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Constructing Non-Linear Shaping Envelops in Current Architecture

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Abstract

The paper focuses on constructing curvilinear structural envelops in digital avant-garde project of the 21st century. Buildings with non-linear shape force relationships between geometry and material which are different than before. Virtual free surface imposes such technical solutions and materials which question the traditional thinking about a building. A few examples, including: The Experience Music Project in Seattle (2000), POLIN Museum of the History of Polish Jews in Warsaw (2005), The City of Culture in Santiago de Compostela (2010) and The Heydar Aliyev Cultural Centre in Baku (2013) will be presented.

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Introduction

The unconstrained creation of free forms in present day architecture has become a new aesthetical paradigm: architectonic requirements have stimulated the search for new types of structures. To execute digital free surfaces, technical mastery of the material is needed, as new geometric solutions often pave the way for exploration of new materials and vice versa [1]. Virtual free surface imposes such technical solutions and materials which question the traditional thinking about a building. This is related to the principle of combining the load bearing structure and the “skin” into one tectonic self-supporting element. The structural envelope is the integration of surface and structure into one. As can be seen, different types of materials can be used as components of structural envelope. Popular are: shotcrete shells, fibre glass reinforced concrete and fibre glass reinforced plastic.

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2. Curvilinear surfaces with shotcrete technology

Initially, shotcrete was used mainly in repair and renovation works as well as for hardening of loose road slopes. Shotcrete is a type of concrete which is sprayed onto the face of curvilinear structures to form a protective lining and support, usually a few tens of millimeters thick. It is most useful in protecting soft or weak material and can be adapted to suit varying conditions. In the XXI century, shotcrete has been used as an important component of multi-layer structural “skins” for digitally designed non-linear shaped architecture [2].

2.1. Structural envelop for the EMP in Seattle

The Experience Music Project (EMP) is a one-of-a-kind project that required new methods of construction - even in the application of shotcrete. The EMP building, with a 9,114 m² footprint, houses the interactive music museum in Seattle. The Building is designed by Frank O. Gehry Associates, but the contractor is Hoffman Construction. In the groundbreaking use of computer technology, the building was designed in CATIA, a software package created for the aerospace industry. CATIA allowed the project team to translate The EMP's three-dimensional shapes into coordinated drawings and geometric data that builders and manufacturers could understand. The museum consists of seven elements resembling irregular, undulating blobs which look as if they were the result of an eruption. The monorail running right through the building and the construction site is also worth noticing. (Fig.1).



Fig. 1. F. O. Gehry Associates, Hoffman Construction, EMP, Seattle, 1997-2000.

As the figures show, it is a geometrically complex project that requires unique construction techniques. Each of the elements is designed as a *semi-monocoque* shell composed of several layers. Their structure is composed of shapes resembling cages with curved steel ribs. Each of the building's 280 undulating structural ribs is unique. At first, the cages were covered from the outside with steel mesh ‘canvas’ on which the liquid concrete mixture was applied with the shotcrete method. In this way, the shell made of a layer of shotcrete 7 - 28 cm thick was created. It is a type of a substrate integrated with steel ribs which acts in the same capacity as plywood does in conventional *balloon frame* residential projects. This is the layer which makes the building ‘real’ and to which exterior cladding is fixed. From each frame, a sufficient number of projections were made, necessary for the assembly of the outer layer of the skin. This layer is installed on the smart metal panel system. This massive project includes 3,300 unique panel assemblies, resulting in over 42,672 m² of metal surfacing [3]. For The EMP, a new method was developed to build complex non-linear “skins” with minimal waste and a reduced ecological footprint, eliminating the need for additional structural construction. This method can be used in the implementation of other buildings with complex geometry.

2.2. Structural “skin” for the City of Culture of Galicia in Santiago de Compostela

Shotcrete was also applied in the implementation of curvilinear forms of The City of Culture of Galicia, according to Peter Eisenman's design. The construction is challenging and expensive as the design of the buildings involves high degree contours, meant to make the buildings look like rolling hills. Nearly every window of the thousands that are part of the external façade has its own custom shape. Eisenman began with the outline and street plan of the

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