

# GRADIENT

**Inflections Editors**

**Tsz Yan Ng**

**Jono Bentley Sturt**

**Faculty Editorial**

**Committee**

**(2021–2022)**

**Matias del Campo**

**Catie Newell**

**Vyta Pivo**

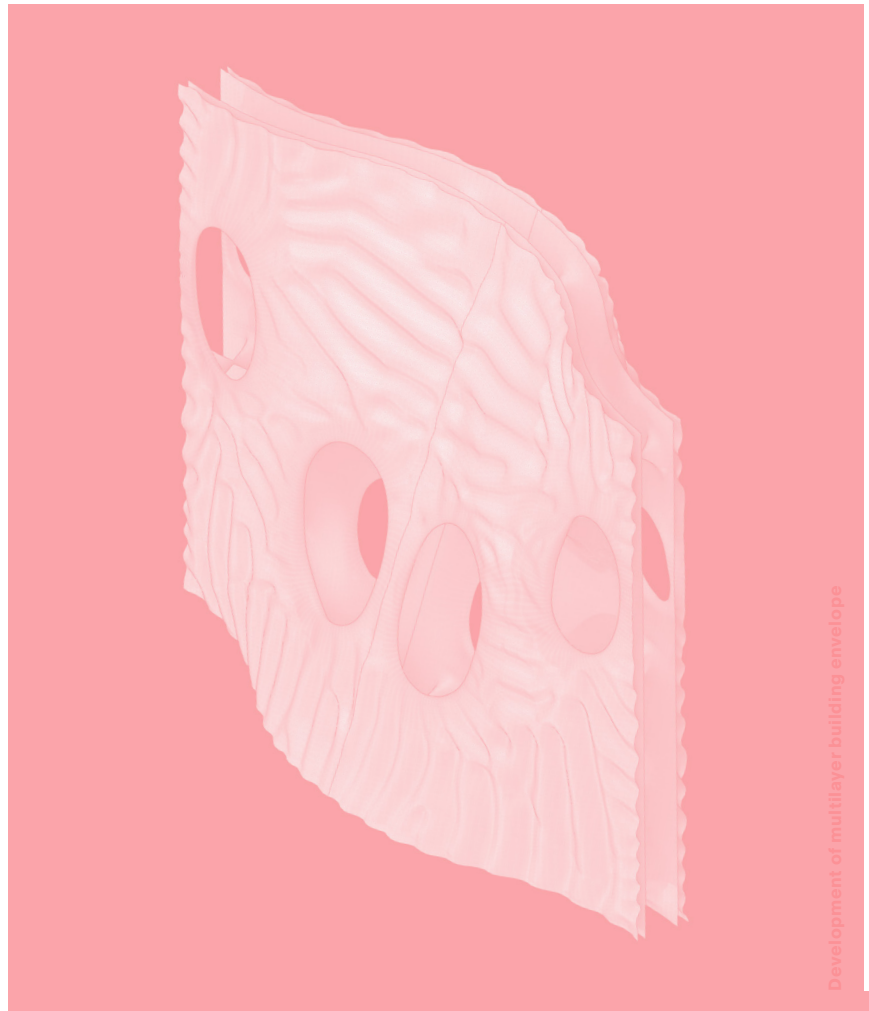
**Jose Sanchez**

**Kathy Velikov**

**Peter von Bülow**



Closeup view of passage between outer cavities, approximately 1" high, 0.5" wide



Development of multilayer building envelope

## FACULTY PROJECT PAPER

**Plastic Architecture:  
3D Printing Building Envelopes**

**TAUBMAN COLLEGE**



Title

# PLASTIC ARCHITECTURE: 3D PRINTING BUILDING ENVELOPES

Completed, October 2021

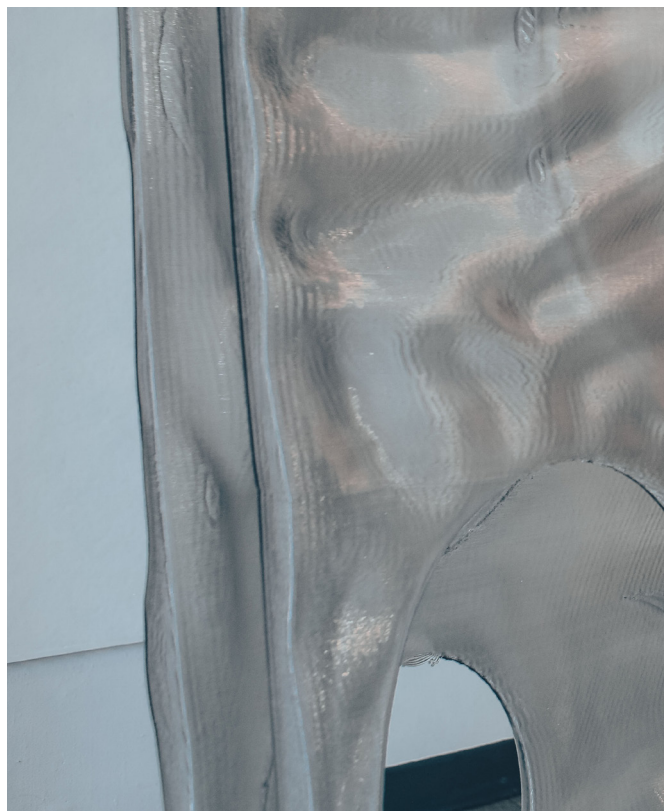
Authors

MANIA AGHAEI  
MEIBODI AND WES  
MCGEE



Modern, high-performance **building envelopes** require the integration of numerous functions within a discrete, panelized construction system. This research began with a question: **“Can additive manufacturing (AM) improve the performance of a building envelope by allowing for the enhanced integration of diverse goals such as light transmission, insulation, thermal mass, natural ventilation, and structure?”**

To answer this, we developed computational design and robotic 3D printing approaches that enabled the large-scale fabrication of integrated envelope systems in one go. This allowed us to create an envelope system that combines the many functions of the conventional exterior wall systems: void for insulation, air and moisture barrier, thermal mass, natural ventilation, and exterior detailing claddings.



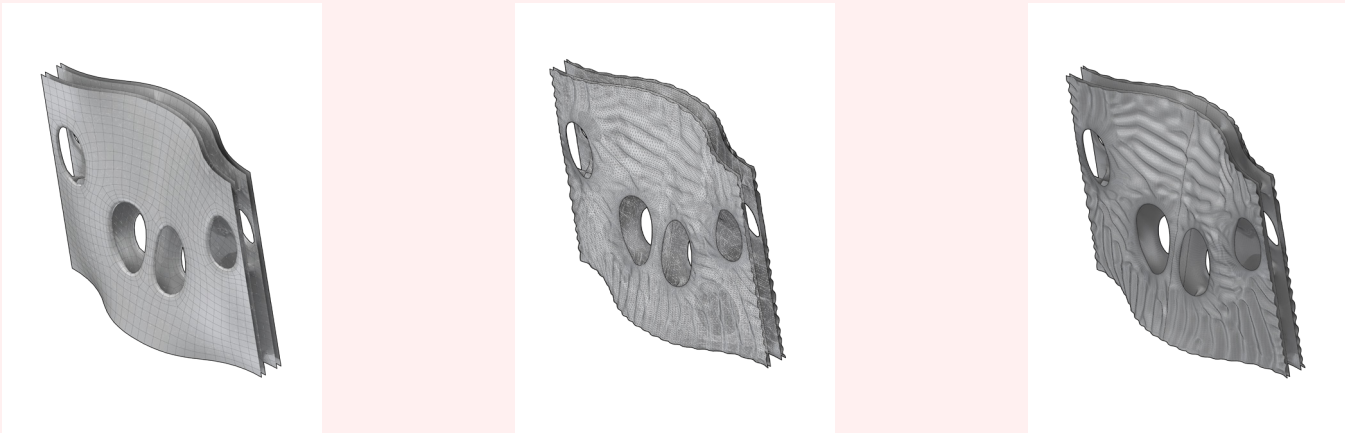
[Fig. 1] Robotic 3D printed multilayer building envelope (2.5 m high×2.5 m wide) with complex topology and reaction-diffusion surface undulation

One of the key capabilities of AM is its ability to produce topologically complex forms. Topology is a branch of mathematics that is concerned with how the geometric properties of a shape are affected by continuous transformations. Famous examples include the Möbius strip and the Klein bottle. By controlling the connectivity of internal passages and layers, this building envelope provides enhanced thermal performance while allowing light transmission, and reducing the need for inefficient glazing systems. In the prototype presented here, two topological regions are created. One connects an inner void with the outside and inside of the façade through apertures, and the other connects the inner void of the outer layer and inner layer.

The outer surface is corrugated through a “reaction-diffusion” algorithm, producing rib-like stiffeners which enhance the structural stability of the outer surface and act as pipes for containing liquid insulation material. This research will continue with investigating the addition of translucent insulation materials like silica gel, as well as phase change materials (PCM) for energy storage. These materials can be placed within the envelope —according to solar gain—in interconnected passages, which allow for efficient thermal transfer.

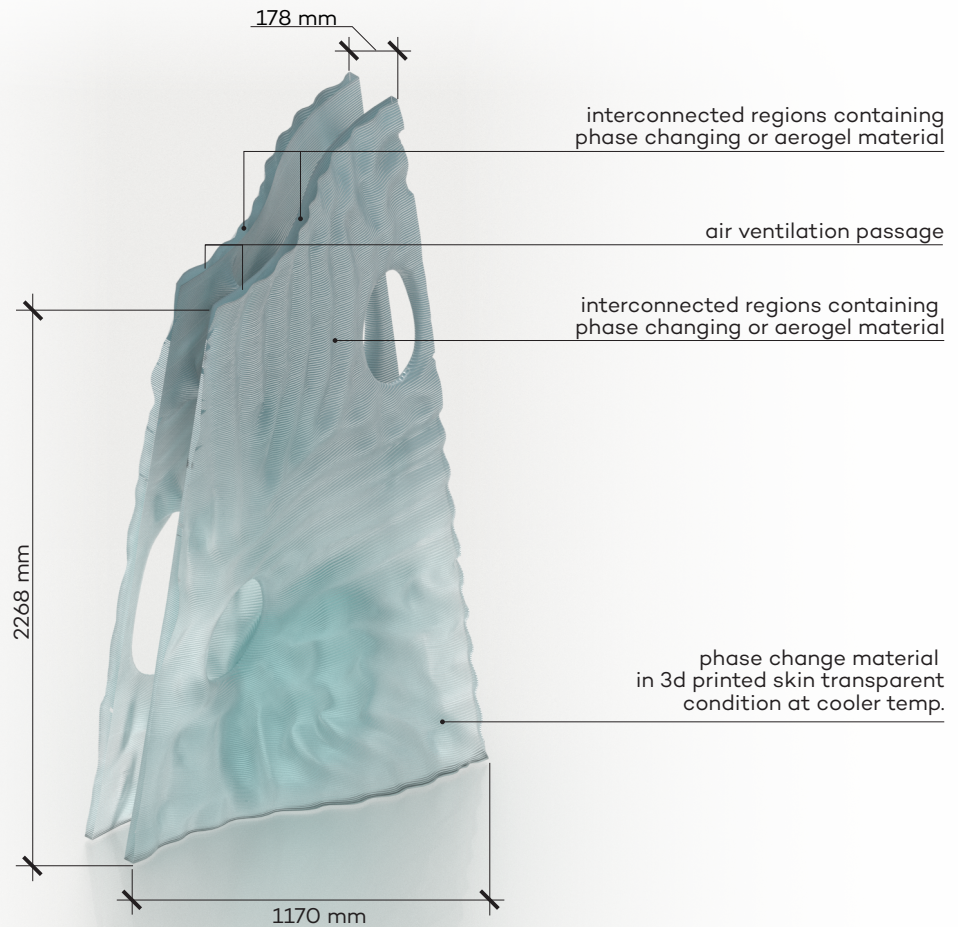


[Fig. 2] 3D model evolution of the multilayer building envelop through the articulation of the layer distances and mesh resolution



[Fig. 3] Development of multilayer building envelope from low resolution (70,000 faces) to high resolution (840,000 faces)

The computational design model of the form enables intuitive exploration of the geometric variation of two topological regions using skeletal graphs of triply periodic surfaces theory (TPST). The reaction-diffusion algorithm is adopted and modified to parametrically react to the global geometric changes. We have developed a large-scale 3D printing system, based on robotic pellet extrusion and algorithms that enable the automatic generation and naming of island pocket tool paths that result from such a topologically complex form. Novel tool-pathing methods were developed to ensure a high-quality surface finish and clean seams at the start and end of each island.



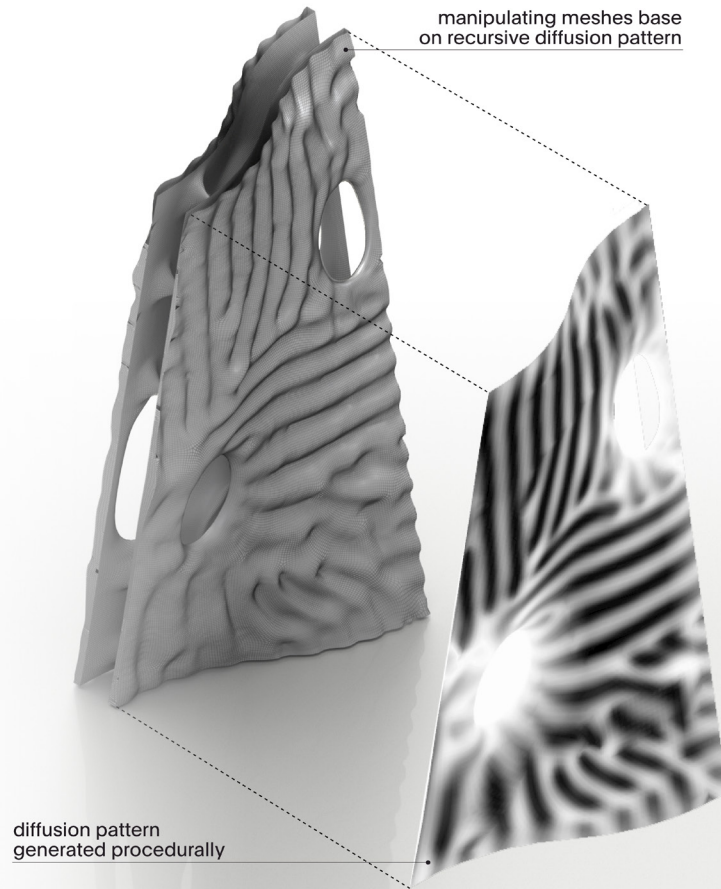
[Fig. 4] 3D model of multilayer panel with integration of thermal modulation systems

These connective surfaces are generated as minimal surfaces; this approach minimizes material usage while increasing the structural strength of the parts.

## PROTOTYPE INFORMATION

Panel Dimensions	2270 × 1170 × 200—230 mm
Wall Thickness	8—50 mm
Material	thermoplastic PETG
Material Volume	41.3 liters of polymer
Mass	44.5 kilograms
Print time	44 hours
No. mesh faces	
low-resolution panel	70,000
high-resolution panel	840,000
Toolpath Length	
low-resolution panel	10,323 m
high-resolution panel	10,333 m

P. 1, P. 2



[Fig. 5] Mesh modified using reaction-diffusion algorithm, generating stiffening ribs and passages for thermal infill.

AM processes have the potential to transform plastics from a low-cost commodity to high-performance building material, due to their ability to precisely tailor form. Plastic is commonly seen as inexpensive, lightweight, disposable, and highly unsustainable. The fact that plastic is seen as an unsustainable material is more of a cultural problem than a technical one. Following the Second World War, plastic has been introduced to society as a material that drives our “throwaway” lifestyle, which has become deeply ingrained in our behavior. Instead of encouraging this culture, advances in recycling and material science have invented plastics that are made from renewable resources and can be reused.

Thermoplastics, as a subset of polymers, have the capacity to transform from a solid to a viscous liquid when heated. In this project, a robotically controlled pellet extruder heats and converts pelletized plastic into geometrically complex, layer-based components.



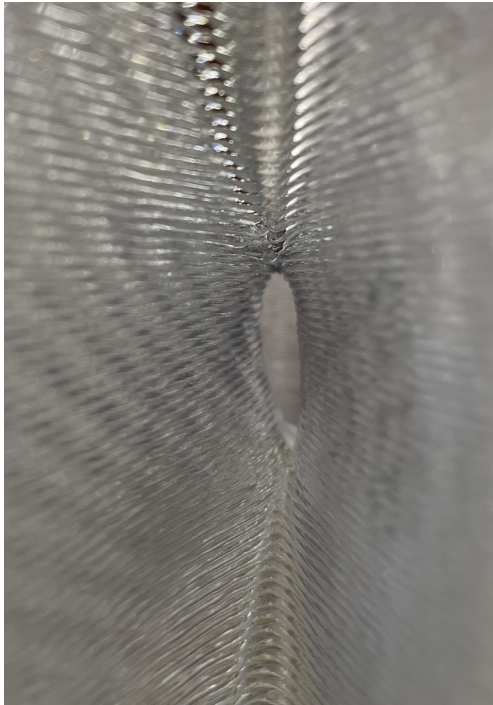
[Fig. 6] Reaction-diffusion pattern is adjusted in scale and mesh resolution is increased using Catmull-Clark methods.

Through computational design techniques, these components of a building envelope are optimized for multiple design inputs, including the structure and light transmission/shading, as well as thermal performance.

This 3D-printed building envelope will expand the range of geometric and topological possibilities for façade construction, allowing the introduction of seamless internal cavities and passages for functional integration and articulated surface detailing. Through functional integration and optimization, future façade systems will possess improved acoustic, thermal, and structural performances. 3D printing plastic, in particular, will allow for recyclable, light, and easy-to-install building envelopes which can be manufactured quickly and on-demand.



[Fig. 5] Seamless internal cavities and passages between different cavities for functional integration and articulated surface detailing



[Fig. 6] Closeup view of passage between outer cavities, approximately 1" high x 1/2" wide.

DESIGN &  
ENGINEERING TEAM

Dr. Mania Aghaei Meibodi,  
Wes Mcgee

Research &  
Fabrication Assistants  
Alireza Bayramvand,  
Christopher Voltl  
Photography  
Christopher Voltl

Funding Credits  
Deploy 2.0 was generously  
supported by Taubman College  
Faculty Seed Fund Grant



Seamless internal cavities and passages between different cavities for functional integration and articulated surface detailing

Robotic 3D printed multilayer building envelope (2.5 m high x 2.5 m wide) with complex topology and reaction-diffusion surface undulation

