Piccardo, Chiara; Goto, Yutaka; Koca, Deniz; Aalto, Pasi; Hughes, Mark

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Challenge-based, interdisciplinary learning for sustainability in doctoral education

Chiara Piccardo
Department of Bioproducts and Biosystems, School of Chemical Engineering, Aalto University, FI-00076 Espoo, Finland, currently KU Leuven, Technology Campus Ghent, Department of Civil Engineering, B-3000 Leuven, Belgium, chiara.piccardo@kuleuven.be, +32 495 63 08 00

Yutaka Goto
Department of Architecture and Civil Engineering, Division of Building Technology, Chalmers University of Technology, Sven Hultinsgata 6, SE-41258 Gothenburg, Sweden, yutaka@chalmers.se, +46 72 993 7022

Deniz Koca
Lund University, Centre for Environmental and Climate Science, Sölvegatan 37, SE-22362 Lund, Sweden, deniz.koca@cec.lu.se, +46 73 380 0687

Pasi Aalto
Centre NTNU Wood, Faculty of Architecture and Design, Norwegian University of Science and Technology (NTNU), NO-7491 Trondheim, Norway, pasi.aalto@ntnu.no, +47 980 25 519

Mark Hughes
Department of Bioproducts and Biosystems, Aalto University, School of Chemical Engineering, P.O. Box 16300, FI-00076 Espoo, Finland, mark.hughes@aalto.fi

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Abstract

Purpose – Doctoral candidates possess specialised knowledge that could support sustainability transitions. Doctoral education, however, often focusses on discipline-specific topics and working methods, making it difficult to 'see the bigger picture'. This summer school on wood construction gathered doctoral candidates from different fields to explore how solutions to complex sustainability issues could be found by working together across disciplines and by engaging multiple stakeholders. Our aim was to report the pedagogical approaches taken, and to understand whether these fostered the candidates' ability to develop systemic solutions and professional competency.

Design/methodology/approach – Twenty doctoral candidates from various backgrounds participated in a 2-week summer school organised by a consortium of 4 universities. Interdisciplinary groups worked on real-life challenges using a systemic approach to co-create

tangible solutions. To support the creation of socio-technical innovations, stakeholders and experts from different fields were involved. The participants completed two questionnaires during the summer school to help elucidate their learning experiences.

Findings – The doctoral candidates showed strong willingness to cooperate across disciplines, though found it important to connect this learning experience to their research. The candidates reported that the experience enhanced their ability to work in a multidisciplinary capacity. The experience identified a solid basis for interdisciplinary learning principles that could be replicated.

Originality – The summer school focused on an innovative learning experience based on a systems thinking approach and the development of interdisciplinary capacity in the research-business ecosystem.

Keywords Higher education, sustainability, doctoral studies, summer school, interdisciplinarity, systems thinking, climate change mitigation, wood construction

Paper type Research paper

1. Introduction

In recent decades, higher education (HE) institutions have been challenged to integrate sustainability into their educational programmes (van Weenen, 2000; Junyent and Ciurana, 2008; Sammalisto and Lindhqvist, 2008; Segalàs *et al.*, 2009; Wyness and Sterling, 2015; Filho *et al.*, 2018; Cheeseman *et al.*, 2019). This has entailed a change in the role of universities which are now expected to actively participate in sustainability transitions (Ferrer-Balas *et al.*, 2009). In this new role, a university should provide learners with new tools to tackle the complexity and uncertainty of multi-scale, human-natural systems. Many scholars from different fields, though, highlight limits to the current ways of producing, organizing, and applying scientific knowledge in addressing sustainability challenges and, in HE, specialized skills rather than comprehensive and integrative skills are often emphasized, when a synergistic combination of both should be fostered (Crow, 2007; Willamo *et al.*, 2018). To overcome these limitations, innovative approaches can be adopted. Systems thinking is considered key in dealing with the complexity of sustainability issues and in overcoming disciplinary silos

(Sterling, 2004; Svanström *et al.*, 2008; Rieckmann, 2012). Systems thinking draws on general systems theory and comprises diverse methods to analyse the dynamic relationships within systems. Although systems thinking is currently a consolidated concept, the methods are constantly evolving. Since the 1990s, system dynamics models have been used to facilitate communication between different stakeholders and to build a common understanding of real-life complex issues (Midgley, 2000). This evolution has included the development of participatory practices across disciplines, which are important when dealing with current societal challenges (Cabrera and Cabrera, 2019). In this context, Senge (2006) defines systems thinking as a 'discipline integrating the disciplines'. Such integration of disciplines is found, for example, in multi-, inter-, or trans-disciplinary research and education which affects disciplinary organization and perspectives, albeit institutional and cultural barriers still exist in the academic environment (Castán Broto *et al.*, 2009; Hein *et al.*, 2018).

1.1 Doctoral candidates and interdisciplinarity

In recent decades, interest in pedagogical practices in doctoral education has grown significantly (Boud and Lee, 2009; Danby and Lee, 2012). The literature on doctoral education has gradually shifted focus from a research- to a researcher-centred approach (Boud and Lee, 2009; Golde and Walker, 2006). This can be attributed to a global transformation in doctoral education that has occurred in the last two decades, as well as a change in the perception of a doctorate from being a research degree to a professional qualification (Thomson and Walker, 2010). In Europe, the Berlin Communiqué (Berlin Communiqué, 2003) and the Salzburg Principles on doctoral education (EUA-CDE, 2010) have boosted the reform of national doctoral programmes, following the concept of a unified HE system promoted by the Bologna Process (Bologna Process Committee, 1999). As a result, in the last decade, the number of doctoral candidates has increased (Hasgall *et al.*, 2019) by 35%, if researchers in the business and governmental sectors are also included (Eurostat, 2019). The increasing number of

candidates has also emphasized the need to rethink doctoral programmes in terms of the employability of graduates, considering diversified (i.e., academic, and non-academic) career paths. At the same time, the transition from an information society to a knowledge society has increased the expectations of doctoral education, in that it should train not only future generations of academics but also highly skilled professionals (Shin *et al.*, 2018). This is coupled with the increasing need to address complex problems reflecting the nature of sustainability issues. In this regard, the literature on doctoral education shows that the use of pedagogical approaches, such as multi-, inter- or trans-disciplinary collaboration and transformative learning can benefit doctoral candidates at different levels, helping them become valuable 'change agents' in society.

Specific training courses to promote interdisciplinary collaboration within doctoral programmes can help candidates allocate time to broaden their research perspective (Bergeå *et al.*, 2006), as well as strengthen their sense of belonging to a 'peer community', so avoiding isolation (Boud and Lee, 2005). Such courses also represent an opportunity to combine academic and non-academic expertise through the participation of stakeholders from business, public administration and non-governmental organizations (Bergeå *et al.*, 2006), generating win-win situations especially in the long-term (Borrell-Damian, 2009). Although these courses are generally organized within a relatively short time span, some experiences have shown long-term benefits for doctoral candidates (Philippi, 2014). Furthermore, the implementation of interaction across disciplines in doctoral programmes, such as joint supervision, group learning and critical conversation events, can increase the ability of doctoral candidates to produce and share knowledge in a creative way across different research fields, with an increase of inter- rather than mono-disciplinary publications (Carr *et al.*, 2018; Muhar *et al.*, 2013).

Analysing doctoral graduates in the United States, Millar (2013) observes that interdisciplinary dissertation research increases publication productivity, as well as the chances of obtaining

employment within HE. However, Castán Broto *et al*. (2009) highlight that the efforts in training doctoral candidates for interdisciplinary research often do not find continuity within the research funding system. Interdisciplinary research still appears to be encouraged by few national funding bodies in Europe (Luks and Siebenhüner, 2007), and is often misinterpreted by European funding programmes (Rosales, 2019), although educational funding programmes and bodies have increased initiatives in this way (e.g. Erasmus+ and EIT Climate-KIC in the framework of the European Institute of Innovation & Technology). At university level, if seed funding can help establish innovative doctoral studies in their initial phase, long-term funding is essential to maintain inter- or trans-disciplinary research (Muhar *et al.*, 2013).

1.2 Doctoral summer schools

In doctoral education, a summer school is a short-term educational programme, usually promoted by a HE institution, providing an intensive learning experience, ranging in duration from days to weeks during the academic summer break. Although the first form of summer educational programmes took place in the United States in the early Nineteenth century, summer schools have only seen significant growth internationally in recent years (Torenbeek and van Rest, 2014). Doctoral summer schools can be valuable elements contributing to the careers of doctoral candidates, offering unique opportunities for intersectoral mobility and international collaboration, consistent with the Salzburg Principles on doctoral education (EUA-CDE, 2016). A number of cases have already shown that doctoral summer schools can support participants in developing interdisciplinary and international networks (Pammer-Schindler *et al.*, 2020). In addition to traditional teaching methods, such as lectures, summer schools usually engage students in active learning, through presentations, as well as small- and large-group discussions, where lecturers or teachers act as facilitators. Furthermore,

considering the significant investment required to implement interdisciplinary doctoral programmes in universities, summer schools can easily allow experimental and innovative doctoral education with good accessibility for doctoral candidates, resulting in instructive outcomes for organizers and valuable inputs for the future development of doctoral schools.

The literature on doctoral summer schools is sparse; however, studies from different research fields highlight that the collaborative learning process is one of their main features. Other educational principles of interaction across disciplines can be identified. Zukas and Andersen (2011) observe that despite the short time period, the 'peer learning' approach, as well as the teacher-student collaborative environment adopted in the summer school can provide doctoral candidates with a comparative perspective on research supervision, stimulating candidates to adapt their skills within an 'unusual' supervision process. Larsen *et al*. (2009) argue that multidisciplinary collaboration in design assignments provides doctoral candidates with improved teamwork skills. Furthermore, the active participation of industrial partners can make the design assignments more realistic and help candidates understand design constraints and develop creative thinking (Larsen *et al.*, 2009; Lippuner *et al.*, 2015). Raciti and Saija (2018) emphasize the importance of field work, field trips and interaction with the local community to fill the traditional gap between theory and practice in research, improving socially-sensitive learning and self-reflection during research activities. The innovative nature of summer schools entails dedicating part of the time to introducing the teaching/learning principles behind them (Vriens and van Houten, 2012).

1.3 Summer school theme

Global challenges, such as resource shortages and climate change, emphasise the need to adopt approaches that integrate perspectives from different disciplines and stimulate new

collaborations between scholars and practitioners. UNFCCC, the United Nations Framework Convention on Climate Change (United Nations, 2015), the main international treaty on fighting climate change, mentions the multidisciplinary nature of the scientific knowledge informing the Convention. Furthermore, the treaty highlights the importance of coordinated actions including environmental, social, and economic considerations. More recently, the Intergovernmental Panel on Climate Change (IPCC) has made efforts to increase interdisciplinarity across working groups to overcome disciplinary bias and the under-representation of human and social science disciplines (Minx *et al.*, 2017; Pearce *et al.*, 2018; IPCC, 2020).

Focus on buildings and building construction is essential in the transition to a low carbon society, since they accounts for 19% of the global energy-related GHGs emissions (Lucon *et al.*, 2014) and 36% of total CO_2 emissions in Europe (European Commission, 2019), whilst between 30 and 50% of material resources are used in building construction (OECD, 2003). In the last few years, the growing role of the bioeconomy in the building sector has highlighted the role of wood-based products. Jonsson *et al*. (2017), estimate that engineered wood products, notably cross laminated timber (CLT), will represent one of the largest forest-based product categories in Europe by 2030, exceeding one million metric tons per year. Wood-based building products are a valuable resource that not only perform their technical function but might also help combat climate change (Churkina *et al.*, 2020). From a life cycle perspective, wood-based products have lower environmental impacts than other building materials thanks to their carbon storage potential and the renewability of the resource. In addition to substituting carbon-intensive, non-renewable materials, increasing the use of wood-based products in the building sector can contribute to climate change mitigation and help reduce resource depletion (Bergman *et al.*, 2014; Buchanan and Levine, 1999; Gustavsson *et al.*, 2006; Leskinen *et al.*, 2018; Sathre and O'Connor, 2010). Whilst substituting non-wood materials appears to be a

more effective approach than substituting fossil fuels (Geng *et al.*, 2017), the carbon benefits of wood substitution also depend on forest management practices, as suggested by the studies of Peñaloza et al. (2016) and Pittau et al. (2018). Increased demand for wood-based products in the built environment might generate a trade-off affecting biomass availability, forest ecosystem services, and the forests' climate change mitigation potential (Wolfslehner *et al.*, 2016). For this reason, it is vital to analyse the entire system and the relationship between the technosphere (wood buildings) and biosphere (forests) subsystems.

Several studies have recently addressed the lack of interdisciplinary approaches in HE to support the role of forestry in climate change mitigation, and to prepare future practitioners to cope with complex socio-ecological systems (Andrade *et al.*, 2014; Öberg, 2010; Vogt *et al.*, 2016; Walentowski *et al.*, 2020). However, to reflect the value of wood-based products, great care needs to be taken to analyse the entire wood value chain, to understand the stakeholder ecosystem and to design wood products, structures, and buildings, so that they can be used in the best overall way to help combat climate change and reduce the over-exploitation of resources.

The EIT Climate-KIC 'Catapult' summer school, here described, was an experimental educational activity designed to provide an innovative learning experience, making use of a systems thinking approach to enhance the interdisciplinary capacity of the research-business ecosystem. The main theme of the summer school was to identify solutions to incentivize the use of wood in construction to mitigate climate change and to advance the transition to a bio-based economy. In this paper, we report the pedagogical and methodological approaches taken, with the aims of understanding whether the challenge-based approach adopted helped foster the ability of doctoral candidates to develop systemic solutions to complex sustainability issues, and to assess whether this approach was perceived to be an important component in the development of their professional competency.

2. Catapult summer school

Aalto University and Chalmers University of Technology, in collaboration with Lund University and the Norwegian University of Science and Technology (NTNU) organised a two-week summer school within the European Institute of Innovation & Technology (EIT) Climate-KIC Catapult programme. All four university partners involved in organizing and executing this summer school are partners in EIT Climate-KIC.

The Catapult programme was supported by EIT Climate-KIC, a European public-private partnership committed to tackling climate change through systemic innovation, to offer learning experiences to young researchers and professionals. The main principles of this programme were to foster in-depth theoretical knowledge, provide real-life challenges, promote interdisciplinary thinking, and facilitate co-creation. The partners proposed the concept for this summer school, and all had worked together with EIT Climate-KIC on topics related to the use of forests and wood construction in climate change mitigation and adaptation.

The summer school ran for two weeks, from 25th August 2019 to 6th September 2019 and was hosted by Aalto University (Espoo, Finland) during the first week and by Chalmers University of Technology (Gothenburg, Sweden) in the second week.

2.1 Learning objectives

The summer school was designed with the following central overall learning objectives (OLO) in mind that were inspired by the general EIT Climate-KIC Catapult summer school concept:

- **knowledge building**, to equip doctoral candidates with knowledge of transformative, socio-technical innovation (e.g., candidates understand the role of forests in climate change mitigation, the wood value chain, wood building systems, etc.).
- **inter-/trans-disciplinary learning**, to provide doctoral candidates with the ability to work in an inter-/trans-disciplinary context (e.g., candidates apply a holistic, systems thinking approach to problems and generate knowledge with stakeholders).
- **systemic solutions development**, to provide doctoral candidates with the ability to create tangible solutions (e.g., candidates exchange ideas with experts and develop new project ideas for innovation in wood buildings).

2.2 Programme

These learning objectives steered the summer school throughout the two weeks. However, the summer school programme was divided in two parts, according to the specific contents. The first week at Aalto University focused on investigating the use of wood-based products, including an analysis of the entire wood supply chain and its impact on climate change mitigation and resource conservation. The second week at Chalmers University of Technology focused on the sustainable use of wood-based products in buildings, with particular attention paid to design for adaption. Travel between the two locations was part of the learning experience, being an opportunity for team development and trust building (Tuckman, 1965), and adopted the most environmentally friendly transport solutions, as recommended by EIT Climate-KIC.

3. Methodology

The Catapult summer school did not set-out *a priori* to explore specific pedagogical hypotheses, however, it was recognised early-on in the preparatory phase that useful educational learning might be obtained by diligently recording the process of organising and conducting the summer school, and by soliciting the views of the participants on their learning experiences, by administering a structured questionnaire. The approach taken in this research might thus best be described as inductive.

As highlighted by the literature, cross-disciplinary research approaches typically consist of participatory and iterative processes and, when they are implemented in research or educational activities, monitoring is important to inform the development of such activities, including soliciting participants' views (Wright Morton *et al.*, 2015). With this in mind, we adopted a qualitative approach, collecting feedback from the doctoral candidates enrolled in the summer school. Qualitative approaches, centred on the views of doctoral candidates, have already been adopted in doctoral-level education with similar research themes (Galvão *et al.*, 2020; Larsen *et al.*, 2009; Lippuner *et al.*, 2015; Philippi, 2014).

The Catapult summer school was divided into three phases: participant recruitment, the learning process, and the collection of feedback. The specific methodological approach adopted in these phases is described below.

3.1 Recruitment of participants

The summer school involved the gender-balanced participation of 20 doctoral candidates, eight teachers, two EIT Climate-KIC nominated Catapult coaches, five experts on sustainability standards and certification, as well as four stakeholders (two companies from the wood industry and two companies from the real estate and building sector).

An open call was announced, with a résumé and motivational letter requested as application materials. In response, 64 applications were received. After an eligibility check, the remaining

56 applicants were ranked according to the relevance of their research to the theme of the summer school, taking into consideration the desire to include as many disciplinary perspectives as possible, as well as their motivation to participate in the summer school. Gender, and the geographical spread of the candidates' home universities were also taken into account. The 20 doctoral candidates were affiliated with 17 different European universities, had backgrounds in life sciences, physical sciences & engineering, and social sciences & humanities. The broad range of backgrounds mirrors the complexity of the summer school's theme and the need to involve many different disciplines.

For organizational reasons, recruitment of lecturers, coaches, and stakeholders took place before the selection of the doctoral candidates. Lecturers comprised representatives from the four university partners and external academics. The lecturers were selected on the basis of the fit of their research expertise to the theme of the summer school. Coaches, not affiliated with any of the participating universities, but with experience in other EIT Climate-KIC educational activities, facilitated ideation, teamwork, and the group formation processes. The stakeholders were selected because of their expertise, their ability to inspire and support the development of the innovation strategies proposed by the doctoral candidates, and their capacity to help frame some of the real-life problems to be solved during the summer school. Further, they provided the specific challenges to be addressed.

3.2 The learning process

During the summer school, doctoral candidates dealt with complex issues linked to one of the most pressing societal challenges - climate change. Systems thinking is generally recognized as being valuable when exploring such complex issues and subsequently supporting decisions that affect our future society (Sanneh, 2018). In fact, systems thinking considers the problem

or issue as a system itself, where different disciplinary domains are involved in seeking solutions (Repko and Szostak, 2020). A concrete problem that needs to be solved is essential when creating cooperation across disciplines (Meadows, 2009). Therefore, a systems approach inspired the learning process developed for the summer school. This learning process, described below, was designed to meet the aforementioned learning objectives. Figure 1 provides an overview of the approach used in the summer school.

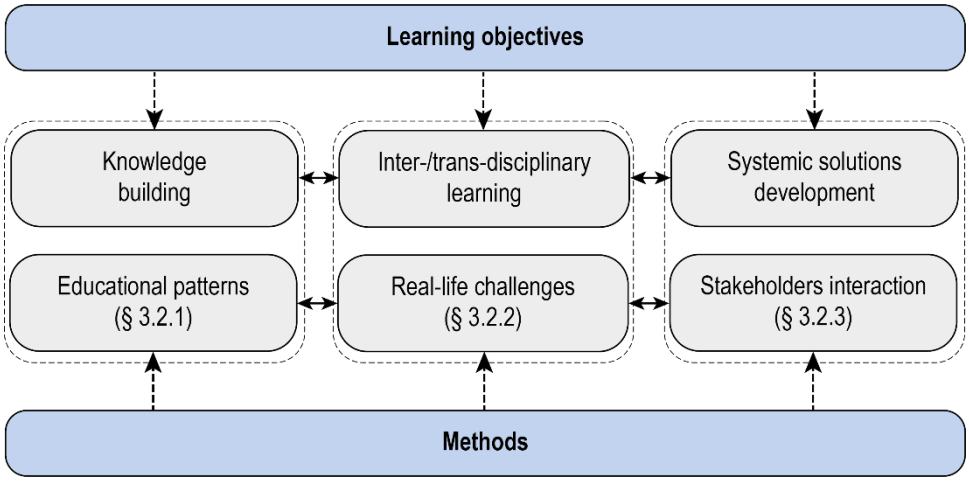

Figure 1. Learning objectives and methods adopted in the summer school.

3.2.1 Educational patterns

Knowledge building consists of increasing the collective knowledge of a community, such as a research team (Scardamalia and Bereiter, 2014), and is built on three main principles: a critical use of the current state-of-knowledge; discourse within a group; and the need to pursue societal goals (Scardamalia and Bereiter, 2010). The members of such a community are not only learners but are also the creators of new knowledge. To support knowledge building, the summer school programme adopted three actions: the provision of basic knowledge; the facilitation of group discussions; and enhancement of innovation capacity. These actions guided the definition of the 'educational patterns', which consisted of three different types of sessions, as follows:

- lectures and field trips (LT), to improve theoretical knowledge and to show real-life case studies concerning the summer school's theme.
- group working (GW), to facilitate the exchange between doctoral candidates in an interdisciplinary context and to encourage them to solve complex problems.
- stakeholder workshops (SW), to integrate theoretical knowledge and to inspire doctoral candidates to adopt a systems thinking approach and systemic solutions through discussions with stakeholders.

The LT sessions were especially important to create a common understanding among participants, considering the diverse backgrounds of the doctoral candidates and uncertainties related to their disciplinary erudition. The lectures provided essential information on the summer school's theme, helping inspire subsequent GW sessions. The GW and SW sessions were coordinated by the university partners and were facilitated by the coaches. Overall, the LT, SW and GW sessions respectively accounted for about 30%, 10% and 60% of the total duration of the summer school, and the sessions were combined according to the needs of the first and second weeks of the summer school (Figure 2).

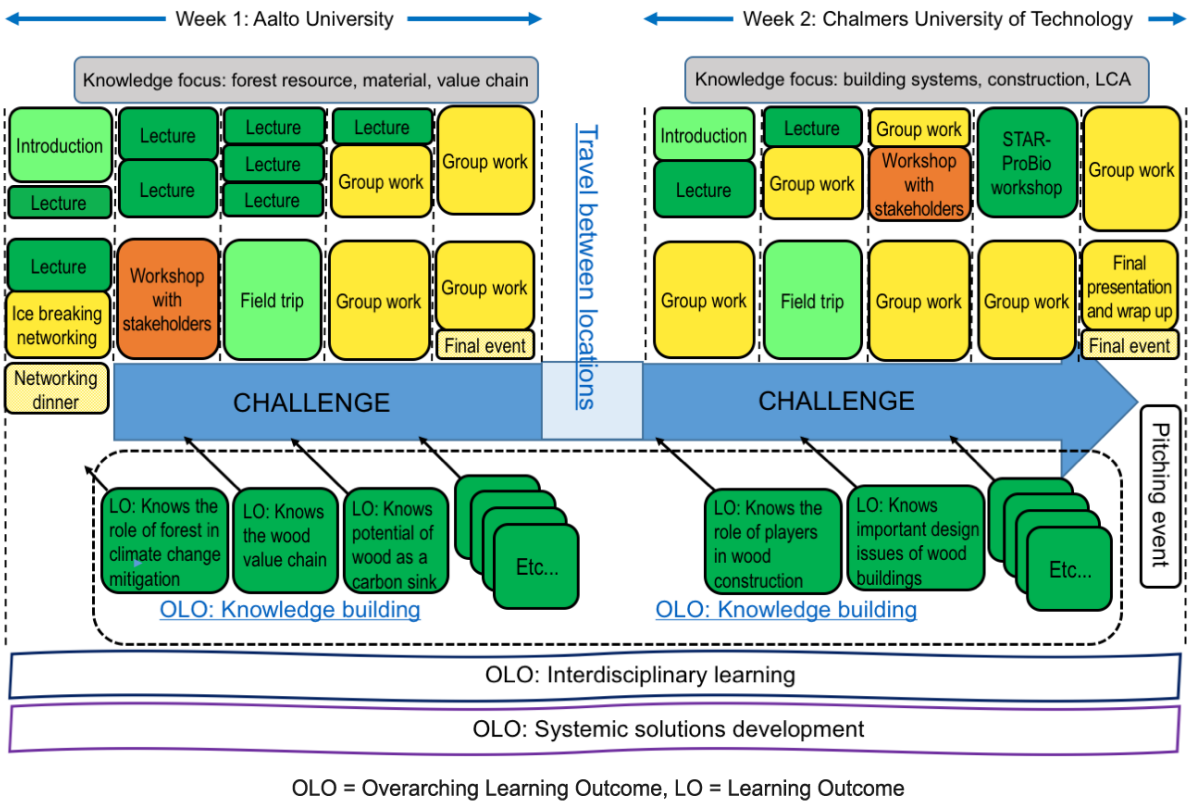

Figure 2. Schematic of the programme highlighting educational patterns (in green, LT; in red, SW; in yellow, GW) used for the summer school presentation to participants.

3.2.2 Real-life challenges

An interdisciplinary approach is a collaborative approach integrating different disciplines to provide a new epistemological framework, as well as linking issues that are not specific to individual disciplines (Klein, 2010). Balsiger (2015), as well as Byrne and Mullally (2016), argue that interdisciplinary approaches not only provide a comprehensive understanding of sustainability topics but also to engage students' creative and analytical skills. The formulation of a shared problem and the development of a common methodological approach are key drivers in interdisciplinary research (Mobjörk, 2010). The literature shows that problem-based learning methods are frequently adopted in inter- and trans-disciplinary education (Tejedor *et al.*, 2018), so to encourage interdisciplinary group work, the summer school engaged doctoral candidates in real-life challenges. The challenges were framed so that the solutions identified

at the end of the summer school could foster significant climate change mitigation benefits. Different, though complementary, approaches were adopted in weeks one and two to explore the challenges. During week one, a vision of the 'increased use of wood in the construction sector by 2050' was agreed upon by all participants, and the doctoral candidates were then asked to identify the main objectives/goals/milestones needed to achieve this vision. The process consisted of several discreet steps. In the first step, during a stakeholder workshop, the two forest-based industry enterprises ('problem givers') were invited to introduce current problems to the doctoral candidates. The stakeholders and doctoral candidates then had the opportunity to exchange ideas on the subjects through one-hour group discussions. Next, the doctoral candidates were asked to list barriers and challenges to fulfil the previously identified objectives/goals/milestones. In the second step, led by an expert in systems modelling from one of the partner universities, the doctoral candidates adopted a systems thinking approach to identify and map several future challenges. The challenge mapping enabled the doctoral candidates to select the main challenges as individual groups and collectively. Furthermore, the challenge mapping provided the context within which the groups developed innovation strategies. In the third step, each group analysed a selected challenge and developed a corresponding innovative solution. Finally, the stakeholders discussed the solutions during a closing event at the end of the first week.

During week two, the integration of wood materials into the design and construction processes was discussed. The process again comprised several discreet steps. In the first step, a single challenge, consistent with the first week's selected challenges, was assigned by the host university (Chalmers University of Technology). The challenge was first explained to the doctoral candidates and then discussed within a one-day workshop, coordinated by an expert from one of the partner universities (NTNU), with extensive experience of facilitating similarly themed events. During the workshop, the doctoral candidates broke down the challenge into

several sub-challenges. In the second step, the doctoral candidates met two stakeholders from the building and real estate sectors to discuss the problems related to the challenge. In the third step, each group selected a sub-challenge and drafted a specific innovative solution, based on the information gathered in the stakeholder meeting. Finally, the innovative solutions were discussed with the stakeholders during the closing event of the second week. A final wrap-up discussion between the academic staff and the coaches was also carried out to summarize the entire learning process of the two-week summer school.

3.2.3 Role of the stakeholders

To support the development of tangible solution, industrial enterprises were invited to participate in the summer school as stakeholders. In recent years, several learning opportunities have arisen from collaboration between industry and universities. A common approach is for industrial stakeholders to present real challenges faced by an organisation or the industry, and for learners to develop innovative and realistic solutions to these challenges (Carter *et al.*, 2017). The participation of stakeholders in the learning setting facilitates the creation of a work-like context.

During the summer school, face-to-face sessions between doctoral candidates and stakeholders were scheduled at the beginning and end of the group working sessions to discuss potential ideas and to assess their feasibility. The stakeholders played similar roles in both the first and second weeks. However, they were involved at different times in the learning process (Figure 3). During the first week, the stakeholders were involved at the beginning of the learning process as ‘problem givers’. During the stakeholder workshop, the companies’ representatives introduced real-life problems and the business system’s needs. This helped the doctoral candidates to develop realistic challenges from existing problems and needs.

In the second week, the stakeholders were involved during the learning process. This helped the doctoral candidates identify existing problems behind the assigned challenge. In both cases, the stakeholders helped the doctoral candidates towards conscious, innovative solutions.

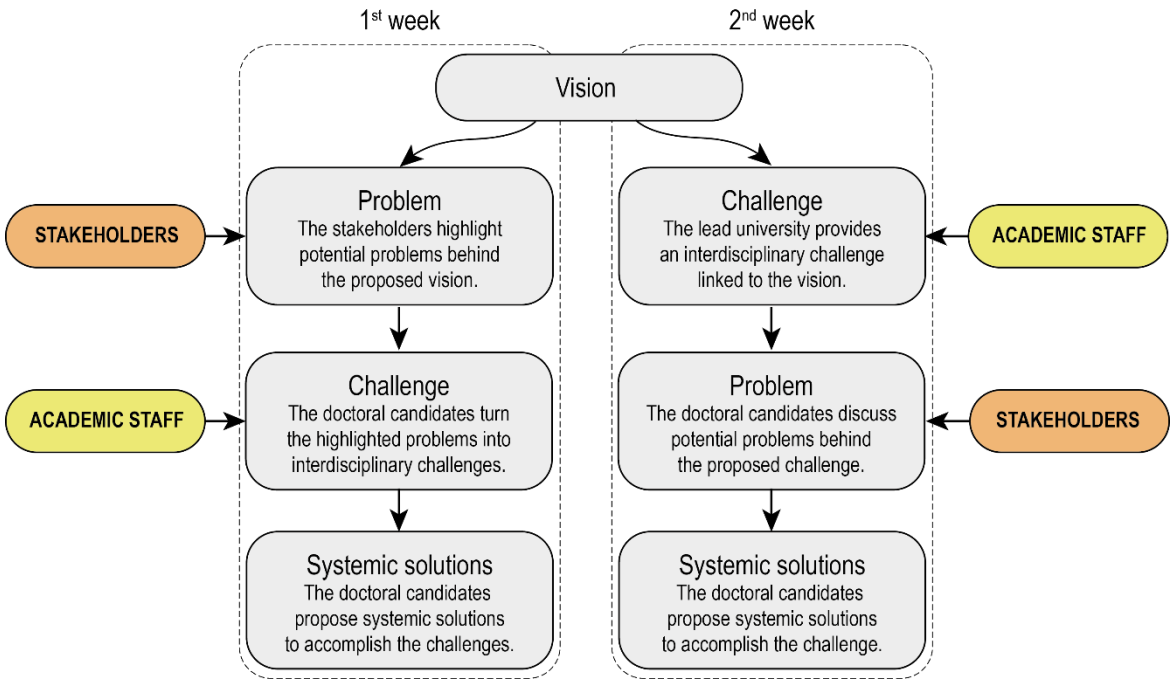

Figure 3. Challenge-based process with the support of stakeholders and academic staff highlighted.

3.3 Collection of feedback

The doctoral candidates were asked to complete two questionnaires, to gain insight into the learning methods adopted. The first was completed at the end of week one and the second at the close of the summer school. The questionnaires were designed to be completed online and anonymously by the doctoral candidates without intervention from the lecturers or coaches. It was explained to the doctoral candidates that the feedback was collected to help the lecturers and tutors learn about how to improve the summer school and similar courses in the future. Anonymity was essential to elicit candid responses. Each questionnaire comprised a series of

questions requiring a response on a 5-point Likert scale and a voluntary short explanation where 3 points or fewer were given in the response.

Both questionnaires consisted of the same questions addressing the following headings: (i) level of satisfaction from the summer school experience; (ii) relevance of the summer school contents; (iii) student learning and personal development. The questions under the first heading focused on overall satisfaction and inquired how well the programme met the doctoral candidates' expectations of the programme, for example: '*How satisfied are you overall with the first/second week of the programme?'*. The questions under the second heading investigated the perceived quality of the lectures and how well the workshops were organised, including support from the coaches, for example: '*How relevant was the overall content of the first/second week of the programme to your research?*'. Finally, in questions under the third heading, the doctoral candidates were asked about how their skills were developed and improved according to the learning objectives, for example: '*Did you have enough time to be able to process the acquired knowledge during the first week of the programme*?'. The second questionnaire also included additional questions on the impact of the whole summer school experience on the doctoral candidates' personal career, for example: '*Have you been able to directly link your own research to the topic of the summer school?*'

4. Findings and discussion

4.1 Feedback from doctoral candidates

The collection of feedback enabled the organisers to develop an understanding of how the summer school impacted the doctoral candidates, in terms of their satisfaction with the experience, learning and personal development.

The questionnaires that the doctoral candidates completed at the end of the first and second weeks showed rather a positive impact. It should, however, be noted that at the end of the second week the questionnaire was completed by only 16 of the 20 doctoral candidates, and consequently the results of the unanswered questionnaires were defined as 'unknown'. Table 1 summarizes the results of the main headings of the questionnaires at the end of the first and second weeks of the summer school.

Table 1. Percentages of doctoral candidates replying to the questionnaire by heading (i.e., i, ii, iii, iv) and range of average score on the 5-point Likert scale (<3, =3, >3).

	1st week			2nd week			
	score <3	score = 3	score > 3	score <3	score = 3	score > 3	unknown
i) Level of satisfaction from the experience	20%	40%	40%	5%	35%	40%	20%
ii) Relevance of the summer school contents	10%	35%	55%	5%	5%	70%	20%
iii) Student learning and personal development	15%	30%	55%	15%	20%	45%	20%
iv) Impact on personal career (only 2nd week)	-	-	-	5%	20%	55%	20%

The questionnaire administrated in the first week comprised a total of 23 questions with a breakdown of 6 questions under heading (i), 11 questions under heading (ii), and 6 questions under heading (iii). The questionnaire administrated in the second week comprised the same questions with an additional 4 questions under heading (iv) on the overall impact of the summer school. Under headings (i), (ii), and (iii) the questionnaires show an increase in average scores greater than 3.0 from the first to second weeks. The specific results from each question under each heading are in Appendix 1 and can be summarized as follows. In terms of overall satisfaction with the experience (i), around two-thirds of the doctoral candidates thought that the programme achieved the goals described in the programme syllabus (60% and 65% in the first and second weeks, respectively) and fulfilled their expectations (55% and 60% in the first and second weeks, respectively). Furthermore, about half of the doctoral candidates considered

the content of the summer school to be relevant to their studies (50% in the first week and 45% in the second week). Regarding the responses in connection to the relevance of the summer school (ii), the vast majority of the candidates affirmed their satisfaction with the lectures provided in both the first and second weeks. However, satisfaction with the stakeholder workshop during the first week was not high with only 15% of the candidates assigning a score greater than 3.0 and 40% assigning a score of 3.0. The doctoral candidates assigning a score lower than 3.0 thought that the stakeholders did not provide enough inputs to the development of the challenges. This suggests that more preparation by the stakeholders prior to the summer school workshop is required to ensure the effectiveness of the learning activity, and that this could be facilitate by closer dialogue between the organisers and the stakeholder about their role. Concerning the students' learning and personal development (iii), between 55% and 75% of the candidates definitely thought that the first and second weeks of the summer school had improved their ability to analyse and solve problems, work in groups, and communicate orally and/or in writing. However, the questions concerning the suitability of the workload and the availability of time to process the acquired knowledge received lower scores, especially during the second week, with only 25% of candidates replying with a score greater than 3.0 to those questions in the second week. This suggests that time management in the summer school should be carefully considered in future editions. A similar issue has also been reported in other intensive courses for doctoral candidates (Philippi, 2014).

In the second questionnaire, doctoral candidates were invited to complete additional questions about the possible impact on their careers (iv). When the participants were asked whether they felt more capable of working in a multidisciplinary context following the Catapult, the response was positive, with 75% assigning a score greater than 3.0 on the 5-point Likert scale. However, it seemed that the doctoral candidates had rather more difficulty in directly linking their own research to the topic of the summer school. In this category, only 45% of the candidates replied

with a score greater than 3.0 suggesting, firstly, that any future editions should pay more attention to linking the participants' own research to the summer school topic, and secondly, it perhaps highlights that research is often very specific, and so connecting it to the solution of larger systemic challenges is a topic that requires close attention. Despite the fact that the participants had difficulty in making this link, they could clearly see that they would be able to apply the learning experiences from the summer school in their future research and careers. In this category, 65% of the candidates replied with a score greater than 3.0.

This result clearly supports the positive impressions of the staff about the education experience, after the daily feedback sessions and one-to-one discussions with individual doctoral candidates. Here below two quotations retrieved from the questionnaires in response to the last question *'Is there anything else you would like to share? Please write your final considerations, suggestions, feelings, ...'*.

'The summer school exceeded my expectations. It was a great experience, and I would recommend it also to others.'

Participant A

'The summer school was a great experience. The material was very relevant to my PhD, and the group work helped me to reflect on the importance of making my research relevant in a changing world.'

Participant B

However, limits to this survey should be highlighted. As the questionnaires were completed anonymously, an analysis of the answers in relation to the doctoral candidates' background (e.g., field of study) was not possible. Such analysis might provide additional insight into the effectiveness of the summer school's contents and into the methods adopted to implement interdisciplinary learning in relation to different disciplines. Furthermore, the questionnaires

aimed to capture only the immediate impact of the summer school on the doctoral candidates. Though, as observed in previous studies (Philippi, 2014; Zukas and Andersen, 2011), the long-term impacts of such learning experiences are usually unknown, and follow-up questionnaires might be useful to understand any behavioural changes in the participants.

4.2 Summer school approach

The overall summer school experience suggests additional considerations on the methodological approach.

Engendering interdisciplinary learning was the key purpose of the summer school and was pursued from its conception, through the recruitment of the doctoral candidates, to the execution of the summer school. The learning environment itself represented a critical factor in supporting the interdisciplinary approach. The organizational structure of the summer school not only helped to balance the contents of the programme, including different teaching and research approaches, but it also ensured a successful interdisciplinary learning experience. The university partners represented different disciplinary entities, including wood materials science, civil engineering, architecture, and systems science. All these disciplinary entities contributed to the conception of the summer school programme.

The broad range of backgrounds and the cultural diversity represented by the doctoral candidates and the teachers laid the basis for learning in an interdisciplinary context. In fact, as observed in previous studies (Lippuner *et al.*, 2015), the intercultural dialogue becomes a prerequisite to move forward. However, the diversity of backgrounds was also a challenge for the participants, who had to overcome disciplinary boundaries when working in groups to solve complex problems or when adapting their language to a multi- rather than a mono-disciplinary audience. This also emerged from the doctoral candidates' feedback.

Group working, which accounted for the most significant share of the summer school time, allowed the participants to develop networking abilities, avoiding isolation. As observed in previous studies (Lippuner *et al.*, 2015; Zukas and Andersen, 2011), group working can contribute to strengthening the sense of belonging to a 'peer community' among doctoral candidates and to facilitate 'peer learning' and 'peer evaluation' mechanisms between the group members, contrasting with standard research supervision that is usually characterized by a teacher-student approach.

The development of real-life challenges was a pivotal element of the summer school programme. The doctoral candidates were tasked with analysing complex problems and providing innovative and tangible solutions within a relatively short time frame. In the first week, the doctoral candidates played an active role in identifying emerging research challenges based on the problems discussed in the stakeholders' workshop. Here, the systems thinking approach was crucial in analysing and mapping the stakeholders' inputs. During the group work, the doctoral candidates selected the research challenges based on their interests and proposed innovative solutions. In the second week, the host university clearly defined the research challenge. Here, problem-solving activities were crucial in developing tangible solutions. The doctoral candidates had the opportunity to discuss the problems related to the assigned challenge in the stakeholders' workshop and, again, to propose innovative solutions. The participation of the stakeholders in the final presentation of the group works was helpful in validating the real-life solutions developed by the doctoral candidates. Both approaches emphasized the importance of the research-business ecosystem, encouraging the integration of academic and non-academic expertise. Stakeholders account for part of the knowledge-building process. Furthermore, as observed by Bergeå et al. (2006), the interaction with experts is crucial to increase the motivation of doctoral candidates.

Collection of feedback from the doctoral candidates increased the organizers' understanding of the summer school outcomes, as well as the self-reflection of the participants. However, the questionnaires had a few limitations. First, the questionnaires were only given to the participants during the summer school itself. Additional questionnaires administrated sometime after the end of the summer school would help understand the long-term consequences of the summer school. Second, the questionnaires collected feedback on the summer school's contents (i.e., lectures, stakeholder workshops, and field trips) without assessing the doctoral candidates' learning. The assessment of the doctoral candidates' knowledge before and after the summer school may be helpful in better understanding the effectiveness of the teaching methods. Third, the number of doctoral candidates replying to the questionnaires represented a varied, though limited, sample, whilst the feedback concerns a single summer school experience. If the summer school was repeated periodically, the collection of feedback could be extended to a larger sample of doctoral candidates. Furthermore, an in-depth analysis may also consider the summer school's outcomes in relation to the doctoral candidates' background (e.g., field of study, language, etc.). Finally, the questionnaires comprised only Likert scale questions but open-ended questions could be included in order to add further depth and context to the results.

5. Conclusions

This summer school explored an experimental approach to deal with an urgent interdisciplinary issue; that of the role of wood-based products and construction in the bioeconomy and in mitigating climate change. In this regard, there is a need not only to improve the scientific knowledge within individual disciplines (e.g., environmental science, forestry, engineering) but also to develop new interdisciplinary knowledge to achieve a more comprehensive

perspective on the forest value chain and climate change. Since this issue is particularly sensitive in Northern European countries, a specific Nordic program could lead and encourage research in this direction.

In the long-term, the approach developed by the summer school could be replicable in future teaching events and be applicable to different sustainability research themes. The promotion of interdisciplinary research in the research-business ecosystem can also enable doctoral candidates to face real-life sustainability challenges becoming valuable 'change agents' inside and outside the academic environment.

The increasing complexity of societal challenges requires the re-thinking of doctoral education. As shown by the literature, there is increasing interest in interdisciplinary doctoral programmes at universities, though they require significant investments. In this transitional period, initiatives such as doctoral summer schools may be considered as a means of boosting interdisciplinary skills among doctoral candidates in an affordable and inclusive way.

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About the authors

Chiara Piccardo is an Assistant Professor of the Department of Civil Engineering of KU Leuven, in the Building Physics and Sustainable Design research group. Her research focuses on sustainable materials and technologies for buildings, with special attention to bio-based and circular materials, using life cycle analysis (LCA) as a methodological approach. She develops interdisciplinary research through a close collaboration with architecture, engineering, forestry and economics disciplines. She teaches courses related to sustainable building technologies in the bachelor's and master's degree programs of the university.

Dr. Yutaka Goto is a researcher in wood engineering with degrees from University of Tokyo (BSc and MSc) and ETH Zurich (PhD). He works as research fellow at Department of Architecture and Civil Engineering in Chalmers University of Technology. His transdisciplinary research focuses on sustainable use of wood in constructions with regards to

engineered wood, structural safety, durability, energy efficiency, indoor comfort, and sustainability impacts.

Deniz Koca is an Assist. Prof. at Lund University, Centre for Environmental and Climate Science (CEC), where he also acts as the coordinator of BIOECONOMY Graduate Research School. His main expertise lies in applied systems analysis, system dynamics modelling and facilitation of stakeholder participatory group modelling process. He has been involved in various transdisciplinary research and education activities with the main task of analysing, interpreting, modelling, simulating and communicating alternative scenarios of complex dynamic environmental and socio-economic issues with a systems approach and within the sustainability criteria. Deniz is a Donella Meadows Fellow and member of the Balaton Group.

Pasi Aalto is an architect and centre director for NTNU Wood at the Norwegian University of Science and Technology. The centre focuses on knowledge development of the sustainable use of forest resources to support a transition towards a carbon neutral and circular society. Through the use of transdisciplinary collaborations necessary to engage academics, students, industry, public bodies and citizens, the centre aims to increase the innovation capacity and engaged stakeholders that actively work with wood products.

Professor Mark Hughes heads the Wood Materials Technology group at the Department of Bioproducts and Biosystems, Aalto University, where his research focuses on the sustainable use of wood products for materials and energy efficient building construction. He is head of the Creative Sustainability in Material and Chemical Engineering program at the School of Chemical Engineering, Aalto University and is the academic lead for EIT Climate-KIC at the university.