Optimization of the geometry of facades based on the results of studies of wind effects

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Abstract. This article considers the possibility of reducing the wind load on building structures by optimizing their shape. The general algorithm for creating an architectural project using simulation engineering calculations is presented. The ANSYS Student software package analyzed the simplest methods of architectural shaping: bevels of ribs, rounding of edges, rounding of faces, vertical and horizontal articulations.

1. Introduction
Creating a material object, whether it be a building or a mechanism, the creator tries out of millions of configurations to choose the one that seems to be the best: throws away superfluous, changes the ratios of components, tries to introduce new elements into the system being developed, - carries out the optimization process. The problem of choosing the most optimal building configuration is largely decided by the architect. However, in the case of such a complex system, it is not always possible to find the best solution.

To date, the design process involves enormous computing power, allowing for a comparative analysis of project proposals. Computer-aided design (CAD) systems are actively overgrown with subsystems that make it possible not only to obtain a set of drawings for an object, but also to conduct its multilateral analysis. Such an analysis helps to draw attention to the weaknesses of the project, which the designer might not have thought about. The SolidWorks software package implements Simulation portfolios for engineering calculations [1]; Rhinoceros 3D continues to replenish the library of plugins with which you can carry out structural analysis; the largest architectural manufacturers such as Autodesk and Graphisoft have long been introducing BIM technologies [2], with the sole goal of increasing the efficiency of the final design product.

Many programs have packages that allow simulation of wind flows [3]. Why do we need such extensions? To answer this question, we denote the general algorithm (Figure 1) for creating an architectural project using simulations.
First of all, a conceptual design is created [4]. It contains information on functional blocks, horizontal and vertical connections between them, as well as the external image of the future building.

Then a search is made for the optimal volume geometry in terms of insulation, heat loss, comfort, cost. Plugins do not give accurate predictions regarding the nature of the wind flow around the building. But in the aggregate of such a multifaceted primary analysis, the most disadvantageous project options are already cut off at the initial stage. They allow you to consider many building configurations in a short time, which is especially important in the early stages of the project.

The next stage is the formation of the planning structure of the building, the determination of its structural scheme, the solution of enclosing structures. Here, the overall space-planning solution of the designed volume is revealed.

Then the building elements are designed: engineering networks, structures, selection of decorative elements and decoration. At this stage, engineers turn their attention to details: the selection of the optimal elements in terms of bearing capacity, cost, environmental friendliness, durability, etc. At this stage, numerical accuracy is needed to make a decision. The existing geometry is only refined to maximize the effectiveness of its work. In particular, the geometry is refined based on the analysis of wind and snow loads.

If the accuracy can be confirmed at the preliminary design stage, then at the final stage it is necessary to obtain data on the behavior of structures that are closest to reality. Currently, such data can be obtained using physical tests, as well as using specialized software systems. However, due to the complexity of modeling the process of wind flow around a building [5], the process of finding optimal geometries is difficult.

2. Methods

The range of wind load can be crucial for such types of buildings as industrial and public. In particular, due to the need to ensure their explosion safety by means of easily erasable enclosing structures. Such elements are able to "knock out" of window openings due to the achievement of some peak overpressure indoors. Excess pressure is released during the explosion, and the supporting structures are not destroyed [6]. However, due to the peculiarities of their design, these elements are particularly sensitive to wind load.

Suppose that on the control volume of a building, mounting areas for easily erasable structures are highlighted. Is it possible to influence the pressure range in these areas of the facade using the methods of architectural shaping at the final stage of structural adjustment?

To answer this question, we will analyze the simplest methods of architectural shaping: bevels of ribs, fillet ribs, fillet edges, vertical and horizontal articulations (Figure 2). To highlight the most advantageous configuration within each subgroup, the ANSYS 2019 R2 software package was used.
Figure 2. The simplest techniques of architectural shaping: a) bevels of ribs; b) fillet ribs; c) rounding of faces; d) vertical division; e) horizontal division.

A rectangular primitive prism was used as the test volume due to limitations of the ANSYS Student academic license.

Calculation-optimization is carried out according to the developed algorithm:
1. Modeling the initial volume in the Rhinoceros 3D environment with control of the number of model faces (should not exceed 300);
2. Import the resulting geometry into the SpaceClaim environment, its parameterization. Identification of the boundaries of the variability of parameters;
3. Conducting a series of field tests in a small wind tunnel of the Educational Research and Production Laboratory of Aerodynamic and Aeroacoustic Tests of Building Construction (UNPL AAISK). Conducting numerical tests in ANSYS Fluent for various angles of attack to identify the most disadvantageous (peak values of the minimum and maximum pressures);
4. In the most unfavorable position, the values of the minimum and maximum pressures are parameterized;
5. Setting up and running the built-in genetic algorithm MOGA [7,8]. Statement of the problem - minimization of the maximum and maximization of the minimum pressure (correction is carried out according to absolute values);
6. Obtaining optimal values of the geometry parameters corresponding to the flow regime with a reduced pressure range;
7. A series of numerical and full-scale tests of optimized geometry for various angles of attack for comparison with the source data;
8. Interpretation of the results. Formulation of conclusions about the rationality of using the investigated method of shaping to adjust the pattern of pressure distribution in the control area of the facade.

Due to its versatility, the ANSYS software package contains a huge number of subsystems, including many built-in optimization algorithms. The genetic algorithm was preferred, because by virtue of its heuristic nature, this algorithm is able to perform selection for a small number of iterations. It is worth noting that heuristic algorithms do not claim to receive exact solutions.

To simulate the flow around a building, we use ANSYS Fluent. When changing the angle of attack and when parameterizing the geometry at the modeling stage, problems arise associated with the automation of the calculation cycle. The ultimate goal of modeling is the ability to automatically rebuild the model and implement the entire calculation cycle by setting parameter values. You can use the Watertight Geometry Workflow, which can interpret a model containing gas volume and building volume, into the calculation area as an instrument to achieve your goal in ANSYS Fluent. Thus, solving problems: the need for repeated parameterization when changing the angle of attack; violations of the model topology when using Boolean operations (subtraction); difficult parameterization of hard-to-reach areas of the "mold" (the calculation area obtained by the subtraction operation).

To implement the optimization calculation, a technology was used to conduct automated calculation cycles using parametric methods in ANSYS Fluent:
Stage 1. Filling the block "Geometry":
1. Creation of the geometry of the investigated volume;
2. Creating the geometry of the computational domain;
3. Creating named sets, including grouped model faces exported as boundary areas (Groups tab, sets inlet, outlet, walls, object_walls);
   4. Overlaying parameters on the geometry and determining the boundaries of their variability.

2 stage. External Workbench Setup:
1. Enabling Beta Functionalities in the Workbench: Tools - Options - Appearance - Beta Options;
2. Creating a Fluent block (with Fluent Meshing): Properties - Use Workflow - Workflow Type - Watertight Geometry.

3 stage. Filling the Fluent Block:
1. Launch of the Watertight Geometry Meshing Workflow;
2. Setting up an automated template for building a grid, which will be saved for subsequent iterations. When setting up areas, it is necessary to indicate that there is no need to simulate the mesh for the building volume (object_walls - dead);
3. Obtaining a mesh of suitable quality (Fluent uses inversion when evaluating quality);
4. Solver setup;
5. Launch the solution.

4th stage. Filling the “Post” block (use the attached Post block to set the output parameters):
1. Creation of expressions, the values of which will be searched. Expressions are formed in the Expression tab according to the scheme: Y (X) @D, where Y is a function (for example, the minimum value); X is a variable (for example, pressure or speed); @ - operator, which stands for "where?"; D is the name of the boundary region (for example, object_walls).
2. Parameterization of expressions (use as output parameter in Workbench).

5 stage. Filling the “Direct Optimization” block:
1. The task of the optimization method - MOGA (genetic algorithm Multi Objective Genetic Algorithm);
2. Setting the variables and the boundaries of their variability (for example, setting the definition area for the parameter "building height - H": 10 ≤ H ≤ 15.5; setting the search criteria for the minimum tear pressure: minValPressure - maximize);
3. Setting up the genetic algorithm: Number of Initial samples - the number of source samples; Number of samples per Iteration - the number of samples per iteration - the number of candidates obtained at the stage of crossing between the original samples; Maximum Number of Iterations - maximum number of iterations - the number of cross-looping. Each sample is a new building geometry involved in its own CFD simulation process. The values of the output parameters at the end of the simulations are entered into the optimization window and participate in the further search process.

6 stage. Results:
1. The selection of the most suitable candidate for the implementation of the genetic algorithm;
2. Embedding parameter values in the Geometry block: Insert as design point;
3. Updating values in Workbench blocks and obtaining data on numerical testing of optimized geometry.

The above technology was applied in testing prismatic volumes. After analyzing the results obtained during the optimization cycles, we can conclude that pressure can be influenced by adjusting the geometry of the building.

3. Results and discussion
Let us consider in more detail the case of optimizing a primitive prism with bevelled edges.

The depth of the bevel located at 45° to the faces of the prism was chosen as a parameter. The boundaries of the change in this parameter are: a complete bevel on the thickness of the material (3
mm) and no bevel. The maximum pressure values were recorded when the volume was located at 45° to the oncoming flow.

During the search for the optimal geometry using the genetic algorithm, a bevel depth of 1.06 mm was obtained (corresponding to 21.2 cm on a full-scale), at which the total pressure drop was 7%. The most significant results were achieved by rounding the faces, however, this method significantly affects the overall geometry of the volume. The results of the optimization cycles are presented in table 1.

| Geometry         | Maximum pressure, Pa | Minimum pressure, Pa |
|------------------|-----------------------|----------------------|
| Primitive prism  | 158.2                 | -557.4               |
| Rib rounding     | 157.8                 | -526.2               |
| Bevel ribs       | 157.5                 | -509.4               |
| Rounding faces   | 158.8                 | -196.6               |

In all cases, the values of changes in the maximum pressure on the facade were small, however, the localization of points with peak positive pressure changed. So, in the case of introducing bevels of faces, the largest positive pressures were distributed along the plane of the chamfer (Figure 3). Thus, by making small changes to the volume geometry, redistribution of vulnerable areas can be achieved, thereby creating pressure concentrators.

4. Conclusion
After analyzing the results, we can conclude that it is possible to adjust the flow pattern in the areas highlighted on the facades by optimizing the geometry of the building elements. In this case, thanks to the pre-design analysis (during which the prevailing directions of the wind flow are indicated), cutting off the most losing volume configurations, as well as the final adjustments of the enclosing structures by means of numerical tests, it is possible to ensure conditions for the high efficiency of the easily erasable enclosing structures.
The described optimization technology can be applied in a wide range of aerodynamic and hydraulic calculations. It is worth noting that the parameterization method is one of the basic methods for changing geometry in the process of numerical search for the optimum. But, despite this, its application seems rational if necessary to obtain a simple finite geometry. This kind of geometry has the property of good scale reproducibility: it is possible to freely validate a numerical test in a wind tunnel or to develop the design of facade elements.

Calculation of the influence of wind effects is mandatory for unique buildings and structures [9]. Therefore, at the request of the designer, calculation and optimization of facade elements can become an integral part of it. Since commercial versions of computational complexes allow modeling and analyzing permeable and high-polygon shells, the possibilities of engineers in the optimization problem can be considered unlimited.

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