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Influence of Structural Schemes on the Shaping of Historical Wooden Buildings: On the Examples of Traditional Chinese Pavilions, Pavilions of the Chinoiserie Style and Ukrainian Wooden Churches

Wpływ układów konstrukcyjnych na kształtowanie zabytkowych obiektów drewnianych na przykładzie tradycyjnych pawilonów chińskich, pawilonów w stylu chinoiserie oraz ukraińskich kościołów drewnianych

Keywords: structural schemes, shaping, Chinese pavilions, pavilions of the Chinoiserie style, Ukrainian wooden churches

Słowa kluczowe: układy konstrukcyjne, kształtowanie, pawilony chińskie, pawilony w stylu chinoiserie, ukraińskie kościoły drewniane

Introduction

Wood has been used extensively in works of architecture since ancient times. Each civilization used its own types of wood and developed its own design schemes and construction techniques. This study puts forward a thesis that wood types and structural schemes used influenced the creation of the image of architectural monuments. Examples of this include historical wooden churches in Ukraine, small Chinese architectural forms: garden pavilions and their modified European copies—pavilions of the Chinoiserie style—as well as Polish wooden churches. By comparing the materials and structures used in authentic Chinese pavilions and the European pavilions of the Chinoiserie style, it is shown how

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Fig. 1. Chinese gazebo in Sofiiivka; watercolor by P. Chang 2020.
Ryc. 1. Chińska altana w Sofijiwce; akwarela P. Chang 2020.

the change of traditional structures led to a radical change in the image of the building.

The example of wooden churches in Ukraine shows a fundamentally different, when compared to China, structural scheme based on wood, due to the different purpose of the church compared to the Chinese pavilion, and other local building traditions. In the Ukrainian wooden church, even the methods of lining the outer walls with vertical boards were important.

The objectives of this study led to a list of academic sources. General sources were studied, which emphasized the need to preserve the authentic historical environment, which directly affects the authenticity of a building.[1] Sources covering general approaches to the restoration of monuments[2] and modern methods of eliminating wood damage in the construction of architectural monuments have also been studied, which indicates the urgency of this problem for many countries.[3] A separate group of sources consisted of publications on Chinese pavilions, which explored their location in the environment, their artistic and design features, the influence of climatic factors[4] and the continuation of these traditions in contemporary Chinese landscape design.[5] Publications on Ukrainian wooden churches were also studied. These were historical sources,[6] as well as contemporary research on wooden Ukrainian church architecture and its features.[7]

The study of these sources allowed to define and formulate research objectives, namely to combine in one study two fundamentally different structural schemes of wood in China and Ukraine in order to show how the type of structural scheme influenced the architecture of the building, since in the Chinese architecture of small forms it was the structure of the dougong and the natural and climatic conditions that determined the distinct curved silhouette of the roofs, just like the traditional girder and girderless structures of Ukrainian log-house churches were optimal for the construction of tower-type churches.

Materials and methods

The methods of historical analysis, comparative analysis and the grapho-analytical method were used in this study. The literature investigated was supplemented by the authors' own research and illustrative materials. This paper is partially based on materials from the dissertations of Yulia Ivashko (a study of the wooden churches of the Kyiv province) and Peng Chang (research on Chinese pavilions and pavilions of the Chinoiserie style), as well as field research of wooden gazebos in Sofiivka and Oleksandriia, carried out in recent years by Y. Ivashko and O. Ivashko. The gazebos in Sofiivka and Oleksandriia made it possible to discuss their stylization in comparison with authentic Chinese gazebos (Fig. 1).

RESULTS AND DISCUSSION

Chinese garden pavilion, its place in the environment, design features and imitation of these forms in the Chinoiserie style

The main factor that determined the appearance of the traditional Chinese garden pavilion was its subordination to the natural environment. The Chinese garden provided a large number of miniature landscapes, collected in a small area, while the garden itself created the impression not of a whole, but of a "mosaic," as if

Fig. 2. Cāng Làng Tíng Pavilion in Cāng Làng Tíng Garden in Suzhou; watercolor by P. Chang 2020.
Ryc. 2. Pawilon Cāng Làng Tíng w Ogrodzie Cāng Làng Tíng w Suzhou; akwarela P. Chang 2020.

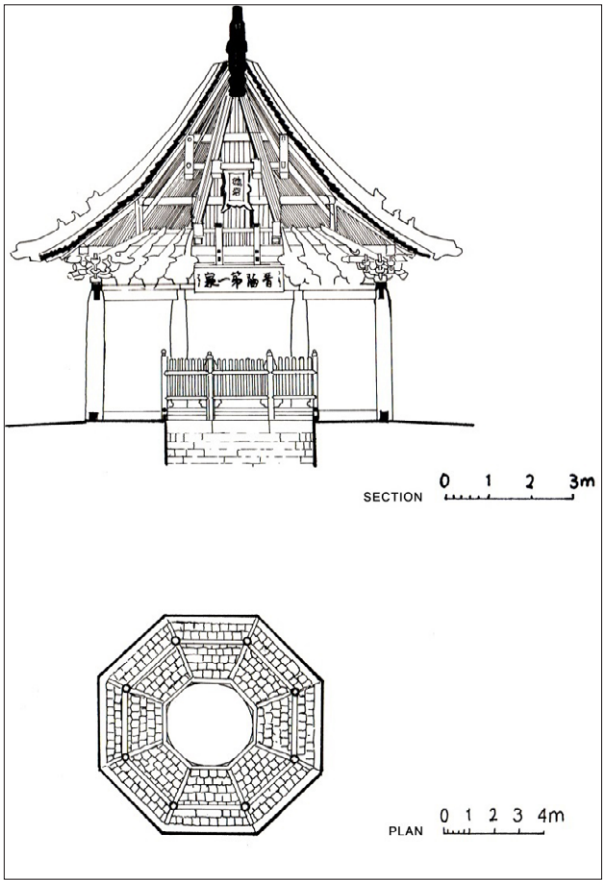


Fig. 3. Nanlao Spring Pavilion of Jinci Temple, Taiyuan, Shanxi Province; drawings by P. Chang 2020.
Ryc. 3. Pawilon Wiosenny Nanlao w Świątyni Jinci w Taiyuan, Prowincja Shanxi; rys. P. Chang 2020.

composed of separate mosaic species, which is emphasized by pebble paths. In the European landscape park, the number of small forms was limited, while in the Chinese garden of Zhuōzhèng Yuán, with an area of about 4 ha, there are 50 buildings, 40 stelae and more than 700 dwarf trees.

The Chinese never considered an artificial building to be the "main element" of a garden—this role was played by an artificial lake with mountains around it, a symbol of "one lake and three mountains," and pavilions were considered a minor addition to the landscape. In addition, they did not necessarily stand by the water, as they could crown a hill or stand in greenery. The appearance of the pavilion was determined by the natural environment, so most non-imperial pavilions stood out not by colors or richness of décor, but by the perfection and dynamism of their silhouette (Fig. 2).

When one compares the ancient Chinese pavilions and the "Chinese" gazebos in European parks, their non-identity is noticeable. Chinese historical gardens and pavilions were arranged according to the canons of Taoism and Buddhism and the rules of Feng Shui, where each element had a certain symbolic meaning, pavilions of different purpose and significance had clearly defined differences, which were not present in European Chinoiserie style gazebos. The pavilions in the emperor's gardens were characterized by bright polychromes, high quality workmanship, the use of expensive wood, silver, stone inlays, or ivory.

The picturesqueness of Chinese roofs was not the effect of the simple aesthetic whim of the customer or the imagination of the architect-designer, as the creation of its original form was simultaneously influenced by local climatic conditions, cultural and artistic traditions, and beliefs.

The roofs were four-sloped (single- and two-tiered), four-sloped with curved ends (single-, two- and three-tiered), they could be hipped roofs with curved faces on an orthogonal plan, in the form of a truncated hip roof with curved upward ends on a hexagonal plane, with a hexagonal plan, a combination of several types of roofs, and the pavilions themselves could be one-, two- and three-tiered, and several types of roofs could be arranged in one pavilion, which gave the building additional expressiveness.

In small buildings, of which pavilions are an example, the roof structure was formed by angular rafters, a horizontal puff and a tiling batten of poles, which rested one end at the foot of the rafter and the other at the puff. The puff was tied with a rope and was not in the same plane as the rafters, which formed the curved shape of the tiling batten, raised to the corners. This ex-

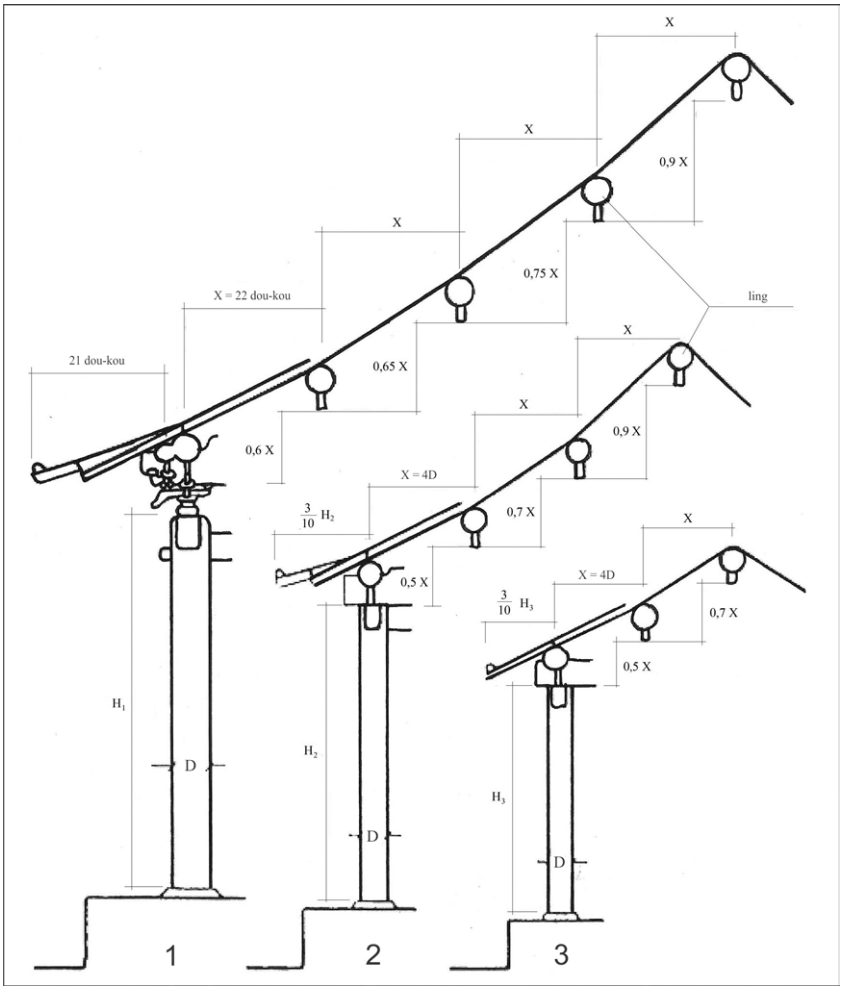


Fig. 4. Analysis of the historic pavilion modular structure in China; drawings by P. Chang 2020.
Ryc. 4. Analiza modularnej konstrukcji zabytkowych pawilonów w Chinach; rys. P. Chang 2020.

plains the origin of the curved shape roofs with raised angles, which spread across China and later in Japan.

In cases where hewn wood was used instead of tree trunks, the influence of bamboo structures was also observable. The supporting structure of round wood consisted of wooden racks connected by tenons with horizontal beams, and in this structure there were no inclined anti-deformation joints, and rigidity was provided only by tenons.

The construction of a traditional Chinese roof with a combination of vertical and horizontal parts consisted of round posts and horizontal girders with rectangular cross-sections, which transferred the load from the roof to the crossbar, and the weight of the crossbar was transmitted by two struts that formed a connecting element (Fig. 3).

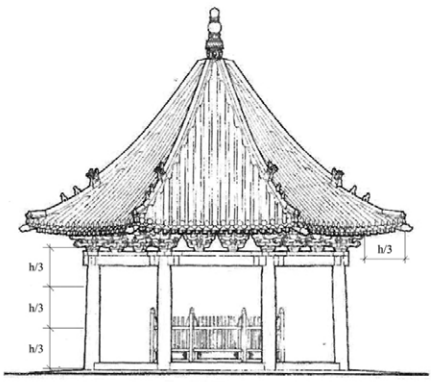
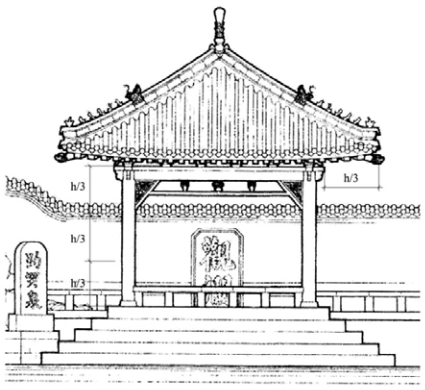
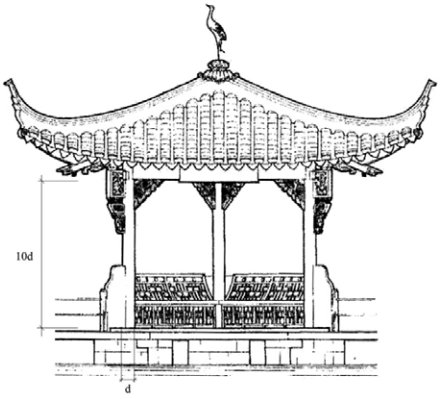
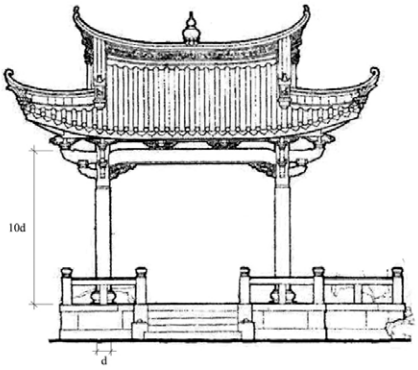
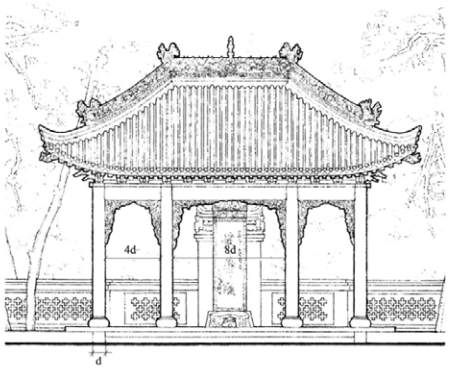
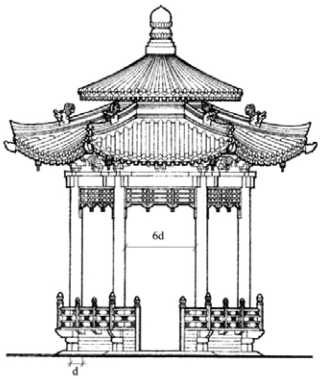
Easy-laid tiles with an S-shape profile were laid on wooden structures using mortar for protection against wind, with the external seams covered with mortar for greater durability, with variable inclination tiling batten for the support of a rather heavy roof. A simpler and cheaper roof of straw, shingles or split and accordingly nested bamboo trunks that imitated grooved tiles were also used.

The main structural elements of the roof—longitudinal girders—were located at equal intervals and their number in the roof structure was always odd, from three to nine. The distance between the girders was related to the size of the column and was equal to its four diameters. The increase in height of one girder over the other is a function of the distance between the girders X and is traditionally expressed as 0.5 X – 0.7 X – 0.8 X – 0.9 X in the case of a nine-girder roof (Fig. 4, 5). These rules provide the characteristic curvature of the roof slopes that characterize the architecture of the Qing period.

The cantilever capital dougong is a purely Chinese structural element. It is formed by beams passed through a column, on which additional elements—brackets—are arranged, which provides the connection of the capital with the system of rafters of the overhanging roof (Fig.5).

The issue of modular construction, silhouette, and metro-rhythmic relations of the historical pavilions of China is inextricably linked with the general theoretical issues of composition and philosophical categories of aesthetics and beauty. As philosopher Friedrich Schiller put it, "A beautiful subject must and even must be regular, but it must seem free from rules."[8]

Indicators of construction modularity

	Examples
The roof overhang is equal to 1/3 of the column height	 Nanlao Spring Pavillion of Jinci Temple, Taiyuan, Shanxi province  Guanlan Pavillion, Baotu Spring Lake, Jinan, Shandong province
The column height is equal to 10 column diameters	 Kaiwang Pavillion of West Lake in Hangzhou, Zhejiang province  The pavillion of the Pujao Temple in the southern part of Xiamen, Fujian province
The distance between the girders is equal to 4 - 8 column diameters	 Memorial pavillion at the Emperor Huangdi's Tomb, Huangdi, Shanxi province  Morning Sun Pavillion of warm springs Huashin in Lintong

Measurements according to Qin Li

Fig. 5. Analysis of historic pavilions modular structure in China; drawings by P. Chang 2020.
Ryc. 5. Analiza modularnej konstrukcji zabytkowych pawilonów w Chinach; rys. P. Chang 2020.

Reflections on the composition can be concluded with a quote from Hippolyte Taine, who asked the philosophical question: "Can we say that works of art are limited to a simple reproduction of the relationship of parts?"[9] If we refer this question to the Chinese pavilions, then in them the perfection of the composition was really understood as a certain mathematical ratio between the parts and the whole, which was enshrined in classical building treatises.

Widespread use of wood determined the types of plans for Chinese pavilions, while European pavilions of the Chinoiserie style were marked by a much smaller number of layout options, especially since not all of them were wooden, most turned into capital buildings with brick walls. The gazebo in Oleksandriia Park is square in plan, while the one in Sofiivka Park is faceted. The pavilion in Sanssouci is even more different in plan from the Chinese models, as it combines curved closed and open parts.

The Chinese Pavilion in Sanssouci embodies the color scheme and decor of the European Baroque: light green walls combined with gold decor of columns and sculptures and a gray-blue roof. The figures and decor do not correspond to Chinese traditions (as, by the way, the pavilion plan, its facades, purely Baroque forms of semicircular and oval openings) that the pavilion is not perceived as an allusion to Chinese architecture, but looks like an original Baroque pavilion, with a slightly unusual décor.

The "Chinese Gazebo" and "Chinese Village" are separated by a main straight alley to the Big Tsarskoye Selo Palace and in no way take into account the Chinese principles of planning in the natural environment. Like the "Chinese Pavilion" in Sanssouci, they are detached from the water, while in China, in the presence of any reservoir, the pavilions were as close as possible to it. Here, too, the pavilion is made expressly bright to contrast with its natural surroundings. This is found in the imperial gardens of China, but is not typical of private gardens, as most ordinary pavilions created an unusual image due to the silhouette, not the decor. The vast majority of European "Chinese" gazebos were a simplified version of Chinese small architectural forms.

Traditional constructions of Ukrainian wooden churches and their influence on the formation and creation of the image

One of the issues that has not been fully addressed by researchers of wooden architecture is the question of the material for the construction of churches and the material influence on the wooden church image formation. Y. Ivashko et al. analyzed the appearance of wooden churches of different districts of Kyiv province and in Ukraine in general.[10]

An analysis of famous wooden churches showed that they used two systems of proportions—integer (modular) and geometric (irrational).[11] In this case, the entire variety of compositions of church buildings, as a rule, can be reduced to several proportional schemes.

Fig. 6. Trinity Church in the village of Luchyn (1764), based on an archival photograph; watercolor by Y. Ivashko.
Ryc. 6. Kościół Świętej Trójcy w wiosce Łuczyn (1764), opracowane na podstawie fotografii archiwalnej; akwarela Y. Ivashko.

Ancient masters approached construction from the standpoint of rationality: first there was a general layout, from the square of a central log frame, and construction was carried out on the basis of this log frame, which acted as a benchmark. In churches of different regions, the proportional basis is either the side or the diagonal of the middle or central log frames.[12]

In the church of Tarashcha, there was the following ratio of parts: the height of the main top consisted of three equal parts, and the height of the walls of the first tier was 1/3 of the total height. The height of the dome also consisted of three equal parts. The proportional construction of the Tarashcha church plan was carried out on the basis of the diagonal of the central log frame square, the length of the side log frames is equal to half the diagonal of the central log frame square.

The construction of churches of the characteristic Polissia type is simpler: the height of the central top consisted of two parts, and the height of the walls of the first tier to the top of the cornice is equal to 1/2 of the total height (Fig. 6).

According to archival sources, it is possible to analyze the direct impact of wood species on the lifespan of a wooden church. Straw, shingles, bast, reeds and tin (iron) were used for roofs. If we talk about the forests of the former Kyiv province, they were pine, oak-pine, and less often composed of hornbeams and oaks, or steppe meadows with oaks. In general, the area of distribution of a particular species of tree coincides with the material of the churches in that area, although there were exceptions to this rule. In the area of pine and oak-pine forests, the churches were mostly built out of pine, in the area of western oak-pine forests, mostly built of oak. In the central zone of the

Kyiv region, with oak-pine and hornbeam-oak forests, oak churches predominated, but there were pine, alder and aspen ones. In the area of hornbeam-oak forests, churches were built mainly using local species. In the lowlands, in wet places, near rivers, there were areas of distribution of alder and aspen, that's why alder and aspen churches were built. There is evidence of church construction out of ash, spruce, alder, and even linden. In general, oak and pine were the main building materials throughout the Kyiv province. There are two known oak churches, which were more than 250 years old, eight known pine churches aged 400 (Fig.7, 8) to 200 hundred years. The age of alder churches was 50–100 years; hornbeam, birch and aspen was less than 50 years; linden—up to 50 years.

There were examples of oak churches with thatched roofs, oak churches with shingles, pine churches covered with shingles, alder-oak churches with thatched roofs, linden churches covered with bast, birch churches roof, aspen churches with thatched roofs. According to archival sources, as of the first half of the eighteenth century, most churches had shingled and thatched roofs, and iron-covered domes were rare.

Round logs, whole and cut lengthwise into two halves, were used for wooden construction, wood was worked with an ax or saw. There were two groups of churches—churches made of beams (for cladding) and churches made of logs (without cladding). The well-made external cladding of the log frame protected it from rain and snow, it was made of boards 13–18 mm thick, located vertically (which illusively increased the height of the church) on the bars nailed to the log frame.

In church construction, the following types of scarves in the corners of the walls were used: a simple scarf with a rectangular one-sided cut from the valley or cutouts on both sides, the so-called "fishtail," "half-tree," "hidden buzzard" or "ordinary buzzard," and for regions with a large amount of precipitation—"round" and "bowl," with the ends of the logs protruding from the wall area.

Two main types of transition from the walls of log frame to the pyramidal top were used—using crossbars protruding from the plane of the walls (Fig. 8) and non-crossbar construction with inclined wedges and formed on their basis of the third type—with crossbars and inclined wedges at the same time. The possibility of using a crossbarless structure with inclined wedges was explained by precise and vertical construction of the log frame, if the frame was not built very accurately, the structure with inclined wedges was further reinforced with crossbars to strengthen the structure of "an octagon placed on a quadrangle."[13]

The main problems of the emergency condition of historic wooden structures are related to the violation of the statics of the building due to changes in hydrogeology, the subsidence of foundations (often due to suction of soil moisture), damp in the structure—in the walls, beams, roofs—insect damage and mold, the painting of internal walls with oil vapor-proof paint. Based on the materials of the field survey, chemical, biological and mycological studies are carried out and, on this basis, priority restoration measures are determined. There are three groups of elements according to their state of preservation: elements in a satisfactory condition, elements partially damaged by rot and beetles that require structural reinforcement, and elements that require complete replacement due to the emergency.

The main problem of existing historic buildings and structures with load-bearing timber structural systems is the extension of their normal operation, which can be achieved by strengthening them. There are many ways to strengthen timber structures, but almost all of them significantly affect the appearance of the structure, which is essential for religious buildings. In this publication, we will discuss modern methods of reinforcement that have recently entered use.

The first option that can be used to strengthen the components and elements of timber structures is to install (in areas of cracking and/or possible occurrence of maximum tangential and normal stresses across the fibers) galvanized steel screws in problem areas based on special calculation. The screws are screwed into pre-drilled holes with a diameter corresponding to the nominal diameter of the screw, minus 2 mm. It is recommended to use a special lubricant to facilitate the installation of screws. The second option to strengthen the components and elements of timber structures is the gluing (in areas of crack formation and/or possible appearance of maximum tangential and normal stresses across the fibers) of steel rods in problem areas based on special calculations. The rods are glued into pre-drilled holes with a diameter corresponding to the nominal diameter of the rod plus 2–3 mm, depending on the diameter of the reinforcement rod, using epoxy glue.

The third option of strengthening the joints and elements of timber structures is gluing (in areas of cracking and / or possible appearance of maximum tangential and normal stresses across the fibers) longitudinal strips of polymers reinforced with carbon fibers in problem areas (Fig. 9). In addition to gluing longitudinal tapes, based on special calculations if necessary, one can use glued bandages of the same tapes of polymers reinforced with carbon fibers (Fig. 9a).

The tapes are placed along the axis of the structure and bandages are arranged perpendicular to the direction of the longitudinal tape on their top. The connection of the bandage to one closed loop is performed by means of overhang, with a divergence of the structure along the length of the reinforcement zone (Fig. 9b). The placement, pitch and number of layers of tapes and bandages are determined on the basis of a special calculation.

Tapes and bandages are glued to the structure as external reinforcement using epoxy glue. The application

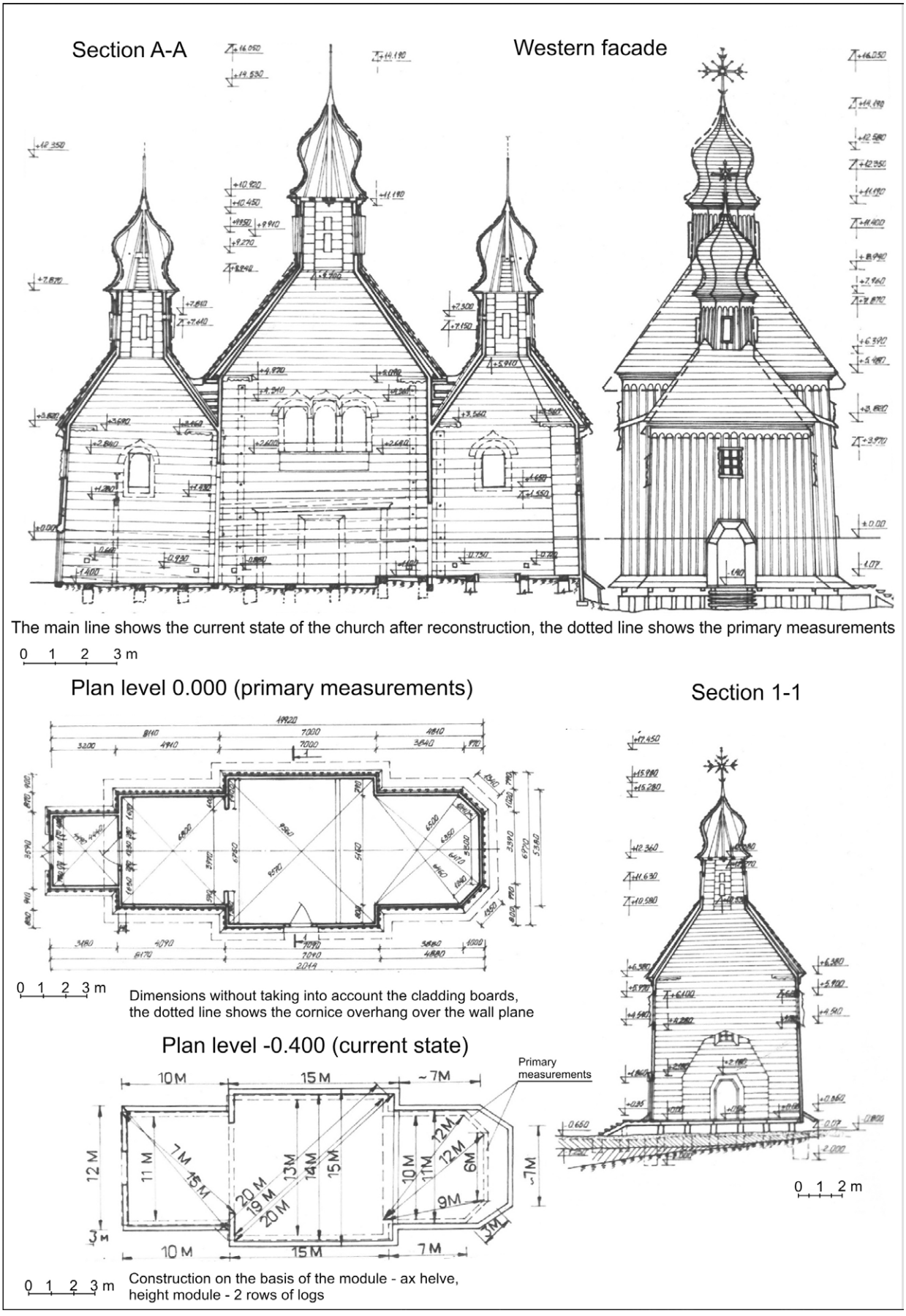


Fig. 7. Dimensional drawings of the Church of Michael the Archangel in the village of Dorohinka (1600); measurements and drawings by Y. Ivashko 1997.

Ryc. 7. Rysunki wymiarujące kościół Michała Archanioła we wsi Dorohinka (1600); pom. i rys. Y. Ivashko 1997.

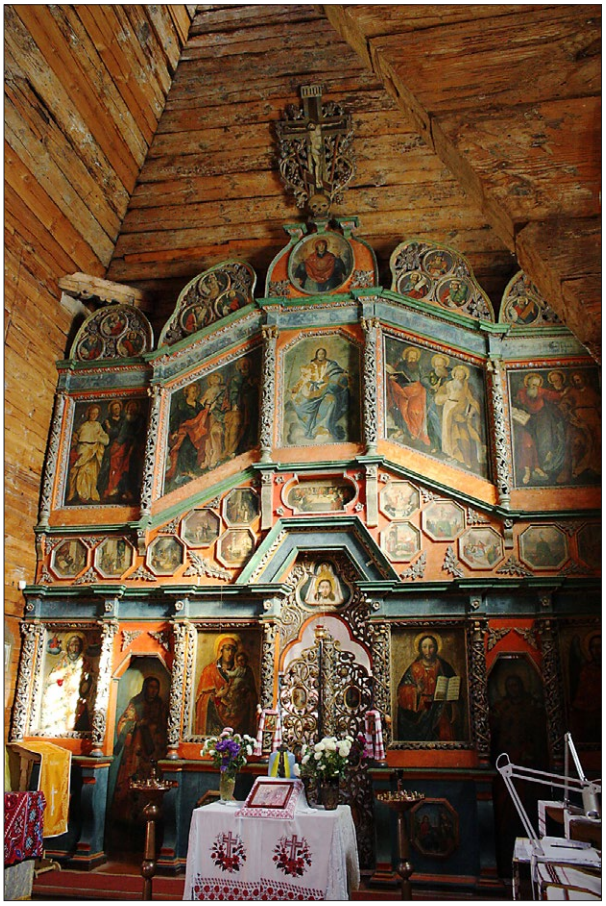


Fig. 8. The interior of the Church of Michael the Archangel in the village of Dorohinka; photo by Y. Ivashko 2007.
Ryc. 8. Wnętrze kościoła Michała Archanioła we wsi Dorohinka; fot. Y. Ivashko 2007.

of the proposed reinforcement options has the following advantages: increasing the load-bearing capacity of components and elements of timber structures, the restoration of the design service life; manufacturability and ease of execution.

Conclusions

Chinese wooden pavilions were based on the local dougong design scheme and the specific modularity of the structural elements, while the Chinoiserie-style pavilions did not borrow from the Chinese design scheme and were only an approximate simplified version of Chinese architecture as a whole. The fundamental difference between Eastern influences on European architecture at different historical stages of stylistic development was that at the stage from Baroque to historicism, architects tried to recreate authentic Chinese forms in a fundamentally different environment and without the necessary basic knowledge of stylistic features, and at the stage from historicism to the Secession (Art Nouveau), architects no longer sought to literally recreate a Chinese or Japanese building, but instead creatively interpreted their design and planning principles, based not on a philosophical-religious basis, but on a rationalist Western one.

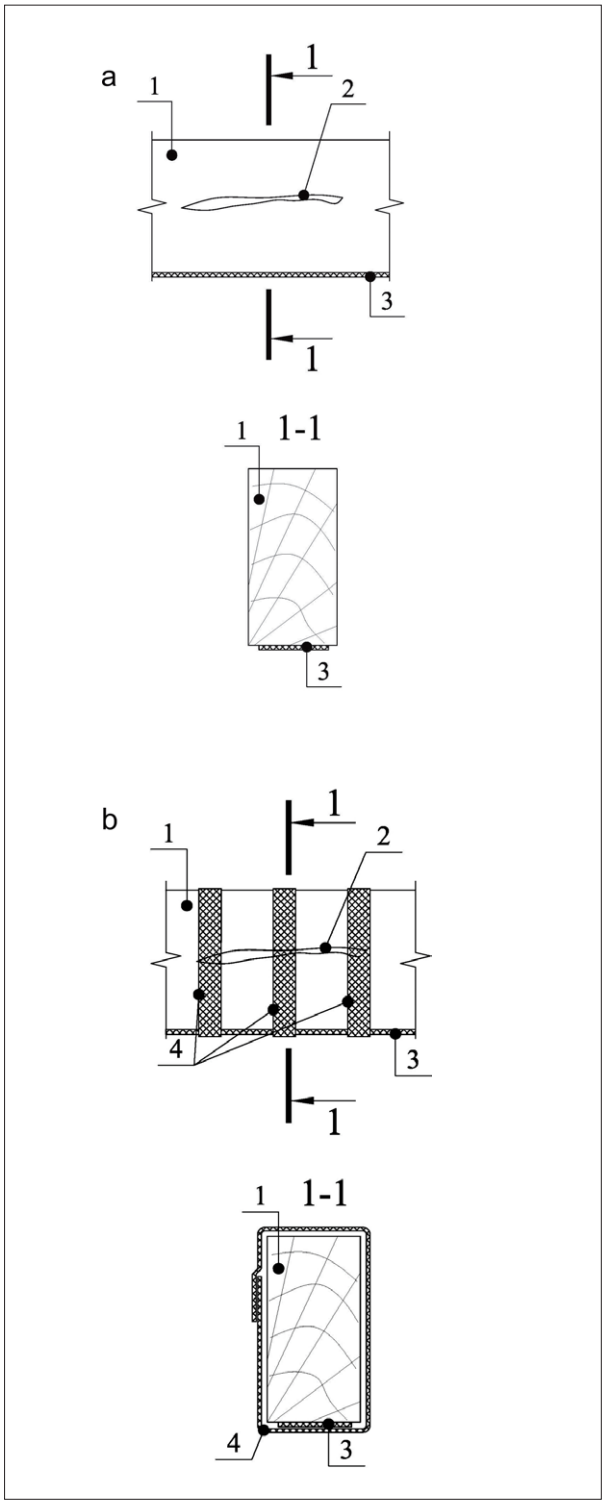


Fig. 9. Strengthening the joints and elements of timber structures by gluing longitudinal strips and bandages of polymers reinforced with carbon fibers in problem areas: a – strengthening by gluing longitudinal strips; b – strengthening by gluing longitudinal strips and glued bandages; 1 – existing timber element; 2 – crack; 3 – longitudinal tape of composite material; 4 – tape bandage of composite material.
Ryc. 9. Wzmacnianie łączeń i elementów konstrukcji drewnianej poprzez wklejanie podłużnych pasów i bandaży z polimerów zbrojonych włóknem węglowym w miejscach problematycznych: a – wzmacnianie poprzez wklejanie pasów podłużnych; b – wzmacnianie poprzez wklejanie podłużnych pasów i klejonych bandaży; 1 – istniejący element drewniany; 2 – pęknięcie; 3 – taśma wzdłużna z materiału kompozytowego; 4 – bandaż taśmowy z materiału kompozytowego.

It is proved that the presence or absence of quality building material for wooden churches in Ukraine affected their durability and complexity of the composition. In general, the area of distribution of a particular species of wood coincided with the material of churches in that area. The churches built of oak were marked by the greatest height and monumentality. There is a group of churches made of beams (for cladding) and churches made of logs (without cladding, their minority in Kyiv region). The transition from log frame walls to pyramidal tops could occur either with the use of crossbars, or without crossbars, with the help of inclined wedges (if the frame was accurately removed and the log structure was static).

The wooden churches of Ukraine and Chinese pavilions, in addition to their building material—wood of different species—are linked by the fact that it was the structural scheme that directly influenced the appearance of these buildings. On the contrary, the pavilions of the Chinoiserie style merely copied the outward appearance of Chinese pavilions in a simplified manner, but did not inherit their structural scheme.

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Abstract

In this paper, without denying the influence of the function on design, the influence of traditional constructive schemes on design is presented on the examples of Chinese pavilions and Ukrainian wooden churches. It is demonstrated how structural systems directly determined massing design: for example, the traditional Chinese dougong construction determined the original shape of curved Chinese roofs, and how the use of log construction in Ukrainian wooden churches—without crossbars or with crossbars—with load redistribution slightly inclined to the central axis, determined tower compositions with a combination of individual masses open to the zenith of the dome in the interior. It is shown how, in the case of a simplified copying of only the external form, without conforming to the form in the structural scheme, the form turns into a decoration, as in the European Chinoiserie style.

Streszczenie

W artykule, nie zaprzeczając wpływom funkcji na projekt, przedstawiony został wpływ tradycyjnych schematów konstrukcyjnych na projektowanie na podstawie przykładów pawilonów chińskich i ukraińskich kościołów drewnianych. Wykazano, jak konstrukcja bezpośrednio przesądzała o rozwiązaniach, np. tradycyjna chińska konstrukcja „dougong" determinowała oryginalny kształt giętego dachu chińskiego, podczas gdy wykorzystanie konstrukcji wieńcowej, jak w ukraińskich kościołach drewnianych – z tramami lub bez, z przenoszeniem obciążeń w niewielkim nachyleniu do osi centralnej – warunkowało układ kompozycji wież poprzez kombinację poszczególnych brył otwartych ku szczytowi kopuły od wewnątrz. Pokazano, jak forma staje się jedynie dekoracją, na przykładzie uproszczonego kopiowania tylko zewnętrznych form bez dostosowywania formy do schematu konstrukcyjnego, jak w europejskim stylu chinoiserie.