Composites joining science and religion

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When aircraft makers start building religious structures, they get a chapel made of modern aircraft materials. And it's not a joke. They were even forestalled by the Russian Orthodox Church, one of the world's most conservative organisations, which commissioned an avant-garde building of the Russian Orthodox Spiritual and Cultural Centre that was built in 2016 at Quai Branly, Paris – within a five minutes' walk from the Eiffel Tower.

The Centre's ensemble stands out against the posh buildings of Paris's 7th arrondissement to the point of being ahead of its time. Not only do its square forms, as opposed to classical Orthodox cathedrals, catch the eye – but also its onion domes made of composite materials. This paper is about how modern builders increasingly adopt aircraft technology.

From ancient Egypt to modern planes and airports

Some sources date the inception of composites use in construction to 1000 B.C. at the latest, when Semitic builders were the first to use a composite material, namely clay bricks reinforced with chopped straw, in ancient Egypt. In our own era, the second half of the 1960s saw growing interest in using composite materials in civil engineering and developing this technology, and the first composite dome and roof structures appeared in the early 70s.

Well-known early examples include the dome of the Suliman al-Dharrath Stadium in Benghazi, Libya (1970), and a roof at the Dubai International Airport (1972), whose composite panels were made in Great Britain.

The use of glass fibre composites in building structures became widespread in the UK and USA in the 1970s and 1980s, with glass fibre-reinforced composite materials used in non-structural prefabricated panels for the construction of the Covent Garden Flower Market (Figure 1), the American Express building in Brighton, and elsewhere. The walls of the Mondial House telephone exchange building on the bank of the Thames in central London are clad with glass fibre composite panels (Figure 2).

Double-layered "skeletal" structures made of pultruded tubes started to be used in 1985.

Fig. 1. The Covent Garden Flower Market in London

At that time, it was the possibility of unusual architectural solutions that was considered the main advantage of composites, rather than reduced weight. It was arguably the first wave of modern composite applications in construction – one that led to no explosive growth or shift of the construction paradigm, particularly as the material was not mature enough while too much was expected of it.

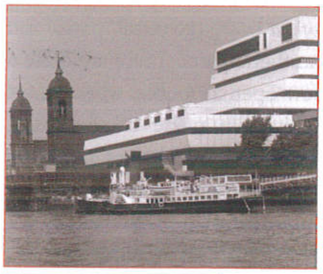

Fig. 2: The Mondial House Telephone Exchange

Records in sports

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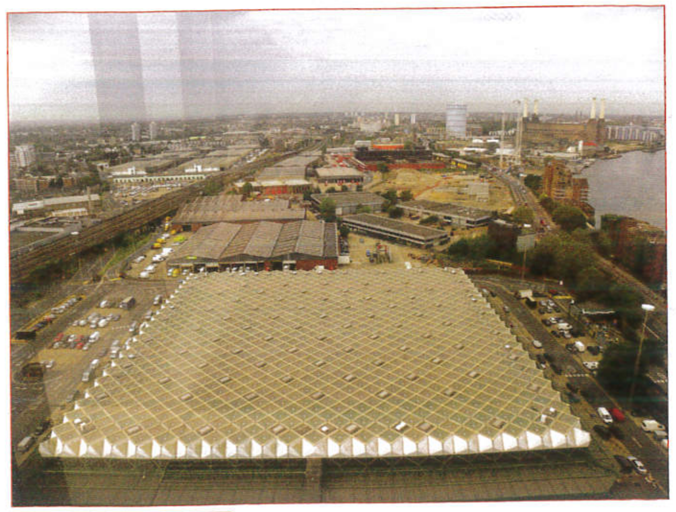

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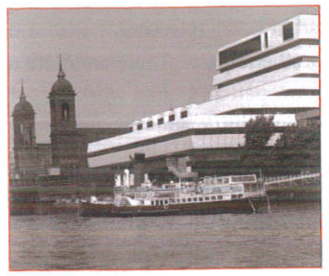

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In the early 21st century, composite materials are again in vogue as carbon-based composites have become somewhat less expensive and are increasingly used in such prestigious industries as sports (sports cars and equipment) and aircraft building. Carbon composite sporting equipment, sports, and racing cars with carbon composite parts are now familiar to everybody, and advertisements for products based on specific brands of carbon fibre make carbon-based composites widely known. For example, it was back in the early 2000s that the makers of the best-known brands of bicycles taking part in the Tour de France and Giro d'Italia stage races began stressing the use of Toray T700 and T800 carbon fibre.

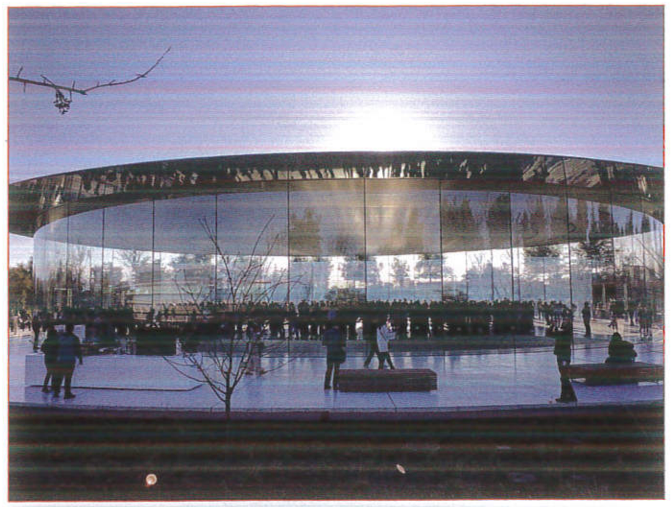

Fig. 3: The Apple Theatre's carbon fibre roof

Fig. 4: Interior view of the Emirates Palace roof

Since the 1980s, the construction industry has only been smoothly advancing in using composites, held back by two main factors: no drastic fall of fibre and resin prices and insufficient heat resistance of polymer resin in case of fire, which prevents full-scale use of composite materials in load-bearing structures.

Recently, there appeared a wide number of interesting large-scale examples of using composites in roof and dome construction. For example, Apple installed a massive carbon fibre roof on the Apple Theatre at its new headquarters at Cupertino, USA. An 80-tonne roof of 44 carbon fibre panels was installed over its glass walls (Figure 3). Each panel is 21.3 m long and up to 3.6 m wide. The panels were made by Premier Composite Technologies Co. (Dubai, UAE), a company with experience in creating large composite architectural structures. The Apple Theatre roof is the world's largest free-standing structure made of carbon fibre. The composite material used enabled the architects to discard additional supporting elements and to produce a striking visual effect, as the building's walls consist of nothing but glass panels.

Another large-scale example is the Emirates Palace (Abu Dhabi, UAE). With an area of more than 14,000m², this huge complex includes 114 domes that use composite materials (Figure 4). The largest dome is 42 metres wide, and the rest are 3 to 17 metres in diameter. The domes consist of composite sandwich panels made of glass fibre and epoxy resin, with a thermoplastic cellular filler. All the domes except the main one and all the vaulted roofs are self-supporting structures without any supporting steel framework. The domes are installed on steel or reinforced concrete ring beams with base plates and brackets.

Still another example is an 8-metre composite dome installed over a telescope in Mary, Turkmenistan. The dome consists of six composite panels individually opened by a hydraulic system. The panels also have a sandwich structure, with their inner layer made of a thermoplastic material and their outer layers made of epoxy-based glass fibre composite. The composite material saved 10-15% of the weight of an equivalent metal dome as well as cost and electricity thanks to smaller hydraulic drive systems.

Composite domes and roofs are stronger than traditional ones and save up to 85% weight. They are much easier to lift and install, and far more convenient to use and repair. Moreover, composite structures are resistant to corrosion and environmental effects.

The Russian Orthodox Centre in Paris

The Russian Orthodox Spiritual and Cultural Centre that opened in Paris in October 2016 is apparently one of the most modern ones. Its minimalistic ensemble was designed by architect Jean-Michel Wilmotte (Figures 5.1 and 5.2). The façade is decorated with natural Burgundian limestone also used to decorate the Louvre and Notre Dame Cathedral, so its domes were also made to match the rough surface of the limestone and the façade's ribbed structure. Using a glass fibre composite material to make the domes was a unique technological solution that minimised the total load on the structure and made it possible to install the domes in a matter of hours. Another advantage of the glass composite domes was that they were made and decorated in a controlled environment, so their manufacture and installation were unaffected by weather. The manufacturers used moulds based on multi-axial fabric and an epoxy infusion resin. The dome panels were made at the Multiplast factory in France, using the vacuum infusion method with an epoxy resin and reinforcing fillers of multi-axial and ordinary 2D fabric whose placement was specially optimised to minimise non-infiltration possibility and obtain a high-grade surface with a total area of 640m², which was then decorated with 86,000 gold leaves.

Fig. 5.1: The Russian Orthodox Spiritual and Cultutral Centre in Paris

Fig. 5.2: The Russian Orthodox Centre's domes

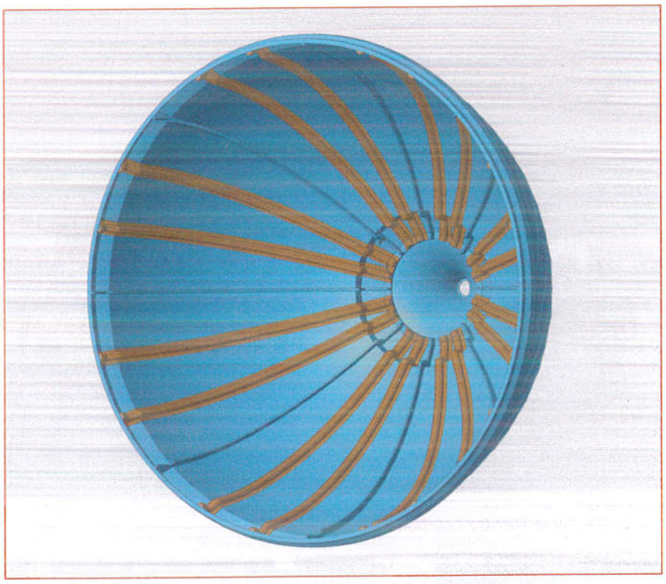

Fig. 6: 3D model of the chapel dome

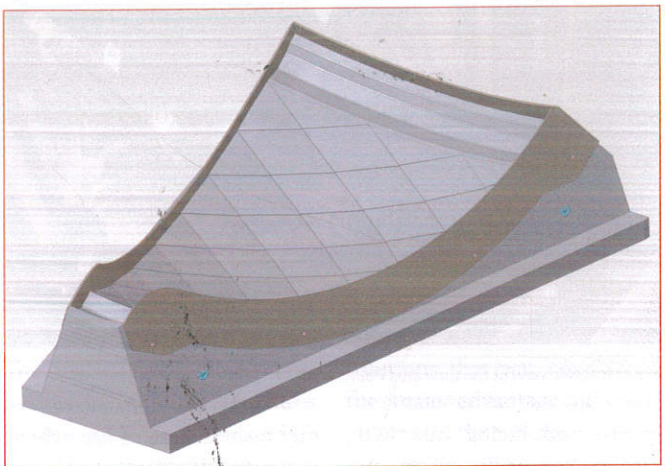

Fig. 7.1: Mould 3D image

A chapel built by Russian aircraft engineers

The process of re-designing aircraft to maximise the use of composite materials is in full swing in modern Russia. The news of the composite dome created in Paris inspired the designers and process engineers of the Voronezh Aircraft Building Joint Stock Company (VASO, PAO), who were interested in it as much as in making composite parts for aircraft.

A chapel dedicated to the "Blessed Heaven" icon of the Holy Virgin was to be erected on VASO grounds. It was initially designed with a dome 4.6 m in diameter and 3.1 m high, based on a steel framework covered with coated stainless steel sheets. But the company's process engineers and their long-standing partners from the "INCMaT" Joint Stock Company developed another solution: making the dome with composite materials (Figure 6), which would reduce both costs and the load on the foundation, on account of the dome's lighter weight.

"INCMaT" JSC not only supplied the resin for the dome but also took an active part in the dome and mould design.

The design engineers faced a number of problems. For example, it was decided that the dome's outer surface was not to be smooth outside but rather imitate a tile roof. That proved rather difficult to implement, as the "tiles" get larger not only from the dome's apex to its base but also in helical order. So it was necessary to divide the dome into several parts and design them so as to reproduce the pattern but also to join each section's "tiling" parts without shifts and keep the pattern continuous. An MDF mould was made for that purpose, with two metal elements superimposed to shape the flanged joint (Figures 7.1 and 7.2). The mould had to be designed to bear at least eight doffs – as many as the lobes in the dome – and thus avoid the need to make a master model or mould. This imposed additional design limitations, for the mould had to exclude small parts to keep stable. Each of the eight dome sections had two flanges. Standard fixture elements were used to attach the flange connection, and the seams between sections were ground, caulked and painted.

In making the composite dome, four-layered multi-axial glass cloth was used as a reinforcing filler, and the ITECMA TK123 resin as a matrix. The design solution provided for rifts with a sponge glass filler. The dome's sections were made using vacuum infusion and cured in a hardening oven at 60°C. The finished dome is shown in Figure 8.

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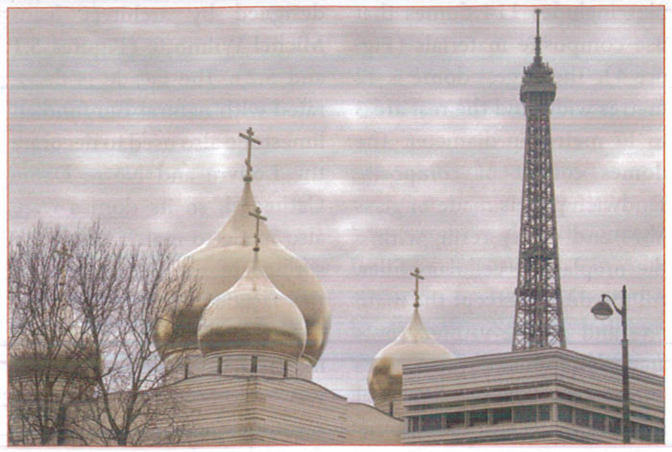

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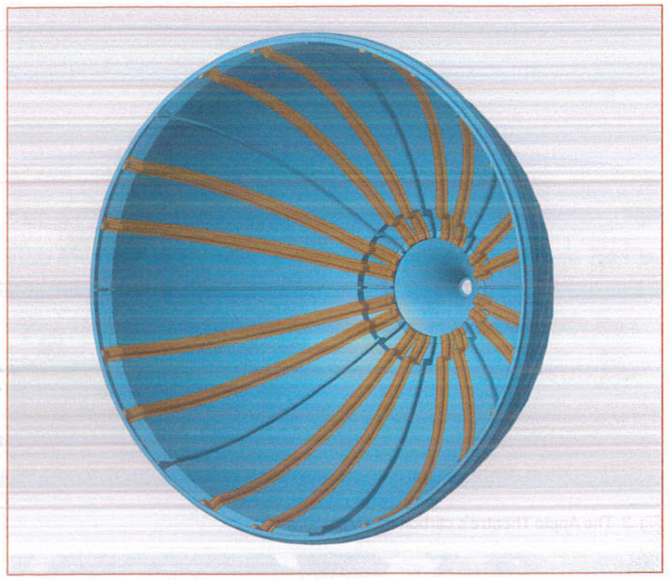

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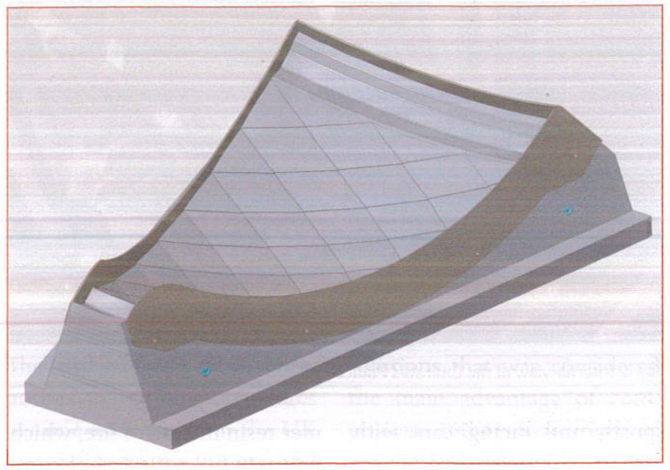

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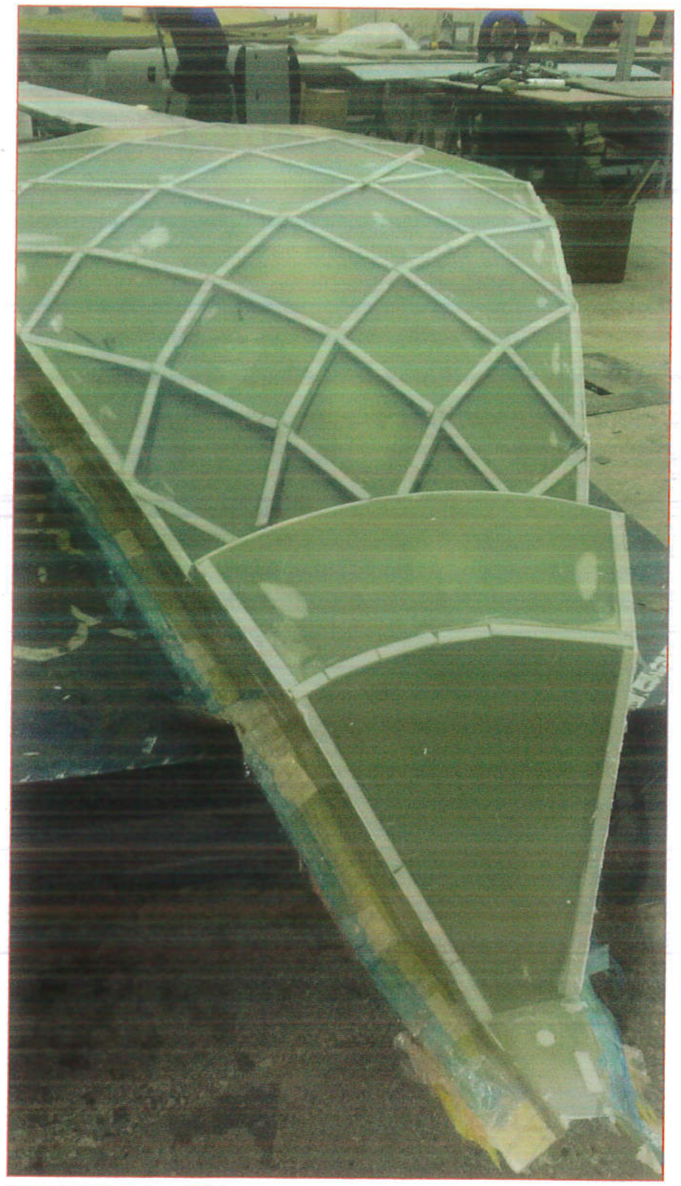

Fig. 7.2: Dome section

Fig. 8: The finished dome

Fig. 9: Memorial chapel in honour of the «Blessed Heaven» icon of the Holy Virgin

After assembly, seam processing and painting, the dome was mounted on a triangular framework made of lightweight metal profiles and placed on its foundation. The glass composite was easy to paint, and the finished surface cannot be distinguished from metal. The finished dome's total weight is less than a tonne, while a metal dome as originally designed would have weighed some three tonnes.

The experience of making the dome showed that the use of composite materials in construction offers great advantages: time and money savings, simple manufacture and installation, and environmental resistance. But their main advantage as compared to classical solutions is the possibility of making entirely new designer structures that would be too heavy and expensive if made from traditional materials. For ordinary structures, simply replacing the materials with composites would save more than 50% weight and drastically reduce the time required. Composite materials are quite easy to paint and are in no respect second to metal structures in terms of visual appearance. The newest developments of ITECMA LLC, including those designed for builders, helped erect a top-quality structure that is easy to service. □

More information:
www.itecma.ru

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