FOSTERING SUSTAINABLE MINDSETS IN ENGINEERING EDUCATION

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ABSTRACT

Transitioning to a more sustainable society requires that universities produce an increasing number of engineering professionals capable of redesigning current production and consumption systems. This calls for restructuring engineering curricula towards sustainability becoming an integral part of engineering education and professional practice. To this end, this paper investigates the intrinsic and extrinsic motivational aspects of professional identity that contribute to consolidating sustainable mindsets in engineering, considering education as its main route. Specifically, we focus on identifying significant personal and education-related factors that contribute to fostering sustainable decision-making and affect the development of sustainable mindsets in engineering students. In order to identify such factors, we conducted semi-structured interviews with a diverse set of students and professionals (N=12). A thematic analysis of survey transcripts present three main components that support the development of sustainable mindsets throughout engineering education: i) Personal commitment, ii) Learning opportunities, and iii) Internalization time.

Keywords: Design education, Sustainability, Design cognition, Design engineering

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1 INTRODUCTION

The pressure humans place upon the environment and its sustainability has become one of the main political, economic, and social issues of the 21st century. Many of the challenges we are facing are produced by technology and a result of Anthropocene — the era of man — which has brought to light a myriad of new challenges (Fox *et al.*, 2017). Engineering and designers shape the development of products, technologies, and services that directly and indirectly impact society and the environment (Papanek, 1995). As technologists, engineers play a pivotal role in implementing new technologies that can alleviate current problems and support sustainable development. The Post-COVID era brings a new understanding of sustainability, which puts engineers and designers at the forefront of societal urgencies (Persun, 2020). Now, more than ever, human society feels the urgency for consolidating new practices and working towards sustainable development.

To this end, our research focuses on the concept of sustainable mindsets (SMs), which is defined as a way of thinking that integrates holistic and systemic approaches related to sustainability into engineering practice and goes beyond technical knowledge (Kassel *et al.*, 2018). Specifically, we focus on the need for fostering SMs in engineering education (EE) and bringing discussions on sustainability into the core of engineering practice. This study adds to established principles in engineering and design disciplines and to the current knowledge of design engineers' mental models (Badke-schaub *et al.*, 2016), by identifying the factors supporting development of SMs and their application in industry. Our overarching goal is for SMs to transition from a research field to a mindset influencing activities including business, policy-making, services, and products, akin to Design Thinking (Brown, 2008) — a popular term describing the mindset of a designer (Brenner *et al.*, 2016) — that is now widely taught in EE curricula and has been integrated into industry design practices (Brown and Wyatt, 2010).

This study intends to explore the development of SMs in EE by investigating psychological elements that contribute to fostering sustainable decision-making in engineering practices. We envision that SM in EE is of such pervasive and systemic nature that it has the potential to affect all academic and industrial engineering practices in the future — today's students are tomorrow's engineers tasked with these challenges — (Halbe *et al.*, 2015). This vision is supported by the notion that the natural environment is increasingly considered a business opportunity, a social responsibility (Griswold, 2017), and a driver of economic development. The success of sustainability-focused projects requires engineers to simultaneously consider economic profitability, technical feasibility, and sustainability, which may require trading-off one of these facets for another. However, very little is known on the scope and nature of what leads engineers to engage in sustainable actions and the aspects that consolidate SMs in engineering practices. The whole process that drives engineers to address sustainability in their projects is poorly understood due to the lack of indicators, theoretical and empirical research in this area. Research exploring the development of sustainable mindsets and the learning processes that facilitate their development are a useful contribution (Griswold, 2017).

This in-depth study dives into what creates and how to develop SM in EE (and beyond) by looking at the structure of mindsets that integrate sustainability into engineering practices. More specifically, it **aims to understand the intrinsic and extrinsic motivational aspects of professional identity (PI) that contribute to consolidating an SM in the field of EE**. This study has three main objectives: O1) to understand intrinsic and extrinsic motivations that lead to development of SMs, O2) to identify the development path for SMs, and O3) to identify approaches that help foster SMs in EE. This study provides a humanistic and impact-driven approach to the research field, providing the much-needed empirical evidence for theoretical models in EE, which are central to understanding and fostering SMs. The perspective of implementation of the knowledge from this study primarily relates to the consolidation of educational practices that integrates sustainability in EE in a way that is accessible and relatable to the students, thus relying on a constructive and self-driven learning model.

2 LITERATURE REVIEW

The last few years have seen the rise of 'sustainable design' as an important albeit still emerging concept in engineering education (Humphries-Smith, 2008). A primary means of discussing sustainability in EE is through design-focused curricula and activities. Design has been described as an ill-defined process, as such many researchers have identified the significance of understanding mindsets, or the individual and shared mental models of teams to the success of design processes

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(Badke-schaub *et al.*, 2016). Design mindsets or design thinking is anything a designer or engineer mentally considers (e.g., a goal, strategy, paradigm, etc.). Ahmed and Christensen (2009) recognise that experienced designers have a different mindset and deploy different strategies to novice designers, influencing the level of innovation, risk-taking, and time taken to complete complex design engineering tasks. So far, most research on understanding designers' mindsets have largely focused on creativity and their underlying processes, for example, the role of analogies (Ahmed and Christensen, 2009), and the role of experience (Lawson, 2005). However, professional aspects become a major psychological component of the person's overall sense of identity, by dealing with the complex structure of meanings related to professional roles, individual motivations, and competencies (Baumeister and Muraven, 1996).

The general construction of PIs formally begins during higher education. Consequently, professors play a pivotal role in the initial development of their students' PI and ways of thinking, based on their teaching of the norms they believe a student should adhere to, reinforced via academic assessments (Murphy *et al.*, 2015). Kunrath *et al.* (2020) highlighted interviews where professors concluded that their focus when teaching was not just to provide the basic technical knowledge but to create a questioning and creative thinking mindset. As a result, students tend to align their perceptions with those of their professors (Trede, 2012) and their active learning choices during education.

Considering that training engineering students in sustainability has become an urgent need and has come into the focus of engineering accreditation boards (Shuman *et al.*, 2005), it is important to understand the motivations and factors that can lead students to opt for sustainability-related courses during EE. It is also important to shape sustainability curriculum such that it helps students develop SMs, apply SMs in professional practice, and to develop technical solutions that can lead to changing current traditional mindsets in industry and society (Lawson, 2005).

Goekler (2003) argues that students effectively learn about sustainability when they develop the ability to think in new ways and engage with different worldviews. There has been considerable previous research that has looked at various pedagogical approaches such as project-based learning (Bernstein *et al.*, 2012), guided-discovery learning (Ramanujan *et al.*, 2014, 2019), and problem-based learning (Steinemann, 2003), to improve the efficacy of sustainability education in engineering. Research has also focused on identifying goals and strategies to consider while performing design activities (Papanek, 1995) that can be adapted to sustainable design. However, existing literature and training on sustainable design does not propose any specific activities (Faludi, 2017) nor extensively explore the role of intrinsic motivations and mindsets in the development of PIs in EE and practice. This study aims to address this research question with the overarching goal of fostering the development of SMs in engineering students.

3 METHODOLOGY

The methodological approach of this study aims to use in-depth qualitative insights. Semi-structured interviews were held with engineering students and graduates at the Master of Science (MSc.) in Engineering level, to evaluate self-perception and psychological constructs regarding sustainability and sustainable design. A diverse set of participants were enrolled in this study to collect broader perspectives of sustainability in engineering. Therefore, we selected participants actively engaging with sustainability in their education and profession, as well as participants not directly involved in any sustainability-related activities. The study population was composed of 12 participants (N=12; 73% Male, 27% Female) equally distributed into four groups: Group 1 - current students enrolled in a course on sustainability or have participated in sustainability-related activities; Group 2 - current students that have never enrolled in a sustainability course or participated in sustainability-related activities; Group 3 - alumni directly working with sustainability; Group 4 - alumni not working with sustainability. All subjects were residents of Denmark and had connections to the Department of Engineering from Aarhus University (36% Danish, 64% Internationals). The interview procedure was based on the recommendations of Miles and Huberman (1994). The interview started with general questions about the relation of sustainability to the profession/education and moved towards specific questions about the interviewee's motivations and triggers (see Appendix 1). The 12 semi-structured interviews were transcribed and analysed qualitatively. Based on the manual transcriptions, thematic analysis was carried out following an iterative process between the authors (Patton, 2002). The qualitative data from the individual interviews were systematically analysed via inductive coding

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(Miles and Huberman, 1994), and iterative coding cycles until a final set of codes had been developed (Patton, 2002). Finally, these codes were further iteratively refined by specifically contrasting the data within each group.

4 RESULTS AND DISCUSSIONS

Results from the analysis of interviews are presented in relation to the study objectives (O1, O2, & O3) described in the Introduction section.

4.1 Attitude, motivations, and triggers

The results demonstrated that intrinsic motivation and personal triggers were fundamental aspects of behavioural change and for consolidating a new mindset. Hence, becoming aware of an issue, and attributing importance to it, was the first step towards a deeper engagement with sustainability. Furthermore, such triggers presented an awareness of the role of engineers with regards to sustainability through a sense of personal responsibility towards the use of resources and future generations.

By discussing intergenerational responsibility, participants demonstrated criticism and concern for the actions of previous generations and industrial activities that have led to the current state of the environment. A participant commented that *"[Previous generations neglected sustainability] and that led to a really bad impact to the environment, like the climate change that we are experiencing right now. So, unless we do something about it, we can't be sure that everything is going to stay the same" (G2-01)*. Based on the perceived environmental impact and the dialogue regarding intergenerational responsibility, participants thus become aware of their role as engineers and engage in a conscious new approach; *"It all comes back again to understanding that what you're doing has some kind of consequences" (G2-02)*. Participants also proposed to take responsibility and act towards creating new solutions. In this sense, understanding the potential contribution of engineering practices toward sustainable solutions, assuming an overall responsibility, and wanting to take part in a global challenge were identified as some of the main aspects of motivation. A participant noted, *"Every one of us also has an obligation through the world to actually take some responsibility" and "It also puts the innovation process within a context that you can actually drive something forward and make the conversation change around" (G3-02).*

In this study, students and professionals were found to be aware of transitions even in the most traditional engineering industries as sustainability is becoming more important for companies; *"Now the companies have reached a point where they are more forced by the policies of the government to be sustainable. The companies are going to put more and more resources to try making the projects more sustainable" (S.G2-01).* When asked if they thought sustainability was important in engineering education (Q2), respondents presented concerns about their future and desire to prepare for new challenges faced by industry; *"Actually, the company where I work also focuses a lot on sustainability and circular economy or these kinds of things. So, I thought that it would be nice to attend this or to participate in this research because it's also important in my work" (G4-01).*

Overall, participants presented an optimistic mindset and were positive about an engineer's role and contribution to promoting sustainability at all levels. A participant mentioned that *"As an engineer, I think we can always find a way to make it economic and environmentally viable, so it pleases the capitalistic companies and the society. I think there's always a way" (S.G2-01).* When asked if they think it is important to think about sustainability when developing projects (Q11), almost all of the respondents (92%, N=11) were positive and suggested diverse strategies to promote the implementation of sustainability in engineering projects (Q12) reinforcing the importance of decision-making attribution and the role of an engineer in a company. Only one participant presented limited belief based on the decision-making attribution and the role of the engineer in the company. They said, *"If you're like a young engineer or you just started, you're not the one making the decisions so at the end it's very difficult" (G4-02).* The respondent further emphasized the need for young engineers to step up with their ideas and to be motivated about sustainability techniques, keeping up a positive mental attitude; *"Of course you can propose it and then if it's a good idea they're going to take it. That's really difficult but we need to put the effort and be motivated to do it" (G4-02).*

Results show the need to develop an awareness about possible sustainability-related issues in projects. The impact of developing a sustainable mindset was highlighted when participants were asked about implementing sustainability in their projects (Q13); *"Since I have this more sustainability*

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mindset I try to apply it whenever I can. And that was because [in that project] I was really aware of the problem and I wanted to contribute as an engineer somehow" (G4-02).

4.2 Development path of SMs

When asked about the roots of their motivation for sustainable thinking (Q17), and to recall when they first started to grow sustainable/environmental awareness (Q18), all participants (100%, N=12) recalled aspects from their backgrounds and/or events from their childhood. Results show that participants' upbringing and early education played a fundamental role in the development of their interest in sustainability. One participant said, *"It slowly stems back to primary school [folkeskole] in Denmark where at some point we had some courses ... where I realized that my family did a bit more than what usually the other classmates of mine did" (G2-02).*

Interview results also revealed that 'time' was an important factor for the development of SM as it was needed for internalizing fundamental concepts, and for the development and integration of personal values into engineering practices. Results highlighted that the development of SM was an integrative part of personal development; *"Sustainability is also kind of a personal development and road because you really learn, you really feel your own values when you're presented with different cases. As well or at least that's what I've experienced" (G3-02).* Thus, the acquisition of practical experience over time promoted and reinforced SM, as described by one of the participants: *"Thinking about sustainability is something that you get much better at with experience because there's a lot of qualitative thinking involved aside from the quantitative aspects. So, qualitative thinking becomes a natural part of your design process only after experience" (G1-01).*

Considering the nature and complexity of developing SMs, we found it is important to start introducing initial concepts of SMs to students at an early stage; *"[Sustainability] it's complex and that complexity a lot of people also have a hard time to deal with. So not only implementing it at a university level but implementing it in the primary school" (G3-02).* Furthermore, such opportunities should be provided to the largest number of people. Another participant noted, *"I think everyone should learn it. I think it should be a part of the school curricula where everyone gets that opportunity to learn. They don't have to go in the depths, but students have to know what sustainability means and what impact you can make. Just a couple of lessons" (G2-01).*

Project work and case studies seemed to be an effective tool for engaging engineers into new ways of thinking; *"Engineering is pretty much based on experience and engineers are afraid if they have to do something new... But I think that good examples can change or motivate young engineers" (G4-01).* Among the interviewed participants, later developments were set up based on successful examples and cases presented at school and university levels, and the connection between specific areas of interest acted as external triggers for motivating the students towards developing SM. Engagement and further interest were associated with correlating sustainability concepts and realistic applications; *"I didn't really have an explicit interest [in sustainability] but when I saw the potential I thought okay fine this would be interesting… I had a little bit of a misconception that was cleared when I saw the projects that he was working on" (G1-01).* The need for demystifying discussions around sustainable engineering practices with tools and techniques while presenting their potential impact was also highlighted in the interviews. A participant said, *"What works for me is to see it visually, see the results see the impact that this project is having in the environment or see numbers, see graphs like how this would affect our future, how could this affect our current situation with climate change. Showing people and engineers what you could possibly do with these techniques and what you could achieve with that" (G4-02).*

Furthermore, participants highlighted the importance of the educational process as a training ground for developing new ways of thinking, and for preparing the professionals to further reach the job market with an already mature sustainable mindset in place. *"It is important to be done while we are studying now because just to develop that habit of thinking that way or having that mindset where you're presented a project, you're not just thinking from the economic side but also the other aspects of sustainability, so I do think that it is important to do it now" (G2-03).*

4.3 Education as the main route to SM

All participants (100%, N=12) agreed that sustainability was an important part of their engineering education (Q2), and their respective engineering fields had a direct relation to sustainability (Q3). When asked about the fields in which sustainability should be a primary focus

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(Q19), the results highlighted the participants' perception of the inherent connection between their field of engineering practice (75%, N=9) with sustainability, and the potential impact of their activities. A participant said, *"[Sustainability] it's important pretty much in every engineering discipline and beyond… [we have to be careful] so we don't use up the planet resources, and future generations can also meet their own goals" (G2-03).*

Higher education thus seems to be the perfect space to develop experience in a safe environment and to promote new ways of thinking that will equip future professionals to solve wicked problems, as in *"if engineers will graduate with a sustainability background it will help like make new innovations into reducing this impact" (G3-03)*. However, responses also revealed added complexity resulting from integrating sustainability in engineering subjects that should be developed throughout the educational process. A participant said, *"We've not had any course about it, or we've not been exposed to that kind of perspective during the bachelor. So, trying to be sustainable adds a totally new layer of complexity on whatever was being done... Whatever you're doing, sustainability is a totally new focus that can be put on top of that" (G1-01)*. Furthermore, 73% (N=8) of the participants argued that their current educational model did not provide enough opportunities for students to engage in sustainability projects and thus to learn through experience. They suggested they did not have a real understanding of the overarching concepts or terminologies of sustainability before taking a dedicated course, which hindered their process of engineering decision-making. After taking part in one specific sustainability course, changes in perception and heightened interest were perceived; *"Sustainability was completely out of the picture for me. Actually, before I took the course I didn't think [about sustainability] at all. Like, I didn't even consider it as an issue at all but now I think it's very important… most of the terms with sustainability I have never heard of before I took the course" (G3-03)*.

Participants suggested several approaches to aid the integration of sustainability in their engineering education. A recurring theme was providing opportunities for enrollment in a sustainability-related engineering course at an early stage in their curriculum. A participant said, *"Maybe to start the education with all these different terms about sustainability and how to design sustainably, so the students have a chance to actually think about it before they get to their master thesis" (G3-03).* Other suggested approaches included case study projects, competitions, and low-commitment activities such as study groups and discussion forums. A few participants also suggested that sustainability needs to be an integral component of every engineering course and that each subject of study should include a possible case study on sustainability. One participant said, *"I think it should be taken in a more holistic way, it should include all the disciplines. It would be nice to have, like in the course, a combination of all the engineering disciplines which opened up opportunities for us to think about how we can design more sustainably in the more holistic way" (G3-03).* The perspective of an integrated approach of sustainability in EE intrinsically proposes a way to minimize evasion and/or bias towards addressing only students with a prior interest in sustainability, as described in *"I probably wouldn't take a pure sustainability class. So, for me to have some understanding of sustainability would probably be to put a bit of sustainability into all the classes instead of having one class about sustainability" (G3-01).*

Five participants (42%) said they had a prior personal interest in the subject and that it was the main trigger to enrol in the sustainability course. However, we observed that enrolling in a sustainability course or project did not necessarily result from a genuine interest in the subject, personal motivation, or perception of sustainability importance but it could rather be due to other inherent learning benefits*; "To be completely honest, I don't really have much of an interest in all the ideas about saving the environment and so on. It's more personally for me, it's not for any altruistic reason or anything like that. It's just interesting to think about, and it somewhat presents itself like a challenge" (G1-01)*. A student that does not have interest in sustainability strive for other triggers that can be relatable to their interests such as *"my motivation is definitely just to use materials more efficiently so we would have more of it, and it will drive the cost down" (G2-03)*. In this way, concerns about one's professional future and preparing for changes in the job market were strong reasons for taking a sustainability-related course. As follows, several factors were identified as contributing to participants not enrolling in the available sustainability-related courses throughout their education such as lack of opportunity, unavailability/timing, or due to the inherent characteristics of their environment i.e., cultural aspects.

Participants' responses showed that there is a need for engaging with sustainability at different levels within the educational institutions and re-evaluating the main educational paradigm; *"In the*

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educator's opinion sustainability is not the paradigm driving technology forward, or the main paradigm, and they have a responsibility to actually teach us various paradigms in technology... I believe technology is tools, it's not a mindset, it's not a paradigm, it's a tool to drive change forward" (G3-02). Further, the participant suggested a holistic approach to the current technology-centric perspective to be seen as a means to drive the sustainability agenda forward. *"Everything is looking from only a technology perspective and that means that they're not having the systems change. Whereas you don't see the value creation that the technology does in a holistic context, and you don't see the negative effects, because we have not been taught to think in systems. So, the system element I believe is the most important thing to get into every education" (G3-02).*

5 DISCUSSIONS

Results from the thematic analysis show three main components that support the development of SM in engineering education. They include, i) Personal commitment, ii) Learning opportunities, and iii) Internalization time.

Personal commitment relates to the motivations that lead one to engage in the subject and develop SMs. These motivations resulted from personal aspects such as genuine interest in the subject, possibility for personal gain, and the perceived contribution towards creating a positive impact. Our findings align with Fogg's Behaviour Model, where three elements (Motivation, Ability, and Trigger), must be in place for a behaviour to occur (Fogg, 2009). These three elements are mutually reinforcing over a period of time to reach incremental readiness to act (Kassel *et al.*, 2018). Our results also indicate that engineers who consider sustainability as an extrinsic feature rather than an intrinsic design objective will tend to trivialize or perhaps entirely ignore sustainability in their projects. These findings are supported by previous research that calls for more holistic integration of sustainability in EE (Kumar *et al.*, 2005). Our results also emphasize the need for aligning students' personal interests in sustainability with relevant practice-oriented educational opportunities. This aspect has also been recognized as a means for influencing professionals to make lasting changes in their behaviours and to maintain the energy and commitment required to bring about broader social change (Griswold, 2017).

Providing adequate learning opportunities is fundamental for developing SMs and can be presented in diverse ways, from upbringing to formal education. To foster the development of SMs in engineering is a matter of creating the opportunity for students to start thinking systemically. EE plays a vital role in this process by providing opportunities for developing experiences for learning and for consolidating practices in a safe environment. Our findings suggest that engineering curricula should provide a diverse set of theoretical and practice-oriented opportunities for students to engage with sustainability. Furthermore, the alignment of such activities with the structure and timing of existing curricula needs addressing; the number of available opportunities and scheduling of such opportunities was mentioned as a potential barrier. The professionals interviewed also pointed out that developing decision-making skills was a central aspect towards applying sustainability in industry.

Internalization time is also one of the primary factors that enable the consolidation of SMs. It relates to the embodiment of concepts and values that promote the implementation of sustainability principles, as well as fluency in the face of a challenge. The sooner a person is exposed to sustainability-related information, the higher their possibilities for developing constructive experiences and integrating their knowledge into practice. For EE, promoting sufficient internalization time requires the introduction of sustainability concepts into engineering fundamentals that is integrative to engineering practices. This finding is supported by other previous works that have called for the integration of sustainability into fundamental engineering courses and activities (Ramanujan *et al.*, 2014). An interesting finding from our study is the suggestion to make basic sustainability literacy available (or perhaps mandatory) to all basic engineering disciplines in different formats, even to those students that are not aware or not necessarily interested in the subject. Educating every student about the basics of sustainability and the role played by their specific engineering discipline in sustainable development at the start of the curriculum can ensure adequate internalization time for the development of SMs. It allows students to have opportunities to engage in several interactions throughout their education where they can consolidate, over multiple attempts, a deeper understanding of sustainability principles and a long-lasting behavioural pattern (Fogg, 2009). Our findings show the importance of building the cognitive agility to adapt, and of making a habit to stay curious over time, and that these aspects matter when fostering sustainable mindsets (Kassel *et al.*, 2018).

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The development of SM throughout EE represents a humanistic approach to professionalism, and also relates to the rise of an impact-driven professional identity (PI) for young engineers. The human-centric aspect of PI (Skorikov and Vondracek, 2011) goes in line with Kassel *et al.* (2018), who proposes three dimensions of SMs based on literature: values (being), knowledge (thinking), and competency (acting). The acquisition of a new mindset at a personal level is so strong that it actively shapes behaviour towards a long-lasting commitment. Brandstätter and Frank (2002) emphasize that mindsets contribute to the explanation of persistence over and above conflicting motivational variables (i.e., feasibility and desirability), and interplay with self-regulative, so-called volitional, mechanisms of goal striving (i.e., implementation). The consolidation of a mindset allows a flexible response to situational demands based on a personal goal and commitment, leading to the implementation of sustainability principles into engineering problem-solving. Thus, considering education as a main developmental route towards the development of SMs, the combination of i) Personal commitment, ii) Learning opportunities, and iii) Internalization time, expands the current understanding of SMs and empirically highlights strategies to pave the way for improving the integration of sustainability into EE and practice.

Based on the results of this study and our literature review, we argue that EE plays a fundamental role in shaping PI with regard to sustainability. Furthermore, it prepares engineering students for tackling future societal and environmental challenges through the development of SMs. Developing SMs in engineering can promote impact-driving engineering practice and for this, sustainability knowledge and eco-literacy should be an integral part of EE, presented very early in the curriculum. Furthermore, developing SMs in undergraduate students poses the opportunity and urgency to generate new teaching-learning mechanisms, where the approach should focus on unveiling how sustainability is part of engineering problem-solving in real cases, as well as the role of engineers towards sustainable solutions and how to engage with it. Finally, there is a need for EE to integrate diverse (engineering) backgrounds with different levels of understanding sustainability into an intentional impact-driven engineering PI. This can be developed by engaging students in systemic thinking about interrelationships between sustainability and engineering and by creating opportunities for students to engage with real-world engineering projects requiring sustainability-focused decision-making.

6 LIMITATIONS AND FURTHER RESEARCH

While the results of this study provide important insights into motivational factors and the components of SM in EE, further work is needed to longitudinally investigate differences within the groups of engineers. This study focused on a sample of students and professionals connected only to Aarhus University in Denmark. This helped us distinguish four groups of participants that were directly linked to the same educational programme and provided an ideal basis for investigating contrasts in perspectives, whilst mitigating other potentially confounding factors, such as radically different educational backgrounds. Thus, the results provide qualitative theoretical insights, but cannot be considered statistically generalisable. Further work is needed to more broadly investigate how the differences highlighted in this study translate to other countries and engineering education contexts.

7 CONCLUSIONS AND IMPLICATIONS

This paper examines the intrinsic and extrinsic motivational aspects that contribute to consolidating Sustainable Mindsets (SM) in engineering, considering education as its main route. This project had three main objectives: O1) to understand the intrinsic and extrinsic motivations that lead to the development of SMs, O2) to identify the development path for SMs, and O3) to identify approaches that help to foster SMs through EE.

Our results described intrinsic motivation and triggers, extrinsic motivation factors and development path, and the role of education in consolidating SM. Based on the thematic analysis, three main components were identified to support the development of SM throughout engineering education: i) Personal commitment, ii) Learning opportunities, and iii) Internalization time. The identified components can guide the development of tools and methodologies that facilitate the integration of sustainability in EE in a way that is accessible and relatable to the students, triggering intrinsic motivation and promoting self-driven learning models.

The novelty of this study is from understanding the drivers for sustainable mindsets and providing empirical data on the structure of mindsets that integrate sustainability into engineering practices. The

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data reveal a glimpse of the cognitive process that drives engineers to address sustainability in their projects, empirically disclosing indicators to guide further research in this area. The results of this study identified three main components that may have been previously identified in terms of sustainability learning and now are brought together to understand the development of a long-term sustainability mindset, which is not necessarily equivalent.

The results of this work contribute to both theory and practice in EE and provide guidance for both educators and industry professionals. This contribution also highlights the importance of a pervasive humanistic and impact-driven approach to EE. From a research methods perspective, our study reconciles the existing "us and them" thinking between different sides of the sustainability debate by gathering in-depth knowledge and perspectives from students and professionals with different levels of engagement with sustainability. With regards to EE, our work discusses educational practices and tools for fostering SMs in engineering students who can consequently apply them in real-world practice and play an active role in creating sustainable solutions. From an industry perspective, our work identified existing barriers and needs for applying SMs in engineering practice.

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APPENDIX

1. 1. Interview Guide

Available at: https://tinyurl.com/kunrathICED2021

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