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STATIC AND DYNAMIC ANALYSIS OF BAR STRUCTURES USING VPL ON THE EXAMPLE OF STEEL DOME

M. Redzynia [1] **E. Kubacka** [2] **A. Wirowski** [3]
[1] BEng, MSc, Department of Structural Mechanics, Łódź University of Technology, POLAND,
redzynia.monika@gmail.com
[2] BEng, PhD, Department of Structural Mechanics, Łódź University of Technology, POLAND,
ewelina.kubacka@p.lodz.pl
[3] BEng, PhD, DSc, Departmentof Structural Mechanics, Łódź University of Technology, POLAND,
artur.wirowski@p.lodz.pl

ABSTRACT: In this note, the optimization analysis of a steel spatial structure was carried out. The object considered in the work is a steel mesh dome characterized by a triangular division, which was defined on the basis of the procedure proposed by Richard Fuller. The optimization analysis was performed using the Dynamo Studio software – definition of geometric models of domes and dynamic analysis, and also Robot Structural Analysis Professional – generation of calculation models of the structure. Finally, the most optimal variants of the mesh dome geometry were selected from the considered ones.

Keywords: parametric design, optimization, dynamo studio, free vibrations.

1. INTRODUCTION

The paper presents an optimization analysis of free vibrations of a selected type of structure - a steel dome characterized by a triangular division, proposed by Richard Fuller.

1.1. Parametric design

Parametric design is increasingly appreciated in civil engineering, especially for complex structures. Owing to it, it is possible to present a general concept about the shape and size of a structure, as well as about specific design solutions, in an algorithmic way without requiring formal programming languages (Bucci and Mulazzani 2000). Such an algorithm contains one or more independent parameters the implementation of which defines the final design. Moreover, analyzed products can be changed interactively or through optimization engines. It is a digital method based on relations and rules which, through definition in appropriate software, allows engineers to manipulate various geometric interactions and generate them as a 3D model. The models are made of a network of connections between geometric conditions, which can be processed in various spatial contexts at subsequent stages of design.
Thanks to the parametric design, it is possible to generate a huge number of similar objects, using the created variable-dimensional schemas and the relationships that occur in them. The schemes are defined by specifying the ranges of variability of certain parameters. The ability to determine, establish and reconfigure geometrical relations is extremely valuable in the parametric approach (Januszkiewicz, 2017). Calculations,

which use parametrization, make it possible to take into account the complexity at individual design stages and avoid additional time-consuming analysis of larger numbers of data.
Over the years, many projects have been developed using the parametric approach. The history dates back to the nineteenth century, when the first parametric models of the designed constructions were created. One of the earliest known examples of a parametric design, the analog method, was the inverted model of a sacral building by Antoni Gaudi (Fig. 1). By modifying the individual parameters of the model, the architect could generate different versions of his project, being sure that the resulting structure would be consistent.

Fig. 1. Multidirectional model of the Colònia Güell church by Antoni Gaudi, 1898-1908.

The analog models were initially designed. However, as computer technology advanced, the projects moved to specialized computer software. Currently, architecture and parametric design are characterized not only by a functional aspect, but - perhaps above all - by an artistic aspect. Architects such as Zaha Hadid have taken parametric design to the next level to create stunning shapes through the design process. The Galaxy SOHO complex, one of the most futuristic projects of the aforementioned Zaha Hadid, located in Beijing, China (Fig. 2) is a spectacular example of the use of digital tools to support design.

Fig. 2. Galaxy SOHO in Pekin, 2009-2021.

The object was shaped on the basis of parametric design and it seems necessary to take into account its extensiveness and complexity of the form. This is evidenced, inter alia, by the horizontal division of the elevation of the solids.

1.2. Structure description

The structure analyzed in this work is a mesh dome, characterized by a triangular division created on the basis of the method proposed by Richard Fuller (Chodor, 2015). The dome has the shape of a half-sphere, and its surface is made of triangular bar elements. The model geometry has been programmed using the

Dynamo Studio software, which allows for its quick modification in the context of optimization analysis. One of the considered variants of the dome geometry is shown in Figure 3.

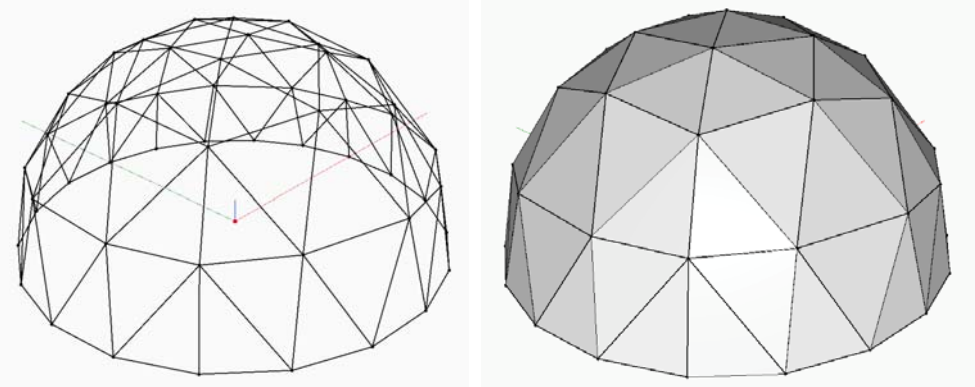

Fig. 3. Model of the analyzed dome in Dynamo Studio.

2. DYNAMO STUDIO

The Dynamo Studio program was chosen as the VPL work environment. It is characterized by accessibility, openness and has also become relatively popular in the engineering environment. Working in this environment involves creating nodes and connecting them through graphical connections, sample nodes and connections between them are shown in Figure 4. Data are sent between nodes. User can create while loops and own nodes (using Python scripts to create more computationally complex nodes). The effect of the algorithm in Dynamo Studio can be visualized on an ongoing basis or sent to other programs for further processing.

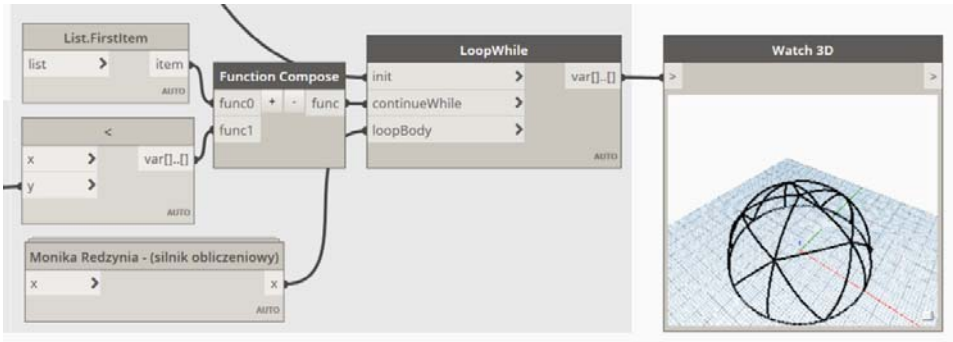

Fig. 4. The part of the created program – sample nodes and connections between them.

The model geometry has been fully programmed using Dynamo Studio, which allows for its quick modification in the context of optimization analysis taking into account a different number of triangular elements that form spatial structure. change in the number of dividing the dome into triangular elements. The geometrical model of the structure was exported to the Robot program, where the static analysis, dimensioning and calculation of the free frequency were performed.

3. COMPUTATIONAL MODEL

The work assumes that the considered mesh dome will constitute an external structure. All bar elements of the mesh dome were designed in a steel structure (steel grade S235) and then kinds were selected from the catalogue of Polish sections, from the family of round tubes. Two-articulated bars of the webs and articulated support of the structure were adopted. It was assumed that the structure would be located in the Łódź Voivodeship, at a level below 300 m ASL. Four variants of the dome geometry were considered. In these

cases, the height of the domes is equal to its radius and amounts to 25 m. The surfaces of the structure are divided into 20, 80, 320 and 1280 triangles. The analyzed variants of the dome are presented in Figure 5. Additionally, in the model, the size of the dome's radius and the height of the center of the dome's sphere can be modified. This makes it possible to create a dome with the center of the forming sphere below or above the ground level.

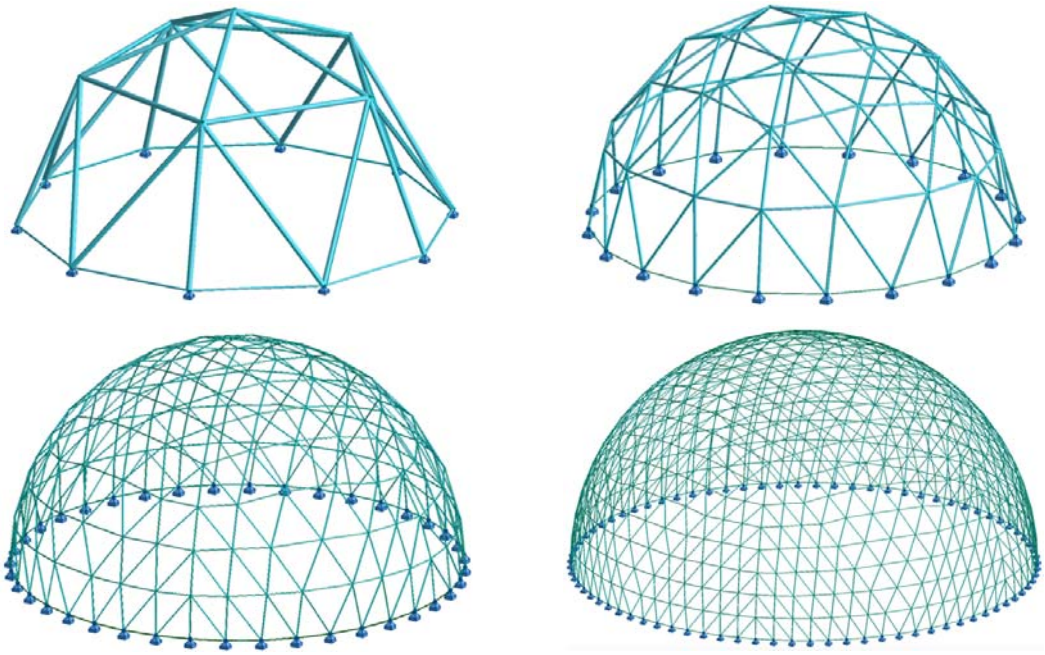

Fig. 5. Geometric models of dome divided into triangular parts.

FEM was used to calculate the dynamics of the dome. The analysis will be limited to testing the structure's own vibrations and we will assume no external loads. The classic finite truss element was used for calculations. To find the frequencies of free vibrations and the corresponding forms of free vibrations of the structure, the values and eigenvectors of the global stiffness matrix were found. The mathematical package https://numerics.mathdotnet.com/ available in the DynamoBIM environment and Python was used for calculations.

4. CONCLUSIONS

Based on carried out analysis, the following conclusions can be formulated:

- Dynamo Studio is a tool that makes it possible to develop parameterized geometric models and then easily modify them by changing the values of selected optimization parameters,
- compatibility of Dynamo Studio, which enables the creation of geometric models, with Robot, which enables static analysis and structure dimensioning, allows to analyze many variants of geometry and optimize the structure in a short space of time,
- dimensioning of several variants of the steel dome geometry made it possible to calculate fundamental natural frequencies of the analyzed models.

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