LEARNING FROM LOGS

Introductory Analog and Digital Pedagogy Addressing Material Irregularity

KYLE SCHUMANN[1]
[1]*University of Virginia / After Architecture.*
[1]*schumann@virginia.edu, 0000-0002-0619-0541*

Abstract. Advanced computational visioning, modeling and fabrication technologies are becoming increasingly accessible to non-expert users, allowing designers to engage complex forms and materials with increasing control and precision. Nonetheless, beginning designers often struggle to maintain authorship when mastering new software, resulting in designs shaped by the biases of the digital tools at hand. The act of translation between physical and digital poses particular difficulty. This paper presents a sequential pedagogy in which students are introduced to both manual and digital analytical and fabrication processes with the goal of understanding, analyzing, and addressing material irregularity. Techniques and tools employed include digital modeling in Rhinoceros, 3D scanning, computational analysis in Grasshopper, traditional woodshop tools, 3D printing, laser cutting, and CNC routing. The outcomes and criteria for evaluating student projects are discussed: in particular, the learning opportunities afforded by using irregularly sized and shaped material that allowed students to develop creative ways of working with standard woodworking and digital fabrication tools. Additional challenges due to virtual teaching and financial considerations are addressed through salvaged materials and democratized technologies.

Keywords. Digital Pedagogy; Democratized Technology; Digital Fabrication; Computation; Material Irregularity; SDG 4; SDG 13; SDG 12.

1. Introduction

This paper presents a sequence of introductory pedagogical exercises prescribed to undergraduate architecture students aimed at rapid skill development in analog and digital workflows. With a focus on analysis and translation, the methods preference accessibility and democratization by using industry standard tools and consumer-grade software and minimizing material cost. Irregular material, harvested from fallen trees on campus, functions as a complex generator containing information on form, age, structure, texture, and more (Carpo 2017).

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Figure 1. Completed student projects

The students are enrolled in the third year of a non-professional, undergraduate, four-year architecture program. The students were previously introduced to woodshop tools in their first year, but due to the COVID-19 pandemic and a shift to virtual learning, time had elapsed since these means of production were engaged. This sequence of assignments served to reintroduce students to these tools and forge a link between analog and digital fabrication through the introduction of advanced computational tools. In particular, the relationship between digital and physical is investigated within a rapidly developing scholarly area in which digital design processes optimize natural form in varying capacities. Many of the processes introduced and skills developed in this set of exercises were applied to longer-term fabrication projects later in the semester.

2. Methods

The pedagogy consists of four exercises that sequentially introduce manual and computational skills through four phases: manual analysis, manual fabrication, digital analysis, and digital fabrication. Emphasis is placed on translating knowledge and understanding between analog and digital workflows and developing strategies for utilizing irregular natural materials that are both scalable and translatable to other geometries and assemblies.

Each student is provided an approximately rectilinear fragment of wood prepared for them prior to the semester in the following manner: wood is rough sawn with a chainsaw to measure six inches deep by a variable width and height, containing a partial void and exposed live edges that retain and display natural irregularities. The wood is salvaged from campus landscaping waste and provided at no charge to students. As such, each wood fragment is of a different age, state of decay, and moisture content. Wood is not dried prior to use, providing opportunities and challenges to engage with a material that will move, warp, and crack — a challenge that some students took on as an opportunity to respond to material behavior.

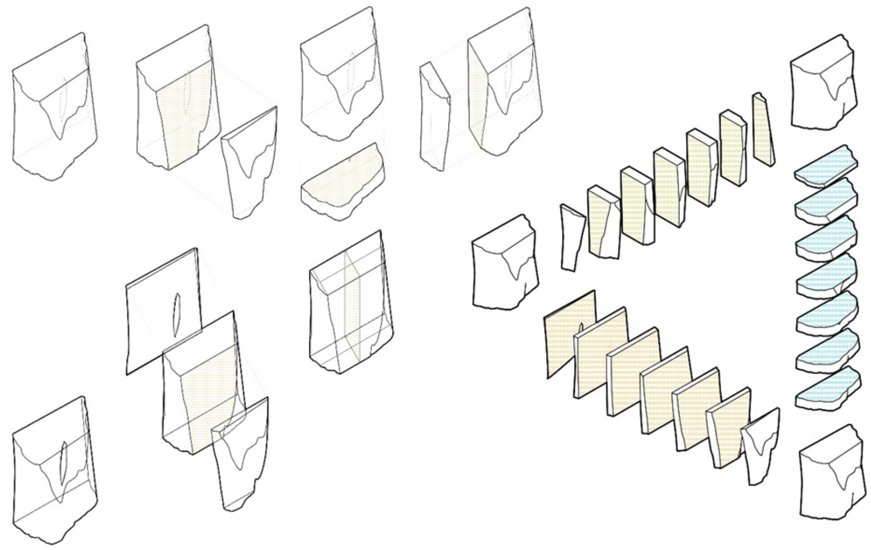

Figure 2. Analytical drawings from manually constructed digital model. Work by Audrey Lewis

2.1. MANUAL ANALYSIS

Each student develops a comprehensive understanding of the wood piece by manually measuring and digitally reconstructing the object as a model in Rhinoceros and a set of axonometric drawings (Figure 2). This process serves to equip students with a baseline set of skills, as many began the project without experience taking precise measurements or in digitally modeling complex surfaces. Commands such as loft, sweep, and boolean operations become a part of the students' modeling vocabulary.

Building on their digital models, students produce a series of axonometric drawings describing physical qualities of the material – geometry, form, texture, etc. These drawings prime students to interpolate characteristics of the organism from which the material was harvested through the production of a subsequent drawing which projects the form of the tree and location from which the material was harvested. A model-to-drawing workflow is implemented across the class in which base drawings extracted from Rhinoceros are completed and assigned lineweights in AutoCAD.

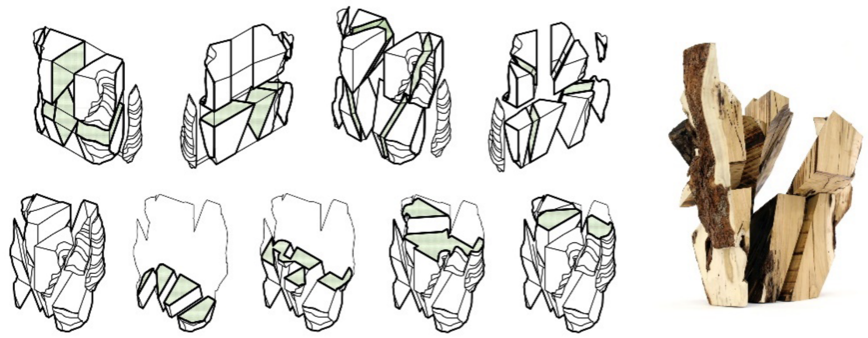

Figure 3. Operations are planned digitally and then executed manually. Work by Turner DeShon

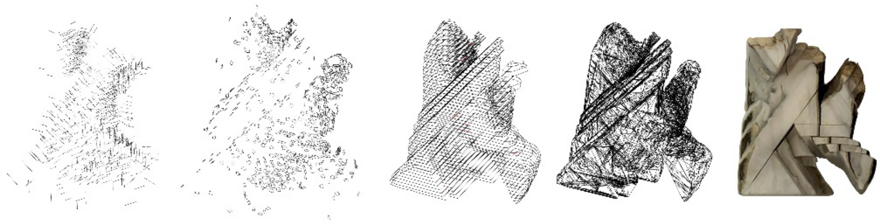

Figure 4. Digital analysis (left) generated from 3D scan mesh data (right). Work by Mak Johansen

2.2. MANUAL FABRICATION

Students are provided a set of operational rules aimed at eliciting a clear formal organizational system: (1) cuts must (a) be straight or angular but not curved, (b) be visible on at least three faces, and (c) result in a single object; (2) glue is allowed but hardware is not; (3) a maximum of one-quarter of the material can be removed. Beginning from their digital models and drawings, students digitally develop operations and then enact them physically in the fabrication lab using analog woodworking tools (Figure 3).

Students receive training on a series of woodworking tools including a planer, jointer, table saw, band saw, miter saw, drill press, and disc and belt sanders. The first step is to square several faces of their material, after which various designed operations can be executed accurately. When employing these tools with their material, students must overcome several challenges stemming from the size and irregular form of the wood. Creative solutions must be developed, including building custom jigs to accurately position and cut material that has several non-planar sides.

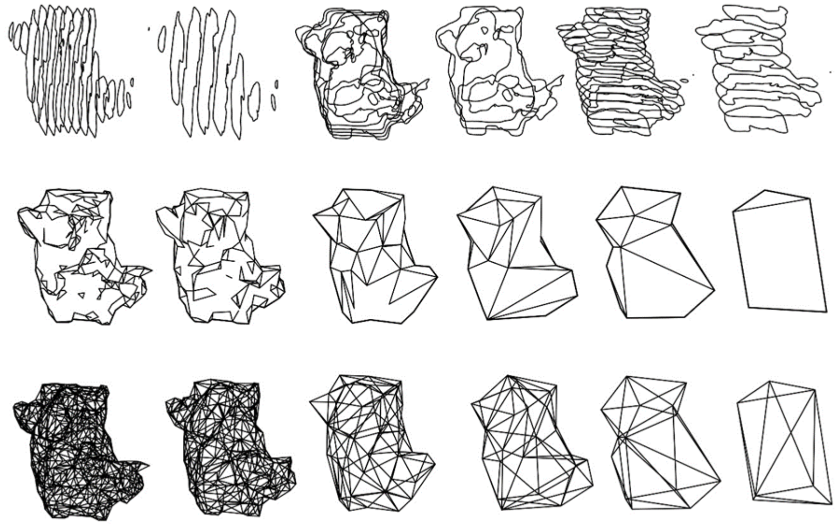

Figure 5. Distillation methods to extract specific qualities or geometries. Work by Abbie Weissman

2.3. DIGITAL ANALYSIS

The transformed material is 3D scanned using a consumer-grade smartphone app (www.qlone.pro) to produce a digital doppelganger which can be compared to the manually constructed digital model. This new model is analyzed computationally in Grasshopper and translated into a series of axonometric diagrams (Figure 4). Focus is placed on understanding and responding to the natural irregularities of the material and how these irregularities relate to the prior operations (Figure 5).

Students are provided with a series of example Grasshopper scripts that each distill data from the 3D scan to extract a certain quality from the object: sorting mesh faces by size and orientation, tracing sharp edges by measuring angles between faces, generating contours and measuring curvature, identifying light and dark zones using mesh vertex colors, etc. (MacDonald and Schumann 2021). The scripts are further developed and customized by the students based on their design intent and material irregularity. This step proved to be the most challenging overall, with students often needing to be individually led through how to develop their script to achieve the desired analysis.

2.4. DIGITAL FABRICATION

Students are introduced to three digital fabrication processes: CNC milling, laser cutting, and 3D printing, through comprehensive recorded videos followed by in-person tutorials. Students develop a second set of operations to perform on their material that deploys one or more of these techniques in response to a material irregularity that was identified computationally in the previous step. A secondary material is incorporated to engage with the pre-existing material (Oyler Wu Collaborative 2021).

A system diagram is constructed to articulate the relationships between design intent, material qualities, computational analysis, and fabrication processes (Figure 6). The system diagram is a critical step in the final part of the sequence, as it creates a platform for the students to synthesize ideas developed throughout and articulate a model of shared authorship between designer and material, mediated by computationally driven analysis.

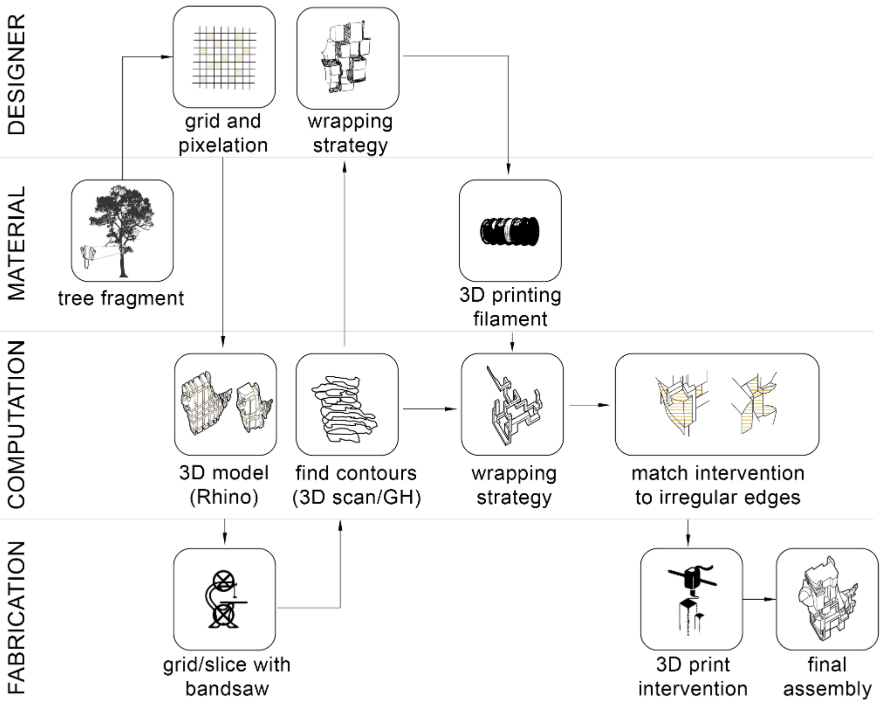

Figure 6. System diagram choreographing design intent, material qualities, computational analysis, and fabrication processes. Work by Abbie Weissman

3. Results

Following the sequence, students gained foundational skills in digital modeling, woodworking, 3D scanning, Grasshopper scripting, and at least one digital fabrication process, as well as an advanced understanding of tools and processes allowing for close engagement with material irregularity.

Providing free salvaged material to students removed financial barriers, allowing all students to begin the project with the same assets, creating an equitable learning environment. Providing students with pre-recorded training videos on equipment and example Grasshopper scripts served to expedite skill building but following up with hands-on training with tools and individual aid in developing scripts proved necessary. This was due in part to the nature of the operations needed, which often required Grasshopper plugins with which the students were unfamiliar. These included Firefly to analyze and trace 2D images, Weaverbird to process and extract data from 3D meshes, and LunchBox to reduce mesh complexity in terms of face count.

Figure 7. Comparing 3D scans (above) and physical material (below). Work by Abbie Weissman

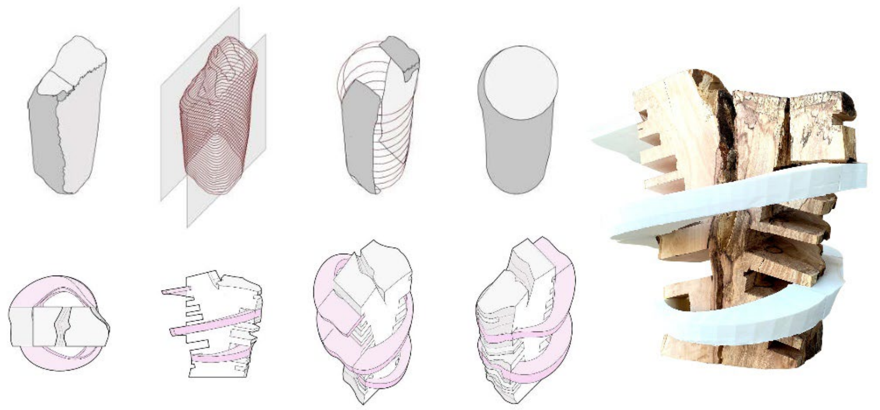

Figure 8. Reconstructing trunk volume by interpolating 3D scanned bark. Work by Daisy Wegener

Projects were evaluated based on ability of the work to convey, emphasize, or respond to material irregularity, its general formal and aesthetic interest, and the level of skill or craft in the physical execution of the work. The most novel projects precisely responded to specific material irregularities in a way that is clearly legible to the viewer. Various methods were implemented, including 3D scanning and distilling to extract critical data, and analyzing 2D images with edge detection. Students are equipped with conceptual and technical understandings of how material irregularities can be understood and processed computationally, preparing them to participate in contemporary advances using computation to advance sustainable fabrication (Self and Vercruysse 2017; Larsen and Aagaard 2019; Johns and Foley 2014; Bechert et al. 2021; Saslawsky et al. 2021).

The success of the project was also evaluated on how well it prepared students for their work over the rest of the semester. Following this sequence, students worked in groups to develop and construct full-scale site-specific installations on campus, using novel wood fabrication strategies. Many students were able to take skills and approaches applied in the described sequence and translate and scale them to larger applications and complex assemblies. This included translating woodworking and digital modeling skills to other fabrication tools, including a CNC waterjet and a mobile sawmill.

Figure 9. Using edge detection to locate cracks and mill wedges. Work by Stuart Ingram

4. Conclusion

One of the largest challenges in implementing this pedagogy was that of working mostly remotely during the COVID-19 pandemic. Students had access to fabrication shop resources throughout the semester, but course meetings were conducted online, and students were often developing work digitally at home while their physical materials were located at school. In future iterations of the course, it is anticipated that the ability to conduct digital work while in the presence of the physical material will allow for an even closer relationship between design intent and material irregularity from direct and constant observation of the physical material.

The challenge of virtual teaching and the need for students to isolate due to the pandemic meant the project timeline was extended past the originally planned dates. Without these issues in the future, it is anticipated that the sequence can be completed over four to five weeks from start to finish. This will allow one week each for manual analysis, manual fabrication, and digital analysis, and one to two weeks for digital fabrication, due to the extended learning curve and machine times necessary on these tools. Each step is introduced independently, but some steps can be introduced on a Friday while the prior is due the following Monday. This slight overlap will allow students some flexibility with their own schedules and allow an extra weekend during which fabrication tools can be accessed to complete any particular phase of the project.

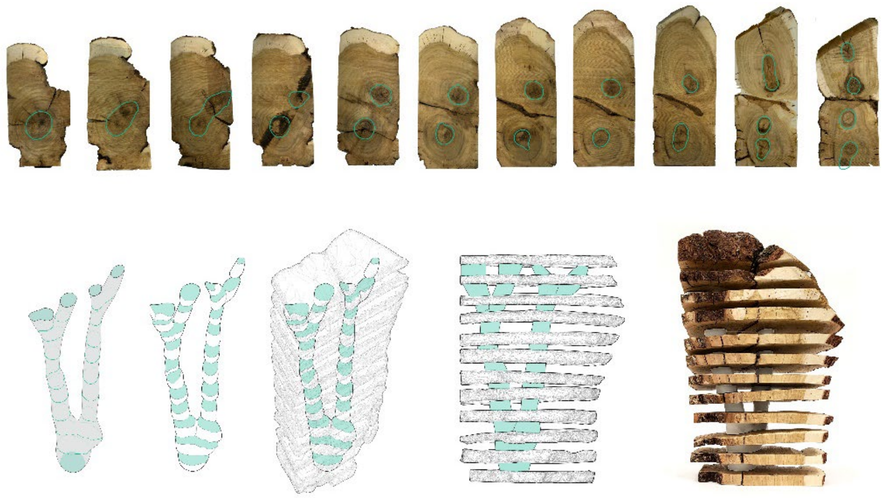

Figure 10. Analyzing 2D images of wood slabs to identify and interpolate heartwood form. Work by Jacob McLaughlin

Another challenge came from the material itself. Since the wood was not dried prior to use, several pieces warped or split throughout the project. Some students viewed this as an opportunity, developing projects that identified these regions with edge detection and operated upon them through digital fabrication methods. This strategy was aimed at materially programming certain behaviors into the wood such that natural distortions were enhanced, exaggerated, or otherwise shaped as the material aged or dried. This built an understanding that while the digital model is fixed, the physical artifact is not static and is subject to transformation as it ages and reacts to various environmental conditions.

The irregular size and shape of the material served to provide some of the most productive learning opportunities for students. The need to develop custom jigs for cutting the material precisely with various saws, a drill press, and a CNC mill demonstrated a contrast between the ease of digital modeling and the realities of physical fabrication. Students were encouraged to develop ways of inventively using the tools at their disposal while still doing so safely, which led to more creative freedom in the fabrication projects that followed. This approach reasserts the authorship of the designer relative to digital tools and analog craft, encouraging students to use tools creatively to realize their designs, rather than altering their designs to fit the available tools. Teaching such approaches through this pedagogical sequence has the potential to build knowledge in advanced fabrication and computation studios and courses prior to embarking on larger and more complex projects, but also to embed an adaptive and fluid understanding of the relationship between analog and digital tools and workflows into introductory design courses.

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