

Material Knowledge and Digital Thinking: Reflections on Research-based Teaching

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ABSTRACT: Digital tools have become a part of most architectural education worldwide. Today, digital tools include much more than just drawing and modeling software. Every aspect of architectural design and development is digitized, and the component and construction industries are increasingly implementing digitization and automation. As such, digital knowledge and literacy in and around the architectural process are vast and constantly changing. While architectural education can include courses and implementations of certain digital tools, it seems impossible to teach all aspects of digital possibilities within the limited timespan of academic education. A strategy and didactic approach to the digital tool can guide the position of the educational institution and structure the ambition and intention of how digital competencies are brought to the students. Focused work on the digital curriculum at Aarhus School of Architecture led to a framework for digital teaching throughout the bachelor's and master's programs. A series of material- and research-based workshops for 2nd-year students were developed within that framework. This paper discusses the content of these specific hands-on digital courses regarding their intention and ambition as components in architectural education.

KEYWORDS: digital workflows, fabrication, education, workshop, wood

INTRODUCTION

From 2018 to 2019, Aarhus School of Architecture set out to update and reform its approach to digital teaching in its architectural education. A task force consisting of staff and faculty was formed to coin an overall strategy for the part of the curriculum that touched upon digital skills and literacy. Until then, digital teaching has been a vital part of teaching, but has consisted of fragmented initiatives without a larger didactic and academic framework. Courses dealing directly with specific software were part of the teaching, and a series of summer workshops included digital fabrication facilities. The focus for the digital curriculum initiative was eventually built around the term Digital Thinking. Digital Thinking is to be understood as critical thinking about how digital technology influences the design process, society, the built environment, and the architect's role. For the curriculum, this meant that the students should be presented with a broad palette of digital tools that can provide them with a high level of competency in using digital design methods and digital fabrication technology for architectural design. Translated into particular courses and workshops, this meant a gradual introduction of digital design and fabrication tools starting from the first year throughout the bachelor's and master's education. A special focus on design and making became a central part of each course, meaning that software, workflow, and digital tools should be taught and introduced to students in a way where the actual utilization of the procedures and possibilities is not predefined but instead an object for critical thinking and individual implementation. Digital fabrication methods allow architects to establish a closer connection between design and realization, as pointed out by Branko Kolarevich (Kolarevic 2004), and it was the ambition to introduce students to these potentials through hands-on experimentation. A series of digital fabrication-oriented workshops were developed in the Digital Thinking curriculum context. Again, the focus was on an open and critical approach to technologies, emphasizing workflow understanding rather than software procedures. Consequently, the workshops catalyze the question: How can workshop-based teaching inform and enrich digital skills and competencies in future architecture education? This paper unfolds a workshop trajectory that was developed with a focus on wood and an ambition of teaching students of architecture digital workflows through hands-on experimentation to understand the fundamental aspects of emerging technologies in architectural design and realization.

1.0 THEORY AND CONTEXT

1.1. Digital engagement

It has become increasingly apparent to the architectural profession that digital technologies have opened new forms of imagining and realizing architecture (Leitão, Castelo-Branco, and Santos 2019; Lidelöw, Engström, and Samuelson 2023). Besides offering new ways of designing, developing, and realizing architecture, digital tools differ from traditional tools in their volatility and pace of evolution (Arteta 2017). Whether the tools are hardware-based or software-based and whether they are targeted at designing, fabrication, or project management, constant

technological development demands attention and adaptability from the profession (Svetel, Kotic, and Pejanovic 2018). For architectural education, this also means that where traditional skills and techniques might have been taught through instructive and tutorial teaching (Fowles 1990), this way of knowledge transfer might have inferior long-term usability for digital tools. Instead, teaching digital literacy should be focused on enabling architecture students to understand and propose the handling of information relevant to the profession. As such, the ambition is to contribute to establishing computational design thinking, as lined out by (Ahluquist and Menges 2011). The most important digital skill might not be mastering particular tools but the ability to engage with and rethink data systems. This approach is aligned with Piaget's constructivist principles of learning, where meaning is created through experience and interactions with the environment (Jonassen 1991).

1.2 Digital literacy in architectural education

Several institutions worldwide have embraced digital media, software, or fabrication as the main elements or part of their education. The Architectural Association in London has its Hooke Park division – an architecture education where students live on a forest campus and, through a design-build education, construct wood buildings using both traditional craft and highly advanced digital design and fabrication tools (Mollica and Self 2016). On their Here East campus, UCL Bartlett offers undergraduate and postgraduate programs, with digital design, technology, automation, and manufacturing as focal points. At ETH, Zürich, and TU Munich, teaching formats revolving around full-scale realization through digital fabrication methods have been developed (Eversmann 2017). For such educational offerings, digital tools for designing and fabricating are both state-of-the-art and deeply integrated into the curriculum. While they and their likes are of great admiration and inspiration for other schools, they also position themselves as specialized educational choices.

For some architecture schools with a Beaux-Arts education background and anchoring, establishing an entire educational path built on digital skills might not be a choice or a possibility. Instead, the implementation of a common base of knowledge within the existing educational framework is the choice. This was the situation at Aarhus School of Architecture, where a common level of digital literacy was sought to be established among the students. Here, the strategy is not to enable all students to have the same skills but to inject a broad range of skills to stimulate diverse and vivid abilities. As such, Aarhus School of Architecture's relatively short digital curriculum elements should be regarded as exemplifying and of conceptual character, even though they have specificity, detailing, and themes that resonate with those of the more specialized schools.

2.0 RESEARCH

2.1. Material research

An ongoing research project was used to develop a series of digital workshops for 2nd-year students. The research project looked into the properties and capacities of wood, emphasizing developing ways of utilizing alternative wood resources. Alternative wood resources are, in this case, defined broadly as unused parts or species of wood. As such, the project seeks to investigate discarded wood elements from harvesting or sawmill facilities and look into the species and forms of wood currently not used in the building and construction industry. The main trajectory of this research project forms around crooked oak logs. Due to irregularities, a large amount of oak wood is discarded. However, through the methods suggested by the research project, these wood parts can instead be utilized when processed based on their divergence.

The research presents a workflow for handling the discrete shapes of natural saw logs in a system that involves collecting material, scanning/digitizing, handling a stockpile, computer analysis, design, and robotic manufacturing. The workflow includes multiple custom-made solutions for handling the complex and different shapes and data of natural wood logs in a highly digitized machining and fabrication environment. The suggested method is established by investigating wood as a material, studying the production lines in the current wood industry, and experimenting in our in-house laboratory facilities.

This up-cycling of discarded wood supply establishes a non-standard workflow that utilizes non-standard material stock and leads to a critical articulation of today's linear material economy. The research thereby gives an example of how sawlogs' natural forms and properties can be directly used to generate new structures and spatial conditions. A parallel trajectory in the research project concerns biodiversity and forest management. In this trajectory, a more diverse forest culture is sought, supported by more diverse use of different wood types. A fundamental issue here is again standardization in the industry. A better focus on individual wood properties and capabilities must be demanded to include a wider selection of wood species in building and construction. Regarding crooked, discarded, and alternative species, the research project argues for much better respect and utilization of natural properties, including fiber direction and mechanical properties.

2.2. Research-based teaching

The three individual workshops for architecture students formed a basis for a didactic strategy and reflection. The workshops are founded on the wood research project, in which selected content has been restructured to suit a 2-

week digital workshop format. The teaching includes a base layer of material knowledge concerning material properties and environmental aspects, and a layer of digital thinking that introduces design-to-realization workflows. The workshops contain hands-on material handling, digital analyses, production equipment (3D scanners, CNC machining centers, industrial robots, etc.), digitally driven design methods (parametric design, 3D modeling, and digital representation), and 1:1 machining and fabrication. Material work plays the lead role in these workshops. However, the materials and digital fabrication facilities are more to be seen as educational props for cultivating enquiring design methods and inventing digital workflows that bridge design and realization. The teaching is built around project development with software and digital tools presented as a pick-and-mix toolset.

The digital workshops started as teaching extensions of an ongoing research project. The students' work served as input and inspiration for the research project and provided insight into material-grounded architectural research.

3.0 TEACHING

3.1. Workshops

The first workshop was formed during the first phase of a newly started research project. The project had a quite open-ended research methodology where the material properties of wood resources were sought, investigated, and expanded through a range of digital workflows. However, when this first workshop was conducted, specific digital workflows and material processing procedures were deployed. The methods were aimed to digitize, and machine, discarded crooked oak branches and utilize those for architectural roof and truss constructions. These workflows and the ideas behind were presented and demonstrated to the students in their raw state. The students were then asked to develop their own uses and architectural investigations from the workflows. In this workshop, the students first went to a local forest where tree harvesting and thinning recently occurred; in groups, the students picked one or two wood logs that they found attractive. In all cases, these wood logs were curvy, crooked, branching or, in other respects, irregular. Back in the research lab, the student used the procedures from the research project of the 3D scan and developed a digital model of the found wood. For machining and processing, two workflows were available: Bandsaw cutting using a custom-built saw on an industrial robot arm and a 5-axis CNC machine. The students were asked first to split the wood pieces lengthwise using the robot setup and then next machine them on the 5-axis CNC with the aim of combining the members into architectural elements. In this regard, the students had total freedom regarding design and architectural intention, but when guided through common discussions and pin-ups during the workshop.

The students were motivated by the opportunity of engaging uniquely shaped wood materials in their design development. The outcome of the workshop showed architectural ideas that were quite different from those from the research project, even though the software and hardware workflows used were developed with a set of architectural components in mind. The ambition of enabling the students to use digital technologies and workflows from research in their formal and practical investigations was achieved.



Figure 1: Students 3D scanning a found wood log. Source: (Authors 2019)



Figure 2: Student positioning log in front of an industrial robot with a bandsaw. Source: (Authors 2019)



Figure 3: Three examples of architectural components produced by students. Source: (Authors 2019)

The second workshop had a different starting point. This workshop was not directly built on research developments but rather a parallel conceptual idea derived during the research project's progress. The idea was to use solid beech wood for joining between wood members instead of using steel brackets. The argument for this is that beech wood has material properties that make it extremely hard and generally has structural strength and static capacities around half the values of steel. At the same time, beech trees are a huge resource in Denmark, but are of almost no use other than a limited amount of furniture production. The students were asked to consider the material properties of the wood, including fiber direction, and invent a construction system with a beech joint as the key element. Both physical limitations of the 5-axis CNC and a gluing strategy for lamination are needed to inform their design decision. This workshop also implemented parametric workflows for architectural exploration, where the beech joint was the key part.

The students learned to experiment with the manufacturing technology and link it to the parametric design approach. The outcome was a series of different joint design solutions that, in different ways, proposed how to implement the properties of beech wood and the possibilities of 5-axis machining. The workshop took place at the beginning of a semester, where the following studies evolved around timber architecture, and the responsible tutors reported a higher degree of engagement in material and structural principles than would normally be the case when initiating the assignment without this type of workshop.

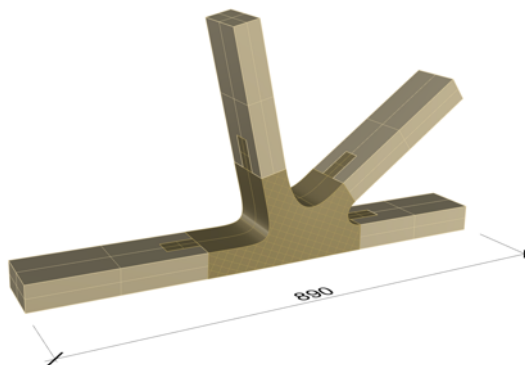


Figure 4: 3D model of beech joint connecting four pine members. Source: (Max Arpe-Sørensen 2020)



Figure 5: Student discussing glue strategy and fiber direction with carpenter. Source: (Authors 2020)

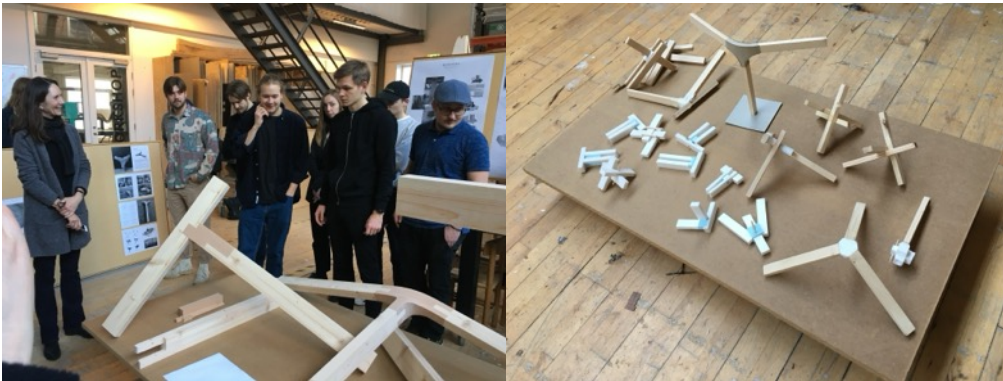


Figure 6: End-of-workshop exhibition of beech wood joint – prototypes and sketch models. Source: (Authors 2020)

The third workshop involving crooked oak was conducted after the conclusion of the research project. As such, it had partly the same conceptual foundation as the first workshop, but now with a much more developed and refined set of workflows and procedures. For that reason, it was decided to use the workshop to investigate and further develop the research. This meant the research project outcome became an example for the students, but with their task to test a new set of workflows still in development. The students were given crooked oak cut into slabs this time and presented with a photography-based digitization workflow and a machining workflow completely based on 5-axis CNC machining. Again, they were asked to develop architectural components based on their material and the possibilities of digital workflows.

The student's investigations reflected a deep engagement in the uniqueness of the given materials, and the results demonstrated a capability of handling the complexity and exploiting the material's aesthetic potential through the introduced workflows and technologies. This allowed a design-to-manufacturing process with high resolution in both the registration of the material and the specificity of the material processing. The outcome of this workshop was presented as real-size prototypes and parametric studies of a larger implementation of the students' concepts.



Figure 7: Student using handheld 3D-scanner to digitize crooked oak slab. Source: (Authors 2020)



Figure 8: Students monitoring 5-axis machining center. Source: (Authors 2020)



Figure 9: Digitized crooked oak slab and final transformation. Source: (Karoline Haugaard Rasmussen, Aase Eikeland Svendsen, Ragnhild Andreassen, Camilla Reiffenstein Christiansen, and Authors 2022)

The three workshops have similarities, where, the most apparent is that they are all concerned with the digital machining of wood. The machining workflow was quite experimental, e.g., the robotic bandsaw, and well-known, e.g., the 5-axis CNC. However, the computational and digitalization workflows leading to the machining were, in all cases, either custom-made or tweaked toward the research project. All workshops were presented to the students as very open-ended regarding architectural creativity and design possibilities but with very specific workflows and material interests as a foundation.

3.2. Reflection

The character of the workshops builds upon the idea of teaching skills to architecture students, which is different from the more tool-focused tutorial-based software course found within the educational domain. Where these courses often take a departure from a specific software and teach certain operations within that software, the described workshops instead largely build upon more experimental and less thoroughly tested processes. More dominantly, the workshops situate themselves away from the classroom and instead inhabit the wood workshop space. As such, the digital workshop in question could appear more like workshop classes teaching craft or artisan skills. However, the claim is that the workshops are digital courses teaching 2nd-year architecture students fundamental computer skills for their education and future careers.



Figure 10: CNC-milled beech joints. Result of workshop 2. Source: (Various students and Authors 2020)

CONCLUSION

The three workshops were born at the intersection of a newly formulated digital curriculum intention and a research project with a strong focus and agenda. As such, they were both a test drive for implementing digital literacy throughout education and a way to transfer research developments into teaching. For both parts, the didactic focus and reflection were built upon conceptual thinking toward digital technologies and how these enable close design-to-realization workflows rather than expertise in specific tools. However, to do so, the specific tools became an essential part of all three workshops. This complex was never resolved as the evaluation of each workshop outcome was rather limited. Each workshop ended with an oral evaluation, but subsequent follow-up on the student's competencies was not carried out. Therefore, no data or indications are available at this stage, which gives uncertainty to the educational outcome of the workshop-based teaching. If the workshops provided the students with the intended critical digital thinking and literacy, they could transfer the workshop's learning to their own or other scenarios. If the teaching intention did not succeed, the student might have gained very specific digital skills focused on wood analysis and machining that might not be widely applicable. However, during the three workshops, it was noted that the students experienced how digital technologies enable the close interlinking of material, fabrication, and design, which was a primary learning goal.

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REFERENCES

- Ahlquist, Sean, and Achim Menges. 2011. "Computational Design Thinking". In *Computational Design Thinking: AD Reader*, 10–29. Chichester: John Wiley & Sons.
- Arteta, Jon. 2017. "A Brief History of Digital Architecture". PhD diss., *The Paradigm of Complexity in Architectural and Urban Design*. https://www.academia.edu/38896521/A_BRIEF_HISTORY_OF_DIGITAL_ARCHITECTURE.
- Eversmann, Philipp. 2017. "Digital Fabrication in Education - Strategies and Concepts for Large-Scale Projects". In *In ShoCK! Sharing Computational Knowledge! Proceedings of the 35th eCAADe Conference*, vol. 1, edited by A. Fioravanti, S. Cursi, S. Elahmar, S. Gargaro, G. Loffreda, G. Novembri, and A. Trento, 333–42. Rome: Sapienza University of Rome. <https://doi.org/10.52842/conf.ecaade.2017.1.333>.
- Fowles, Robert A. 1990. "Teaching Architecture: A Complete Action". *Design Studies* 11 (2): 81–88. [https://doi.org/10.1016/0142-694X\(90\)90022-5](https://doi.org/10.1016/0142-694X(90)90022-5).
- Jonassen, David H. 1991. "Evaluating Constructivistic Learning". *Educational Technology* 31 (9): 28–33.
- Kolarevic, Branko. 2004. *Architecture in the Digital Age: Design and Manufacturing*. New York: Taylor & Francis.
- Leitão, António, Renata Castelo-Branco, and Guilherme Santos. 2019. "Game of Renders: The Use of Game Engines for Architectural Visualization". In *Intelligent & Informed: Proceedings of the 24th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA)*, 655–664. Wellington, New Zealand. <https://doi.org/10.52842/conf.caadria.2019.1.655>.

- Lidelöw, Sofia, Susanne Engström, and Olle Samuelson. 2023. "The Promise of BIM? Searching for Realized Benefits in the Nordic Architecture, Engineering, Construction, and Operation Industries". *Journal of Building Engineering* 76 (October): 107067. <https://doi.org/10.1016/j.jobe.2023.107067>.
- Mollica, Zachary, and Martin Self. 2016. "Tree Fork Truss - Geometric Strategies for Exploiting Inherent Material Form". In *Advances in Architectural Geometry 2016*, edited by Sigrid Adriaenssens, Fabio Gramazio, Matthias Kohler, Achim Menges, and Mark Pauly, 138-153. Zurich: vdf Hochschulverlag AG.
- Svetel, Igor, Tatjana Kosic, and Milica Pejanovic. 2018. Digital vs. Traditional Design Process. In *Places and Technologies 2018 – Keeping Up with Technologies to Adapt Cities for Future Challenges: Proceedings of the 5th International Academic Conference on Places and Technologies*, 453–60. Belgrade: Faculty of Architecture.