Present research aims to evaluate polyvinyl butyral and zinc oxide as consolidate of old dried wooden material and investigate the efficiency of zinc oxide as a supplement on the distribution, penetration and retention of the consolidate in the "patanus orientalts-L" wood samples. Samples used for this research all belong to Qajar period. They were obtained from the same artifact and had the same, relatively sound condition. Cross sections were cut and obtained in a chamber with controlled temperature and relative humidity and weighted afterwards. Zinc oxide was used in 0.5, 1 and 1.5 concentrations in the polyvinyl butyral matrix of 10 % concentration. Efficiency of consolidate was evaluated by weighting, distribution and penetration in the wood and were examined by Fe-SEM and EDX. Concentrations 0.5 and 1 % of Nano- zinc oxide increased the penetration of consolidate and all three concentrations of zinc oxide increased the retention. Penetration of Nano- zinc oxide in the lumen as well as uniform distribution of it in the wood structure was also observed by microscopic observation" [8, p.207].

A detailed overview of the emergency condition problems is placed in the restoration documentation "Preservation and restoration of architectural monuments" [12] of the Ukrrestavratsiia corporation and the publications of the corporation's specialists. In Ukraine, wooden walls were built from oak, ash, larch, pine, spruce and fir by laying logs connected in the corners using the "Saddle Notch", "Dovetail Notch", "A Half-Tree Notch", into poles (frame); the wall cladding with the use of a "hacksaw" and "shiplap" methods.

An analysis of the problems of restoration and preservation of authentic wooden structures of Chinese pavilions made it possible to recommend those technologies that were applied at the objects of restoration of Ukraine, especially since the main reasons for the emergency condition of the wooden walls were caused by a change in the hydro-geological conditions of the building, subsidence of the foundations, absence or damage of waterproofing, and, wetting of structures (more than 25%), and, as a result of these facts, there was decay of wood and damages by the wood-destroying insects, which led to deformations and destruction of structures, deflection and failures. In all cases, they started restoration works after a detailed examination of the technical condition and damage rate of the wooden elements. It made it possible to identify those areas that were subject to restoration by the repair method with adding the insertion, where the new materials were used. The wooden structures also were exposed considerably to atmosphere and biological influences, increased humidity, decay, timber worms, fire, and need to be preserved with antiseptic, flame retardant and bioprotective agents. For antiseptic processing of wood on architectural monuments, Ukrainian broad-spectrum biocides "Ambizol IS", "Carbocide", "Phytoside", a solution of dichromic sodium, sulfuric acetic acid and water have proven themselves well.

The Ambisol product is a mixture of dithiocarbamic acid derivatives of sodium hydroxide and urotropine in water. It is designed to protect various types of building materials from fungal biological damage. For processing, a 5% solution of the product in water is used.

From imported products, we used products of the company "Remmers" from Germany, and MIPA produced by the company "Sadolin", Estonia. Methods of protection against wood destroyers are reduced to preventive measures, mechanical, physical removal of insects, as well as the extermination of insects using high and low temperatures and high-frequency currents, a chemical method using solutions, suspensions, powders and aerosols of insecticide poisons.

For fire protection of wooden structures and their transfer to a state of difficult inflammability, Ukrainian Endotherm product has proven itself well. The composition of Endotherm includes a suspension of flame-retardant pigments and fillers in a solution of a copolymer of vinyl chloride with vinylidene chloride insolvent. From foreign manufacturers, the products of Remmers and Caparol companies, Germany.

For partially destroyed wooden elements, it was used the reinforcement method - deep soaking with solutions of polymers and monomers with their consequent solidification.

Methods for strengthening wooden walls, used by specialists at the particular objects in Ukraine are as follows. First of all, these are methods that provide the statics of the building and the entire "base-foundation-structure" system. This is the removal of atmospheric precipitation from foundations and walls and ensuring the optimal temperature and humidity conditions inside. In particular, during the restoration of the wooden Trinity Cathedral in Novomoskovsk, a canopy over the base was constructed for this purpose. It was carried out into practice waterproofing over the brick base and wooden corners of the log house walls; the roof and the roof coating were renovated with the replacement of emergency sections. To ensure the waterproofing of the walls from capillary absorption of soil moisture in the Trinity Cathedral, the brickwork of the basement was injected with hydrophobic solutions.

The experience of restoration of the wooden Trinity Cathedral can be useful for the restoration of the wooden pavilions of China, especially in the regions in the East and Southeast with high humidity and high rainfall. Since the completion of construction in 1779, the cathedral has been continually suffering from wood decay due to the absence of wood blind areas and organized drainage from the basement. Despite repeated repairs and the replacement of the wooden foundation with a brick one, the problem remained. The capillary suction of soil moisture led to wetting of timber work and squinches, the decay of the wood and timber worm damage, wetting of roof structures, loss of bearing capacity of beams and belts. It was amplified by painting the interior walls with oil paint with the formation of a non-permeable layer. In addition to the restoration measures mentioned above, after identifying the causes of the emergency condition of the monument, it included remote and oil-bearing interior painting. A decrease in the moisture level of wood can be achieved either with acetone impregnated with butyl methyl acrylate monomer and with benzol catalyst with a solution temperature of 80 °C (the solution is left for 10 hours) or by impregnation with alcohols, followed by coating with the polyethyleneglycol solution. The wooden surfaces of facades are most often painted with lime paints, especially with increased humidity of the walls.

In case of deformation of the building, measures are being taken to replace the old emergency foundations and lay the foundations of stone, concrete, as it was done in the Intercession Church of the village of Lozova, which was built in 1700.

If the building is constructed of logs, the logs are sorted with the appropriate numbering and jacks, the rot-damaged timber works are replaced with the help of a wedge or lever on the support. This method was used in the Trinity Cathedral in Novomoskovsk and the Church of St. George in Drohobych, it enables replacing not only the timber works but also belts, squinches, beams and apply when the repair with the insertion of damaged beams is performed.

The emergency state of foundations and wetting of the roof are often the causes of the emergency state of ceilings and cupolas. Their restoration is reduced to the opening of the logging vaults from the protective cover and clearing from destructive areas, impregnation of wood with antiseptics, insecticides, structural strengthening of the timbering vaults by coating and injecting through holes, strengthening of wooden structures and unloading of the point bearing on damaged bars, replacement of damaged fragments of circling and strengthening deformed circling with twin boards on bolted joints, the making of a wooden binding on treenails, reinforcing brace struts of the central column, cornice, making the protective cover of the wood shingle.

Conclusions

At the beginning of the 12th century, the traditional Chinese constructive scheme of the Dougong was formed, and ancient treatises summarized the centuries-old experience of form-making in the architecture of public and residential buildings, created the basis for the typification of building elements and structures. Without exception, all buildings were divided into 9 groups with the definition of the height of the platform or basement and dimensions according to the purpose. The principle of "tsai" was important – the dimension and modularity of the constituent structural elements, which was divided into eight levels according to the dimensions of the object.

In the Chinese pavilions, such modules and ratios were provided that, together with the method of raising the edge columns (in the Song era) and the type of construction of dougong (in the Qing era), determined the original shape of the roofs:

1) doukou (width of the dou groove) – the primary module that determined the diameter of the columns, the dimensions of the beams, the distance between the axes of the dougongs, which was fixed and unchanged (11 doukous);

2) the module equal to the size of cross-section of beam console "gong" in Dougong:

3) tiao – the distance between the main and secondary axes of the supports, the diameter of the column support, since the distance between the spans is four diameters of the column;

4) jian – a modular cell, a measure of length and width, formed by two transverse rows of columns connected from above by a system of beams, and then the length of the building was determined by the number of purlins along the facade, that is, the number of "jian" cells placed in a row; and the depth, in turn, depended on the size of "jian" and the number of pillars in the transverse row. It was possible to increase the area of the premises by assembling jian modules in both longitudinal and transverse directions. This enabled usage of the term "pavilion of five jian."

5) kaijian ("open jian") – the measure of the room width, equal to the width of the jian, most often was 1 jian (approximately 3.3 m);

6) the height of the supporting column, fixing the overhang of the eaves (1/3 of the height);

7) the distance between the longitudinal purlins of the roof, which were located at regular intervals and their number in the roof with a ridge always ranged from three to nine,

8) increase in the height of one span over the second 0.5 X – 0.7 X – 0.8 X – 0.9 X, where X is the distance between the spans;

9) Dougongs (the number of Dougongs between the columns determined the width of the purlin along the facade, the central span was the widest and had 6 – 8 Dougongs. In some cases, the Dougongs formed a diminishing row – 6, 5, 4. The narrowest, connected with the gallery purlin, contained 1 Dougong.

10) the width of the purlin – the brackets for the transition from beams to galleries were 1/3 –1/4 of the purlin width.

While identifying the main problems associated with the types of ceilings in the Chinese pavilions, then for the tent and gable roofs, this is the movement of the supports, the decrease in height, the wave-like deformation.

Since the Chinese constructive scheme of Dougong is based on wooden beams and elements, we dwell in detail on the causes of the emergency state of wooden beams, the accident rate of which is caused by subsidence of foundations and footings, improper resting on the walls, wetting of the support nest, lack of waterproofing beam-wall, the occurrence of "dew points" in the nest of support, the appearance of condensation during freezing of the wall. The following methods of reinforcing of the wooden beams were applied at the Ukrainian objects:

– the repair with the insertion of metal or wooden mending plates on the parts of the beam or the entire length with the removal of the destructed parts and the use of tie supports;

– the repair with the insertion using the mending plates on both sides – beams from the channel bars and clamp bands;

– increasing the number of beams, by decreasing their pitch with increasing load on the floor; isolating the contacts of the beams with the wall with the use of mastics and waterproofing the nests of the beam supports;

– conservation of damaged wood in ceiling structures either by "compound" filling with synthetic resins on a beam cleared of damage with wood reinforcement or by impregnation and drying of wood with antiseptics, flame retardants and treatment from timber worms;

– reinforcement of the wooden ceilings by installing additional supports under the supporting beams;

– reinforcement of the wooden beams of ceilings with trussing rods with the use of wooden mending plates, coupling bolts and tie rods;

– unloading the structure by additional supports.

In an extreme case, when wooden beams are damaged completely along the entire length, they are replaced with new wooden or reinforced concrete, metal or combined reinforced concrete along metal beams (ceiling of the palace in Baturin).

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