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Designing Innovation - The Role of Engineering Design to Realise Sustainability Challenges

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Abstract

Sustainability challenges drive innovation, yet few studies attend to the role of design to realise innovation. This paper report from a full day workshop and panel discussion with 100 delegates at the ICED 2021 conference. Industrialists, academics and societal representatives discussed how to deal with five conflicting themes. It is argued that innovation actors will need to take a joint action to the problem, industrial value chains need to co-innovate and that long term challenging targets are powerful metrics to drive transformation.

Keywords: sustainable innovation, design education, design methods, sustainable design

1. Introduction

The world is in continuous transformation, offering challenges to humanity and expecting us to change our behaviour to create a sustainable future. The call for action on the global sustainability challenge (UN, 2016) has wide implications for both technology and human behaviour. There is a need to upgrade existing systems and develop new, innovative solutions. This paper reports on a full day, hybrid workshop and panel at the ICED 2021 conference in Gothenburg, with over 100 attendees. The consensus of the industry and academic participants was that the global sustainability challenge will define the future of engineering. This paper elaborates on some of the implications this will have on the practice of engineering design, the training of engineers, and the relationships between engineering companies and universities.

The sustainability challenge brings the need for new solutions (e.g. Hallstedt et al., 2020), giving a strong market position to the industries who can meet them best. Design engineers have a central role to play in this transformation, but their ways of working and skills sets will need to adapt. Sustainability is commonly defined in terms of the three pillars of economic, social and ecological sustainability (Elkington, 1998). Mebratu (1998) argues further that these dimensions depend on each other, where economically sustainable solutions rely on sustainable social constructs that in turn rely on a sustainable ecological system. Therefore, any economical solution such as a new product or system, needs to be actively based on social and ecological sustainability principles. Product development therefore needs to think in terms of much longer time scales then the life cycle of individual products.

Now decades established manufacturing industries have relied predominately on evolutionary development, refinement and optimization, now they need to make fundamental step changes. For example, electrification or 'hydrogenification' of powertrains will require radical and innovative changes to all vehicles and has already disrupted the market as new actors have already been established. These changes to products must at the same time not introduce undue risks or compromise their safety. Well established, robust and efficient design processes will need to be modified at a time when digitalisation and the emergence of AI and better simulations are fundamentally affecting the way companies are working. This implies the need to re-invent both engineered products and engineering design processes on system level. Designers are critical, in facilitating a smooth transition while at the same time creating disruptive solutions. While designers already have many of the required skills, new skillsets will be required; and more designers are needed who can work in a new and transformative way. This requires the crossing of many disciplines to innovate, not only within engineering but also with non-engineering expertise from law, social sciences, natural sciences, economics and other areas, not traditionally engaged in design. While the awareness of the need to tackle sustainability is increasing, the measures, tools, methods and skills are still lacking or have not been widely adopted. This paper reports on a discussion of these issues during the workshop at ICED 21 and highlights barriers and enablers for innovation from a product development perspective.

2. Emerging trends in product development

Engineering is central to the development of future generation products and systems, where new needs and new scientific discoveries will be deployed. The required innovation realisation processes need to start decades before the expected solution is expected to be fully operational.

Many reports, papers and strategies (e.g. EPAS, 2019; IDE, 2021; Design Council, 2018; or the white papers and ongoing discussions by the World Manufacturing Forum (2021)) address trends in society and technology, yet few study what is required from a design perspective to maximise the utility of these technologies in new products and solutions. The new needs arising from sustainable challenges, need to be understood and transformed into actionable problem statements, requirements, and criteria. This paper focuses on the trends of how to realise sustainable innovation. The participants of the workshops have argued that there was never a more exciting time to be an engineer, since the sustainability challenge can only be realised through radical and transformative innovation.

Forecasting technologies and needs are consequently of major interest, and many actors (academic, institutional, governments) have invested time and effort in preparing for the future. Digitalisation, electrification and the quest for circular economy solutions are well recognised trends, yet their effective implementation in industry has just started, with several pioneering examples visible. Replace trusted and established ways of working requires great collective effort. Design research has addressed sustainability for a relatively long time, proposing new and improved methods and tools without having a significant impact on industrial practise. Not until recently, did sustainability challenges rise to the top of manufacturing companies' business agendas as business opportunities (e.g. Hallstedt et al, 2020, Brones et al., 2014).

A study made in 2018-2020, the authors of this paper led an initiative, with interviews and an international workshop (Isaksson and Eckert, 2020, Eckert et al., 2019) where the focus was to assess in what way the future of design and product development was impacted by trends in technology and society. The study took a 20-year perspective and one of the more interesting insights was the increasing diversification and conflicting trend-driven topics that could be identified. After decades of companies being driven by the short-term goals of shareholder returns, companies now realise that they need to think in terms of longer-term disruptive innovation, that delivers their long-term survival as well as greater sustainability of their products. This means that companies have to embrace the conflicting trends shown in Figure 1 and find innovative solutions while maintaining sound and effective products and businesses. To have an impact on sustainability, the products and systems need to be able to penetrate the market and push out less sustainable competing solutions.

Another observation was that many technological trends that are already known and expected to remain relevant will drive change for many years to come. These trends were presented at the beginning of the 2021 ICED workshop and the panel discussion picked up on these themes and discussed in what way these impact product development practices, methods, tools and skills.

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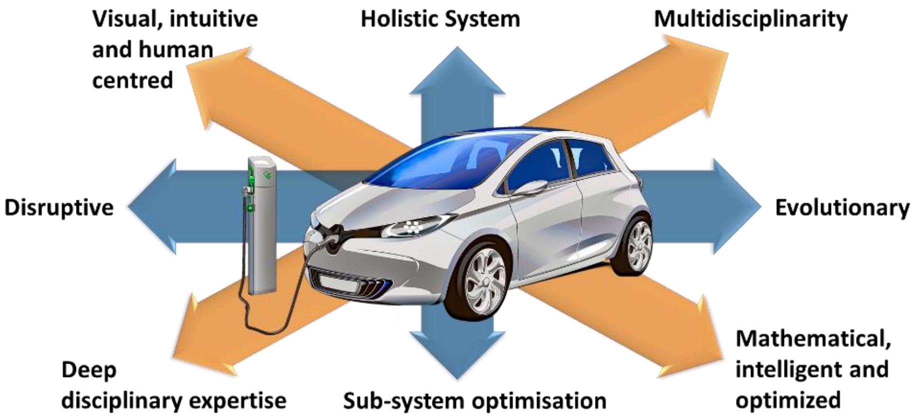

Figure 1. Tensions that challenge engineering designers in product development (Isaksson and Eckert, 2020)

3. Methodology

The findings reported in this paper took the conflicting topics from the 2020 report as a starting point for a workshop and panel discussion at the final day of the ICED 2021 Conference in Gothenburg. The conference theme "Design in Motion" set the focus on sustainable transformation through design throughout the conference. A set of keynote speakers were invited to the conference, giving their perspectives and experiences on the theme. At the inauguration of the conference on the Monday, the President of the Swedish innovation agency Vinnova, Darja Isaksson, stressed the important role that the engineering community has in an eco-system for innovation and that transformation will require not only shining examples but the transformation of entire value chains. Professor Katherine Richardson, University of Copenhagen, talked about 'Human-induced climate change reduction through design' and, Professor Marco Cantamessa, Politecnico di Torino, presented 'Shaping the future through Design'. Volvo Group presented their electromobility transformation effort, while Volvo Car spoke about how they transition to agile work processes. Anders Forslund, founder and CEO of Heart Aerospace, a commercial electric aircraft manufacturing start-up company, presented how they relied on smart design and engineering strategies to mature and develop their first aircraft. Anders Forslund also attended the panel on Friday.
The workshop ran on Friday after the end of ICED and was open to all ICED participants. There were 50 attendees via two physical locations in Gothenburg, and around 50 delegates participating remotely via ZOOM. The ICED organisers had invited industry representatives, academics and a Nordic innovation representative to attend a panel.
The workshop started off with five short inspirational keynote speakers who expressed their views on the future innovation in engineering design, which will be summarised in section 4. This was followed by 5 breakout groups following the themes, highlighted in section 5. The themes were derived by the authors based on an analysis of the findings of a prior workshop, on the trends in products developed in 2018 (see Isaksson and Eckert, 2020; Eckert et al. 2019). The results were captured in “miro boards”. A mix of academic and industrial "topic leads" helped to feed back to the plenary the groups' results as an input, to a panel discussion with industry and academic experts.
The inspirational keynote presentations and the panel were all recorded, summarised and analysed by the authors and the topic leads and sent back to the participants for review when cited. The thematic sessions were summarised by topic leaders, who in conjunction with industry experts provided a summary of the discussion. This was distilled into a report which was reviewed by multiple participants.

4. The challenges facing industry

In 5 to 10 minutes inspirational keynotes experts, were invited to reflect about their views on the challenges that engineering companies in their sector will face, which brought out common challenges around sustainability, systemic thinking and the need to collaborate on an unpredicted scale.

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According to Mikael Schön (Volvo Cars, SE) the automotive industry is subject to four mega trends: electrification, autonomous drive, more intelligence in the vehicle and shared mobility. While these trends exist simultaneously, which is dominant depends on specific circumstances. He also saw sustainability as a true business driver in the automotive industry and pointed out that this can only be achieved through active collaboration within the entire supply chain. The integrators in the field rely on the interplay with their suppliers, as much of the impact in manufacturing is governed by the extended supply chain, particularly in relation to embedded carbon. Manufacturing and product development-oriented companies are important actors in the sustainability transition, because of their dependence on natural resources and competences and their ability to affect larger supply chains. He pointed out that the speed of change in a sustainable society is not sufficient, and the time to reach the UN's 17 Sustainable Development Goals (UN, 2015) is limited.

Martin Aston (Förvanda, UK) comes from an aerospace supply chain background. He stated that "established manufacturing industries have generally left an era of evolutionary development, refinement and optimization, and need to also make fundamental step changes, e.g. electrification or 'hydrogenification' of powertrains in transport solutions and so forth. Robust and efficient design processes and product solutions need to be replaced and significantly renewed – without compromising safety and excessive risk." This implies:

1. The need to re-invent on a system level. Since succeeding in their disruptive innovation, many industrial sectors have operated within an environment of incremental development and evolution for a long period, and their design processes have evolved to suit. It's a long time since they experienced the need for disruptive innovation – many of those working in these sectors have never done so.
2. Although engineering is also important within those evolutionary phases, the engineering contributions in early, disruptive phases of new products is critical and of a different nature. It requires a specific culture, mindset, tools and methods.
3. Designers require new skillsets. The next generation of engineers must not work in isolation, but instead act in an "Integrated eco-system" of companies, combining units of expertise and synchronise this with many different societal actors. It will be engineering rather than science that meets the societal needs and the sustainability challenges. There will be a need for fundamental scientific and engineering knowledge, but in addition also deep expertise in digital techniques and communication skills. The future of disruption, both in emerging needs and new knowledge, provides an opportunity for product developers (and engineers/designers in particular) everywhere!

These sentiments were echoed by Christopher Jouannet (SAAB Aeronautics, SE) who argued that to solve the systemic problems, "good engineering" in traditional disciplines would not be sufficient. A design approach is required that articulates and attends to new, systemic problems. Many disciplines will need to come together to innovate, not only within engineering but also with non-engineering expertise from fields such as law, social, science, economy and other areas not traditionally engaged in design.

All industry speakers made it clear that these challenges cannot be addressed by a single company but require collaboration across the entire supply chain ecosystem. Niina Aagaard (Nordic Innovation) emphasised that the need to act in collaboration goes beyond supply chains, to the need to form regional and potentially cross-national clusters where companies can work together and learn from each other. Robin Teigland (Professor of Strategy and Management of Digitalization in the Entrepreneurship and Strategy Division at Chalmers) gave a talk on systemic innovation in Peniche, a traditional fishing community in Portugal which struggled due to declining fish stocks, as an example of the possibilities that creative collaboration offers. She works with the Peniche Ocean Watch (POW), a new economic multi-disciplinary ecosystem that builds on the community's traditions and takes a bottom-up approach. For example, they are working with the Norwegian drone company, Birdview to use an AI-enabled drone reconnaissance service to locate and identify fish stock. This reduces the carbon footprint and freeing up the fishermen's time. One activity, that this enables, is the collection of used and damaged fishing nets can be turned into pellets for the large-scale additive manufacturing (LSAM). Currently they are working with Swedish Sculptur and Ekbacken Studios to design and produce high performance furniture from the fishing net pellets using LSAM, but the long-term goal is to 3D print boats.

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5. The breakout groups

The breakout themes focussed on engineering design practise, rather than technological trends. While the themes were identified before the workshop, they resonated very much with the topics brought up by the keynote speakers (during ICED) and the inspirational speakers from the same morning. The first topic focussed on the need for collaboration across companies, engineering disciplines and the wider stakeholders. This collaboration is an important enabler for radical innovation, which can take engineering companies out of an incremental improvement mind set. One of the main rationales for innovation is sustainability. To address these challenges engineers will require different skills and the ability to operate in different ways of working.

5.1. Design of multidisciplinary solutions

One challenge in the multidisciplinary design for realising sustainable innovation is overcoming the "power struggle" between traditional disciplinary systems and to create a co-creation culture. This is seen on a technological level as well as a regional, organisational and institutional governance level. The future solutions and their value rely on integrated and synchronised solutions involving different areas of expertise such as electrical, mechanical, software or chemical engineering as well as, computer science or maths, as illustrated in figure 2.

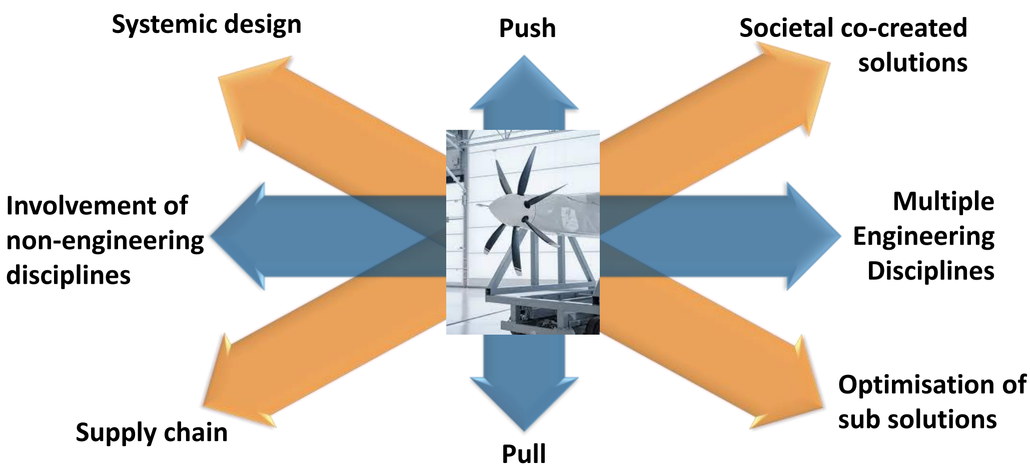

Figure 2. Tensions in focus for realising multidisciplinary design

In addition to "classical" multidisciplinary design in engineering, which optimises the trade-offs between thermal, mechanical, and electrical effects, more systemic dimensions need to be included such as the socio-ecological impact of technologies and materials. Technologies and materials are typically provided by suppliers who need to be brought into the product development process. Companies and their suppliers need to engage in even tighter co-creation with societal stakeholders. In addition, it will be a very important role for engineering designers to facilitate the integration of engineering disciplines and "non-engineering" disciplines, such as legal, political, social science, whose insides need to be more firmly integrated with the functional units, that create the product specifications. The ability to communicate between such diverse disciplines will become even more important. The interplay between engineering and science needs to be revisited as science bring new insights yet rarely offers pathways to applying them. At the same time the underlying science for new radical solutions is still missing. The risk of bringing immature technologies to the market is high, because the actual scientific effort and time to understand technologies may be longer than industry can afford.

5.2. Design of disruptive solutions vs evolutionary design

Sustainable innovations are likely to require disruptive innovations, not "only" radical innovation. According to Christensen's "The innovators dilemma" (Christensen, 2016), a disruptive innovation completely changes the scenery for the actors and the products on a market, e.g., by realising new

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business models or introducing new technology, that open a much wider market. Disruptive innovation may or may not, rely on novel technological advancements. In established manufacturing industries, radical vs evolutionary design predominantly addresses the level of newness (radically) of technological solutions, that can improve already existing products targeting an existing customer base. This is also relative to the present technology in use. Radical technologies may be a part of the next generation products and systems, but these also have to co-exist with existing solutions over a relatively long period of time. One example is the societal infrastructures such as roads or buildings that exist over a relatively large time perspective. This highlights the need to include a wider set of stakeholders in the set up. It also points to a managed transition to new technologies, where many systems will be gradually replaced or advanced.

Larger established companies are frequently leading the way in advancing radical technologies but rely largely on established business practices. However, there is also an openness within established organisations to embrace new ways of working; to be prepared and agile for future scenarios. Frequent steps to realise disruptive innovation are through mergers and acquisitions; or established companies starting new companies and brands to foster innovation. To foster innovation, the culture within organisations needs to raise awareness for the need to innovate to address societal challenges.

At present, industry is missing the practices, tools and methods to achieve more sustainable innovation. As complexity increases, it is becoming more difficult to quantify key measures, such as sustainability. There is a paradox that resource efficient, circular solutions may require simplicity and clarity. The ability to make trade-offs between different sustainability goals e.g. waste management, energy management and longevity in designed solutions is not apparent. What seems most "sustainable" from a shorter perspective, may be unfavourable in the long term as it risks making products and systems less agile. A life cycle perspective is often lacking, or at least difficult to include in a design situation.

5.3. Design of sustainable solutions

For companies to be able to transform to a more sustainable and circular economy, they need to change their business models. This also means that companies need to be able to clarify and define business benefits and risks for different choices, consider different time perspectives and how to create common values among stakeholders in the socio-technological ecosystem, and to translate risks and opportunities into tangible design. Offering life cycle solutions means that the manufacturer takes a greater risk upfront and brings in another element of uncertainty for these companies.

To meet sustainability targets, not only technologies and solutions from companies are needed, but an active push from other agents is too. Governments need to set requirements, investors need to demand that sustainability targets are met, and key stakeholders, such as cities and regions to need create incentives for the development of more sustainable solutions for the market. Feedback loops which increase or decrease costs, can influence decisions in companies for more sustainable solutions and are important control mechanisms, e.g., legislation, increased tax, bonus, tax reduction etc.

Many existing tools and methods, developed both in academia and in industry, still need to be adapted to be applied in product development processes. Specific decision-support is required for the following areas:

- digital models, including sustainability requirements to visualise consequences early in the innovation process, e.g., simulation models to optimize for more sustainable solutions.
- sustainability criteria, which enables companies to avoid sub-optimisation by identifying and prioritizing aspects of sustainability which address all dimensions of sustainability and all product life cycle phases.
- key performance indicators, for sustainability in suppliers and processes to monitor defined targets to generate impact further up in the value chain

To be able to integrate sustainability in daily engineering work, sustainable design should be a core skills among engineers.

5.4. The designers of tomorrow

The engineering workforce is becoming more diverse including more women and coming from a broader geographical background. Emerging directions for design skills, knowledge and expertise are

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already shaped by the recent and current evolution of engineered systems towards heterogeneous / multidisciplinary systems integration with user centric servitisation features. As products become more interdisciplinary, so will the design teams and the skills basis of organisations, so that the future engineers will require a broader socio-technical skills base, to collaborate effectively across disciplinary boundaries and more importantly carry out cross disciplinary trade-offs. Developments in technology for design, in particular digitalisation, require engineers to embrace design meta-skills, to exploit the increased speed of simulation and analysis for greater exploration of design spaces, and have the courage to be creative. A high degree of mathematical and computational skills will be required to handle rapidly advancing simulation and analysis tools. Design engineers will need to understand how to handle, analyse and interpret the insight from ever increasing data sets to accelerate product development and enhance robustness of systems. At the same time, they will need a greater awareness, understanding and operational knowledge of sustainability and ethical responsibility that is expected to be embedded in design. Typical skill sets will include:

- Master Integrators: This requires going well beyond own area of technical expertise, and to take a full value chain perspective, to spot, translate and leverage creative connections across all the relevant technical areas, the commercial landscape, and the broader business context, to accelerate the innovation pipeline
- Problem Explorer: Expected to go beyond problem finding and problem fixing and to be able to convert complex challenges into exciting growth opportunities with agility and optimism using a player mindset. This meta-skill allows him/her to engage colleagues and build winning partnerships that unlock hidden value in innovation.
- Domain Knowledge Custodians: This requires deep domain expertise as well as a solid foundation in engineering. Their responsibility is to create and analyse detailed solutions and identify problems that will arise from the details of implementations and the practicality of use.

As technology and working practices change, engineers also need to upskill and evolve throughout their careers. This puts an onus on engineering companies to provide a learning culture and ecosystem, which will also become a strong factor in recruiting, developing and keeping skilled engineers. Lifelong learning needs to be at the core of career pathways which to enable expertise development on the job with rewards and progression following demonstrated technical mastery in combination with true business acumen. The learning journeys must be individualized to a greater extent to reflect the different starting points of the individual engineers but also the diversification of roles. Companies and individuals need to be willing to invest and collaborate for competence development. In particular, the development of deeper knowledge and expertise required for domain experts requires significant investment of time and resources, which will likely go beyond what a single company is likely to be able to provide.

In short, this calls for greater investment, collaboration and integration for learning across multiple companies and multiple universities to develop and validate domain expertise and experts. In turn, this will likely open opportunities for engineering design and domain experts to offer knowledge and expertise as a service as a sustainable pathway for domain experts. New methods of gaining knowledge and credit from microlearning are required.

5.5. Design and Development work practices of the future

The ongoing pandemic has demonstrated the ability of humans and society to adapt and change. Remote working instantly became the norm in many organisations, remote collaboration has become widely accepted and technology has enabled new ways of working. This gives ground for optimism that companies can also to adapt to meet sustainability threats and challenges.

There is a wider push in the area of digitalisation, with digitalised ways of working within design and development becoming widespread. Technologies offer tremendous opportunities to share information nearly instantaneously and to gather and process vast amount of data. However, this is not without its risks. Historically technology and engineering have solved many issues yet created new ones as

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consequences were not thought through. This is limited by current experience and understanding and requires long term and systemic thinking.
The ability to instantly communicate and collaborate across distances in combination with the abrupt shift to remote working (from home) has its upsides and downsides. Reduced travelling is positive from an environmental perspective, and in many cases, for individuals and their family life. Family life illustrates how these changes can be a double-edged sword: that closeness to home opens the possibility for a stronger and simpler family life, but conversely brings work into the home, making a clear demarcation between private and professional life harder as employees become accessible 24/7. The practical advantages of digital meetings notwithstanding, face to face meetings provide additional "bandwidth" which is well known to be important for innovation and gives the opportunity for serendipity.
Work practices have already changed and will continue to change at a pace, many organisations and institutes are not well prepared to handle. Homebound work as one example, raises many issues, for example greater autonomy of engineers needs to come with increased trust and delegated responsibility, that employers place in their staff. The digital context also raises ethical concerns related to integrity, decision making and trust.

6. Panel Discussion

As the questions from the breakout group participants arose, the panel discussion picked up on many of the issues discussed above, such as the need for holistic sustainable systems, effective knowledge management or live long learning. However, the mixture of perspectives across the panel, coming from industry, academia and professional organisations, brought up a number of new issues that have not been highlighted before, around the collaboration between academia and industry and the role that policy makers, can and should play.
To meet the challenge the planet is facing, industry and academia need to operate in a joint up innovation ecosystem in which tools, people and skills can shared. For example, at present many engineering tasks require expensive proprietary software, which is prohibitive for small businesses to purchase and makes large companies reluctant to explore new approaches. While academia develops new tools, the time scales to implement them is rather slow, why a closer collaboration between industry and academic is required to obtain faster solutions. To achieve this, skilled academics and industry experts needs to be freed up to devote their time and expertise to tackling the current challenges. At present, professors typically spend a very substantial fraction of their time on administration and bidding for competitive grants. While an element of competition increases quality, the present system is wasteful. Therefore, more stable funding mechanisms, and governance is required. Similarly, different companies developed expertise, that would be highly beneficial to non-competing companies, but few mechanisms for sharing this exist. Experts in academia and industry would benefit from new ways of sharing their knowledge and gaining internal and public recognition for it. In parts this ecosystem already exist and lessons can be learned from this. Inspiration can be gained from the open source or gaming community where shared tools that support their ways of working freely. Different countries have their own successful mechanisms for collaboration between industry and academia.
This requires better collaboration with policy makers. To achieve our sustainability goals a vision of these goals is required. For example, Norway set the clear goal, that all domestic flights are to be electric by 2040. This opened up new markets and gave electric plane companies, such as Heart Aerospace, the courage to start. To achieve these goals, both radical innovation and incremental change will be necessary. The means that the overall goals need to be broken down into ambitious, but realistic subgoals, that companies have a chance to meet. Engineering companies also need to understand when they have met the goals and be able to communicate this. This requires a set of clear measures that companies can assess their solutions against. However, this is not an issue of narrowly optimising particular products to meet thresholds, but to take a systemic look. It needs to be clear what success is measured against. For example, electric cars have many benefits for those in the immediate vicinity of cars but have serious downsides across the supply chain. Clear goals are also important in enabling technology pull by companies. For company to have clear requirements, and a creativity and

holistic way of generating requirements, they are usually able to find suitable technology, which can be accessed through an improved collaborative ecosystem.

7. Conclusion and Recommendation

Design is an integrative discipline, focussed on exploring and understanding diverse and complex needs, and combining technologies and resources to develop sustainable solutions. Design skills and approaches are needed to realise innovation. The design skills and approaches currently dominating are based mechanical and/or mechatronic products. Now immaterial and intangible aspects need to be combined with emerging technologies to create integrated solutions.

Concluding observations from workshop and panel discussion:

- *The Sustainability Challenge has no short cuts*. We need to acknowledge and accept the systemic dimension of sustainable development. Searching for simple answers risks driving sub optimisation and causing non-intended consequences. Hasty actions may create new problems. Changing our society will also take time, fundamental skills such as improving systemic and life cycle perspectives need to be the basis for durable initiatives. As sustainable innovations are likely to also involve our own behaviour, the engineering design approaches will need to be able to include impact on behaviour.
- *Innovative solutions are needed*. Transformation to sustainable solutions will be based on new ways of thinking and solving problems. Disruptive solutions do not need to be more complicated and can often incorporate existing solutions. The nature of expected innovations will rely on the ability to co-create and collaborate to succeed.
- *Engineers need to think and act systemically*. Systemic and life cycle thinking are needed. Engineering skills need to include both technical skills and soft skills such as ethics, entrepreneurial skills, and interdisciplinary communication. These also serve to attract people who are motivated to make a difference, into engineering programmes at universities.
- *Ambitious and achievable goals*. Governments need to set and articulate goals for companies to relate to. The success of e.g. the UN2030 SDG's demonstrates the power of relatable goals as normative values and inspiration. To complement these, firm statements on ambitions and commitments are also needed. Progressive emission regulations are examples of the latter, however, precise measures risks putting the focus on single objectives, such as CO2. None of the sustainability goals can be seen in isolation.
- *Proven adaptability and resilience*. Engineering companies instantly implemented remote working when COVID-19 started. Agile practises are being implemented to enable software intense solutions in the manufacturing industry. The ability to act on sustainability challenges is gaining attention, but an imminent threat is stronger than strategic drivers. Unclear risks and consequences do not act as strong drivers for innovation. Many engineering organisations put huge effort in firefighting (delivery) or cost driven optimisation, while sustainability champions are often not integrated into the overall organisation and may need to shout to be heard across the organisation.

There are a number of practical steps that could be undertaken to support the transition to a more innovative engineering design culture

- *An innovative education and knowledge ecosystem*. The transformation of skills requires innovative educational system solutions, where industry practitioners can interact with university students, researchers, and educators. To share the development of relevant knowledge (research) that can be used for education and change, set the focus on the quality of knowledge generation and transfer. The governance and effectiveness for developing such an ecosystem will need to go hand in hand with incentives and opportunities. Sustainable development will become the new norm with a more sophisticated understanding constantly evolving. Research in engineering design needs both to develop an understanding of the problems originating from global and sustainable challenges and make recommendations and show case best practices based on the same understanding. These recommendations need to

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address the transformation of current practices more than developing "ideal" recommendations.

- *Develop design as a key cross disciplinary skill in engineering education.* Industry needs to advocate the importance of developing a generation of problem solvers, using their knowledge in science and engineering to develop solutions to complex and systemic problems. A focus could be on creating a critical mass of advanced leaders and specialists in sustainable engineering design transformation.
- *Communities of practise across organisational boundaries,* which offer incentives sharing and developing sustainable practices and challenges. "Roundtables", "inter-organisational trainee programs" offer means of sharing insights and experience; and inspire to business development. Sustainable innovation, in particular, depends on collective and collaborative efforts, where norms, practices and insights in sustainable innovation benefit from being established in a wider sense. Standards and agreements need to be developed and deployed. Businesses require incentives for B2B sharing of sustainability knowledge.

The workshop brought forward examples and insights, that would benefit from being investigated and transformed into concrete actionable steps. Some issues are difficult and abstract, and require fundamental research, whereas others can be addressed via sharing and acting once the awareness exists. Other may require investment, into developing widely useable support tools based on existing and proven knowledge. While multiple approaches to sustainable development exist, a collective understanding of when these are most effective need to be advanced. For example, while Circular Economy solutions may be brilliant in some situations, they may not necessarily be the best approach in all situations.

What came out clear was the expectations that engineers in general, and engineering designers in particular, have an increasingly strong role to play in realising sustainable innovation. It is imperative that value of design and technical design expertise as the enabler of change and innovation in the material world is recognised. The main reason is because we need to understand and transform needs into novel solutions, which is in fact, is close to the definition of design.

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