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Dragons – a unique fusion of art and engineering

1 Introduction

Excon worked together with the Czech glass company Lasvit to create an impressive work for the Imperial Pacific Hotel on the Northern Mariana Island of Saipan. This monumental light fixture and giant illuminated jewel took three years to bring to fruition, resulting in two metal and glass dragons, each weighing twenty tons, that are the focus of visitors' attention as they enter the hotel lobby. Individually the dragons are each a magnificent gem, and together they form a single impressive piece of jewelry.

Each dragon's body is sheathed with 13,000 crystal scales, and each scale is encrusted with nearly two hundred individually attached Swarovski crystals. Stretched out fully, each dragon would reach a length of 50 meters. Its eye alone is an impressive 220 × 90 cm.

The crystals not only reflect light, but are also illuminated by programmable LED modules that can be individually controlled by computer. The dragons can, for example, "change their skin" from pink to green at the touch of a button. Preset effects are also available, including color changes or even light waves.

2 Architectural and structural design

The aim of the project was to design, manufacture, and assemble the supporting structure of each dragon, including its suspension, connection points, wires for assembling the scales, and elements for mounting other components of the sculpture.

During the preparatory work on the dragons' support structures, the designers rejected two variants: one utilizing a supporting spine on which the cladding elements would be suspended and one with a supporting shell. Neither of these variants met the two primary conditions for assembly and maintenance: clearance within the structure (including the placement of internal switchboards) and the ability to replace individual scales. Therefore, a third variant was selected. The load-bearing element of each supporting structure comprises a hollow space truss structure made of circular rings with tubular cross bracing, which simultaneously forms the overall shape and line of the body, 32 m long with a contour height of 13 m. The two dragons are nearly mirror images: the only minor differences are in the positioning of the suspension points resulting from the layout of the supporting ceiling structure above.

The final version of the project resulted from long hours of fine-tuning the shape of the supporting trusses that created the necessary support for the back-lit glass shell. Also important was selecting the proper structural material for all cross-sections of the support elements that was readily available and sufficiently corrosionresistant for the duration of transport and installation in the aggressive coastal environment. Corrosionresistant steel 1.4404/316L, also known as surgical steel, was selected.

The structure is suspended from eleven different lengths of Macalloy SC460 stainless steel compact strand cable. The positions of the cables were determined by the size and weight requirements of the individual elements of the structures, taking into consideration the spatial rigidity of the overall structure. The cables are 16 mm in diameter, except for the cable under the greatest load (behind the dragon's head), which is 19 mm in diameter. All bars are fitted with tensioning elements and strain gauges that monitor the forces introduced during assembly to facilitate assembly and adjustments.

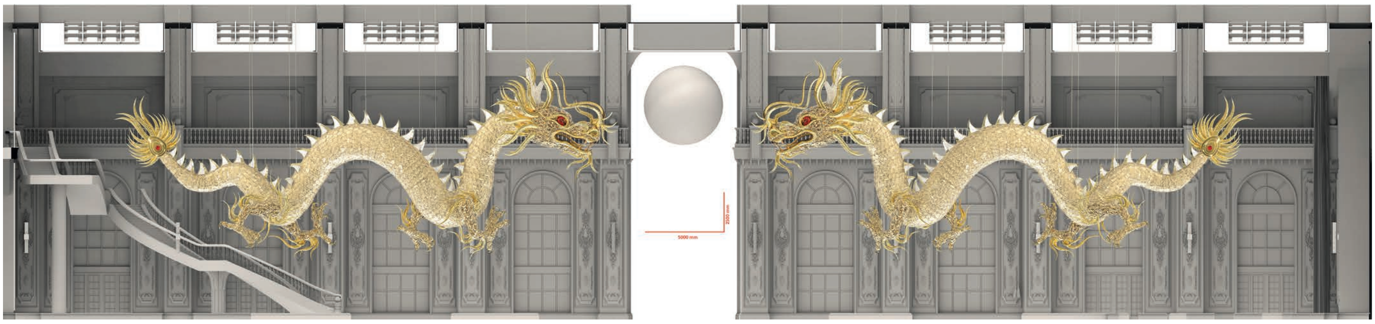


Fig. 1 Basic idea of the structure

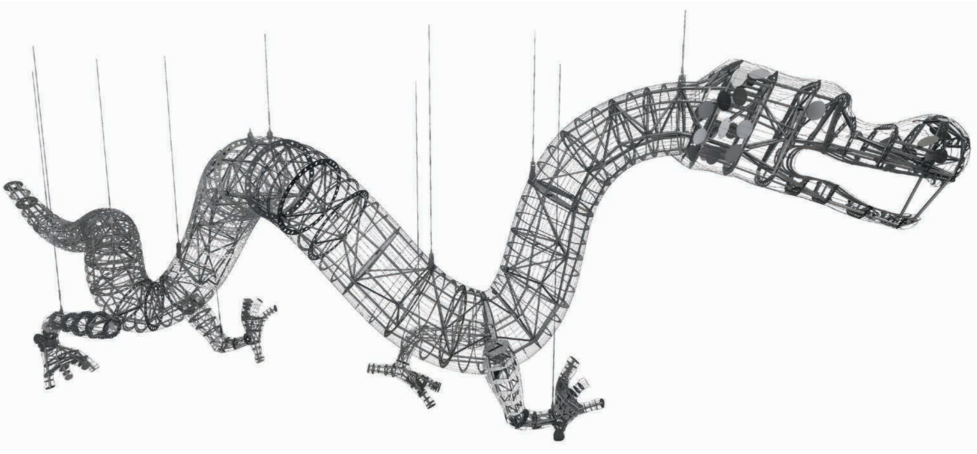


Fig. 2 Overall diagram of the truss support structure

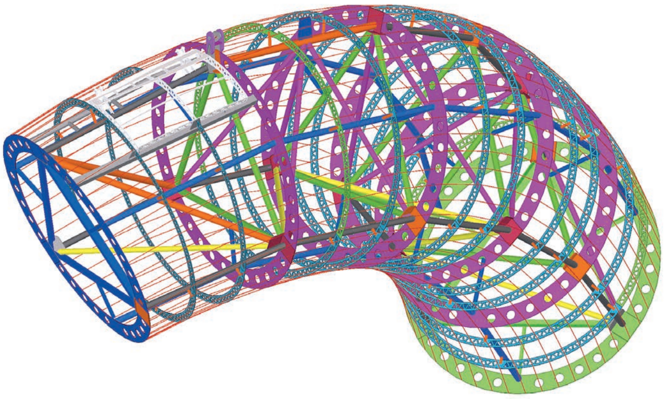


Fig. 3 3D model – basic structure without additional components

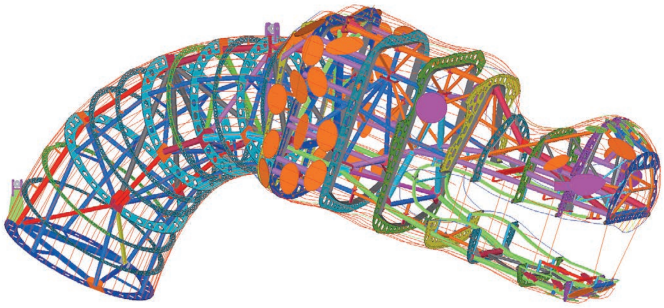


Fig. 4 Detail of the head structure with attachment points for the installation of additional elements

In addition to the weight of the steel structure itself and the weight of the shell made of glazed scales, the support structure also bears the weight of the additional components (beard, claws, eyes, teeth, tongue, dorsal spines, massive tail, etc.) that no dragon can be without. Another constant load is the electrical equipment: the junction boxes, cables, connectors, light fittings, etc. The additional weight of the people who must be present directly on the structure during assembly and servicing was also taken into consideration.

No part of the main structure repeats, as its shape is curved vertically and horizontally, and the additional components are also varied. Based on feedback from the investor, designers modified the contours of the structure multiple times throughout the design process to improve the appearance of the mythical creature, which also affected the support structure.

Thanks to the smooth collaboration with Lasvit's designers, we were all able to work entirely in the 3D models with regular bidirectional updates, which allowed us to work simultaneously on the static, structural, and artistic aspects of the design.

The following images show the complex shape of the truss support structure in more detail. It comprises transverse circular braces with a maximum diameter of 2.2 m, to which the tubular elements of the space truss are connected.

The weight of the circular braces is reduced by drilled holes, which are then conveniently used to direct the cabling for the LED components. The subsupport elements

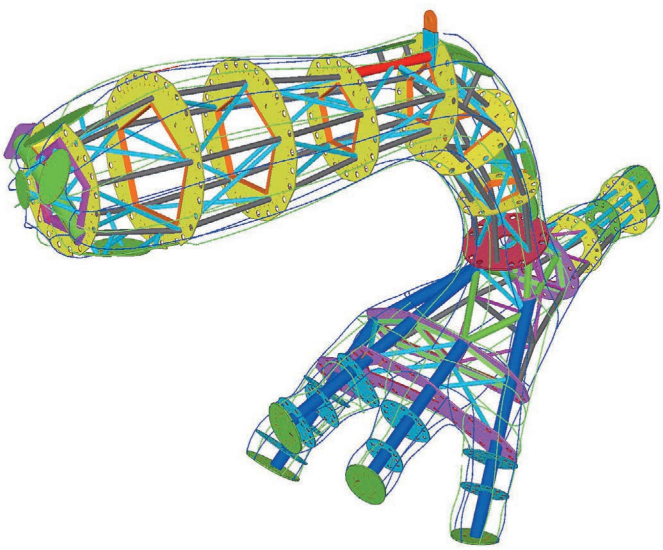
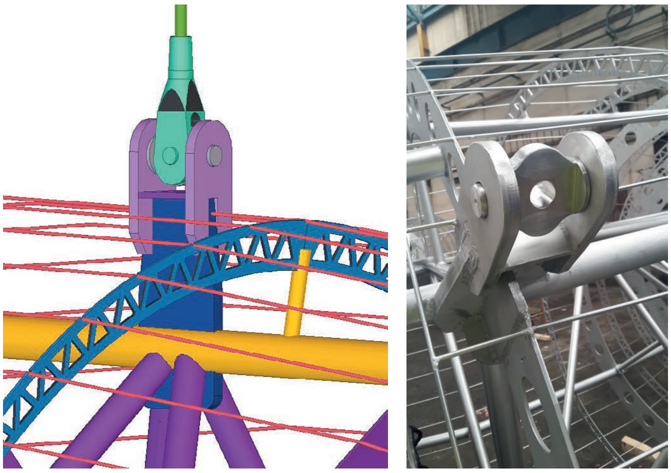


Fig. 5 3D model – dragon leg

then protrude from the basic tubular truss to form the desired shape or support an ornamental feature. The entire structure is covered with a system of heavy-duty longitudinal wires for attaching the scales, which, although not foreseen in the static model, were nevertheless used as a stabilizing element in the design of the transverse rings.

A separate chapter in the preparation of the static and subsequently the structural model was the creation of the shapes of the main external components of the dragon's body. These included supports for the tail, dorsal spines, claws, eyes, tongue, teeth, and long flowing hairs on the head section of the sculpture. These had to function statically, as well as take into consideration coverage with an intricate layer of scales while still looking natural.



a) b)

Fig. 6 Cardan hinge: a) 3D model; b) actual hinge during pre-assemblys

3 Dynamic calculation

The island of Saipan is part of the North Mariana Islands, a Western Pacific archipelago located in a tectonically active area. The design, therefore, had to include an analysis that demonstrated sufficient structural safety even under seismic loading. The original intent to attach the dragon by thin, flexible horizontal rods with damping elements to the building structure was rejected for aesthetic reasons. The final decision was to leave the dragon freely suspended, and the analysis focused mainly on determining the maximum horizontal deflection during forced oscillation. Too much deflection would have compromised the function of the tie rod connections. Eigenfrequencies (natural vibration frequencies) were determined on the global model, which became the basis for calculating the maximum horizontal deflection (or maximum rod deflection angle).

A team at the Institute of Theoretical and Applied Mechanics in Prague then verified the result using a separate simplified calculation. Here the structure was simplified and modelled as a nonlinear pendulum with one degree of freedom. The pendulum was assumed to be kinematically excited by typical accelerograms corresponding to the expected earthquakes to approximate the expected maximum response.

Analysis of the system showed maximum lateral deflections of some elements that required modification of the design of specific structural details. Where the hinge anchor detail rotation exceeded the manufacturer's allowable value, designers added lateral hinge elements between the structure and the hinge to allow for such large deflections (s. Fig. 9).

Finally, the resulting static and dynamic design was verified and validated by an independent firm, Finley, who certified the documentation for the US authorities.

4 Structural model

The entire digital 3D structural model was created in Tekla Structures. The modelling process encountered many obstacles due to the size of this non-standard structure and some of the atypical details required, as seen in the images.

The actual work on the structural model was also tailored to the production of the individual elements, as it was necessary to accurately identify all the parts of the structure not only by their number but also by their position (right, left, top, bottom). The DSTV data was exported directly from the structural model to machine production to minimize manually produced complex shaped parts (manual production always poses some additional risk).

A crucial detail of the structure was the locations of the hinges, which were placed based on the results of the static and dynamic calculations. Universal joints (cardan hinges), i.e. a longitudinally rigid joint allowing articulated movement in both directions, were used. The central section of the hinge was milled from a single circular section to avoid any defects and imperfections that might arise from welding.

For the production process, manufacturing and assembly aids were prepared as part of the structural modelling, together with drawings and tables of the geodesic points of the individual assembly units and the overall structure. Unusual for this project was the documentation of the production assembly of each unit. Due to the spatial complexity of the entire structure, it was practically impossible to position the assembly accurately using traditional dimensioning. Therefore, the position of each of the transverse rings was described by the local coordinates of the centre and the main connection points in relation to a preprepared 3D assembly grid.

5 Production and pre-assembly

The construction parts were produced serially, primarily by machining. The prepared and machined parts were assembled into mounting units using the assembly documen-

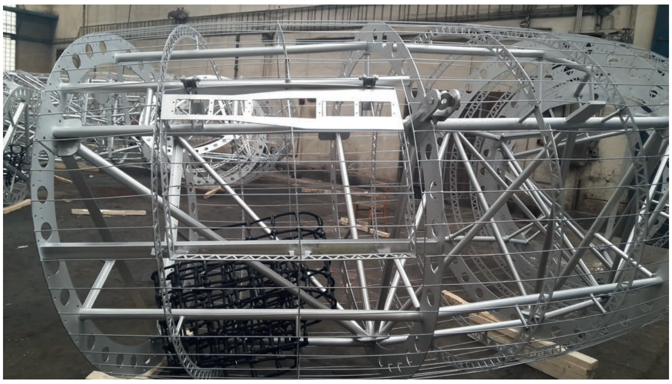


Fig. 7 Finished unit ready for pre-assembly

tation for each unit. First, each transverse ring was secured in space according to its coordinates and then connected by partial welding of the primary support tubes to the previous ring. This was followed by the fitting and securing of the next ring, and so on. By consistently securing all the rings on the unit using a single coordinate system (and not in relation to the previous ring), we avoided the buildup of possible minor errors and inaccuracies. After complete assembly, each unit was aligned geometrically, and this measurement was checked against the 3D structural model. Once the correct shape was confirmed, the unit underwent final welding and preparation for preassembly.

Due to the atypical nature of the entire structure, a complete preassembly was carried out prior to the final installation. This required finding a sufficiently sizeable empty hall with all the necessary facilities for assembly. For this purpose, the EXCON hall in Teplice, which had been conveniently cleared to install new equipment, provided sufficient space.

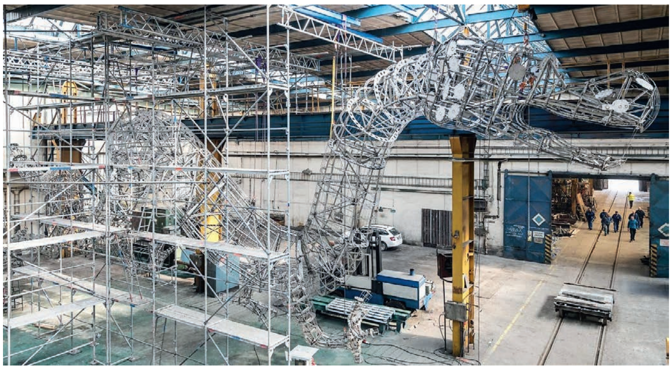


Fig. 8 View of the assembled truss structure

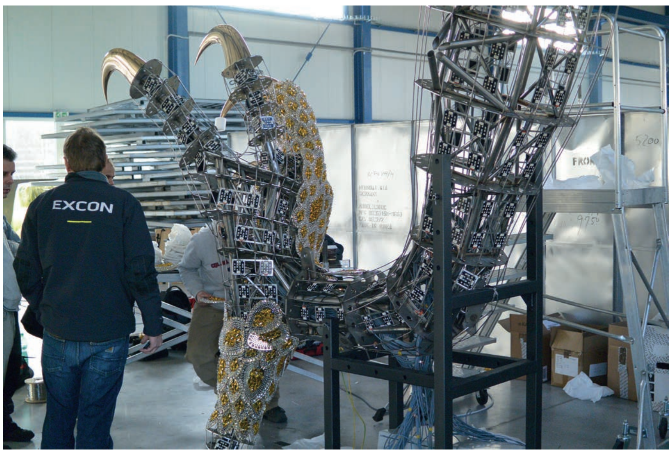


Fig. 9 View of the structure, cladding and components of one unit

Preassembly was carried out in a similar manner as the planned assembly on Saipan. For the final assembly, it was also necessary to verify all the centres of gravity of the individual assembly units and draw up a detailed assembly procedure. This was the only way to assemble the individual units on site using only the permanent mounts and assembly hoists (no cranes and other lifting mechanisms could be used) while maintaining the necessary precision at the connection points.

Preassembly was carried out on both truss structures to check the overall shape, structural assumptions, and all necessary electrical, cladding, and individual component connections. It was also essential to check all welds in parallel. Structural components were then marked, disassembled, and prepared for the overall passivation of the corrosionresistant structure. The heaviest unit – the head – weighed in at 840 kg, the body unit 725 kg and the heaviest leg 260 kg.

As part of the pre-assembly, tests were conducted on the functional continuity of some parts of the glass cladding and individual components and the internal LED lighting. Additionally, the conditions for the movement of the workers inside the truss structure were verified (e.g. to check that there was enough space for the assembler to move inside each part of the assembled structure).

6 Assembly of the structure

On-site installation took several months. Most parts were transported by ship, with air transport used for some (primarily smaller) parts.

As the assembly site was quite far away, all necessary tools needed to be prepared. In addition, coordination of the structure's anchor points was essential during the construction of the whole building. The first thing that was checked prior to final assembly was the readiness of these points to avoid collapse or damage to the structure. All fabricated components were also rechecked for damage in transit before actual assembly started.

The entrance hall where the assembly was to take place was already complete, so great care had to be taken to avoid damage to finished surfaces. First, the first truss structure was assembled and handed over for subsequent mounting of the electronics and cladding elements. Only after the first truss structure was successfully completed was the assembly of the second truss structure begun. An interesting and necessary part of the assembly was adjusting the forces in the metal cable hangers as measured by strain gauges to ensure that the reactions introduced by the cables into the structure corresponded to the designed

Fig. 10 View of the completed sculpture

values. The strain gauge measurements were carried out at each assembly stage to verify that the results conformed to the design.

The technicians were able to move around inside the sculpture during the assembly of the support structure and the subsequent installation of the shell and internal electrical equipment. In total, some members of the team spent up to two months on-site inside the steel monster.

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