Ph.D. Thesis, Abstract

COMPUTATIONAL CARPENTRY:
Material- and Fabrication-aware Design Systems

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The first computer-aided design (CAD) software mimicked how a real draftsperson would draw manually using a pen. Since then, the development of user interfaces and parametric modeling tools have significantly increased the possibilities of different geometries that can be easily modeled on the computer. However, it is relatively challenging to physically materialize complex designs. Digital fabrication aims to bridge this gap between the digital and physical worlds by directly exporting instructions from a computer to a fabrication machine.

Digital fabrication is typically a one-directional process that translates the digital model into the physical artifact. This one-way approach is usually sufficient for uniform materials such as plastic and metal. However, solid wood is a nonuniform material; its visual appearance and physical performance are influenced by the volumetric grain pattern. Moreover, the natural outer shapes of wood (before cutting a tree into orthogonal planks) are organic and irregular. Given this non-uniformity, there is potential to find synergies between design goals and the existing material structures. This thesis aims to explore this potential by establishing two-directional processes between the digital and physical worlds—from a physical material to a digital model in addition to the information flow from a digital model to a physical artifact.

When processing wood via digital fabrication, computer-numerical control (CNC) milling is commonly used to program a tool head to move along a path while removing material from a solid block. As do other modes of fabrication, CNC milling has specific fabrication constraints. In typical workflows, such constraints are not addressed at the stage of system design, and this often leads to advanced hardware setups for physically realizing a given output. In contrast, in this thesis, we define systems that respond to specific fabrication constraints, which help ensure that outputs can be fabricated with relatively accessible hardware. We focus on 3-axis CNC milling, which can help reduce fabrication costs and facilitate implementation in society, compared to the use of more inaccessible and expensive hardware, such as 6-axis CNC milling with a robotic arm.

Based on these objectives—to leverage the material non-uniformity of wood and to aim for relatively basic fabrication setups—we formulate an approach wherein design systems are informed by the unique structures of the materials at hand and/or they respond to fabrication constraints of 3-axis CNC milling. We refer to it as material- and fabrication-aware computational carpentry. We present three case studies to exemplify and evaluate this approach: designing wood joints, building with naturally shaped tree branches, and modeling the annual ring pattern of wood. Finally, we summarize the insights gained from these case studies, discuss the contribution to the field of digital fabrication, and present an overview of the directions for future works.

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