ROCZNIKI INŻYNIERII BUDOWLANEJ – ZESZYT 17/2017
Komisja Inżynierii Budowlanej Oddział Polskiej Akademii Nauk w Katowicach

BIOCLIMATIC ARCHITECTURE: TRANSFORMATION OF AN INDUSTRIAL PARK

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Keywords: *industrial park, bioclimatic architecture, performative design, windbreak, wind analysis*.

1. Introduction

With the integration of computer simulations and computer-aided design to architectural and civil engineering, new possibilities in design have emerged. The evaluation of building's performance early in the conceptual stage of design and before the realization itself becomes crucial in the prediction of the reciprocal influence of the built and natural environment. In the unpredictable and ever-changing environmental and weather situations, the bioclimatic design offers a way to build in harmony with nature and even to enhance local microclimate. In the past, however, the respect for nature was not that important in the building industry. This approach has created many extreme situations in the built environment. Nowadays, architects and engineers are reconsidering their design strategies and offer solutions for ecologically and aesthetically exhausted lands – brownfields.

“Emscher Park”, located in the Ruhr region, was used for mining and industrial production for almost 150 years. After the decline of industries in the region, the debates about the renewal of the region started in the 1980s with the project named IBA Emscher Park which proposed the change of the brownfield by opening the park to the public and inventing the artistic reasons for visiting it [9].

“Lower area Vítkovice” is a technologically unique industrial area that was opened in 1828 and used until 1998 for coal mining and electricity, coke and iron production. There was a polemic about destroying the complex after the primary exploitation ceased. In the end, the industrial architecture was preserved for the future generations and is now listed as a National Cultural Monument. The revitalization project suggests a gradual transformation of the site. The northern part is opened to the public and, except offering a concert hall in a gas container and exhibitions in one of the blast furnaces, it hosts on a yearly basis a big music festival called “Colours of Ostrava” [10].

Another example of a re-use of an old, industrial architecture is the “Gasometers” project in Vienna. The four huge cylindrical structures served as gas tanks and, in 1995, it was decided that the revitalization design would be proposed by four world-famous architects. The old gas tanks were changed into housing, cultural center, shopping center and offices. Three new architectural shapes were built in addition to the old gas tanks [8].

As observed in this paper, a transformation of an industrial architecture is not the only important thing, but also a site-specific bioclimatic architecture, designed using computational tools. The study of design techniques, that provide real-time feedback on the sun or the wind situation early in the conceptual phase, could be an advantage for long-term sustainable design solutions.

"Breathable walls" is a project that investigates various designs of a building envelope system developed specifically for the desert environment of U.A.E. The designs utilize the cooling effects of the wind and, at the same time, aim to prevent the transmission of sand through the "Breathable walls". The systems are developed using computer simulations, as well as a simple physical wind test for the analysis of the wind behavior in the conceptual stage [4].

Another windbreak design, which reacts to the ambient conditions, is a porous kinetic structure and developed to the prototype stage. Using Computer Fluid Dynamics (CFD) software and a mini wind tunnel, the ability of the windbreak to mitigate the unpleasant winds in Melbourne is evaluated [6].

The following case study combines approaches described above. As a new design strategy, it proposes a possible transformation of an industrial landscape, and, furthermore, the main idea is based on the analysis of the specific weather and environmental situation of the site, focused on the element of wind.

2. A case study in Stockholm's Loudden Docks

The Loudden Docks was one of the key ports in Stockholm, on the waterline of the Baltic Sea. The oil terminal served for storing heating oil, petroleum, naphtha and diesel until 2011 when it was closed. The industrial zone occupies an area of approximately 680 m x 120 m (Fig. 1). Cylindrically shaped reinforced-concrete silos block the access to the waterfront. The silos are approximately 13÷34 m in diameter and have various heights from around 10 to 30 m.

Within the framework of the Stockholm Royal Seaport project, a sustainable transformation of the eastern part of Stockholm's harbors (Hjorthagen, Värtahamnen port, Frihamnen port, Loudden) is planned. The old industrial zones should be replaced by new residential blocks and office buildings by the year 2030 [11, 12].

The unique urban character of the Loudden Docks, however, could benefit from an alternative design approach that is presented in this case study. The main idea for the transformation is based on the analysis of the specific wind situation of the site.

3. Analysis of the site's weather conditions

The dense placement of concrete silos predicts the overall quite extreme microclimate of the site (Fig. 1). The silos are shading each other throughout the year. The wind flow squeezed between the grouped silos is also significantly influenced by the site's morphology. The data for the wind analysis are taken from the EnergyPlus web database [2]. The files in *epw format can be imported in Autodesk Ecotect and converted into the graphical form.

Based on the obtained data, two most important directions of the wind are selected: i) westerly winds because they are the most frequent throughout the year, and ii) southerly winds because they are the strongest. Annual average wind speed 6 m/s is used as a reference wind speed at 10 m above the ground for westerly winds and 9 m/s for southerly winds in the

CFD simulations. For the wind analysis of the current situation, the geometry of the smallest silos is left out, whereas three buildings on the south-west are kept for the simulation purposes (Fig. 1).

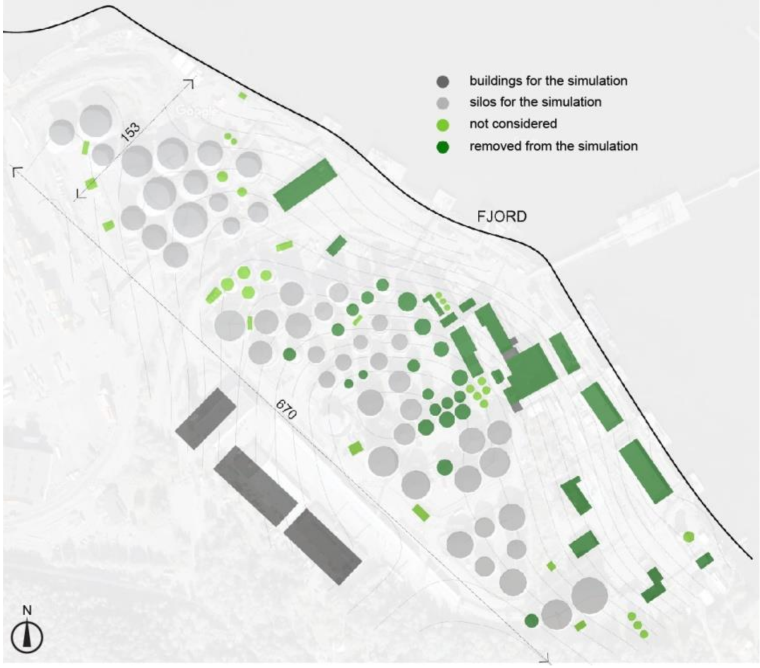

Fig. 1. Loudden Docks (green – buildings and silos that not used in the wind simulations).

The analysis of the wind flow through the grouped silos is made in Rhino CFD – a plug-in for the 3D modeling software Rhinoceros. The velocity gradient of the wind speed is approximated using the logarithmic function [1]. The terrain category is set to “suburb, forest, regular large obstacle coverage” which is 0.75 m. The domain size is 1175 m x 830 m x 175 m for the westerly winds and 863 m x 1137 m x 175 m for the southerly winds. The domain size is created with regards to the best CFD guidelines [3]. Both simulations consist of something less than 2 million cells whereby the cells are denser around the geometry of the silos. In Rhino CFD, the boundary conditions are set by setting the wind attributes. The simulations are made for the whole site, but only three silos are selected for the proposal (Figs. 2a and 2b). The cutting plane for displaying the results is placed 1.75 m above the ground, so the wind flow at the pedestrian level can be captured.

Within the Reynolds-Averaged Navier-Stokes (RANS) turbulence model, Chen-Kin (k-ε) turbulence model is used. The advantages and disadvantages of using k-ε model for CFD simulations are described in [7]. The simulation is stopped when all the error values are less than 1%, which means the convergence can be considered acceptable. It is observed that, around the selected silos, the wind flow is deflected to the sides, accelerated and with an occurrence of turbulence on the leeward side of silos.

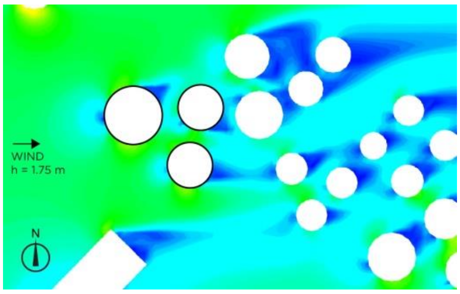

Fig. 2a. Rhino CFD simulation for westerly winds at 1.75 m height above the ground.

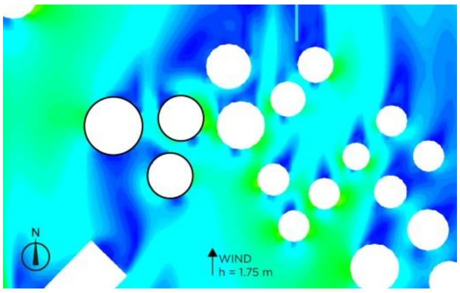

Fig. 2b. Rhino CFD simulation for southerly winds at 1.75 m height above the ground.

4. Bioclimatic transformation of the industrial site: A design of the windbreak

In the ecologically and aesthetically changed environment, the wind speed is decelerated, and the wind flow is directed using newly designed architecture. The relationship between the wind and architectural shape is examined.

Three silos are chosen for this project. They are reduced in height and serve as swimming pools in the summer and ice rinks in the winter (Figs. 2a and 2b). The intention is to create a windbreak around the leisure activities for swimming and ice skating. This windbreak is designed based on the analysis of the specific wind situation of the site and directs the wind away from the pools.

As the first step of design, an inclination of the future barrier is tested in the Flow Design CFD software. This software enables a quick analysis and understanding of the wind behavior around designs in the conceptual stage. It is chosen for evaluating the inclination of the barrier, as well as the final windbreak's design for the following reasons: i) the analyzed geometry (mesh) does not need to be "waterproof" and ii) the simulation can be set up in a straightforward and very fast way. Turbulence in Flow Design is solved using Large Eddy Simulation (LES) mathematical turbulence model. A simple block with a rectangular cross-section is oriented perpendicularly towards the wind flow and subsequently in an angle of 30º from the vertical plane (Figs. 3a and 3b). The dimensions of the barrier are 0.6 m x 6 m x 12 m. The inclined barrier has the same height as the straight one.

The input wind speed for both cases is set to 9 m/s. The vertical plane for displaying the results is placed in the middle of the barrier's length. The exports from the software are made right after the simulation is "stabilized". Maximum wind speed is displayed in red, whereas the darkest blue color represents the wind speed equal to zero. It has to be stated that the color range is different for the two cases. The input wind speed, in the case of the straight barrier, is shown in green (Fig. 3a), whereas for the inclined barrier it is displayed in cyan (Fig. 3b). The wind scale bar cannot be adjusted in Flow Design (therefore, it may be harder to read the results correctly). With this in mind, the results can be interpreted as follows: i) the inclined barrier can ensure calmer wind flow on the leeward side, although some turbulence is still present, and ii) the inclined barrier has an ability to deflect the wind to the longer distance behind the barrier.

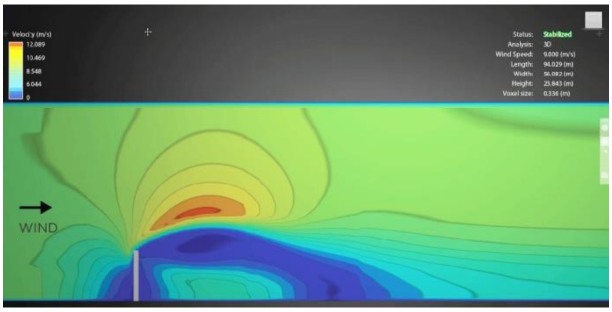

Fig. 3a. Wind simulation made in Flow Design for the perpendicular barrier.

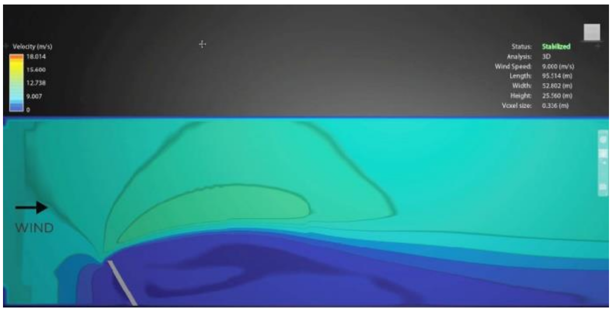

Fig. 3b. Wind simulation made in Flow Design for the inclined barrier.

5. “FlowBrane” design

The final shape of the windbreak (“FlowBrane”) is designed using 3D modeling software Rhinoceros and its graphical algorithm editor Grasshopper. The goal is: i) to create a wind barrier that would deflect the wind from the area of 3 silos in desired directions, and ii) to achieve a wind-protected recreational zone.

Two B-splines are a basis for the creation of the windbreak. Their shape is drawn in the top view in the modeling software, based on the observed wind flow around the selected silos. One curve is drawn around two silos that serve for swimming/ice skating and is fixed during the formation of the new 3D shape. The outer curve is variable, and its 30 knots are lifted to various heights based on the horizontal perpendicular distance between the two B-spline curves (Fig. 4) [5]. The parametric definition in Grasshopper enables to modify the resulting architectural shape by changing the outer B-spline. The lift angle in every knot is calculated, and the final shape is formed. The parametric constraints are applied: the minimum lift is 2 m; the maximum one is 7.25 m. The lift is dependent on the measured distances between the two curves. Subsequently, the lift angle is calculated (it varies from 20.45º to 34.41º). The resulting windbreak is 83.3 m long and around 32.8 m wide in the widest part, and it is designed as a tensile membrane that spans around the swimming pools.

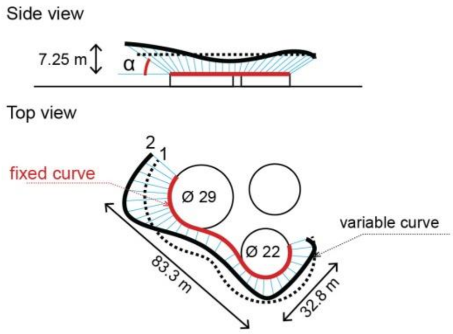

Fig. 4. B-splines drawn in Rhinoceros.

6. Wind performance evaluation

Flow Design software is chosen to test the parametrically designed tensile membrane, along with the three cylindrical silos and the two closest buildings on the south. It is not possible to set a wind profile in the software, therefore, for the simulation of the wind 1.75 m above the surface of the swimming pools, the power function is used for the calculation of the input wind speed [1].

$$\frac{U(z)}{U_{ref}} = \left(\frac{z}{z_{ref}}\right)^{\alpha} \tag{1}$$

where $U(z)$ is the horizontal wind speed at height z, U_{ref} is the reference wind speed at reference height z_{ref}, and α is the power law exponent.

Using the formula above, the input wind speed for the simulations is calculated. The value 5.79 m/s is used for the westerly winds and 8.68 m/s for the southerly winds. The values are calculated for the height 7.75 m (6 m + 1.75 m) because the height of the silos in the 3D model is 6 m (for the purposes of the wind simulation). The change in the wind flow caused by the designed "FlowBrane" is observed, together with the drag coefficient (resistance in the wind) and wind pressure on the surface of the designed windbreak. In the simulation, the resolution is set to obtain the voxel (volume pixel) size less than 1.5 m. The relation of resolution and voxel size is dependent on the size of the tested model. The wind tunnel size is approximated according to the best CFD guidelines.

Figs. 5a and 5b show the wind flow around the designed tensile membrane and depict the state of calculation right after reaching the "stabilized" state.

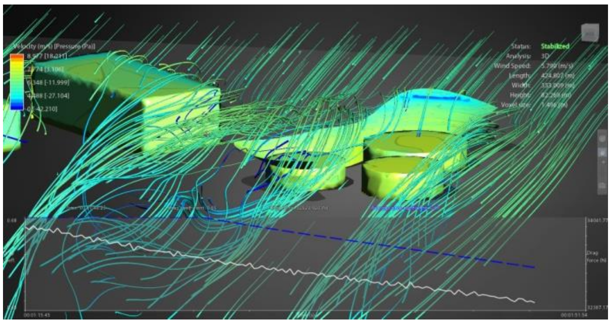

Fig. 5a. “Flowbrane” – performance in the westerly winds.

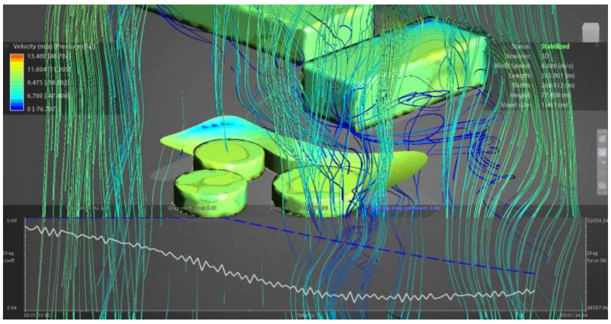

Fig. 5b. “Flowbrane” – performance in the southerly winds.

7. Conclusion

Using the benefits of the parametric approach together with CFD simulations, an architectural shape (“FlowBrane”), that alters the wind flow and serves as a windbreak, is proposed. The character of the wind flow is altered by this intervention which is based on the actual wind situation of the site.

The effects of a simple wind barrier perpendicular and inclined to the wind are tested to observe whether the future architectural shape should be inclined towards the wind. This test shows that turbulence will occur few meters above the inclined barrier, but should not disturb the planned leisure activities behind the windbreak. Low-speed turbulence is formed close to the ground. The wind flow is deflected to a longer distance behind the inclined barrier so the leeward side should be better protected from the strongest winds. Based on these findings, a tensile membrane, inclined towards the wind, is proposed around three selected silos, and the results of the wind test in the prevailing westerly and strong southerly winds show the following:

i) In the westerly winds, the membrane provides a sufficient deflection of the wind from the pools. However, on the leeward side above the bigger pool, the wind goes down very sharply. Also, a weak turbulence is formed above the smaller pool.

ii) In the southerly winds, the wind flow is again deflected by the newly added wind barrier. The two buildings on the southern side serve as an obstacle to the wind flow and the turbulence in formed. Moreover, the buildings cause the wind flow to accelerate in-between them. This turbulent and accelerated wind is directed around and above the designed “FlowBrane”. In this case, the bigger silo is protected more efficiently.

Acknowledgement

This paper was realized with the financial support of the Grant Agency of the Slovak Republic VEGA 1/0302/16 and VEGA 1/0674/18.

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Summary

This paper describes a possible integration of bioclimatic and performative design into the ecological transformation of a brownfield. The proposed design approach is verified on a case study in Loudden Docks oil terminal in Stockholm. It is observed how an architectural intervention, that is based on the study of the ambient conditions of the site, can improve the microclimate and create attractive public spaces. The study focuses on the element of wind and the reciprocal relationship of the wind and architectural shape.