PULP: Research and Experimentation in Biodegradable Thin Shell Structures

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This presentation documents in-progress design research in temporary, biodegradable structures. The experimental, thin-shell monocoque structures have been cast using a variety of cellulose-based materials, and represent a sampling of the outcome of a studio taught at three different architecture schools.

The work and the process of making the work serves as an example of how designers can take responsibility for both where the materials that they choose come from, and also, where they end up. Made of exclusively recycled paper and fabric pulp, the structures have the capacity to biodegrade completely. The idea for the experimental structures came from witnessing the dumpsters overflowing with models and scrap material at the end of each semester. The conviction underlying the work is that mindful handling of resources should begin in architectural education if it is going to successfully make its way further into the discipline, profession and construction industry.

Beyond handling the materials directly, students gained insight into the microstructures of the materials through the tools and knowledge offered by Peter Bush, material scientist and director of the microscopy lab at the State University of New York at Buffalo. The design task shows students how materials are responsive and constantly changing; they are not static, fixed objects. Paper is a particularly ephemeral material, highly vulnerable to moisture. Designing something with an intentionally short lifespan, and witnessing how it can break-down and decay, introduces students to the transformative nature of materials, and shows how degradation and eventual decay could be a design strength. The projects are unique in that they expose students to an entire lifecycle of a full-scale spatial project, from conception through fabrication and finally, decay and complete disintegration. The process of decay and disintegration is studied with the same rigor and emphasis as the fabrication methods, through cast swatches. Because the work – both process and final, full-scale structures – is completely biodegradable, the studio avoids the creation of needless waste.

INTRODUCTION

This paper documents some outcome of on-going research into thin-shell, cast paper structures made using either recycled paper products or other cellulose-based materials. The research aims to find ways to make lightweight, temporary structures using materials which are considered waste and which have the capacity to biodegrade. At the core of the research is also the desire to deepen our understanding of materials with which we work; toward that end, the research has included cross-disciplinary cooperation with a material scientist, Peter Bush, who has expanded our insight into our palette of cellulose-based materials by describing them using the language of material science, and helping us to investigate them using microscopy.

This paper will focus on:

- the cross-disciplinary material research that anchors each research studio,
- the scaling-up process involved in moving from cast paper swatches to room-sized monocoque shell enclosures,
- the expectation that the cast shells can biodegrade, and swatch tests done to observe how the cast paper responds to an outdoor environment.

Three examples of room-size shells will demonstrate different ways of working with the constraint of minimal formwork; in the spirit of the research, formwork, which often adds unnecessary waste in a construction process, had to be fundamentally rethought.

To-date, the research studio has been taught four times at three different architecture schools: the Peter Behrens School of Arts (Germany), Daniels Faculty of Architecture at the University of Toronto (Canada) and SUNY Buffalo (US). Research has been undertaken in collaboration with Georg Rafailidis, Associate Professor of architecture at SUNY Buffalo, and is on-going.

WHAT IS CELLULOSE?

Each research studio to-date has started with an effort to understand the materials with which we plan to work: papers

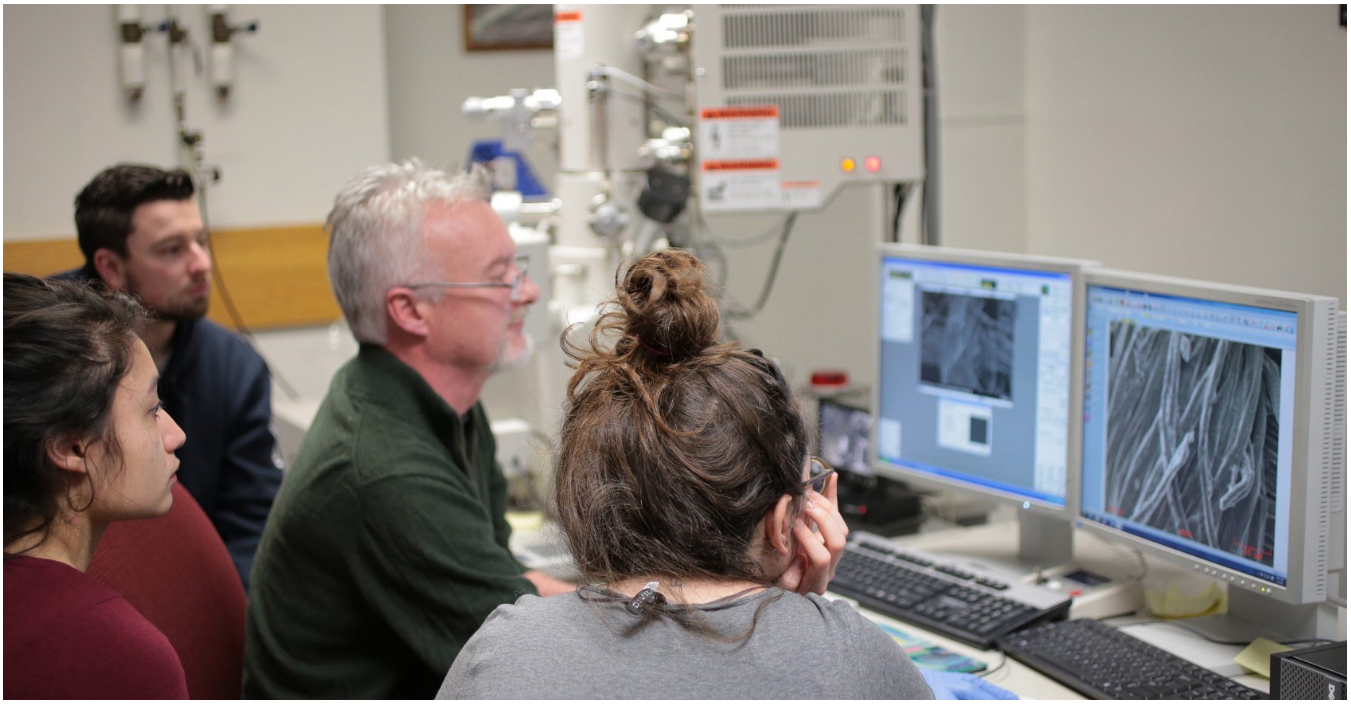

Figure 1. Peter Bush demonstrating microscopy to architecture students in the PULP studio. Photograph: Stephanie Davidson.

and fibers. Students are asked to gather cellulose-based materials that are available to them for free or at a low cost, and are available in large quantities. Materials studied to date include toilet paper, paper towel, cardboard (from boxes), printer paper (taken from the library recycling bin), tissue paper, cotton linters as well as self-harvested fibers such as grass clippings, cat tail flower and seaweed, among others.

Since beginning this research in 2016, we've relied on the material scientist Peter Bush at the State University of New York at Buffalo. He has shared his wealth of knowledge about materials and opened the microscopy lab that he supervises on campus to various cohorts of architecture students over the years. And over the years, the interdisciplinary collaboration with Peter Bush has become less of a novelty and more of a critical anchor to the research. Peter Bush as distilled aspects of material science that are relevant to designers, like the categorization of materials into three groups: inorganic, organic and composites. And he uses the wide array of objects in his lab – a kind of cabinet of curiosities – as vehicles to explain how everything around us can be broken down into its elemental make-up. Knowing about these elements can explain a lot about the behaviors of these objects and materials. The motivation for bringing cellulose materials to the microscopy lab was to see how our understanding of their microstructures might better equip us to handle the materials and anticipate their behaviors and potentials. Having a material scientist as a resource for the research and learning also helped contextualize information that we'd gather about the elemental make-up of our chosen materials. Cellulose, for instance, is made-up of carbon, hydrogen and oxygen. Carbon is found in all living things, and Peter Bush reminded us that we too, as humans, are compositions of elements – relatives, in a way, of all organic material. The lessons and insights picked-up through microscopy, which included both SEM and stereomicroscopic investigations really opened the students' eyes to the materials' complexity on a different scale. Zooming-in, we could observe and appreciate the microstructures of the materials, which helped prepare us to work with them physically.

SWATCHES: LEARNING HOW TO CAST PAPER

After zooming-in with microscopy, research and making was focused on zooming-out and scaling up, students transformed their cellulose-based materials into pulp, which is a suspension of paper fibers in water. Using pails, plastic laundry-tubs and self-made molds and deckles, students cast paper in manageable swatch sizes, around 8x10". In this phase of the research, students were able to witness first-hand what they'd observed in the microscopic images of paper: the mechanical interlock of fibers that contributes to the strength and integrity of these cast sheets or planes. Swatches were used as a quick way to test the behavior of various fibers as well as combination of fibers. Different thicknesses were also cast, and some binders were added to observe any stiffening effects they might have. Although adding wheat and rice flour does contribute some additional stiffness to cast paper, we have observed that, in the extremely humid workshop spaces where this casting is being done, these binders also make the cast paper more prone to developing mold. When scaling-up to room-scale enclosures, materials were chosen based on a few key criteria: they had to be available for free or little cost at large quantities, and they had to transform into pulp simply, and they had

Figure 2. Student shredding printer paper gathered from the recycling bins at the university library. Photograph: Stephanie Davidson.

to be proven, based on swatch tests, to cast easily into large, strong planes either through the use of a mold and deckle or a texture sprayer.

ROOM-SIZED CAST PAPER MONOCOQUE ENCLOSURES

From the range of materials and techniques tested in swatches, and later, in three-foot spans, various approaches have been taken to-date to scale-up to fabricate full-scale cast paper shells. These approaches are characterized by their structural typology, approach to formwork and, of course, material composition. Here, I'll share three large-scale cast paper shells that each used a very different set of variables. It should be noted that very little precedent exists for fabricating thin shell structures using paper and fibers at full (room) scale. One aim of the research is to use a trial-and-error approach to develop a catalogue of various fabrication methods for this particular type of temporary structure.

EXAMPLE PROJECT 1: RECYCLED PRINTER PAPER SHELL USING PNEUMATIC-AGGREGATE FORMWORK

Students: Derek Chan, Jonathan Der-Yeong Wan, Haley Davis, Connor Harrigan, Xinghuai Huang

This project used printer paper sourced from the recycling bins in the university library. When students send files to print, an orange separator sheet is printed so that students can easily separate their prints from others in the printer output tray. These separator sheets are immediately thrown in the recycling bin beside the printer, and offer a consistent source of free, waste paper. Another advantage of working with standard-sized US letter paper is that devices like paper shredders are designed for this paper format. To prepare their pulp, students took turns shredding the printer paper with a standard shredder purchased at an office supply store. Because most printer paper is made with recycled content, it tends to break-down into pulp quite easily. Standard latex balloons were tied into bunches and used as pneumatic-aggregate formwork. This type of formwork could also be described as a room-sized mold. The negative space of the room was filled with around two thousand balloons tied-together in aggregate modules or "clumps" to ensure density. The volume of balloons was then held-down using netting. The netting, pulled in tension, created a continuous surface onto which pulp was sprayed using a texture sprayer. Several layers of recycled paper pulp were sprayed over a 10-day period and the balloons and netting were removed once the sprayed paper shell had completely dried. The resulting monocoque typology, though a highly irregular shell at the room scale, is characterized by small-scale, regular surface deformation caused by the doubly-curved geometry of the formwork – balloons. The balloon geometry acts like a corrugation which stiffens the membrane of the overall shell geometry.

EXAMPLE PROJECT 2: KRAFT PAPER SHELL USING SUSPENDED BURLAP FORMWORK

Students: Jose Ruel Valdehueza Bozzolo-Fabia, Richard Runfola, Jarrett Trudeau, Ryan Vigiolto, Nicholas Wheeler

Like other groups, the students in this group used the dimensions and scale of their workshop space as a parameter for the cast paper shell. Also like other groups, fixed elements in the workshop space were exploited as parts of the formwork for the shells. Unlike other groups, this group used a process that lead to a more controlled, predetermined formal outcome. Burlap was used in this project as formwork, sewn using a cutting pattern derived from a Rhino model. Because the burlap remained part of this shell, it could also be considered as an integrated armature. When sewn together, the formwork was both suspended from the ceiling and walls as well as fixed to the floor. The full scale model was made to approximate the behavior and form of a smaller model made with stretchy fabric. A texture sprayer was used to apply several layers of coarse and heavy kraft paper pulp over a two-week time period. Pulp spraying is always a totally immersive process, with pulp covering surfaces beyond the cast paper shell. Because it has no additives it's highly responsive to water and can just be wiped away with a sponge. The resulting cast paper shell was rigid enough to be self-supporting – all of the cables holding it in tension were cut on the day of the final review. It's important to note a couple of challenges that arose with this particular fabrication system: firstly, the shell was supported by four legs/feet rather than a continuous bottom perimeter. These four points were visibly under stress and prone to buckling. Because of the high humidity in the workshop space, reinforcing the four

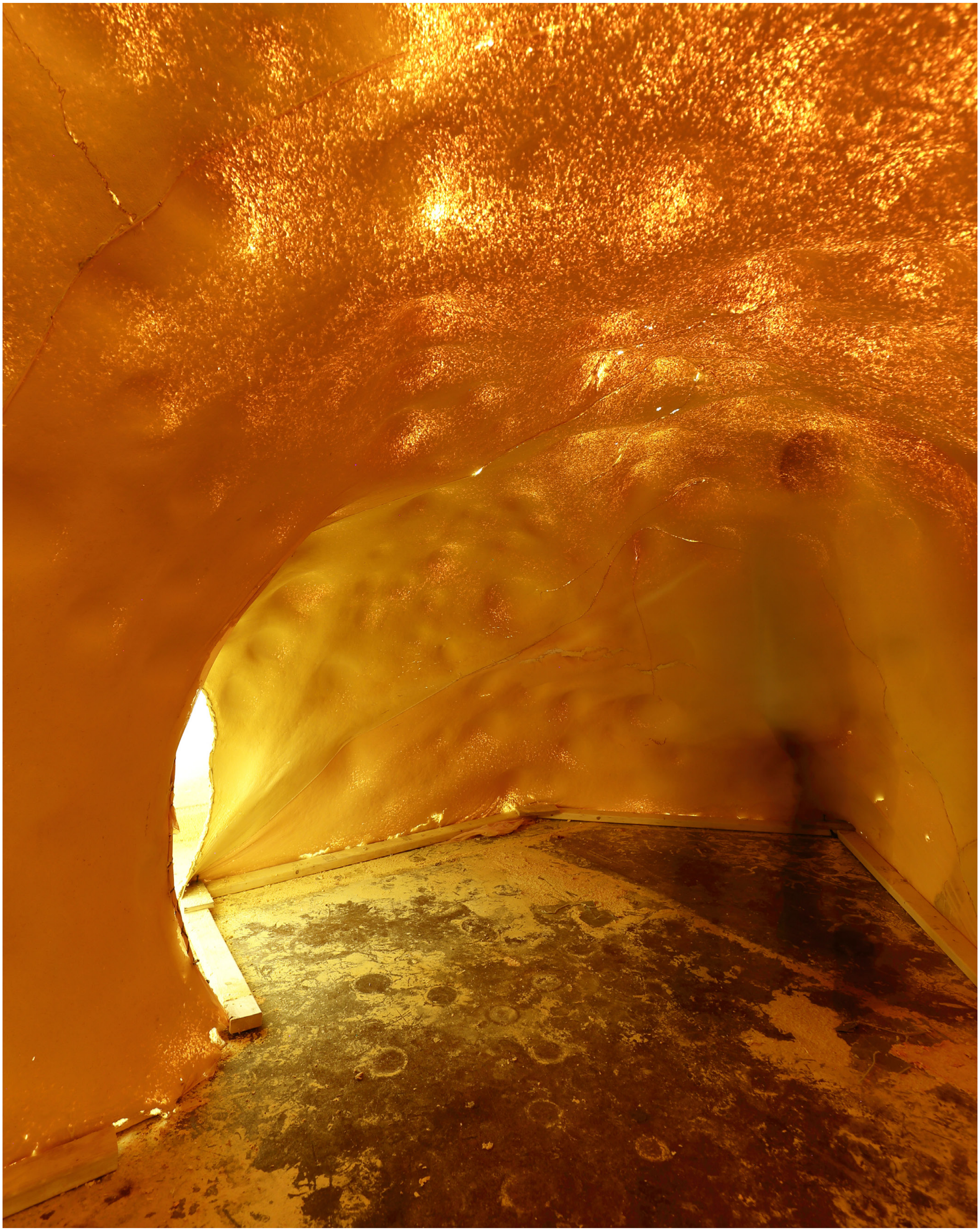

Figure 3. Interior view of room scale cast paper structure made using balloons as formwork. Photograph: Georg Rafailidis.

Figure 4. Interior of room scale cast paper structure made using a suspended fabric formwork. Photograph: Georg Rafailidis.

Figure 5. Image caption. Image credit.

legs at their base wasn't feasible – the additional density of pulp didn't dry. Also, the legs were angled steeply. The steep angle of the four legs caused the heavy kraft paper pulp to slide downward.

EXAMPLE PROJECT 3: WIND-FORMED CATTAIL SHELLS

Students: Grace Shih-En Chang, Hoda Farahani, Jeremy Keyzer

The third of three projects that I'll share contrasts from the cardboard and printer paper projects in its material selection and more unpredetermined formal outcome. Pulp was made, in this project, from the cattail flower. As with most natural fibers harvested from their source, the material had to be boiled for several hours in order to break-down into a slurry consistency that could be manipulated further as cast sheet material. The material was strained and blended repeatedly. Compared to paper pulp, the cattail pulp was finer and didn't accumulate into a sheet using the mold and deckle used in traditional paper making. Cheesecloth was used as a substrate to compensate for the lack of mechanical interlocking in the cast, fine cattail fibers. Students used a combination of painting the pulp onto the cheesecloth with fans constantly running in order to help the sheets dry and to aid in air circulation in general, since studio environments for this type of work were consistently very humid. In order to achieve a degree of rigidity that allowed the panels or sails to sit self-supported on the ground, pulp was applied daily for around 10 days. Ultimately the fans required to help in drying and air circulation had an impact on the three dimensional deformation of the cast planes. The structural typology, though hanging, could best be described as a wind-formed shell, since the three dimensionality of each plane was largely determined by the orientation and force of the wind driven by the fan or fans used for each sail. Interestingly the cat tail shells share some physical tendencies with a predecessor, a grass shell (students: Colin Kelly, Henry Saldana), in that both natural fibers shrink a lot when drying, creating significant surface deformity. As mentioned with the balloon formwork group, the small-scale surface deformity – whether incidental or a planned part of the formwork - contributes additional rigidity to these monocoque shells, regardless of their overall geometry.

CONCLUSION

This research and the outcome to-date is meant to shift our attitude toward decay-prone materials, and consider ways in which to harness this weakness to make temporary structures that are able and meant to disappear, and even add aeration and nutrients to the soil where they end up. More broadly, the research encourages a view of materials and assemblies as things that are constantly transforming instead of looking at materials as object that are fixed in a certain geometry or spatial composition. This research has been focused on demonstrating that it is possible to create large-scale monocoque structures using different methods that are each light on formwork and create little or no waste. The formal outcome of the research done so far shows that large-scale cast paper shells can be cast using a wide variety of source material and techniques, following different structural logics that best exploit or respect the capabilities of the material. Next steps of the research will look at the eventual decay of the structures as well as concrete use scenarios.