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Developing Cross-level Collaborative Learning Opportunities in Engineering Education: A Case Study

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Abstract. The need for systemic change in sustainability transitions is challenging the formats of architectural and engineering education. However, there are still few possibilities (if at all) for architectural and engineering students to engage with the students at technical schools and craftspeople directly and to develop a thorough understanding of how practical, hands-on knowledge can inform design and engineering and vice versa. The lack of structural exchanges between students at different level institutions jeopardizes continuity between design and practice; it further creates a divide between future engineers and craftspeople; and by extension, it compromises the implement-ability of sustainability approaches. This paper discusses the experience of a cross-level learning collaboration for a course on circular product design. It describes the course set up, and especially the structured exchanges between architecture and engineering students with students of carpentry to develop one to one scale prototypes using biobased materials. An in-depth analysis of the course outcomes and student feedback help identify the benefits and the challenges of engaging in learning exchanges and their respective implications for students and tutors alike. Results illustrate the intricacies of said collaborations and how they ultimately affect pedagogy and learning.

Keywords: Architectural Engineering Construction (AEC) Education · Cross-level Learning Partnerships · Making pedagogies · Pedagogies of Care

1 Introduction

The need for systemic change in sustainability transitions is challenging the formats of architectural and engineering education. The axioms spatial production and architectural objects have traditionally relied on are changing along with the value systems that produce them causing friction to academic curricula and learning pedagogies [1]. Several models of learning (re)emerge to tackle the complexity of sustainability and circularity prerogatives along with the feeling of uncertainty and unknown-ness of the world they bring with them not only because of the rapidity of changes, but also because of their open-textured character [2]. These models aim to produce “socially robust” knowledge in all areas of society and the interconnection of industry, politics and research in a transdisciplinary way [3, 4].

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Transdisciplinary learning (TL) is founded in the need to form learning alliances with society where different knowledges and interests are represented and a dialogical relation with societal partners forms a continuum between theory and the real-world challenges [5]. This translates to pedagogical models like challenge-based learning (CBL) where different stakeholders are represented and consulted, and their perspectives and priorities considered and included in the decision-making process. Learning in these settings embraces the notion that multiple knowledges can exist and encompasses other ways of knowing of the world such as intuition, feeling, and bodily knowledge [6]. Furthermore, TL pedagogical models that are exposing students to real-world challenges situate knowledge in specific contexts and require that learning in these contexts takes the form of actionable knowledge. The production of knowledge is therefore situated in the learners' capacity to prioritize diverse information and input, decide upon a course of action, and many times even participate in carrying out the selected action. Providing students with performative spaces where it is required to make choices becomes thus increasingly more important.

Socially inclusive learning environments are not foreign to AEC education with examples dating as far back as the 1970's such as the *community-based design pedagogy* also *design-build learning*. Whereas the first sought to democratize design and the decision-making processes between people and the environment in which they live in [7], the latter further opts for direct hands-on collaboration with (local) communities and with outputs that can range from small-scale building products to entire buildings [8] whereas making and making together with others, is a central learning activity.

Making pedagogies (MPs) are common in AEC education as the 'doing devices' they rely on are easier to find and to apply [14]. MPs are valued in AEC education for their experiential, open-ended character, and their capacity to integrate both mind and body [9]. Being rooted in the real world, they rely on cross disciplinary collaboration; therefore, knowledge is constructed not consumed, further contributing to MPs systemic character [8].

The current pressure to decrease the carbon footprint of building materials and to consider alternative, bio-based options has increased the relevance of MPs. Many AEC courses now shifting to hands-on, collaborative making activities to investigate new materialities and to explore anew or revisit older methods of integrating these materials in construction as building products. In this light, MPs offer the space to experiment and to rethink of objects, bodies, materialities and their mutual relationships within higher education (HE). Through making, the maker not only "writes" with material to construct the logic of a system but also makes sense of the relationships between the user and technology [12] which is an important factor in identifying what new skills and competences the use of biogenic materials brings forward.

Nevertheless, although making pedagogies are proliferating, there are currently few possibilities (if at all) for architectural and engineering students to engage with the students at technical schools directly and to develop a thorough understanding of how practical knowledge can inform design and engineering and vice versa. The lack of structural exchanges between students at different level institutions jeopardizes continuity between design and practice; it further creates a divide between future engineers and technicians; and by extension, it compromises the implement-ability of sustainability approaches.

So, how can we guarantee that design and engineering research can be seamlessly integrated with construction? Can engineering education provide with opportunities where theoretical and designerly engineering knowledge are seen as a continuum with practical knowledge and hands on making? Can we foster non-competitive, collaborative learning environments for the two groups?

This paper shares the teaching and learning experiences of tutors and students of a course on circular building product design and making that addresses this gap. The course has been founded on the principles of transdisciplinary learning and making pedagogies discussed here. But for its specific scope, it further borrows from the notion of pedagogies of mattering (PofM) for their capacity to [a] focus on the caring of connections and relationships as opposed to individualistic, competitive higher education systems, [b] acknowledge how human relationships are entangled with the contexts they occur in, and also consider the impact of objects, bodies and materialities have on learning, and [c] recast being, doing and knowing where teaching and learning becomes also an in-situ practice of relationality [10]. Furthermore, considering that pedagogies of care include everything that we do to maintain, continue and repair our world so that we live in it as well as possible [11] are far more relevant in the education for sustainability and circularity.

2 The Case Study

The Circular Product Design Technoledge course is a MSc2 elective course of 5 ECTS at the Faculty of Architecture and the Built Environment (A + BE) at TU Delft with an overall duration of 10 weeks where students meet twice a week for a half day. It is open to both students of the building technology and the architecture master tracks. In that sense, it is a cross-disciplinary course.

The course aims to draw attention to building products and how they are affected by the transition to the circular built environment. Architects and engineers are usually not the ones designing building products and often have very little knowledge about them. However, transitioning to a circular built environment requires that architects and engineers can make informed decisions as to what product best fits their purposes each time; and they might be required to reuse existing products or redesign using existing materials or parts of products. Finally, it requires knowledge by the building industry to create circular building products, to source materials and to understand how these are geared into the architectural decision-making process. Therefore, knowing how products are designed, made, and supported is essential for making the transition to the circular paradigm. As is developing a continuum between theory and practice to ensure design ideas can be implemented and are informed by the those responsible for materializing them.

The course explores the domains of materials, design, manufacturing and management and their interrelations all the way from the original product conceptualization to their end-of service life. It comprehensively sketches how social, technological, and economic factors affect building products by questioning [a] the way material and design choices affect a building product's life cycle, [b] our manufacturing technologies for making new products using secondary or biobased materials as primary resources, but also [c] how the designers' roles and [d] the manufacturing companies' business models are affected by these changes and [e] the kind of organizational schemes that need to be introduced to facilitate the transition.

The course is split into two parts: whereas Part A focuses on analysing existing products and systems, Part B requires that students design their own systems based on the input knowledge acquired in Part A. Whereas students are originally exposed to the experiences of others, for the second half they are required to experience themselves the process of designing and making of circular building products.

The course is normally structured around several different training activities and different learning spaces that are distributed over the ten weeks of its duration. These comprise input from practice (lectures or excursions), case study analysis, design and making.

2.1 Setting the Stage of the Cross-level Institutional Collaboration

With biobased materials becoming increasing more relevant in construction, this year, the course set out to explore different options for integrating biogenic materials in structural, roof, wall, floor, and facades systems. Following the course structure, for Part A, students received input from expert guests across the canvas four domains and explored the current biobased building product market in the country. For Part B, they were then asked to develop a comprehensive design detail for a building's structure and enclosure and to then build 1:1 prototypes of a selected representative aspect of their design.

For this course, making was included as an activity for its capacity to [a] engage students in a physical relationship with a wide range of materials but to [b] also involve them in the actual processes of these materials' fabrication on site and to [c] include them in the embodied experience of working with biogenic materials. To use Ingold's metaphor [13], the making process was conceptualized as a "correspondence" process between design and engineering students, crafts apprentices, materials, construction techniques, tools, bodily labour where knowledge production was distributed.

It was anticipated that the use of wood would be central to the biobased building products made by students of A + BE; and therefore, a structured collaboration with students from ROCvA (ROC van Amsterdam) and the carpenters' program was crafted. Vocational education students follow a one-day a week study program; their coming to work together with students from A + BE would become an integral part of their program further contributing to their understanding of the processes that lead to the design of products while at the same time, including their own knowledge on the matter.

2.2 Enacting the Cross-level Institutional Collaboration

The overall prototyping process took place over a period of four days spread over the last two weeks of the course. Making workshops took place outside the classroom at The Green Village (TGV), next to the site of intervention, the actual site of the faculty's future bio-lab and an equally accessible space for both student groups. An enclosed space of approximately 30 m^2 was allocated to the students by TGV as well as the space in front of this room, out in the open. Although all groups picked a specific area to work in, there was a lot of shared in-between space and a continuous flow of people throughout the making sessions.

Materials were not predetermined in the curriculum and students were free to make their own choices based on their original research or their personal fascinations. Materials like hemp and lime were offered by TGV as well as some leftover secondary materials from one of their renovation projects from within the site that had recently been made available. For the most part, students of A + BE reached out to companies or secondary material providers alone to either procure small quantities of specific materials' or collect specific waste objects they required for their projects. Additionally, some experimented with novel materialities; in one of the prototypes, sorghum fibres were used instead of hemp.

Some electrical tools were brought in by tutors of ROCvA; but some of the A + BE student groups also brought in their own equipment. Interestingly, some hand tools like rammers were custom crafted on site. Only one group developed part of their façade using digital technologies (CNC milling) but still worked manually to produce the rest of the elements like all the other groups. Some groups even created their own moulds for casting, glulam beans, and DLT walls and slabs.

Students of ROCvA were not involved in selecting the materials but were heavily involved in the making processes. Each group of students from A + BE was matched to one student from ROCvA. For reasons of safety, students from ROCvA were assigned to handle all the electrical equipment. There was no other clear allocation of tasks and for the rest, students worked together throughout the four sessions; not only were ROCvA students helping resolve the more practical matters of organizing the workflow, but they were also consulting with their group on issues of technical detailing.

2.3 Evaluating the Cross-level Institutional Collaboration

The process and products of this learning experience have been systematically recorded through observation, interviews, and surveys and further assessed across the original learning objectives of the course, and students' satisfaction levels.

The course offered both A + BE and ROCvA students learning opportunities to develop different competences. With regards to the course content and its focus on working with biobased materials, both groups were able to experiment and learn from the direct exposure to several biobased materials and their respective fabrication techniques thus gaining knowledge that is tacit. Following Collin's categorization [15], tacit knowledge in this case was *relational* as it relied on how A + BE and ROCvA students interacted and complemented each other; it was *somatic* because it required physical, bodily involvement; lastly, it was also *collective* because it heavily relied on students monitoring each other while doing and learning implicitly from one another. For A + BE students in particular, the knowledge produced also became *explicit* as they were required to document and to reflect upon their work for the final reports. This was not the case for ROCvA students who follow a different learning path; however, they were also given the opportunity to reflect upon this experience and to redefine their roles within the making process through direct feedback to their tutors. Furthermore, for this course learning was also *transversal*, as the decision making was collective. Meaning that A + BE students from building technology had to adjust to input received by the other A +

BE students from architecture but also ROCvA students, the makers, as well. And that paved the way for developing skills and competences of negotiation, and collaborative working, but mainly, it built a sense of acknowledgement of how each party contributes to construction and how important it is to listen to and consult with everyone involved and to not act competitively.

Students from both institutions were asked to evaluate their learning experience. A survey was handed out to all students. Out of the 26 A + BE students 11 handed in their input and 1 out of the 5 ROCvA students assigning the collaboration experience with a 5,75 out of 7. Nevertheless, during the course's evaluation, several points were raised by the students on how to improve this learning setting. Most of the input received by them related to their feeling of uncertainty during the making days. This uncertainty was attributed to several different factors.

The making phase where the collaboration took place was highly dependent of the outputs of the A + BE students' design process that evolved through weeks 5 to 8; therefore, preparation time for the actual prototyping was limited. This resulted in uncertainty in terms of the availability of materials. (Student input: *The prototyping went well but it was sometimes very unclear which materials we would be able to use when.*). Same observations were made with regards to the necessary tools or thereby the lack of, which in turn led to even adjusting the original idea for the dimensions and scale of the prototype. One of the groups that built with DLT lacked large enough clamps to hold the structure together with their original dimensioning and ultimately developed a thinner wall element than the one that was originally planned.

Uncertainty also manifested as in the lack of knowledge of some of the building methods required to realize the desired prototypes; reed cladding for example, required technical skills that no student from either school possessed. This resulted to less satisfactory application results. Same with hempcrete ramming: no one had anticipated the amount of labour it required, or the drying time for the building blocks casted on site. In one case, the mould produced for casting hempcrete blocks was too complex for the consistency of the mix, leading to cracks and the ultimate detachment of one of the overhanging parts.

Most uncertainties, however, were related to the conditions of this cross-level collaboration itself. These included the task distribution between students of A + BE and ROCvA, lack of communication, and the unevenness in the capacity of A + BE and ROCvA students to carry out certain tasks. (Student input: "*The prototyping days with the ROC students can be more structured. The ROC students were not aware of what was expected from them," or "Although I really like the idea of an interdisciplinary approach to the design task, I felt like it was quite difficult to include our assigned ROC student into our process (…) Having more time for this could have helped," or "I liked working together with the ROC, but it did really matter who of them was helping you as some would think with you and others just followed orders," or "I really enjoyed having them come over during the building days, but it could have been more extensive; involved in designing the detail construction maybe?").*

3 Discussion

Based on the students feedback several directions for improvement have been identified. One direction would be to initiate A + BE and ROCvA student collaboration at the earlier stages of design. Another direction would be to provide all students with expert input on various fabrication techniques before the beginning of the making sessions. And maybe, and most importantly, guarantee that more time is spent in establishing the foundations for this collaboration in a mutually beneficial way.

However, despite this endeavor's high level of uncertainty students exhibited an increased sense of responsibility: they not only sought to deliver the prototypes on time, but to also procure materials and to actively engage in all decision-making processes with their groups within the limited time given, make their own tools where necessary, and adapt to the limitations of the set up thereby contributing to the transversal learning mentioned earlier and the development of necessary soft skills for both types of professionals.

This ambiguity raises a critical issue for the future planning for this type of cross-level collaboration courses and by extent to the making pedagogy tradition this course builds on; on the one hand, following students' suggestions, facilitating their exchanges by either assigning them with more time or by preparing better could lead to more satisfactory results. On the other hand, should the complexity of the endeavour be minimized, there may be less chances for students to develop their creativity, their communication skills, and their resilience in tackling complex situations.

Ultimately, this dilemma falls into hands of tutors, and this is also why PofM become relevant here as well; both approaches become key to balancing between learning objectives and student expectations effectively. Coordinating such cross-level, making collaborations requires a constant monitoring of all processes, empathy and a high level of adaptivity to care for all the parties involved.

4 Conclusion

While engineering curricula are gradually focusing on sustainability transitions and making pedagogies proliferate, a divide between higher education institutions and technical schools remains. Opportunities for cross-level institutional collaboration such as the one described in this paper, can help create a continuum between architecture, engineering design and practice, and strengthen the ties between these diverse professional identities. They can also advance a 'new production of knowledge' that is both theoretical but also practical and embodied, one that can contribute positively to the systemic changes required by the current sustainability goals. Experience from this course showed that students welcome such collaborative learning environments; however, the uncertainties related to it, especially those that deal with task distribution and unevenness of capacity, need to also be considered and addressed. This can be achieved through structuring the collaboration more clearly, or by giving students of different education levels the opportunity to spend more time together and prepare for their joint task. Most of all, however, it requires that tutors on both sides establish a caring environment that is dynamic and therefore can be at any moment adapted to accommodate the being, doing and becoming of all the people involved in the learning process.

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