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# Architecture from textiles in motion

**Erica HÖRTEBORN*, Malgorzata A. ZBOINSKA*, Delia DUMITRESCU[a], Chris WILLIAMS*, Benjamin FELBRICH[b]**

* Chalmers University of Technology, Göteborg, Sweden. erica.horteborn@chalmers.se

[a] The Swedish School of Textiles, University of Borås. [b] University of Stuttgart.

## Abstract

Wind is one important concern when it comes to its impact on textile structures within architecture. One method to limit wind-caused displacements is to heavily pre-stress the structures. We discuss an alternative approach, in which wind is seen as a positive design parameter for architectural textiles. We explore how one could work with the shape and internal structure of the textile to design architectural structures which become kinetic volumes when airflow is applied. The implications of such a design approach are formulated based on a two-day workshop at the conference Advances in Architectural Geometry (AAG) 2018. The explorations embraced digital and physical simulations of textile behaviors arising from the presence of wind. Smart textiles, whose structures can be changed using heat, were employed to explore how the geometrical expressions of textiles under wind load can be affected through local internal textile property changes. The ambition was to investigate the possibility of dynamically altering the 3-dimensionality of the textiles by reshaping them in real-time using airflow. The main conclusion from the workshop is that the dialogue between the digital and physical simulations seems to play an important role in supporting and enhancing the process of designing the geometrical expressions of textiles subjected to dynamic influence. A combination of the digital and the physical design tools enables the creation of a unique workflow to generate architectural design typologies that would have been difficult to develop if such complementary design tools have not been employed.

**Keywords**: Textile architecture, architectural form design, digital wind and textile simulation, physical wind simulation, research workshop

## 1 Introduction

Textiles as design materials in architecture are considered formless. One of the key properties of textiles is their flexibility as they move, bend and adapt to external forces. In tensile architecture, textiles are designed to follow a pre-designed shape, with coated woven fabrics stretched until the resulting shape is virtually stiff; this to avoid deformation by wind. But what happens if we allow movement in the textile? What if wind becomes a design variable that decides upon the expression of a textile architectural form?

As a building material textiles are starting to gain more interest in architecture [5]. The possibility of creating seemingly endless variations of textiles with different behaviours and functionalities is very appealing from a design perspective. Similarly appealing is their great potential of becoming a more sustainable choice for architecture - an easily-transported and lightweight material that can be made from a range of different yarns, including recycled and recyclable textile fibres, wood and other organic materials.

## 1.1 Textile architecture

The textile architecture that we see today embraces mainly tensile structures made from a hybrid combination of polyester membranes and steel cables, pioneered by Frei Otto in projects including the Dance Pavilion at the Federal Garden Exhibition 1957 [7], the German Pavilion Expo 67 and the Munich Olympic Stadium 1972. These types of structures are designed to only work in tension, which makes them very efficient structurally, enabling them to span large distances with little material. At the same time, they are designed to remain static. Furthermore, in terms of geometric expression, these structures are bound to an anticlastic surface typology only. Exceptions can also be found, however. They include the non-tensile use of textiles, in designs in which the softness of the material in combination with the movement of air was embraced as an aesthetic quality. Example projects include the Book House by Olga Sanina and Marcelo Dantas (2012) and the COS X installation at Milan 2015 by Snarkitecture. In the first case, the textile was designed to hang so that it is free to move with the slightest breeze. In the second example, the textile is loosely draped from the ceiling so that airflow caused by people walking through the space can move the respective textile strips. Both projects are more or less temporary structures, and the lightness and flexibility of their textile components are of great advantage not only for creating an ephemeral atmosphere of a building, but also for practical reasons, such as ease of packaging, transport and mounting.

### 1.1.1 Wind simulations of textile behaviours

Allowing the textile structures to move with and adapt to the can will efficiently lower the wind loads, but opens up for new challenges. Wind loads on structures in the scale of buildings are usually evaluated in either wind-tunnel tests or in computational fluid dynamics (CFD) simulations. For textile structures, it is especially difficult to accurately simulate interactions with wind. Researchers have been able to accurately simulate this behavior of the flapping of a flag in steady wind, in 2D and 3D, in reasent years, making use of the immersed boundary (IB) method [6]. However, especially the simulation in 3D still remains a challenge [10] and consumes high amounts of computational resources . These complications mainly result from the fact that the mass of the air in the boundary layer around the structure is significantly higher than the mass of the textile, thus large deformations occur, especially in the case of loose fabric. [8]. The motion of the fabric mirrors the vortices and turbulence of the wind which makes it difficult for the traditional mesh-based CFD analyses to handle the analysis. The deformations cause the mesh model of the textile and air around it to get tangled up if it is not rebuilt often enough. Re-meshing the model requires considerable computing power, making these calculations less applicable for early-stage design and iterative design processes. However, as exact load calculations are rarely of interest in these early design phases, other less precise simulation methods capable of real-time computation seem more relevant for that purpose. Specifically, the physically based animation (PBA), a field of research in computer graphics, game-engine development and movie animation, offers useful techniques. Here, a set of particles is simulated to act under the influence of various physical forces and constraints. These constraints range from external forces imposed onto the system from outside, such as gravity and wind, to internal forces that interconnected particles exert on one another, such as spring forces, shape retaining forces or triangular force connections. Additional constraints incorporate collision detection or the definition of immobile particles (anchors).

PBA solvers typically aim at resolving the Newton-based law of forces that the multitude of constraints exert on each individual particle as efficiently as possible, without trading-off too much accuracy. Currently, the popular approaches include position-based dynamics (PBD) [9] and the more recent projective dynamics (PD) [1]. PBD, due to its simplicity and robustness, is widely applied in game engines, such as Nvidia® PhysX™, Havok Cloth™, and Bullet. Maya® nCloth makes use of the PBD paradigm in a 3D modelling environment. PD, on the other hand, is a state-of-the-art technique for geometry processing and constraint-based modelling. Its C++ implementation Shape-Op [2] and especially its descendent Kangaroo, a plugin for McNeel's Rhinoceros® and Grasshopper®, gained popularity among architects and designers for its modular goal-based design, robustness and generality.

Another game-engine called Nvidia Flex combines a very efficient GPU-based implementation of PBD with fluid particle simulation by means of smoothed particle hydrodynamics (SPH) and thus offers a unified platform for simulating a wide range of particle properties. It is accessible to the .Net environment through the platform FlexCLI and available as a Grasshopper® plugin called FlexHopper (figure 1), both of which were developed by one of the authors. With FlexHopper, the simulation of high resolution textiles is possible through the definition of an ordered particle set, spring and triangle constraints, a wind force, anchors and arbitrary additional constraints. FlexCLI and FlexHopper can be found open-source in a Github repository [4].

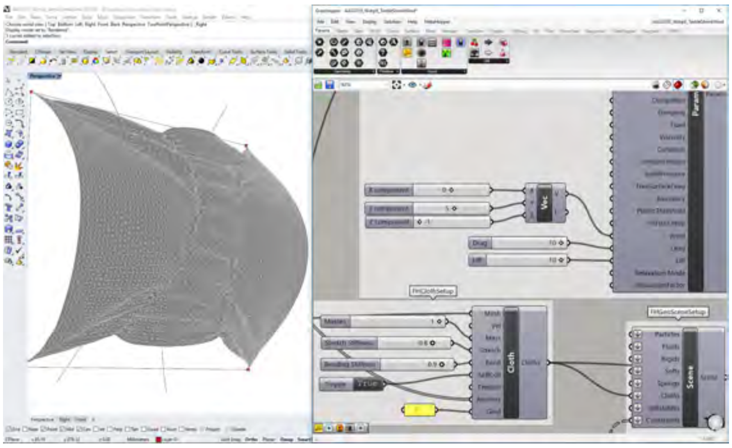

Figure 1: A GPU-based simulation engine, Flexhopper, used in the research workshop.

As mentioned earlier, yet another tool to comprehend the behavior of a large-scale textile system is a downsized model in a wind-tunnel. The discrepancies between this approximation and the actual behavior of fabric architecture mainly arise from the issue of scaling the material system (thickness of the textile and connections, material properties and strength) and the scaling of Reynolds number. Furthermore, the directionality and unpredictability of wind gusts can be problematic. Despite that, the physical simulations are usefull and relevant, especially for early-stage design of textile architecture, as they provide visual feedback for at least some of the textile behaviors, which from the standpoint of aesthetic explorations is a virtue.

## 2 Aim of the study

In light of the presented background, our main aim was to generate initial insights on the relevance of using a combination of digital and physical wind simulations in early-stage exploratory design of textile facades. The aesthetic expression of the textiles in our study was informed by two interrelated factors: the internal structure of the textile, intentionally altered across the textile piece to achieve varied wind deformations and therefore varied aesthetic effects, and the action of airflow, transforming the geometrical shapes of textile facade elements in real time. On the one hand, our focus was to explore how the internal structure of textiles can affect their behaviour and geometric expression when in movement. On the other, to evaluate the usefulness of a range of design aids for exploring the design alternatives for such textile architecture in movement, ranging from digital simulations of aesthetic expressions and behaviours to physical models set in motion by moving air.

## 3 Research design

A workshop involving architectural designers with different levels of design experience and computational competence was chosen as a vehicle for generating the research insights on the subject of designing textile architectural elements informed by airflow and wind.

The research setup in the workshop assumed the development of textile facade concepts using digital simulations and physical models. The processes were executed in 4 groups of 2-3 designers. The digital workflows embraced 3D modelling and parametric design of facade concepts and the simulation of their thermal shrinkage and deformations caused by wind. The physical workflows embraced creating models of facade concepts, generated by first changing the textile structures using heat, applied using various methods, and then by exposing the models to airflow influence using a dedicated fan.

### 3.1 Workflow

The first day of the workshop embraced introductions to the state of the art in textile architecture design, the fundamentals of textile design and knitting and digital wind simulations. After these introductions, the participants explored the principles of simulating textile shrinkage and wind deformation, by working with an example file and a code in which the parameters of the textile and airflow could be altered. After this hands-on trial session, the participants were given smaller textile samples to test different heating techniques, get a basic understanding of the material behavior and explore different heat application patterns on textiles.

On the second day, each group of designers developed their final concepts and models of textile facades informed by airflow. The output embraced video-animations showing selected digital simulations of textile behaviors and bigger textile pieces, representing the design proposals.

For this study, two simulation tools were used; The earlier described Flexhopper and a custom program, written in a Java-based textual programming platform, Processing. The program was relatively simple, fast and platform-independent, but had less intuative modelling and interaction options, as it is text textbased scripting. It treated the fabric as a grid using 3 node quadratic B spline elements to calculate the forces due to the bending stiffness of the fabric, which is important in controlling how the fabric drapes. Having found the forces, the equations of motion are integrated using the Verlet algorithm[11], which is essentially the dynamic version of dynamic relaxation which, despite its name, is used for static problems. The script can be found at: http://www.archeng.se/tools/.

### 3.2 The heat-induced textile typologies

The yarns of our textiles were Trevira CS PEMOTEX® and COMFIL® PET [3]. Both have thermoplastic properties; they exhibit both a shrinkage and stiffening behavior. However, their behavior and end-expression are not identical. Trevira CS PEMOTEX® shrinks 40% at a temperature of 100 °C but changes occur at a temperature above 70 °C. So variations in temperature affect the density and elasticity of the textile surface. After shrinkage, the textile surface is still flexible (Figure 2). The COMFIL® PET starts to change at 130 °C, its melting point is at 235 °C and the shrinkage effect is more dramatic (between 40-60% depending on the temperature). Variations in temperature affect the density and elasticity of the textile, which becomes rigid after heat treatment (Figure 2). Furthermore for both types of yarns the textile expression is dependent on the number of threads.

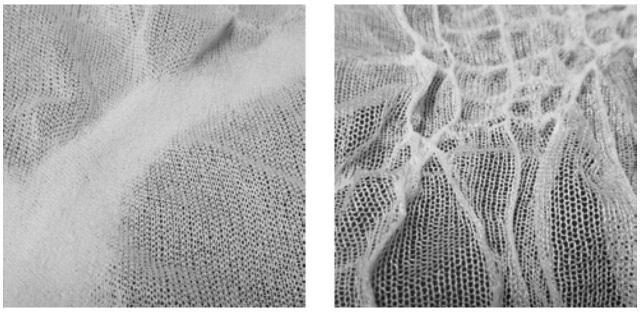

Figure 2: The textiles used and examples of modifications. Left: Trevira CS PEMOTEX®, interlock knitted with 2 yarns. Right: COMFIL® PET, single jersey knitted with 1 tread.

For the workshop, the textile structures were knitted in single bed as Single Jersey and as Interlock. The Single Jersey structure is elastic in both x and y direction, while the Interlock is less elastic in the y direction. Both structures were produced in the same flat knitting machine in gauge 10/inch with the same stitch length but with 1 and 2 threads. The reason was to provide material structures with varying form and weight which would affect their aesthetic expression when airflow was applied.

The heating techniques used, to alter the textile structures, in the workshop were: blowing warm air with a hairdryer, ironing on the flat and using the edges and tip of an iron to "draw" points and fine lines. In Figure 2, the textile on the left is modified with a hairdryer and the one on the right is modified using an iron.

Upon the completion of heat changes, the textile pieces (50x200 cm) were point-mounted onto a 2x2 m wooden frame. The airflow was generated using a Trotec® TTW 45000 Wind Machine, with an air flow rate of 12 650 l/s (45 600 $m^3$/h) and a maximum air pressure of 70 Pa. The airflow was applied as a frontal force to shape the textile pieces.

## 4 Results

The two different digital simulation methods seem to have led the participants to work in with their respective designs in different ways. The groups that worked with Flexhopper tended to explore variations of one design. This was probably caused by the intuitiveness of the graphical interfaces of the visual programming environment Grasshopper/Flexhopper and of Rhinoceros 3D. Owing to these, the users could instantly see in the 3D model the effects of applying changes to parameters affecting heat shrinkage pattern proportions within the same design. The groups working with the Processing code, on the other hand, tended to explore several different heat shrinkage designs. This was probably caused by the fact that alterations of heat patterns could only be done by using bitmap image brightness value remapping. Therefore, different images representing different heat patterns were explored. Figure 3 is showing a comparison between a digital simulation, made in Flexhopper, and a textile sample, with the same pattern and wind applied. Figure 4 is showing a comparison between a digital simulation from the Processing program and a physical model, both having the same geometric pattern.

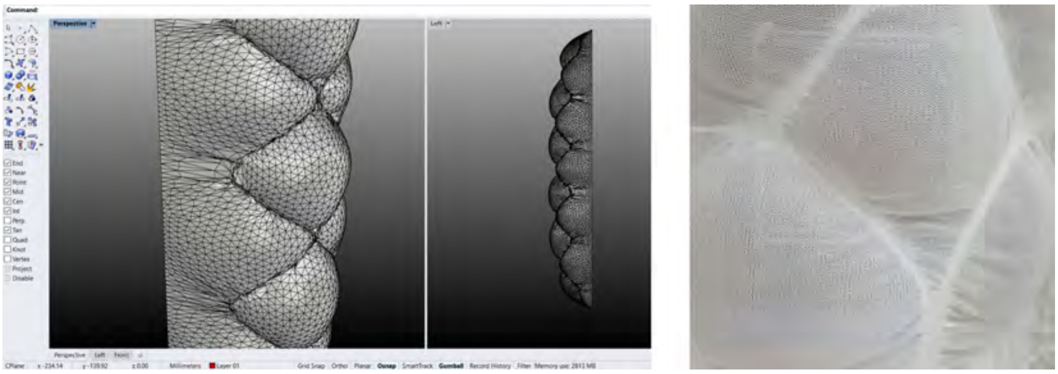

Figure 3: Comparison between a flexhopper simulation and a textile, with the same curve pattern, in wind.

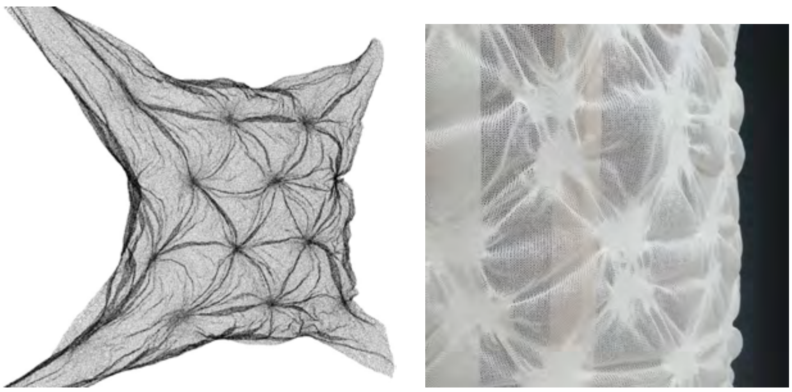

Figure 4: Comparison between a simulation made with the processing program and a textile, with the same repeated geometric (chesterfield) pattern, in wind.

The modification possibilities of the textiles seem to have mimicked the ease with which it was possible to modify the digital models, with the number of produced physical models similar to the number of digital ones. Some examples of the variations of patterns of physical models can be seen in figure 5.

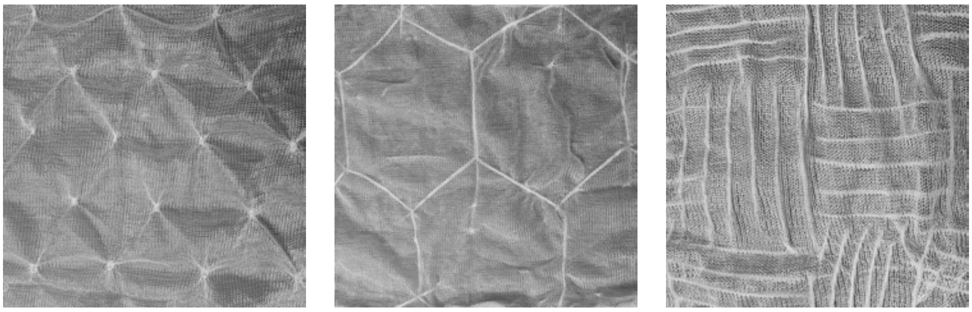

Figure 5: Explorations of geometric geometric heat patterns in the Single Jersey COMFIL® PET textile. Design team: Mathias Bernhard, Oldouz Moslemian and Hiroyuki Tachikawa

The produced textile samples can be divided into three typologies; organic irregular patterns, tubes, repeated regular geometric pattern. The final models of 3D textile volumes that the wind shapes the textiles into can be seen in figure 6.

Figure 6: The final result from the workshop: modified textiles mounted on the frame, with wind applied

## 5 Conclusion

While it is difficult to make completely accurate digital simulations of wind and textiles, an important conclusion from our study is that even less accurate simulations are still inspiring and useful for the purpose of the conceptual architectural design process. The design tool strategy investigated in this workshop has proven effective for trying out and communicating different cross-disciplinary design concepts by linking textile and architectural design. The physical models enable meaningful explorations of different geometrical patterns of heat-changed textile zones in relation to the applied wind directions, gives an understanding of the material behavior and further inform their digital translation into new form-generative processes. The explorations of the different design variables such as textile form, wind intensity or direction, would however be less fruitful and more time consuming to explore if only physical models were employed in concept development. For this reason, it can be concluded that physical and digital models have equal importance in the conceptual design phase. They complement each-other, providing a broad overview of the material behaviors and the aesthetic consequences arising from their fine-tuning.

## 6 Acknowledgements

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