Innovations and traditions: application of fiberglass for revival of dome roofs of church monuments of architecture

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Abstract. This paper is aimed at determining the dome roof design most suitable for the restoration of old churches with a weakened ability of load-bearing walls and the improvement of the operation of enclosing structures. The authors compare the designs of church dome roofs. They justify the use of fiberglass in the manufacture of dome roofs of church monuments of architecture from the decorative-aesthetic and constructive perspective. They study the aerodynamic characteristics of the church dome roof to determine the most difficult design places. Solid works suite-based visualization is used in the study.

1. Introduction
The erection of churches obeys strict and rather conservative architectural laws and rules that regulate almost everything, from the proportions of the future structure and its space orientation to construction technologies and designs of architectural elements. One of the most important architectural elements of the church is the dome roof. Over the centuries, church dome roofs were made of wood and metal. However, progress is implacable, and fiberglass - a plastic composite material consisting of a glass fiber filler (glass fiber, quartz fiber, etc.) and a binder (epoxy and polyester resins) is often used in the construction of modern churches [1].

2. Relevance
Russian church architecture in the post-Soviet period as an art, was banned [2]. However, the changes that occurred in the 80-ies of the XX century in the life and religious consciousness of people led to the need for massive construction of new churches [3]. At the same time, the seventy-year break led to the fact that a significant part of ancient Orthodox churches in Russia, which are church monuments of architecture, is in an unsatisfactory condition. This is preconditioned by the lack of a timely care for them and the termination of their use. The question of restoring Orthodox church buildings must be studied comprehensively, because the prevention of the disappearance of the cultural heritage and its preservation for the next generations are one of the most important missions of the humanity. Restoration of churches is accompanied by several organizational and technological peculiar features, which are preconditioned by the complex architectural and spatial shape of the building and its architectural elements [4].

The experience of church building presented in the literature is reduced to general recommendations that meet the canonical church requirements based on Orthodox dogmatism and the
church building tradition [3]. Therefore, it becomes necessary to compare the architectural elements of churches - dome roofs - by the most characteristic features: shape and design.

After studying the literature dealing with the research subject, it has been established that most of works are devoted to the history of Orthodox architecture [5-10]. Scientific publications dealing with the research subject mainly reflect the problems of the development of Russian church architecture, the condition of the modern church design practice and organizational and technological solutions of church reconstruction [2,4,11]. Most Internet sources deal with the use of fiberglass in church building [12-14].

Thus, the types of church dome roof designs are insufficiently studied. The determination of the dome roof material most suitable for the restoration of old churches with a weakened ability of bearing walls and the improvement of the operation of enclosing structures requires additional studies, namely, determining the influence of aerodynamics on the dome roof of a church building, taking into account its configuration and wind directions.

The objective of the research is to determine the dome roof material most suitable for the restoration of ancient churches with a weakened ability of bearing walls and the improvement of the operation of enclosing structures.

3. Theoretical part

3.1. Church dome roof design

3.1.1. The design of a wooden church dome roof. The frame of the dome roofs up to 3 m in diameter is usually made with wooden bent elements cut by a pattern from several paired boards 40 mm thick and fastened to the central pillar serving as the base for the Cross. The bent elements are used for wooden radial roof boarding with the pitch of about 300 mm or covering boards of cross plywood bands 4-5 mm thick laid in 2 layers. In case of a scale-like surface of dome roofs, horizontal centerings cut by a pattern with a pitch corresponding to the size of the scale are attached to the curved elements. The dome roof design is made of wood with the moisture content of no more than 12%. Wooden elements are attached to each other on wooden dowels made of hardwood: oak, beech, ash tree.

The drum of the wooden dome roof can be brick or with a metal frame and wooden centering rings used to fasten the wooden roof boarding, which is plastered over the steel grid [3].

The specific gravity of hardwood is 600-720 kg/m³, and metal - 7800 kg/m³, i.e. a wooden dome roof is much lighter than a metal one. However, for dome roofs with the diameter of over 3 meters, an additional metal frame is required, which increases the weight of the item, so the installation of such dome roof requires a lot of elevated operations using special equipment [12].

A shingle - short, thin, shaped like the dome roof, ornamented boards made of aspen, pine or oak - is used to cover wooden dome roofs. In this case, it is necessary to take into account their location on the roof and select the layers in such a way, so that the water from the roof did not flow "towards" the layer. Since the tree is prone to rotting, the dome roof is treated with special impregnating compounds, covered with metal, titanium nitride or gold leaf. The average life of a wooden dome roof is no more than 10 years.

3.1.2. The design of a metal church dome roof. The basis of the structure is: a support ring, a central pillar fastened to the ring by the braces and curved centering-bent elements. Depending on the size of the dome roof, the bent elements are connected to the pillar in one or several tiers with metal bracing beams. A rafified roof boarding made of metal strips is installed between the bent elements in 40 - 50 cm. A coating made of iron sheets punctured in the shape of the dome roof and connected on rebates is attached to it. The apron is fastened on steel brackets with the pitch of about 150 mm with a galvanized roofing steel strip attached over the top. The metal elements of the dome roofs are welded with high-quality E-42A electrodes. After the dome roof is erected, all the elements after cleaning from rust should be twice treated with an antirust compound - lead oxide [3].
The metal dome roof is the heaviest: at the diameter of 1.78 m, its weight is 880 kg, and at the diameter of 3 m - more than 1.5 tons, so the installation of such dome roof requires a lot of elevation operations using special equipment.

Copper, stainless steel or galvanized steel is used for coating of metal dome roofs. 0.8 - 1 mm thick sheets are generally made in the form of scales with joint soldering. Any direct contact of steel dome roof structures with a copper coating is prohibited. Since the metal is prone to corrosion, it requires a complex treatment, coating with primer and paint, titanium nitride or gold leaf, however, it provides environmental protection for no longer than 10 years. Periodic maintenance at height is needed to protect the dome roof from corrosion damage. The average lifetime of a metal dome is not more than 20 years [3,12].

3.1.3. The design of a fiberglass church dome roof. Fiberglass has a relatively small specific gravity, so the weight of a fiberglass dome roof is noticeably lower than that of a traditional metal one - a fiberglass dome roof with the diameter of 1.78 m weighs about 95 kg, and with the diameter of 3.2 m - 530 kg. A fiberglass dome roof does not need additional reinforcing metal structures, since fiberglass reinforced with glass fiber has a sufficiently high strength, i.e. is a self-supporting material. Although a supporting metal frame for the cross is needed for large dome roofs - more than 3 m in diameter. A fiberglass dome roof is completely manufactured at the production site, its installation takes one day.

To prevent abrasive wear, the surface of the fiberglass dome roof is treated with a gel coat - a special decorative protective coating for composite materials, the color of which can be chosen according to the RAL catalog. The gel coat has a satin gloss (iridescent in the sunlight); glitters and texturing particles can be added to its composition; it does not require further treatment and special care; it provides environmental protection for more than 50 years. A fiberglass dome roof can be also covered with titanium nitride or gold leaf.

The drums of such dome roof are also made of fiberglass; at the diameter of more than 3 m they are additionally reinforced, but, in any case, they are quite light.

Fiberglass has a chemically inactive surface, i.e. high resistance to corrosive environments and atmospheric influences, therefore the average life of a fiberglass dome roof is 100 years or more [12].

Besides, fiberglass has the following properties: temperature resistance, low thermal conductivity, radio transparency, high dielectric parameters (lack of electrical conductivity), relatively low production costs. It should be noted that it is relatively easy to launch the production of fiberglass items (such ancillary production can not only significantly reduce the cost of construction operations, but also become a separate income item) [13].

The advantages of fiberglass for making church dome roofs over the traditional materials include:

- fiberglass can be made in any color, i.e. you can immediately make a dome with a yellow substrate for gold leaf, while you can omit intermediate primers, saving time and material;
- the surface of a fiberglass dome can be made perfectly smooth, to be more exact - polished, since the more mirror-like the surface for gilding, the brighter the gold shines;
- a fiberglass dome roof with the diameter of up to 2.4 m is made by a solid matrix and has no visible joints, which means that there is no need for reworking and plastering of the joints, without which a metal dome roof of any size cannot do, since it is made of sheet material [14].

One of the examples of a church crowned with fiberglass drums, domes and dome roofs is the church of the Iveron Icon of the Mother of God in Izhevsk. In "Construction Market" magazine (2014), specialists of Kraftplast Ltd. responsible for the erection of this amazingly beautiful object share the nuances of the technology: "First, specialists developed a three-dimensional model of the bulbous domes, prepared the drawings, then, the frames with curvilinear metal surfaces were made using the water abrasive cutting technology, then shape-generating molding tools were gathered for the model, then casts were taken from the model, in which the dome spirals were made from a glass composite. 16 spirals were cast for each tower, then, they were assembled and sealed. The dome
drums were made using the same technology. They also have a complex surface and peculiarize the building” [1].

Comparative characteristics of the church dome roof designs are given in Table 1 [12].

Table 1. Comparative characteristics of church dome roof designs.

| Comparative features | Wooden dome roof | Metal dome roof | Fiberglass dome roof |
|----------------------|------------------|-----------------|----------------------|
| 1. Specific gravity   | 670-720 kg/m³    | 7800 kg/m³     | 400-1800 kg/m³      |
| 2. Diameter - weight ratio | 1.78 m – about 80 kg, 3 m – about 130 kg. | 1.78 m – 880 kg, 3 m – over 1.5 tons. | 1.78 m – about 95 kg, 3 m – 530 kg (taking into account the decorative gel coat). |
| 3. Additional accessories | Wooden frame – for dome roofs with the diameter of up to 3 m, metal frame – for dome roofs with the diameter of over 3 m. | Metal frame. | An additional supporting metal structure for the cross is needed for large dome roofs – with the diameter of over 3 m |
| 4. Coating | Shingle | Copper, stainless or galvanized steel. | No coating with other materials is needed. |
| 5. Environmental protection | Treatment with special impregnating compounds; coating with metal, gold leaf or titanium nitride, which provides environmental protection of no more than 10 years. | Complex treatment, coating with a primer and paint, it is also possible to cover with gold leaf or titanium nitride, which provides environmental protection of no more than 10 years. | Coating with gel coat (special protective coating), which provides environmental protection for more than 50 years. |
| 6. Drums | Brick, concrete or metal drum. | Fiberglass drums, at the diameter of more than 3 m - additionally reinforced. |
| 7. Assembly | A lot of elevation operations, as well as assembly and erection operations using special equipment. | Completely manufactured at the production site, the installation takes one day. |
| 8. Corrosion | Wood is not corrodible, but is prone to rotting. | Metal is corrodible. | Fiberglass has a high resistance to corrosive environments and atmospheric influences. |
| 9. Average service life | no more than 10 years | no more than 20 years | 100 years and more |

3.2. Study of aerodynamic characteristics

Regardless of the dome roof design and the material, from which it is made, according to the canonical church requirements, dome roofs crown a church, and, therefore, are located at a sufficiently high altitude. In addition, usually churches and temples are located in an open space surrounded by a landscaped green area. All this causes large wind loads on the dome roof.

SolidWorks suite, as well as FlowSimulation complement was used for the study. A simplified model of the church with a bell tower was taken for calculations to analyze whether such structural element would influence the wind load on the dome roof [15,16].

Depending on the wind direction, the church dome roof is exposed to various wind loads due to the complex configuration of the building [17-20]. In case of the west wind, the bell tower blocks the wind flow, resulting in low pressure areas and swirling between the bell tower and the dome roof on the drum. (Figure 1a). If the wind blows from other parts of the world, southern, eastern and northern, the dome roof takes the whole wind flow (Figure 1b).
Figure 1. Wind speed: a) west wind; b) south wind.

At the wind speed of up to 20 m/s, there may appear the high wind pressure on the dome roof. Due to the low weight of the fiberglass dome roof, the turning moment may occur. It must be particularly taken into account when calculating the fastening of the dome roof to the drum.

Thus, the aerodynamic characteristics of the dome roofs of architectural objects of the national heritage are quite favorable, since they have an aerodynamic shape. But when building a whole composition of dome roofs, it is necessary to analyze the design in order to get minimum swirling to reduce the load. It is also necessary to take into account the possible occurrence of the turning moment of the dome roof at a low weight of the structure, which necessitates to study wind loads.

Consequently, dome roofs can be made of fiberglass, which is cheaper to produce, rather strong and durable. This will greatly simplify the task of building and reconstructing dome roofs of such architectural objects.

4. The practical relevance
The practical relevance of the research lies in the possibility to implement the research results when calculating the aerodynamic influence on the dome roof at different wind directions, taking into account the structural features of the building, comparing the wind pressure on the dome roof, determining the dome roof design most suitable for the restoration of old churches with weakened bearing walls, determining the turning moment necessary for selecting the dome roof mounting method.

5. Conclusions
Fiberglass is best suited for making dome roofs of church monuments of architecture, since:

1. The decorative properties of fiberglass, as well as the ability to take any architectural shape, allow you to observe the church requirements and the church tradition.

2. Gel coat of the fiberglass dome roof does not only provide environmental protection for more than 50 years, not requiring further treatment and special care, but also performs a decorative-aesthetic function.

3. The simplicity of the fiberglass dome roof design, as well as a long service life are very important for the restoration of ancient churches with a weakened bearing capacity of the walls.

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