Material Uncertainty: An Introduction to Digital Design and Fabrication

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Introduction

Tim Ingold's *Making* (2013) frames design as a time-based development of form. Traditionally understood as a preconceived idea, he describes form as a confluence of human activity, material performance, and environmental forces. This conception of form embraces uncertainty as an integral part of the design process.

In "Material and Computation" – an introductory course in digital design and construction in architecture - we examine intrinsic material properties and their manipulation over time as the basis of computational design. Students design building components and assemblies using the tactility of materials to ground the learning of computational methods. The uncertainty of material behavior enriches this learning through a hands-on experience of complex digital-analog relationships. To negotiate uncertainty students invent methods of working with materials at precise moments, while allowing materials to behave freely at others. The course instructs students in an algorithmic framework of constants and variables to plan out these interventions. In this way "computation" becomes more than a tool to realize form, it becomes a way to think about and orchestrate networks of materials over time: encoding instructions about material manipulation which account for the uncertainty of material behavior.

The outcomes of this approach display the behavior of materials over time. The traces of their working – etched holes, twisted strands, surface impressions – are revealed in the final form. These traces fix the materials at a stopping point in time and imply further motion. Their forms show what dynamic properties like thermo-plasticity, viscosity, and elasticity look like when captured in time. A wood veneer could bend further, a plaster cast bulge more, a twisted strand gain one more degree of rotation.

Integrating material properties with computational tools emphasizes the dynamic potential of computational design processes. And it grounds this potential in empirical knowledge of the physical world. In this way computation and materiality inform each other as time-based knowledge frameworks. Rather than documenting a fixed form, the computer is used as an instrument for interacting algorithmically over time with the built environment. Likewise, rather than approaching materials as inert receptors of mental images they are engaged as snapshots in a continuum of forces and energy over time. At an early stage in design education this shifts conventional understandings of materials and computation. It fosters a more dynamic and nimble mindset for confronting the physical demands of the built environment and new technologies with which to meet these demands. Thus students are presented with buildings through the lens of time: in what came before, what will come after, and what occurs dynamically within them over the course of their lifetime.

Research Question

Conventional understandings of materials in digital practice either willfully impose virtual form on raw materials; or rely on production tools like Revit to make tacit decisions about materiality (Hall, 2016). This course challenges this conventional understanding by asking if intrinsic material properties can be a basis for learning design tools. Can foregrounding material properties bridge the abstraction of computation and the reality of material production and rebalance digital design's ambivalent relationship to material tolerances and behaviors? This is an alternative model of digital design which uses the study of material behavior to knit together digital and physical design outputs.

This is an ethic of making which privileges process and time over image or custom. This framework conceives material formation as a snapshot in time of a larger life span: from raw extracted element to machined assemblies to degraded or disassembled parts. In this model, rather than pursuing form as an end in itself, form emerges as a confluence of human action, environmental factors, and material behavior.


Figure 1. Making baskets in the sand. From Making, Tim Ingold. By permission.

This ethic is informed by studies of making practices by British anthropologist and archaeologist Tim Ingold. Ingold conducts empirical investigations into making and material engagement, modeling material culture through the lens of time, environment, and intrinsic material properties. According to Ingold, viewing objects like a cup or coin through the lens of time resists our ability to pin objects down in a single static form. The lens of time reframes the coin as a snapshot in larger environmental and human processes such as ore extraction, metal alloy manufacture and stamping, physical handling, weathering, and decay. Seen through this lens the coin, as an object caught in the flow of time, will continue to assume new and unpredictable formations through the further impacts of environmental and social flows (Ingold, 2013). He conducts a live experiment of this theory with students, investigating the impact of time and environment on material formation during the process of making baskets on a windy beach. In this exercise, students weave reeds around vertical stands of wooden branches. Under the influence of tired muscles and the constant driving of the wind the weaves loosen and the baskets gradually lean, embedding time in their formation (Figure 1).

Objective

Similar to Ingold's challenge of static form the objective of this course is to challenge the apparent certainty of digital technologies with the uncertain behavior of materials over time. And, moreover, to speculate how a mutual exchange of material and computational capabilities can expand our insights around each. The semester's project is the design of physical and virtual prototypes for architectural components and assemblies. The goal is to look at architectural components like bricks, w-sections, and glass panes not as fixed, finished entities, but rather as elements caught in the flow of time. By fostering this understanding students can see the opportunities for their own intervention into this flow and that at the level of the prototype their ideas and values can have impact. To bolster these objectives we instruct students preliminarily in a hierarchy of construction component technologies (Fernandez, 2001), building material families (Fernandez, 2006), and manufacturing technologies (Thompson, 2007).

Method

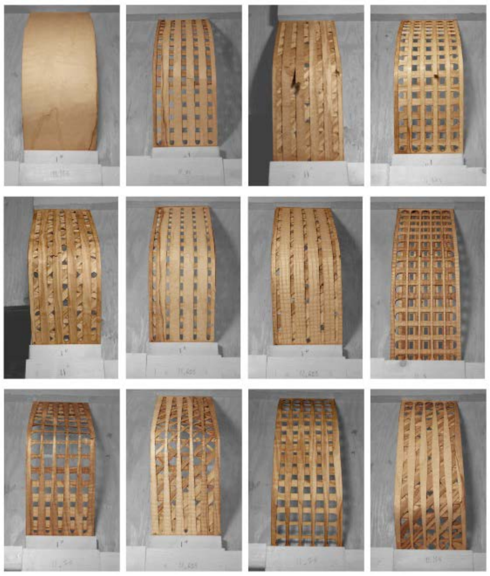

Figure 2. "Perforated Wood." Material investigation. Student: Stas Klaz.

The term is organized in a three phase sequence: physical experimentation, digital design, and digital fabrication. This ordering foregrounds physical experimentation in order to ground later digital prototyping and digital manufacturing in material behavior and properties.

The first phase, Material Variation, is a period of systematic material investigations. It helps students develop methods to direct the outcomes of a proto-manufacturing process, establishing a dialogue with their material. Students select a single material from the material families of ceramics, metals, polymers, composites and organics. They burn, twist, fold, rip, boil, melt, and smash samples of materials like paper pulp, plaster, steel, cardboard, and acrylic. From these experiments they identify a particular material property, like ductility in sheet metal, to then study systematically. In the project "Perforated Wood," the student bent and twisted wood veneers, developing an interest in controlling their elasticity in bending. Systematic investigations tested a variety of perforation patterns and their effects on the bending behavior of standard sized panels (Figure 2).

In the second phase, Motor Schema, these physical investigations are abstracted into simple geometric drawings which simulate material behavior. This is achieved through a network of constants and variables, similar to examples introduced from craft manuals (Peck, 2006), the geometric descriptions of natural forms by D'Arcy Wentworth Thompson (Thompson, 1992), and computational geometry texts (Pottmann & Bentley, 2007). The drawings students make define fixed point, line, and plane geometries against which transforms such as rotation, translation, etc. are performed. These drawings form the basis of geometric algorithms which can be entered into a graphic algorithm editor, like Grasshopper for Rhinoceros 3D, to animate the range of motion. For instance, in "Cardboard Dynamic Folds" an adjustable pattern of variably spaced and angled lines describe mountain and valley folds for a cardboard sheet (Figure 3). By defining the coordinates and relationships between parts the student was able to define a parametrically adjustable model which could adapt to a range of geometry sizes. In addition to accommodating a range of dimensions, the model can also animate each cardboard sheet's range of motion.

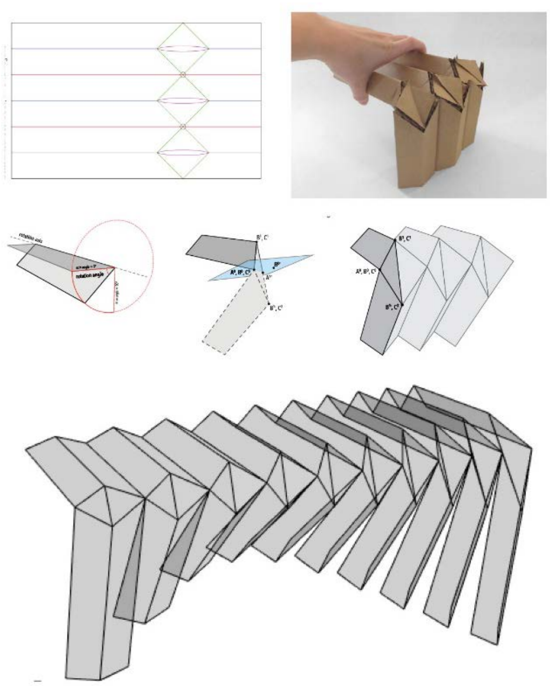

Figure 3. "Cardboard Dynamic Folds." 2D drawing, 3D parametric model, and physical prototype. Student: Emily Wilson.

These animated drawings are then refined to create underlying geometries for architectural components. This step provides essential information for translation of the virtual explorations back to physical components. To accomplish this students do not need to produce a surface model simulation of the final form. Rather, they construct a network of abstract shapes to describe the fundamental dynamic relationships between material parts.

In the third phase, Material Animation, this dynamic underlying geometry is used to apply digitally animated geometries to matter. This is accomplished in two ways: the underlying geometry directly informs CNC tool operations, or it is used to create a jig through which to work the material. In the instance of "Cardboard Dynamic Folds" the scaffold of lines was translated to a CNC mill file, creating a die to press and puncture the cardboard sheets. From a close examination of the properties of the cardboard sheet the mill file's dimensions snap into the intervals of corrugations in a standard cardboard sheet for ease of folding (Figure 4). In another example, "Twisting" - an investigation utilizing the ductility of steel piano wire twisted into multi-nodal joints - an assembly was created from digital files for both a nodal network of steel rods as well as a braiding mechanism assembled from CNC milled parts. The required lengths of steel rod were read from the nodal network model and then fed into the braiding mechanism. Through the braided joint the project bound together a set of rods into an elastic, lightweight lattice (Figure 5).

Findings

This is a process which produces materially efficient components that are highly adaptive and whose production generates new knowledge. As the designs are formed out of intrinsic material properties their shapes do not require extra energy to "fight" the material. They work with the material to maximize the output of energy invested in the artifacts. Minimal effort is needed to form the components, easily crafted from hand work tools. As the assemblies are not made from a preconceived form they are rooted in constant-variable relationships. This makes them formations, not forms, which can take on a variety of configurations and respond to a variety of site conditions. And finally, as they grow out of a process of discovery their production is a method of knowledge generation. They are novel artifacts which could not be predicted at the investigation's outset. The ensuing exploration and invention generates new discoveries of behavior and new methods of working.

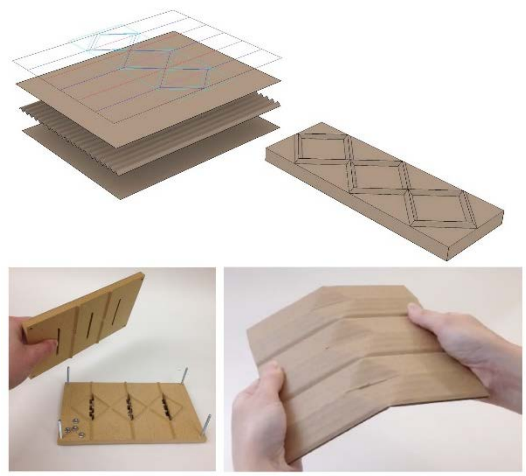

Figure 4. "Cardboard Dynamic Folds." CNC milled die for creasing and puncturing cardboard sheets.

Conclusion

In the construction of Gothic cathedrals a master builder directed masons using wooden templates which the masons would use to trace the shapes onto stone. Ingold argues that these templates - tools for communication between master builder and masons - were actually incomplete instruments. The masons did not use them to mechanically execute the traced shape. If a templated stone did not fit in place the mason departed from the sketch and shaped the stone to fit. In this way the overall form of the cathedral grew organically as an adaptive process over time, not as the perfect execution of a predetermined form. The wooden templates were not final documents to be faithfully executed, but served more as a stage direction around which material was adapted.

This challenges conventional ideas of buildings as static entities (Yaneva, 2011). The template is not a complete or static form or instruction. It is the beginning of a process. The stone, too, is incomplete even when set in place. It is chiseled and modified as abutting stones are brought into contact with it.

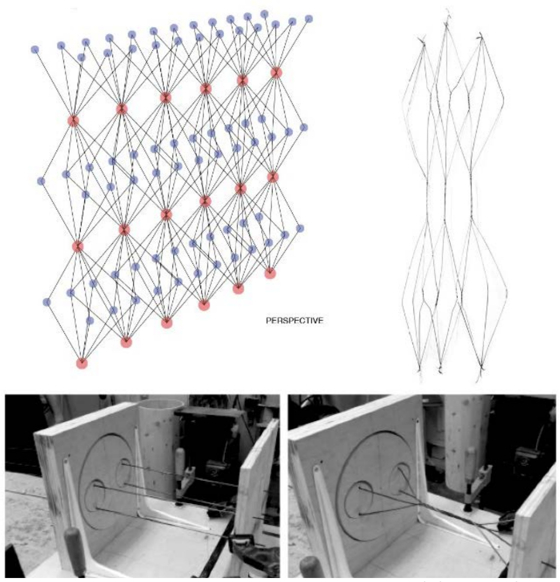

Figure 5. "Twisting." 3D parametric nodal network, physical assembly, and CNC fabricated braiding mechanism. Students: Lewis Gallacher, Patrick Spelliscy

And it will move and settle. And so, too, the building itself is continually incomplete. Ingold's model describes the act of building and the object of the building as bound in a network of perpetual incompletion. As Stewart Brand notes in *How Buildings Learn*, building – both process and object - is forever ongoing, continually conducted by builders and inhabitants alike (Brand, 1994).

In "Material and Computation" this time-based conception of building extends to digital practice through the contingencies introduced by materials. This challenges the notion of computational tools as precise devices. Like the use of the template as an instrument of stage direction, the use of computation and jigs in student projects merely facilitates a dialogue between designer and matter. It does not dictate the final form. The back and forth between computer and material reframes the rules and capacities of each. We can begin to think of the computer as an uncertain instrument of choreography. And we can consider material as a systematic algorithm. Like Ingold's students weaving baskets in the wind, this model emphasizes digital practice as a confluence of agents acting together at a particular juncture in time, not a predictor of form. In this way the act of building and the object of the building in digital practice are taught as fluid and dynamic entities, not complete products: continually formed and forming over time.

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