Digital Wicker

Interdisciplinary and Research-Informed Teaching Concepts Exemplified Through Textile Fabrication Processes for Willow Structures

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ABSTRACT: This paper presents a research-informed teaching (RIT) and learning approach that fosters interdisciplinary collaboration and hands-on experimentation for a dynamic advancement of academic research in the field of sustainable architecture. Additionally, transdisciplinary collaborations with various research partners and funding bodies within academic education underline the relevance of the teaching results and the importance of building and testing the developed concepts at architectural scale. This paper presents the example of interdisciplinary teaching courses that are part of a strategy for rapid innovation at the intersection of research and teaching at the Professorship for Digital Design and Fabrication (DDF) at the Karlsruhe Institute of Technology (KIT). They enable students to gain transformative knowledge in interdisciplinary teamwork focused on the intertwined topics of architecture, digital construction technology and sustainability. Here presented is one case study of the resulting student work, which addresses challenges in the construction sector through the exploration of low-emissions processing for circular materials such as willow, highlighting its rapid regrowth and adaptability of digital fabrication processes. The knowledge gained through these research-informed teaching methods is applied through the production of experimental prototypes that are used to visualize construction innovation for public discussion.
Keywords: research-informed teaching, design-through-making, digital fabrication, interdisciplinarity teaching, sustainable architecture

1. INTRODUCTION

In the context of architecture, digital design and sustainability the Professorship for Digital Design and Fabrication (DDF) at the Karlsruhe Institute of Technology (KIT) promotes the development and implementation of practical solutions and concepts for a resilient future of the construction sector.

The linear approach of today's construction sector results in significant waste generation and is responsible for over a third of global resource demands [1]. Consequently, the sector stands at the forefront of the global shift towards a circular economy, for example through natural and regenerative materials based on local sourcing and processing of rapidly renewable materials. Digital design and fabrication methods emerge as key enablers for the industrialization of such natural materials, addressing their scalability in construction. Digital methods contribute to a shift from standardized serial production to individualized mass production of resource and climate-adapted building components. With a research-informed teaching concept, DDF's research-informed teaching can empower future generations with the knowledge and skills necessary to address these challenges.

2. RESEARCH AND TEACHING

The teaching concept focuses on developing individual competencies within interdisciplinary teams at the intersection of research and teaching. In the context of the dynamic field of digital design and fabrication, this means not only mastering current tools but further contributing to the development of novel approaches. Digital technologies in architecture enable the exploration of the broad spectrum of possibilities within the entire design, planning and construction process. The inclusion of research into teaching underlines the importance of maintaining flexibility and curiosity to adapt to upcoming changes through constantly evolving technologies.

The integration of digital technologies, tools and methods into architectural studies enables and is enabled through interdisciplinary collaboration with other departments, which is ensured by forming multidisciplinary teaching, research and student teams within the courses.

2.1 Research-informed teaching

Research-informed teaching (RIT) describes different approaches in which research is integrated into teaching in higher education [2,3]. It encompasses the concepts of research-led, -tutored, -based and -oriented, which reflect different levels of practice and theory involvement and further vary by the student's participation (Fig.1). All these practices play a significant role in the teaching of DDF, focusing especially on the active participation of students in the research projects and their development, through research-oriented and research-based teaching. Research-oriented teaching emphasizes constructing knowledge through research and inquiry skills [4]. Based on this idea, the students are guided through a series of specific research questions to understand the existing state of art regarding materials, construction systems and digital fabrication processes. In addition, research-based teaching highlights the opportunity that students can independently generate scientific knowledge, by going through the entire research process [5].

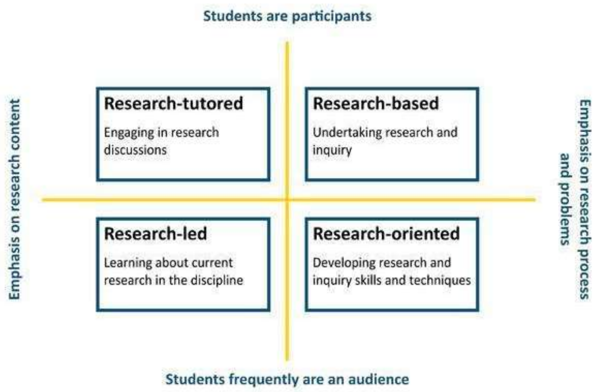

Figure 1: Healey, M., Jenkins, A., Developing undergraduate research and inquiry, The Higher Education Academy, Heslington (2009).

DDF offers the opportunity for students to participate in all phases of the research and project development within one semester, by developing a clear aim and framework for each class, while also ensuring knowledge transfer for the students of the consecutive semester projects. These learning styles encourage curiosity, problem-oriented, critical thinking and creativity to enhance subject comprehension. The autonomy of the students is supported by the opportunity to develop their own concepts and inform them through hands-on experiments, explorative prototyping [see paragraph 4.2] and individual research. Based on a widespread exploration of the emerging novel architectural design and construction repertoire through individual design work, resources are subsequently focused on the development of the most promising concepts in interdisciplinary group work.

In conclusion, research-informed teaching involves students actively participating in the research process - bridging the gap between teaching and research by combining theory and hands-on experimentation.

The interdisciplinary teaching and student teams actively merge architecture, engineering, mechanical engineering and automation, while further including experts in materials, structures and circularity.

2.2 Teaching methods

Within the course structure, students are guided through various "development phases". These phases encompass investigations on state of the art, architectural and structural design, concept exploration (Fig. 2), rigorous testing, the construction of customized machinery, hands-on digital fabrication and the construction of 1:1 scale research demonstrators (Fig. 3). Throughout the semester, skill-building tutorials introduce the students to computational design and digital fabrication tools, without requiring any prior knowledge.

In an initial investigation phase, students individually dive into specific topics related to the context and the state of the art concerning the aspects of the course. They then form groups to focus on advancing the state of the art in various development areas, applying a research-oriented and design-through-making approach. These groups also explore the architectural potential and possible further research tracks. Finally, students collaborate closely as one large group, merging knowledge from previous phases, to work on the final developments for a research demonstrator. This includes producing 1:1 scale building components through digital fabrication, conducting structural and assembly tests, as well as planning for exhibiting the final results. By following all these stages of the process, the students gain hands-on knowledge about research, digital design, fabrication and construction methods and at the same time generate valuable research questions for follow-up projects.

In this research-informed teaching approach, both group work and individual work hold relevance. Multiple individual investigations are gradually combined to form strong ideas through discussions, testing and refinement. These ideas then branch out into various research paths that lead to further concepts resulting in iterative research and learning loops. These loops involve distinct work phases, punctuated by meetings and discussions with all participants, followed by further work phases, which foster knowledge refinement and ensure continuous improvement. This research-informed teaching approach actively promotes a wide range of interdisciplinary and collaborative groups, cultivating effective communication, diverse perspectives and collective problem-solving. These groups benefit not only from the diverse focus areas and expertise but also from the processes, approaches and soft skills contributed by the various backgrounds of the individuals within the group.

Figure 2: Exhibition of conceptual student work.

Figure 3: Transfer into 1:1 scale utilizing research facilities.

3. CASE STUDY: CIRCULARITY THROUGH DIGITAL DESIGN AND FABRICATION

The built environment is currently experiencing a growing awareness of the overdue digital transformation towards a circular economy. This momentum has been triggered by initiatives such as the European Green Deal and circular economy plans developed by governments at various levels, including national, regional and local actors. According to the World Economic Forum, the built environment is one of the sectors with the greatest opportunities for making a circular economy a reality. However, to accelerate the adoption of circular practices in the built environment, scalable innovation and the development of more ambitious regulations need to be at the forefront.

The principle of circularity focuses on the minimization of waste and the reduction of the environmental impact of products and systems. Circularity requires the material, the process and the product to be understood as a unit. By considering environmental impacts from the earliest design stages, the use of rapidly regrowing materials such as willow is an excellent foundation to facilitate long-term circularity in construction and enable short-term emission reductions through scalable but energy-efficient processing. This commitment to environmental responsibility aligns seamlessly with the deployment of digital design tools. By incorporating circularity into digital design processes, designers can create products that are more sustainable from the outset. Digital tools allow for the exploration of alternative design options, optimization of material usage and evaluation of environmental impacts, enabling the development of products that are environmentally responsible throughout their lifecycle. These tools empower designers to optimize their creations and make well-informed decisions throughout the design process. In this context, willow is well suited to both criteria, as it meets sustainability requirements and has great flexibility to be processed with various digital methods.

It is crucial to acquaint students with digitally enabled circularity concepts within architectural design studios to emphasize their grasp of innovative prospects. Connecting consecutive courses and utilizing results from previous courses fosters a complex and comprehensive perspective. Courses thereby do not only have educational value but generate relevant research results as a base for future students' work. This research-informed teaching approach also reinforces a pragmatic mindset towards repurposing existing resources, including existing knowledge and encourages students to think creatively about materials and processes, transcending their originally intended use.

3.1 Materiality

As an example of such digitally-enabled sustainable material choices, willow is a rapidly-renewable material that is widely available in Europe. It is thereby a great option to substitute conventional building materials. Willow regenerates quickly, allowing for multiple harvests within a short period of time. This fast regrowth makes it a highly efficient and renewable source for various applications with reduced ecologic impact, lessening the need for more finite building materials.

Wetland environments, commonly categorized as swamp areas, traditionally deemed unsuitable for standard agricultural or forestry practices due to their waterlogged nature, offer a promising opportunity for cultivating willow. The utilization of these specific terrains presents a distinctive prospect to optimize land-use efficiency in a way that diverges from conventional practices. It serves as a pioneering solution to effectively cater to the escalating need for renewable materials without engendering competition with established realms such as traditional food production or forestry operations. The unique ecosystem of swamp areas, with their inherent characteristics as carbon storage in combination with the high carbon sequestration potential of willow plantations could provide ecologically favorable material streams on multiple levels. The cultivation of willow typically involves fewer chemical inputs and less energy compared to the production of more conventional building materials. It has a lower carbon footprint, contributing to sustainability goals.

Additionally, willow is highly flexible, which makes it suitable for various digital and textile construction techniques, such as weaving and braiding (Fig. 4.). Weaving with willow involves using individual willow branches or twigs to create various woven objects, typically baskets and other small structures. Willow's flexibility further allows for the creation of curved and intricate structures, making it a versatile choice for certain designs. Untreated, the material is biodegradable, meaning it can decompose naturally over time, reducing the environmental impact when structures reach the end of their lifespan.

Figure 4: Bending of braided willow branches.

3.2 Digital fabrication

Digital fabrication offers numerous advantages, such as increased precision, customization and efficiency. Natural materials often have variations in their properties, composition and dimensions, which can pose challenges in industrialized fabrication processes, as the machines and software are typically optimized for standardized materials. In an initial design studio of DDF, students tried to rethink established digital methods and transfer them for the use of willow. For this purpose, tests were carried out with individual and combined willow branches to see what behavior they show. The advantages of digital fabrication were tested for dealing with willow in order to understand how this natural material behaves, especially its irregularities (Fig. 5). For example, individual willow branches were braided by raspberry pi controlled robots or pulled through a self-made splicing machine to connect them and create an infinite filament. Over the following semesters, the machines underwent refinements and adjustments, gradually evolving and enabling novel design and construction concepts (Fig. 6).

Digital weaving, also known as computer-controlled weaving, involves the use of computer technology to control weaving looms and create woven textiles with precise and intricate patterns. However, weaving a larger structure from willow with digital machines is unusual and therefore requires research and testing.

In weaving, there are typically two sets of threads: the warp threads (vertical threads) and the weft threads (horizontal threads). The warp threads are mounted on the loom and are attached to a warp beam, while the weft threads are inserted by the weaving mechanism. The weaving process as well as the mechanized weaving process must be adapted and optimized for working with willow and material-specific irregularities.

During the test phases in the courses, students took a close look at how the material can be processed more efficiently and the scalability of the process.

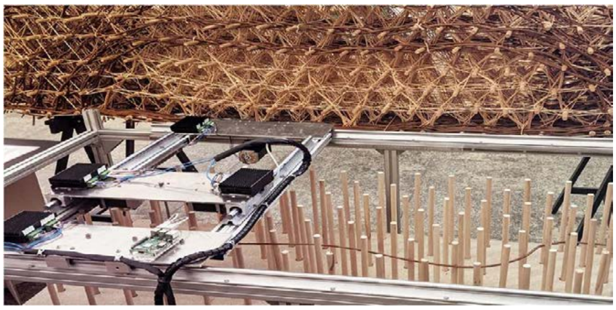

Figure 5: Digital fabrication concept from interdisciplinary student work.

Figure 6: Digital prefabrication of willow structures as scalable construction technology based on initial student work and subsequent development within interdisciplinary research.

3.3. Prototyping, evaluation and research transfer

The obtained knowledge about circular material systems and digital fabrication methods are directly integrated into the production and construction of experimental prototypes. Thus, direct discoveries and references are taken up and tested in small-scale models and experiments. Individual findings from smaller prototypes are subsequently combined into circular digital construction concepts by the students and the feasibility of the envisioned digital design and fabrication process as well as the technical performance are tested at a larger scale. Testing of building components at a 1:1 scale allows not only to evaluate the technical performance of novel construction methods but also to assess their architectural design qualities. The resulting research questions can form the base for third-party funding proposals and the teaching-based concept development serves as a base for interdisciplinary research projects in larger consortia. Integrating the expertise of these research partners into ongoing teaching activities closes the loop of an intertwined research and teaching strategy.

Exploring novel architectural design and construction concepts and testing their application relevance can be massively accelerated through quick prototype iterations at various scales. This approach requires careful evaluation of the potential and limitations of the concept and an iterative framework in which concept development and hands-on prototyping alternate. Choices regarding fabrication and construction strategies can thus emerge through immersive, experiential learning as well as research- and experience-based decision making. During this process the validation of a concept is as valuable as unveiling of further relevant research questions. Within the first design studio initial questions about structure, circularity and digital fabrication methods were explored, which thereby raised further questions for the following semester on actual applications, integrating earth as the load-bearing component and optimizing the digital and circular production processes. Exploratory prototypes serve as concise experiments to gain insights into these questions and test important assumptions and concept properties. Initial explorations and prototypes on a smaller scale (Fig. 7) act as an immediate testing of basic theories and concept ideas, such as the general structure or processing options. They further give valuable insights and conclusions to inform further exploration on a larger scale, which then act as a holistic proof-of-concept validating design, material and fabrication choices. (Fig. 8).

The development process of the prototypes considers reciprocal relationships of several topics such as material streams, production technology, structural design, construction detailing, building physics and architectural design on different scales, ranging from the hybrid material system to the detailed tailored arrangement in tailored and fully recyclable building components and their reversible assembly into a construction system [6]. This involves structural design and structural tests of plant-based building components through digital simulations and executing small-scale qualitative tests [7]. Material investigations concentrate on exploring the behavior of earth- and plant-based materials, conducting initial tests to identify effective combinations. Machine construction aims to design, test and operate custom machinery for the digital fabrication of demonstrator components.

4 INNOVATION STRATEGY

To ensure a societally relevant impact of our work we employ an innovation and research strategy at the interdisciplinary interface of research and teaching that rapidly turns speculative and future-oriented explorations into real-scale application-oriented prototypes through the following six steps:

- Widespread concept exploration: rapid testing of speculative concepts in teaching formats.
- Focused 1:1 prototyping: funneling resources towards promising concepts emerging from step 1.
- Fundamental research: third party funded investigation of research questions emerging from step 2.
- Applied research: evaluate technological and architectural potential in full-scale demonstrators.
- Architectural building projects under the academic umbrella: evaluate economic and ecologic application potential under market conditions and provide a visible full-scale proof of concept implementation.
- Technology transfer to industry partner or university spin-off.

We are currently following and implementing these steps with two of our research endeavors: willow-earth hybrid structures and digital wood upcycling. While our digital wood research is currently within the earlier stages 2-3, our research into willow-earth composite structures yielded rapid success: Within only two years we successfully passed steps 1 – 4 starting with the master design studios “DigitalWicker” in winter term 2021/22 exploring digitally enabled concepts for design and fabrication of willow structures and “Digital Wicker 2.0” testing its combination with earth as hybrid material system in the 1:1 demonstrator “InterTwig” in summer term 2022. In-depth research of the digital design and fabrication methods for willow/earth hybrid construction was subsequently funded through the research projects “ReGrow” and “WillowWeave” and successfully tested at the Bundesgartenschau Mannheim 2023 in the demonstrator project “ReGrow Willow”. The follow-up research grant “ReSidence” is focused on applied research and development of a ceiling construction component including structural, fire and sound certification. In parallel, we receive numerous requests for applications in architectural projects and are currently preparing step 5 as an architectural application of fully certified willow/earth/wood hybrid ceiling components and anticipate the exploration of its market potential in 2025.

Figure 7: Exploratory prototype in teaching context

Figure 8: 1:1 scale research demonstrator "ReGrow Willow" at the Bundesgartenschau 2023 in Mannheim

5. CONCLUSION

Universities can play a pivotal role in shaping a sustainable future for the construction sector by challenging the linear approach in today's industry and advocating for low-emission and circular material cycles through the exploration of digital design and fabrication processes. The emphasis on materiality, exemplified by the case study of natural willow-earth composite, showcases the importance of environmental responsibility from the earliest design stages. The circularity of willow as a rapidly renewable construction material, particularly if grown in denaturalized former wetlands, holds enormous ecological potential. The development of bespoke digital fabrication processes enables a local low-emissions processing of such harvested materials by addressing challenges posed by inhomogeneous non-standardized grown building materials. In combination with digital design strategies, innovative circular construction concepts are enabled, simultaneously focussing on precision and efficiency while also incorporating concepts of redundancy and robustness in the design process.

The integration of research into teaching, with a focus on interdisciplinary collaboration, proves instrumental in developing individual competencies and fostering a dynamic exchange between academia and practical application. The structured innovation pipeline, from knowledge discovery to 1:1 prototypes and large-scale demonstration objects, showcases the transformative potential of such teaching methods. Furthermore, the collaborative and explorative prototyping efforts demonstrate the practical application of sustainable design principles, by efficiently visualizing construction innovation in a public discourse.

The presented research-informed teaching approach generates societally relevant innovations as a base for a digital transformation of the construction sector towards circular material streams and low-emissions construction. At the same time, it enables students to gain first-hand learning experience for creative problem-solving in interdisciplinary and internationally diverse teams as key transformative competencies to foster a culture of innovation and sustainability in practice and research.

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