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An Application of the Shark Skin Denticle Geometry for Windbreak Fence Design and Fabrication

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Abstract

Windbreak fences in open and urban areas can be used to effectively reduce the wind velocity. In this paper we examine how the geometrical shape of the windbreak fence can optimally mitigate wind velocity. We propose an approach for windbreak fence design based on a bionic parametric model of the shark skin denticle geometry, which improves the reduction of the wind velocity around and behind the windbreak fences. The generative model was used to estimate improvements by variations in the parameters of the fence panel's geometrical shape, inspired by shark skin denticles. The results of the Computational Fluid Dynamics (CFD) analysis indicates that the fence surface inspired by shark skin performs much better than both flat and corrugated surfaces. Taking into account the complex geometry of the surface inspired by shark skin denticles, we propose a fabrication process using an expanded polystyrene foam (EPS) material, created using an industrial robot arm with a hot-wire tool. Creating EPS moulds for the shark skin denticle panels allows for a richer variety material to be used in the final design, leading both to higher efficiency and a more attractive design.

Keywords: bioinspiration, shark skin denticle, windbreak fence design, generative models, CFD

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1 Introduction

The geometry of the shark skin denticles and the advantages of their application have become an area of active research in the last several years[1–4]. The design of drag-reducing surfaces often mimics the geometry of shark skin denticles on a micro scale[5–11]. Bionic principles, which include the understanding and implementing the characteristics of organic structures, are often used in architectural and urban design[12–15]. However, these applications of shark skin denticle geometry do not analyse performance at the macro scale, which are common in architectural and urban design of aerodynamic structures.

Wind in the open and urban space can be controlled by a plane fence whose primary benefit is the reduction of wind velocity[16,17]. These kinds of fences can provide protection to crops, animals, people and their property, from unfavourable climate conditions[18]. A windbreak fence is a structure that creates a shelter effect by decreasing the wind velocity near and behind the structure[19,20]. Many studies focus on the shelter effect of the traditional fence. The aerodynamics of a fence depend mostly on the geometry of the fence design and its orientation relative to the wind[21]. However, only a few studies analyse how features in the geometrical structure of the fence can improve their shelter efficiency[22,23].

We use a Computational Fluid Dynamics (CFD) model in order to examine aerodynamic characteristics of various fence designs; CFD models have the ability to simulate the wind flow effect around the fences in a fast and computationally efficient manner[24–27]. Further, CFD models can be used to provide a realistic and precise wind flow simulation around structures with a specific geometry and variations thereof[28]. A parametric generative model allows modelling of complex three-dimensional shapes and optimization of parameters of the fence's geometrical shape like it was applied in this work. The shark skin denticle panel represents the shape inspired by the shark skin denticle which is multiplied on a surface to create windbreak fence.

The aim of this paper is to analyse shark skin den-

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ticle geometry at the macro scale, applied to windbreak fences, in order to reduce wind velocity. The proposed approach takes into consideration geometrical characteristics of the shark skin denticles, their shape, and orientation. The results provide an insight into the efficiency of these geometrical parameters. The results also illustrate the use of the fence's geometrical shape inspired by shark skin denticles in terms of windbreak performance, with a significant improvement in the response of the most common fence use scenarios. We will make considerations for the fabrication of bionic shark skin denticle panels on a macro scale level. Robotic fabrication is used to create moulds for bionic shark skin denticle panels which can be further used for a rich variety material, leading both to higher efficiency and attractive design.

2 Geometry of the bionic shark skin denticles

In this section we focus on the design of the windbreak fence based on the geometrical characteristics of shark skin. Creating the parametric model of bionic shark skin denticles reflects the biological prototype, but is also used to create geometries which are suitable for wind reduction, as well as adequate final fabrication. Shape characteristics of a single shark skin denticle that were used in the design of the parametric model are denticle base shape, latitudinal cross section, and longitudinal cross section (see Fig. 1).

The parametric model was generated using 3D CAD modeling software Rhinoceros, and Grasshopper, a visual programming language which is a Rhinoceros plug-in. The fence geometry was modelled in Grasshopper and the parameterization necessary to study shape variations was included.

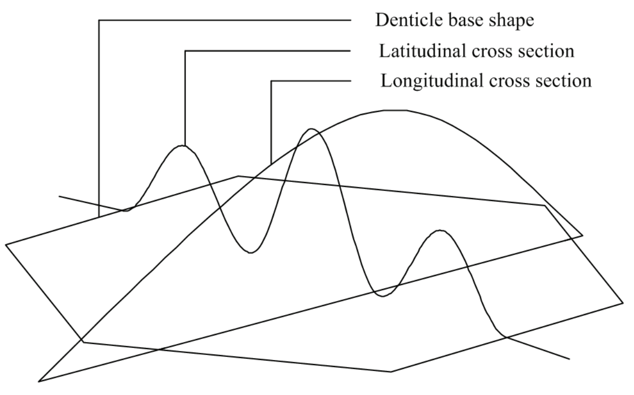

Fig. 1 Hexagonal base shape and cross-section curves of real shark skin denticle geometry.

Based on the micro-structure of real shark skin denticles, the approximate shape with a hexagonal base has been previously proposed for the large-area fabrication[11]. The denticle base shape was created in Grasshopper by a panelling system. The base can have a regular or an irregular hexagonal shape and therefore various dimension and scales of shark skin denticle panels are possible. The latitudinal cross section implies generating a curve that mimics the wavy geometry of the real shark skin denticle and the longitudinal cross section can be modelled as a symmetrical or an asymmetrical curve.

The surface of the denticle base shape and its latitudinal and longitudinal cross sections need to be extruded in a mutually perpendicular manner and trimmed in order to reach the final shape of the shark skin denticle panel. Because it is not possible to directly perform CFD simulations for complex geometry, the fence geometrical shape presented in this paper is simplified. The longitudinal and latitudinal cross sections curves are converted to curves of degree 1 (Fig. 2).

3 CFD model

The simulation of the wind flow was performed using the Autodesk CFD software. We used the same computational domain in all simulations to assure the same volume within which wind flow is simulated, regardless of the fence design.

Velocity inlet, pressure outlet and slip symmetry of the side walls are different boundary conditions of the computational domain defined as:

(i) perpendicular wind direction on the one side of the computational domain;

(ii) the pressure value on the opposite side of the computational domain;

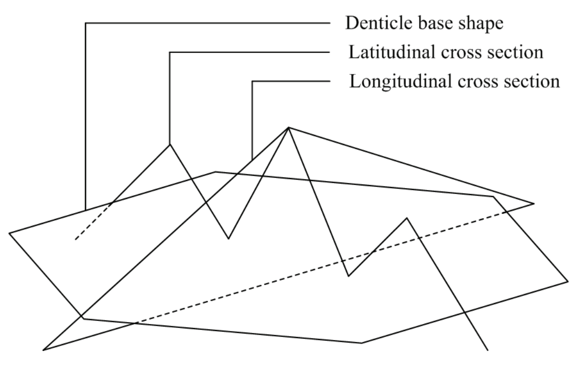

Fig. 2 Hexagonal base shape and cross-section curves of simplified shark skin denticle panel geometry.