SBINBEN:

Smart Bio-inspired Building Envelopes

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Executive summary

This project explores the formal characteristics and architectural potential of programmable textiles. Specifically, it is shown how dynamic 3D surface geometries may be generated by printing rigid 2D patterns onto pre-stretched fabric. The resulting surfaces have aesthetic and structural properties similar to adaptive skins found in nature. The SBINBEN report demonstrates the value of this shape-making process, focusing on its potential to substantially improve the design, manufacture and performance of building facades.

The project responds to a pressing question in today's quickly urbanizing world: How might buildings perform better to ensure the health of people and the planet? In particular, how can building skins achieve greater human comfort and energy efficiency?

SBINBEN's design proposal targets under-performing multi-story, glass buildings that do not meet today's energy or aesthetic standards. The project explains the value of adaptable, lightweight building skins and demonstrates how an innovative new process may change the look and feel of our cities in the years to come.

Key Words

Smart Textile, Biomimicry, 3d Printing, 4d Printing, Gaussian Curvature, Developable Surface

Photo of dome prototype exhibiting positive Gaussian curvature

Project description written by the Principal Academic Tutor

Within the present multidisciplinary project, the whole workflow is supposed to be chronologically organized as follows:

1. identify the main challenges that buildings in smart cities have to face;
2. provide a study of the state-of-the-art in the field of adaptive structures and specifically of morphing, kinetic building façades, highlighting the strengths and weaknesses of each approach and the attainable results;
3. propose a novel approach to efficiently actuate and induce the morphing of the façade;
4. quantitatively study the energy efficiency of the proposed solution, through digital models;
5. build a small-scale prototype of the proposed solution, to also discuss relevant technological details.

To frame all the proposed activities, it can be stated that structures have been typically conceived with invariant geometry and mechanical properties to withstand the environmental excitations. To self-adapt under a continuously changing external environment and to also self-monitor their health, bio-mimicking can be considered as a natural development. Accordingly, the goals of making the structures adaptive under variable environmental conditions and of optimizing their behavior are pursued by inducing changes in their configuration, as is typical for the smart structures. To adapt the structure layout for sensing, actuating and possibly energy harvesting and harnessing processes, functional materials and control strategies have to be suitably applied.

A specific focus is proposed on polymeric films, since they allow a significant deformation which might be used to change the system configuration to withstand the variable exciting conditions, while the action they require are conversely limited. Hence, very flexible spatial configurations are envisaged by focusing on lightweight structures, whose capability of self-adapting to variable environmental conditions and interaction with humans is strongly based on an embedded smartness, tailored on customer needs. The technologic goal of this work is to somehow close the gap between the fields of soft stimuli-responsive smart materials and compliant morphing structures, also exploiting parametric design tools.

Team description by skill

Haykaz Poghosyan, from Armenia. He graduated in Architecture (bachelors, masters) at Armenian National University of Architecture & Construction and he is currently enrolled in Architecture Design (masters) at Politecnico di Milano

Isabella Flore, from Italy. She graduated in Architecture (bachelors) at Politecnico di Milano and she pursued her studies in Architecture (masters) at Politecnico di Milano

Mahsa Bohlooli Zamani, from Iran. She graduated in Engineering in Naval Architecture (bachelor) at Amirkabir University of Technology and later in Architecture (bachelors) at Politecnico di Milano. She is currently enrolled in Management of Built Environment (masters) at Politecnico di Milano

Massimo Fontana, from Italy. He is currently enrolled in the 5-year master's degree in Building Engineering / Architecture at Politecnico di Milano

Natalia Antonenko, from Russia. She studied Interior Design (bachelors) at SPbGHPA of Alexander Shtiglitz and she is currently enrolled in Interior Design (masters) at Politecnico di Milano

Nina Romanova, from Ukraine. She graduated in Architecture (bachelors) at Odessa State Academy of Civil Engineering and Architecture and she is currently enrolled in Urban Planning & Policy Design (masters) at Politecnico di Milano

Timothy Liddell, from the United States of America. He studied Architecture (bachelors) at Cornell University and is currently enrolled in Product Design for Innovation (masters) at Politecnico di Milano

Goal

Reflecting on the state-of-the-art, one must acknowledge that the best building envelopes in the world already perform very well from an energy perspective. But their facades are like works of art: singularly designed at great expense to hang on new, pristine walls. They do not, in any substantial way, address the world's energy crisis. Data shows that the most problematic building envelopes are, in fact, those already in existence. Thus, the best shading solution is one that is adaptable and easily applied to existing building enclosures and can pay for itself through energy savings. Thus, it is important to keep material and installation economically viable.

Team Objectives: Facades can perform many quantitative and qualitative functions. For this project, we focus on mediating energy flows incurred from incidental sunlight. Specifically, we consider how shading can reduce unwanted energy gains while maintaining optimal daylighting levels. In terms of energy, this reduces cooling loads within a building and the need for artificial lighting. It improves thermal comfort and reduces glare.

Adaptive skins of plants and animals serve as a source of inspiration, as they have been for builders throughout the course of human history. Today's standard building shell materials resemble the hard, cold surfaces of a cave. We ask ourselves, how might buildings perform if they were covered in soft skins? These considerations led to the team's focus on textiles, and the desire to explore this ancient and rapidly advancing technical material. The digital revolution offers new opportunities as well and it is an aim of this project to show how sensors, processors, and actuators can be deployed alongside smart materials in an autonomous and proactive system.

Starting from the proposed brief and the general research framework on adaptive structures, the team defined key aspects of the project to give a clear, effective answer to current problems. The ability of the structure to adapt does not depend on a single property but on the combination of many features that allow it to respond better to its environment. The team decided to focus on three main criteria: performance of the building, meaning for the community and impact on a global scale.

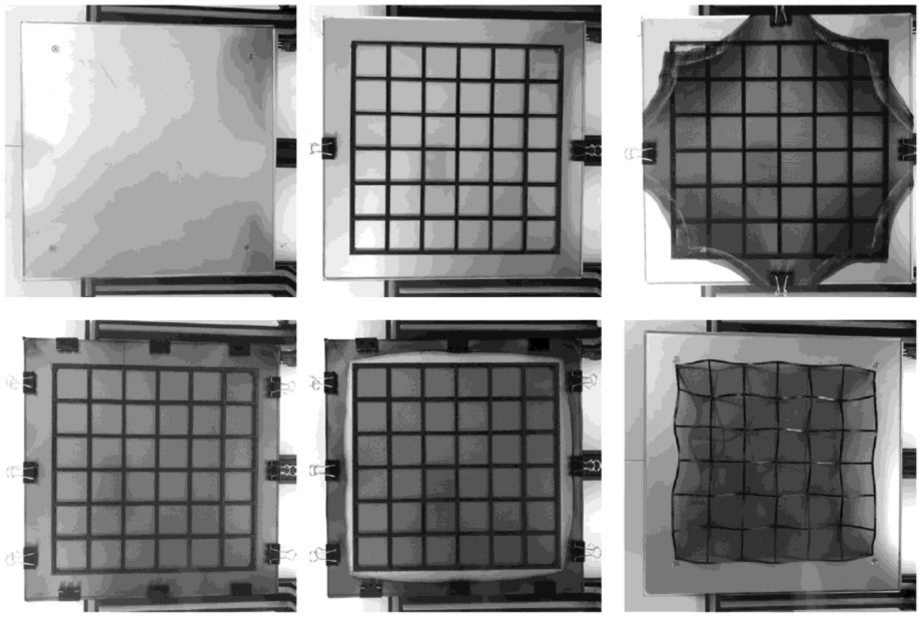
Understanding the problem

Performance, building: The first investigation on the performances of buildings helped us formulate some relevant design features such as responsiveness and adaptiveness, and to highlight the importance of energy saving characteristics. The three main objectives are: (1) regulate energy gain; (2) maximize daylight; (3) reduce glare.

Meaning, community: A second important aspect that the team investigated regards the significance of the project within the urban context and its influence on the community through visual communication. The relevant features are: (1) attractiveness; (2) communication; (3) didactics

Impact, globe: Finally, on a larger scale, a project of adaptive architecture has an impact on the environment, having the opportunity to conserve (and even produce) energy, reduce smog and avoid building waste. Accordingly, additional objectives include: (1) conserve energy, (2) reduce smog; (3) reuse existing buildings.

Target Buildings: The design proposal targets under-performing multistory, glass buildings that do not meet today's energy or aesthetic standards. Many of these structures were built in the post-war period when social and political circumstances called for quantity rather than quality of indoor space. Target buildings include both those built in the Modernist tradition of Mies van der Rohe and those built inside the Communist bloc. In the age of the hanging 'curtain wall', decisions regarding a building's envelope are typically separate from questions of structure. Steel and concrete are almost perfectly interchangeable today in today's high-rise buildings. Yet the SBINBEN project takes a particular interested in rehabilitating reinforced concrete structures that have a high embodied energy, since their demolition constitutes a great material waste.



Steps of SBINBEN's fabrication process: (1) pre-heat bed; (2) print lower layers; (3) stretch and clip fabric; (4) print upper layers; (5) cut excess material away; (6) detach part from printer bed and allow 3d deformation to occur

Four 'Hypar' prototypes after being coated; each exhibits slightly different structural characteristics based on the coating material

Exploring the opportunities

High-Performance 'Skins': In the natural world, skins represent a boundary between external and internal conditions. They mediate energy flows, offer protection, expel waste and create the visual identity of a being. The performance of skin can be attributed to different physical characteristics including shape, movement, color and chemistry. The SBINBEN project is particularly interested in performative shapes, as these can be replicated using the team's hybridized material process. Several biological case studies were explored, serving as inspiration during the team's concept development phase. Architectural case studies were also considered, especially those with high-performance and visually 'performative' building envelopes.

Smart Materials; Smart Systems: The first building skins were literally made of animal skins. Eventually, textiles using animal and plant fibers replaced animal skins and provided new versatility. This early form of biomimicry is considered one of the first examples of human 'technology'. And over the past few centuries, the textile industry has continued to be a driver of innovation - kicking off the Industrial Revolution with mechanized production and anticipating the Digital Age with binary punch cards.

Whereas the history of skins, textiles and buildings stretch back thousands of years, digital technologies represent an abrupt break from the past and an opportunity for new, unprecedented performance. Stated simply, it is now possible to embed intelligence - the ability to dynamically respond to external stimuli - into non-living objects. This goes far beyond simple action-reactions, like a hunter's trap. It enables responsivity with a degree of perception, computational power, and actionability that far exceeds that of human actors.

The field of programmable materials has emerged with the aim of embedding the 'smartness' of our digital world back into the very molecules of material. The SBINBEN team was especially inspired by Lining Yao, who's work at MIT and Carnegie Mellon University has infused materials with life-like, responsive behavior. In just the past few years, other scholars around the world have begun to work at the intersection of smart materials and digital fabrication, achieving extraordinary results.

SBINBEN's contributions: Academic projects to date have had a range of objectives, from theoretical to aesthetic. The SBINBEN project is unique in placing emphasis on real-world building applications. Regarding architecture itself, the SBINBEN team takes a slightly unconventional approach: focusing on the profound need to improve existing buildings at a reasonable cost. It is observed that the best building envelopes in the world already perform very well, reducing and even producing energy. But these facades are costly and complex. The use of smart fabrics with an economic shape-making process could be a game-changing innovation in the world of performance facades.

Generating a solution

A New Way of Shape-Making: The SBINBEN team set out to answer the question: Is it feasible and economically viable to replicate high-performance surface geometries found in nature?

After extensive prototyping, the answer appears to be yes. SBINBEN's process involves 3d printing with thermoplastic (PLA) on stretched textile. The design input is a 2d pattern of plastic ribs and/or tiles, which is printed below and above the fabric layer, locking the fibers symmetrically in their outstretched position. When the textile is released, the printed areas remain elongated, resisting compression and bending. The unprinted areas contract, causing distortion of the entire plane into a 3d form.

To gain a better grasp of the geometric principles at play, a catalogue of shapes was printed using consistent materials and print-settings. The following observations were made:

- The interplay between elongation and contraction generates complex, non-developable, gaussian curvature.
- Depending on the print pattern, the resulting parts will have two or more states of structural equilibrium. When a force is applied, the surface 'pops' from one state of equilibrium to another in a process called snap-buckling.
- Folding may be induced, creating an origami-type effect characteristic of developable surfaces. The SBINBEN team calls these deformed developable surfaces "Def-Dev's"
- New software platforms permit shape prediction based on specific physical inputs, and a reverse workflow from desired 3D shape to 2D input pattern

Interior and exterior renderings of proposed building skin for the Pirelli 39 tower in the Porta Nuova district of Milan, Italy

Scaling up the Idea: There are several advanced manufacturing techniques able to replicate the prototyping process at a large scale. These are discussed in the SBINBEN report in terms of feasibility, cost, and novelty. The most promising process involves 'plotting' material onto a moving sheet of stretched fabric, collected onto a roll, shipped to construction sites and deployed. This strategy reduces the complexity of machines, allows for continuous production and lowers transportation costs.

Several textiles already exist for building applications, with varying degrees of durability. The important thing is that the selected textile has enough elasticity, so it can generate the desired surface deformation. Thin films could be used in place of fabric if necessary in an analogous process. Some of these contract when exposed to heat and could therefore be 'post-contracted' rather than 'pre-stretched'. The interplay of forces within the hybridized material perform similarly regardless of how the tensile and compressive force differential is introduced.

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