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Co-evolution of design research and industrial development: empirical insights from European manufacturing companies

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ABSTRACT

While many studies have analysed societal and technological trends, what these imply for product development practice is less clear. However, engineering design research has typically responded to existing challenges in industrial practice, instead of looking forwards to create tools and methods in parallel with technological developments. This paper reports on the findings of a three-stage process with 12 interviews and two workshops, in 2018 with ca 50 participants and 2021 with ca 100 participants. Experienced engineers working on complex engineering products and engineering design researchers reflected on developments in engineering, which were analysed from the perspective of how they would affect design practice. The paper summarises trends the participants identified in manufacturing, energy, transport, digitisation, product design and product development practice; and highlights differences in expectation between 2018 and 2021, in particular around the speed in which sustainability policies and changes to work practice are adopted. The paper analyses the interaction of trends, pointing to the increasing interaction of products with each other and with services, and the implications of the rapid advances in digitalisation, which increase the need for disciplinary integration. The paper ends with a discussion of research questions arising from the analysis in this paper.

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Trends in product development; empirical studies; future of engineering design

The imperative for change in design practice

Technology is constantly changing and so are the societal and market needs for new products and production techniques. Design researchers need to understand these new needs and develop design techniques in a changing world. A too strict focus on technological advancements to meet new needs is arguably too narrow, as technology is only as good as the designers' ability to integrate it into products and solutions that address these needs. The academic design research community sees one of its main roles in supporting designers in industry to design in more efficient and effective way and thereby generate better products (e.g. Blessing and Chakrabarti 2009). However, to date, this support is largely reactive

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with a built-in time delay: problems in industrial practice are analysed and tools and methods to overcome them are proposed. This approach requires a radical rethink so that new tools and methods are developed in parallel with new technologies and other anticipated changes to industrial practice, so that they are ready when they are required. Unless this can be achieved, the tools and methods that are available become a hinderance to addressing urgent industrial social needs.

This paper reports on one such endeavour, where academics and industry experts came together to discuss changes in product development processes that they foresaw. The focus is on engineering design in product development rather than the wider business processes included in product development.

Companies typically have long-term technology strategies or product strategies drawing on market analyses or technology forecasts or forecasting methods, but equally need a strategy for adapting or advancing their development processes to put the skills, tools, methods and processes in place to achieve their goals. The challenge is to understand where new practices need to be developed, so that the theory and techniques to support them can be put in place by the academic community, and companies can plan for adaption. On the same note, universities face the expectation that they will provide engineers with new knowledge and skillsets, often at short notice.

This paper analyses design and development impacts of trends reported by interviewees and participants of two industry/academia workshops in 2018 and 2021, to learn how design processes of complex engineering products in established companies are changing or are about to change. The study was looking for emerging behaviour that is likely to become more prevalent in the future. The purpose of the study was threefold:

- To encourage industry leaders to take a long-term perspective on adapting their skills, processes, tools and methods.
- To call the engineering design research community to arms to be proactive in addressing future challenges.
- To inform the teaching of undergraduate and postgraduate students as well as lifelong learners

The participants of the study represent different sectors and countries, but all were involved in the development of complex engineering products and systems with long life cycles, such as cars, aircraft, production equipment or batteries. These products are often designed and produced for 20 years or longer; and have long planning cycles. For example, Norway has announced its intention to operate solely electrical aircraft on domestic routes by 2040.[1] To be ready for this, aircraft companies need to reduce their development time and embrace innovations, such as lightweight materials or effective batteries, and build up trust in design solutions for new products to be certifiable in time. In the aerospace business, there is a large understanding that a step-wise development strategy is needed, typically stretching over many years and even decades. Some key concepts in product development practice also have a long take up time. For example, agile processes were discussed in computer science since the 1990s (Fowler and Highsmith 2001) and are still seen as up and coming in mechanical engineering (e.g. Albers et al. 2019). Similarly, additive manufacturing goes back to the 1990s, but how to benefit from it most in product development is still an active research area (e.g. Schmitt, Zorn, and Gericke 2021).

The paper begins with a brief discussion of the different efforts to understand future developments by academics, public bodies and industry, before describing the methodology of the study. The following section summarises typical trends mentioned by the participants and discusses the changes in emphasis between the two workshops in 2018 and 2021. We present an analysis of how engineering companies are likely to be affected by the highlevel challenges that these trends bring, including research questions that arise.

Forecasting the future for product development

Dator (2019, 4) points out that 'the future cannot be predicted because the future does not exist … but alternative futures can and should be forecast … [and] preferred futures can and should be envisioned'. The field of future study concerns itself with forecasting envisioning and transforming the future along six pillars (Inayatullah 2013): (1) Mapping the past and present (2) Anticipation of the future by picking up on weak signals and emergent phenomena (e.g. Borjeson et al. 2006). (3) Timing patterns of change. (4) Deepening an understanding of the future through a systematic analysis. (5) Create scenarios of alterative futures. (6) Transforming the future. By expressing and visualising potential futures, a dialogue becomes possible (Gall, Vallet, and Yannou 2022). The identification of trends forms part of the first pillar. The term trend refers to a 'general development or change in a situation or in the way that people are behaving' according to the Cambridge Dictionary.[2] In a statistical sense the term trend is usually 'considered as a smooth additive component that contains information about global change' (Alexandrov et al. 2012), however the details vary (Bryhn and Dimberg 2011). In fashion, the term trend refers to aspects of the appearance and construction of fashion products that relate to a particular season or time in history. Fashion is 'an expression of the times' (Perna 1987), which manifests through trends, i.e. periods of mass adoption that vary in longevity (Jackson 2007). While some effort is made the analyse fashion trends statistically from images (see e.g. Mall et al. 2019), fashion trend prediction is usually impressionistic and based on the experience that where some lead many others will follow. **In this paper, trends are seen as emerging behaviours that are likely to become more prevalent in the future**.

The European Strategy and Policy Analysis System (ESPAS 2019) summarised a similar mindset in a report for the European Union as: 'We may not be able to provide a linear, predetermined chart – from port of departure to port of arrival. But what we can do is extrapolate insights from current global trends; explore some of the key uncertainties that will shape Europe's future; and better anticipate some of the choices and decisions that might confront us in the coming decade'. As such, scenarios of the future are one way to explore possible pathways and analyse their implications.

Predicting the future of the engineering

Predictions of the future for engineering fall into several categories: those that highlight the problems that will occur and therefore need to be addressed, and those that analyse the emerging technologies and therefore the opportunities that are afforded in the future. Most studies contain elements of both.

There are many reports and literature of different forms that address the future of engineering. The widely recognised UN Sustainable Development Goals[3] has a global influence on national agendas and investments, not at least in R&D, skills development and transformation in national and regional agendas (EU 2016). Forecasts of what the future holds for education in engineering identify skill gaps amongst employees (IET 2019). Another type of influential reports are technology-specific roadmaps, such as the roadmap for automotive propulsion technologies towards 2040[4] or the digitisation roadmap by the Institute of Digital Engineering (IDE 2021), outlining what products may need to be designed and developed.

Governmental and political organisations, such as the European Union, commission forecasts to shape their policies and funding target areas. Non-governmental organisations conduct research into likely futures to highlight the urgency of their agendas, influence policy makers, or inform their members (see e.g. Design Council 2018). However, companies also analyse trends themselves to plan their future product offering and be ahead of their competitors in entering new markets. There is a tacit assumption that as industries invest in technologies, the design capabilities 'come for free', however, there have been some activities predicting product development trends. National funding agencies, such as DARPA, address the strategic interest in understanding how to combine design with technology development to maintain or gain market share.

Trend studies in industry

Companies carry out their own studies in different industry sectors, for which systematic approaches have been developed. Since the 1950s, technology forecasting has been carried out systematically (Rohrbeck, Battistella, and Huizingh 2015). This is usually focussed on a particular technology, for example, Makridakis (2017) who reviewed AI trends and their impact on society and firms. He discussed the relevance of accuracy in prediction by comparing his 1995 paper (Makridakis 1995) forecasting the state of information technologies with practise in 2015. He found that he had largely correctly predicted the implications of technologies already identified as trends by 1995, such as the societal and market impact of the Internet. The innovation literature seeks to understand conditions for innovation based on how technologies have been used to transform the market. Yoon, Lee, and Hwang (2022) described the recent mobile industry transition as an episodic change.

Studies of the impact of industrial trends on product development practices are however less frequent. Finger and Dixon (1989) reviewed the state of art of mechanical engineering design capabilities, and their analysis of gaps are ignited the academic community and is in some ways still relevant.

Technology roadmapping

Technology roadmapping has been carried out by governments and companies since at least the 1980s to understand how a particular technology is likely to develop, and has been applied more widely over the last 20 years to include political and societal change (see Kerr and Phaal 2020, for an overview of the history of technology roadmapping and de Alcantara and Martens 2019, for a systematic overview of the literature). 'A roadmap is an extended look into the future', which inventories the possibilities of a technology. It can elicit fundamental support for technology (Galvin 1998). Roadmaps can act as boundary objects between different stakeholders (see Star and Griesemer 1989). A technology roadmap combines a technology forecast with product planning and resource allocation and shows the interactions of markets, products and technologies (Phaal, Farrukh, and Probert 2001). It is usually developed by a group of experts through workshops, who – depending on interest – follow different systematic steps and generate prescribed visualisations (see, for example, Phaal, Farrukh, and Probert 2004). The emphasis can either be on a single technology over time, in particular new and potentially disruptive technologies (see Kostoff, Boylan, and Simons 2004) or map out multiple technologies deployed within the same organisation over a given time horizon, typically 10–20 years. Technology roadmapping has been criticised for not being sufficiently adaptive and missing changing customer perspectives (Kim, Beckman, and Agogino 2018).

Technology scouting

Technology scouting is a systematic approach by companies whereby they assign part of their staff or employ external consultants to gather information in the field of science and technology and through which they facilitate or execute technology sourcing (Rohrbeck 2010). The process is carried out by internal experts or consultants, who draw on large formal and informal networks (Wolff 1992). It can be directed at a specific technological area or looking more generally for promising new technologies. The goals of the process are to identify technologies and trends early and raise awareness for opportunities and threads and thereby stimulate innovations. The scouts visit trade fairs and look at academic publications and maintain a personal network with key suppliers or academic institutions to assure not only awareness of trends, but also a pathway to acquiring them. Potential technologies are identified, selected and assessed before they are disseminated to interested parties in the organisation (Rohrbeck 2010). In particular, the process is applied to open innovation sources (West and Bogers 2014; Boisseau 2018).

Prediction of trends in product development

Some attempts have been made to forecast the future of product development in general. Coates (2000) outlined a number of trends in his agenda for the future of engineering design, including the ability to master the increasing complexity of a connected world, for example, affordable housing for the developing world, embracing nano engineering and more. It also demonstrates some of the pitfalls of predicting the future, such as the uptake and global penetration of mobile connectivity, which has had effects that were difficult to imagine only 20 years ago. Other researchers have addressed future needs in particular areas. For example, Heisig et al. (2010) conducted a survey into the knowledge and information needs in engineering, capturing contemporary practise and future expectations. They found that engineers assumed the solutions to their current problems would be trends in the future. With European partners, the same team also developed a roadmap for research on modelling and managing engineering processes (Heisig et al. 2009) with ambitious time scales of resolving research issues by 2020. While some research has gone on in the meantime in this area, the overall themes are still as current as they were.

The gap lies in understanding how different technological trends might come together and affect the engineering design practice in the future.

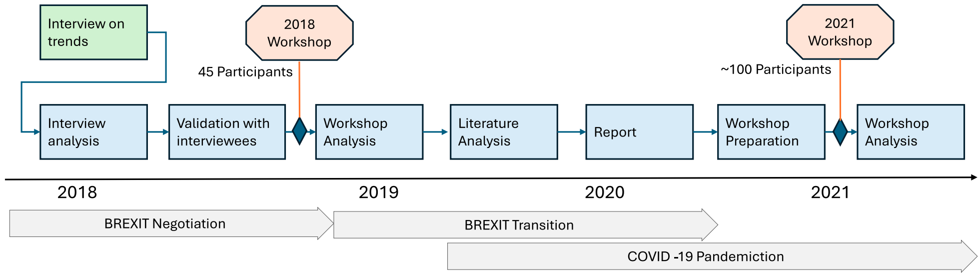

Figure 1. Overview of the methodology.

Methodology

The methodology followed a highly iterative and interactive process, as illustrated in Figure 1, where the results from previous steps were shared widely with the participants of the next step. In the spring of 2018, a first interview series was conducted with 12 industry experts in large well-established manufacturing companies. They all had key roles in product development in their respective organisations, and were also experienced in product development research, and so were all in a good position to reflect on several dimensions of product development practice. The overall objective was to capture the common challenges for industry to develop next generation products. An analysis revealed issues that were used to organise a 2 two-day workshop in September 2018 to which 50 experts from industry and academia were invited. Results from the interviews and workshop were compiled into a report (Isaksson and Eckert 2020). The most pertinent areas that arose from analysis of the interviews and the 2018 workshop were used to structure a workshop in 2021 with nearly 100 participants.

Selection of the participants

The study was designed to encourage the participants to freely share their ideas, express their concerns about the future and be open about their interpretations for development in the future. This required individuals who were able to reflect on their current and future practice. The authors knew the interviewees (Table 1) and most of the participants of the first workshop (Table 2) personally and selected them because they were experts who took a long-term perspective and had in the past been willing to share, but were also happy to have their views challenged. As the aim of the study was to foster discussions in and between industry and academia, the participants were selected to offer complementary views coming from different roles and industry sectors.

As the workshops were held in Sweden, most of the industry experts represented Swedish-based companies, however, experts from the UK, Germany and Ireland look part in the interviews. Except for the second workshop, where North American academics took part, all participants were European.

The interviews

The interviews were a rare opportunity for the participants to step back and reflect on the future of product development and engineering design. The interviews were held in English

Table 1. Interviewees. Participants with ∗ took part in the interviews and both workshops.

Company	Country	Range	Sector	Size	Product	Area of expertise
Volvo Trucks*	SW	global	Automotive	Large	Trucks	Configurational design
Husqvarna	SW	global	Consumer products	Large	Forestry and gardening equipment	R&D strategy
Saab*	SW	global	Aerospace	Large	Aircraft	Engineering methods
Inocean*	SW	SW	Energy	Small	Offshore turbines	Project lead
AVL	DE	global	Automotive	Large	Electric powertrain	Batteries
Trumpf	DE	global	Manufacturing equipment	Large	Laser cutters	Product platforms
MAN	DE	global	Automotive	Large	Trucks	Product strategy
EireComposites	IR	EU	Manufacturing	Medium	Composites	CEO
Perkins	UK	global	Automotive	Large	Diesel engines	Design processes
Airbus	UK	global	Aerospace	Large	Aircraft wings	Systems engineering
Rolls Royce	UK	global	Aerospace	Large	Jet engines	Systems engineering
Energy Catapult	UK	UK	Energy	Small	N/A	Modelling and simulation

Table 2. Participants in the 2018 workshop. Participants marked with ∗ also took part in 2021 workshops.

Companies	Volvo Group, Volvo Car, SAAB, AIRBUS, GoCo (Gothenburg Co Valley), Inocean, Astra Zeneca, GKN Aerospace, SKF, CoClear, Zenuity, Essity, CEVT, Teradata
Universities	Blekinge Institute of Technology∗, University of Bradford∗, University of Cambridge, Chalmers University of Technology∗, Jönköping University, Karlsruhe Institute of Technology, University of Liverpool, McGill University∗, Mälardalen University, Université du Luxembourg, Luleå University of Technology∗, The Open University*

or Swedish by one of the authors and three of the interviews were conducted jointly. All interviews were recorded, and the interviews conducted in English were transcribed. The participants had between 8 and over 30 years of experience and were selected to cover a range of industry sectors. The conversation with the participants centred around three open questions in the context of engineering in product development:

- What trends do you foresee?
- What skills will be required to address future challenges?
- What can universities do to support you in this?

The interviews were intentionally semi-structured, where the participants could reflect on their expectations for their industry sector and their own companies, which brought up a mixture of technological and design process-related issues. The topic of skills covered both current and existing skills and the challenges of hiring people with relevant skills as technology changes and new synergies are required. The responses represent the individuals' experience and expertise rather than their employers' standpoint.

The workshop in 2018

The first workshop was carried out over two days in September 2018 in Gothenburg. The first day was hosted by GoCo, an organisation set up to develop an innovation arena south of Gothenburg, and the second took place on university premises.

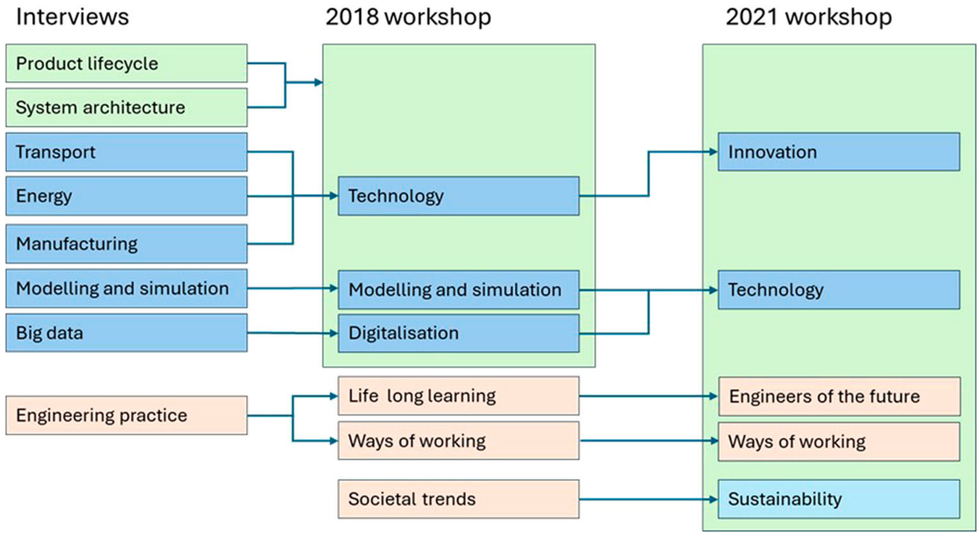

Figure 2. Evolution of the topics between the interviews and the workshops.

The participants were a combination of industry experts recruited from the network of the authors and typically had between 10- and 30-years' experience as well as company representatives invited by GoCo. The international academics are collaborators brought together via special interest groups on design process and design practice in the Design Society.

The workshop started with a keynote on sustainability trends affecting engineering design and a summary of trends identified in the interviews.

For the first day of the workshop, the participants were placed into 6 groups of 4–6 participants and rotated through 6 thematic stations, each led by an experienced academic after 30 min of discussion. This enabled the participants to get to know each other and develop ideas together. The themes emerging from the interviews were abstracted and regrouped to focus on trends in product development rather than technology development, as shown in Figure 2. Social trends were added as a theme to encourage the participants to reflect on the social trends that will affect engineering practice. As the authors knew the participants, see Table 2, the groups were carefully assembled to get a balance of industrial engineers and academics as well as different sectors and a mixture of reflective and extrovert people. Representatives from the same organisation were split into different groups.

The second day was less structured. The participants formed three groups, reflected over the discussions on the previous day and discussed the resulting research questions and teaching requirements. The group discussions were documented and presented to the other groups.

The workshop in 2021

The second workshop was set up on the last day (August 20th, 2021) of the 23rd ICED conference as a hybrid on-line and on-site workshop. 50 people attended physically, split on two sites in Gothenburg, and close to 50 attended on-line. All ICED delegates had an open

Table 3. Interviewees. Non-academic participants giving input in inspiration talks and/or in the panel.

Company	Country	Range	Sector	Size	Product	Area of expertise
Volvo Trucks*	SW	global	Automotive	Large	Trucks	HR
Volvo Car	SW	global	Automotive	Large	Cars	R&T
Saab*	SW	global	Aerospace	Large	Aircraft	Engineering methods
Heart Aerospace	SW	SW	Aerospace	SME	Aircraft	CEO
Nordic Innovation	Norway	Region	Government	SME	Policies	Chief Operations Officer
Förvanda	UK	SW	Complex Products	SME	Strategy	Research Strategy
GKN Aerospace	SW	global	Aerospace	Large	Aerospace Technology	VP R&T

invitation to attend, and in addition a number of people were specially invited. The ICED conference had the theme of 'Design in Motion', where a series of keynotes and several papers had addressed the role of engineering and product development in societal and industrial transformation. As Figure 2 illustrates, innovation and sustainability were added as topics and technology was merged with digitalisation. *Ways of working* were kept as a topic and *Lifelong Learning* was widened to cover the general skill and training issues.

The workshop investigated the role of product developers and engineering designers in realising products and solutions for sustainable innovation, see Isaksson and Eckert (2022). The workshop had as the 2018 workshop, inspiration talks before dividing into thematic group work sessions. The findings of the interviews and the 2018 workshop were presented to all participants. At the end of the workshop, there was a facilitated panel discussion with invited participants, who gave their views on the findings and responded to audience questions. Table 3 lists the invited participants.

Analysis

The interviews were recorded and transcribed. The first author conducted a thematic analysis (see Braun and Clarke 2012) around the three questions, identifying and grouping key trends and looking for different wordings for similar phenomena. The interviewees also commented on a wide range of topics such as migration, globalisation and Brexit. The analysis focussed on the comments about engineering design practice. The issues mentioned depended on the participants' roles and the nature of their products. For example, the expert from the energy catapult in the UK talked largely about energy infrastructure and modelling and simulating it. Whereas the electric power train expert also mentioned infrastructure but his comments on modelling and simulation were centred on the battery. Therefore, no quantification of relative importance or impact of the trends was either possible or intended. These categories were used to plan the following workshop. Summaries of the interviews were sent to the interviewees inviting them to comment as well as the workshop participants to prime them.

At the end of the first day of workshops the academics running the stations summarised the themes they saw coming through at this point and the group discussed the findings. These summaries formed the basis of further analysis. The authors headed two sessions and discussed their insights with the colleagues running other stations.

At the second workshop, the talks were recorded (video, audio) and transcribed when they touched on relevant topics. Workshop participants captured their contributions in shared, online Miroboards. The breakout group leaders summarised their findings before the panel discussion at the workshop and provided written summaries after the session.

Throughout this process, the topics also evolved between the interview studies and the workshops, see Figure 2. The 2021 workshop brought in additional topics to reflect the themes of the ICED conference. The boxes represent product development themes that came out of the interview study and were discussed in the context of other themes at the workshops.

Limitations

The findings were gathered from a range of participants who were largely European and working in transport manufacturing, and in consequence, this is a limited study. Although it is likely that technological and societal trends are largely global, the attention and priorities given to the same trends are not. Hence, the attention to topics such as sustainability is likely to be influenced by political and regional situations. Another limitation is the sole focus on predominantly large, established and complex products, and not consumer goods and software intensive products. As such, a focussed survey on global coherence and product type differences is recommended for comparison or validation of the generality of the findings.

Overall, there was little disagreement amongst the participants, who remarked that maybe the group was too homogeneous to bring out different perspectives. However, the prominence given to particular trends was surprising for the participants. For example, everybody agreed that digital driven approaches are becoming more important to product development in 2018. This was again emphasised in 2021 and would probably by one of the main issues if the workshop took place now.

The participants were drawn from the engineering design research community and their industrial collaborators, who in turn invited others to the workshops. In organising the interviews and workshops, it was necessary to strike a balance between inviting experts who are willing to volunteer several days for the activities and an ideal sample set of industrial representatives.

Trends mentioned by the participants

The participants discussed the future of product development practice in the context of megatrends that are widely discussed by the general public and comment on particular issues that will increase in importance in their professional context.

Megatrends in the background of product development

Product development takes place in the background of wider societal trends, such as increasing globalisation, urbanisation and global population (see ESPAS 2019 on megatrends). The need to be sustainable was mentioned in all interviews and both workshops. The notion of the triple bottom line (Elkington 1998) emphasises the interconnected nature of sustainability, where ecological, societal and economic sustainability are seen together as mutually dependent pillars of sustainability (Geissdoerfer et al. 2017). These interconnected dimensions of sustainability impact legislation, regulation and national and international agendas, such as the UN Sustainable Development Goals, the SDGs (UN General Assembly 2015).

Two trends in particular were highlighted by the participants as backdrop to the discussions reported in the paper:

- **Limited availability** of materials, water and energy has begun to impact the lives of many people and the conditions for both societies and industry, and has led to new and innovative solutions. Established materials, such as plastic, and solution principles, such as combustion engines, are being phased out. To increase performance or durability, companies are looking to alternative materials that are scarce like lithium or subject to unethical production methods, such as cobalt.
- **Circular Economy** is being embraced and has become a real success factor. However, the emphasis is generally shifting from purely focussing on environmental factors to also including social aspects (Kim et al. 2020).

Each sector has a slightly different framing of the trends. The following quote from a keynote speaker for the 2021 workshop, which summarised the trends for the automotive industry, is typical for how trends were contextualised for specific businesses or sectors:

> The [automotive] industry is struck by four megatrends: electrification, autonomous drive, more intelligence in the vehicle … [and] shared mobility. – Volvo Cars

The owner of the composites manufacturing company commented on how his business will be affected in the following way:

> There'll be less hands-on stuff and there'll be more automation and the skills will be more engineers, computers and software modelling and rule made test parts but we, you know, probably less production - EireComposites

Summary of the anticipated trends

The participants brought up a number of well-known trends. This section lists the trends and the implications for engineering companies, in terms of the product properties they will have to design for or the changes in design or manufacturing practice. The following list, but gives a flavour of the range of changes the participants foresee.

Table 4 summarises pertinent trends and their implications for engineering design practice that have been mentioned by several participants in the interviews as well as discussion in the break-out groups of the workshops.

Changes between 2018 and 2021

The research described in this paper describes a 3-year journey, which spans the COVID-19 period. It brought disruption to life and work and introduced a shift in awareness and priority on several topics between the 2018 and 2021 events. These are captured in Table 5. The trends and implications were nearly the same in 2018 as in 2021, but their relative importance and significance differed notably. This period saw the partial transition to remote or hybrid working, which was expected in 2018 because of the challenges of recruiting skilled

Table 4. Technology trends.

Trend	Implication on engineering design practice
	Manufacturing
Additive manufacturing	Enables new business models:
	– Mass individualisation
	– Customers make spare parts where and when needed
	– Design houses with local production
	Manufacturing
New materials	– Materials rather than structure as core competitive competence
Robots	– Multipurpose robots for flexible production
	Energy
Sustainable local production	– Increased pressure on national grid
	– Unclear and uncertain subsidies discourage developers
Batteries	– Multiple gadgets powered by same battery
	– Automotive batteries reused in buildings
	Transport
Electric mobility	– Mix of fuels and electric vehicles
	– Require system level change to provide clean energy
Autonomous	– Safety concerns, largely as IT problem
Interconnected	– Journeys as a connected service
	– Shared ownership of cars and batteries
	Digitalisation
Modelling and simulation	– Augmented, mixed and virtual reality
	– Exploration of the behaviour of complex integrated systems
	– Shift from physical to virtual testing
	– Integration of different modelling and simulation applications
Digital twins	– Life cycle of individual products traced
	– Validation of simulation models to enable real time exploration
	– Life cycle information as part of design decision making.
Big data	– Sensors allow monitoring for condition-based maintenance
	– Integration of data with different quality
	– Data collection designed into the product
	– Great optimism around use of AI
	Product design
Product lifecycle	– Fuzzy system boundaries, embracing services and interventions
	– Use of legacy parts / subsystems vs. ability to tailor and optimise
	– Design for upgradability as a part of Circular Economy
	– Difficulty to monitor ownership as manufacturers continue to increase responsibility for manufactured products through life
System architecture	– Clear modular architectures to enable systems design
	– Sharing of modules with competitors shifts focus on IP critical technologies
	– Design the integration of the products with their environments (Systems of Systems)
	Product development practice
Sustainability	– Environmental policy becomes a major driver also for business
	– Need for tools to monitor sustainability throughout the product life process.
Ways of working	– Greater variety of engineering skills, in particular data handling skills becoming core
	– More system thinking skills required
	– Disciplinary boundaries breaking down
Processes	– More agile and resilient processes needed
	– End of the dominance of stage gate processes will amplify
Workforce / Contractual arrangements	– Becoming more diverse: background, gender, entry point
	– Stable core team at company
	– Remote experts with flexible work arrangements
	– Routine tasks done by gigging engineers
	– Robots as colleagues – Co-Robots enter more engineering disciplines
Lifelong learning	– Work force more mobile and responsible for its own learning
	– Collaboration on training between universities and companies
	– Learning ability seen as a competence

Table 5. Shifting focus between 2018 and 2021.

Topic	2018	2021
Remote working	– Mentioned as one of the trends impacting global development work practices. – Building on research since 1990s CSCW (Computer Supported Collaborative Work).	– Companies reported on a nearly instant implementation of remote working, following Covid -19 lock down.
Rising importance of sustainability	– Mentioned as one of the main trends, driving change for reducing CO2. – Automotive industry gave equal importance to autonomous driving and electrification.	– Sustainability had shifted from strategically critical to business critical. – Automotive industry focus on implementing electrified and hybrid solutions with higher priority than autonomous.
Nuanced understanding of lifecycle design	– Focus on efficiency in production. – Focus on introduction of new technologies (e.g. autonomous, electric, …), while companies at the same time need to maintain their established product offerings, production and customer support. – Life Cycle perspectives important, yet not critical in discussions	– Circular Economy surfaced as the main mechanism to realise sustainable targets. – Circular Economy entering companies' top level KPI's for e.g. increased use of re-used and recyclable materials
Lifelong learning	– The participants had a clear picture of the skills that they would need in their businesses and in particular, the new interdisciplinary skills. – Ability to bridge disciplinary skills (e.g. math, programming) with transdisciplinary skills (systems thinking, integration) were raised as critical.	– Much greater recognition that these skill gaps could not solely by filled by recent graduates and that engineers in the workforce would need to upskill to acquire them. – Lifelong learning seen as the means to give them the individual skills profiles they required.

engineers locally. Post-COVID reports on change in practice are appearing (such as Hölttä-Otto 2023) and several changes are here to stay. Sustainability was clearly on engineers' minds in 2018, when they expected that it would become a routine part of all processes, but the speed with which sustainability was accepted and adopted as a key issue was greater than expected. In 2018, it was not clear whether autonomous driving or electrification would come first, but by 2021, the emphasis had shifted to electric for cars or hybrid systems for larger commercial vehicles. Circular economy principles permeate national and international legislation and incentives, while manufacturing industries have put Circular Economy high on their agenda. Academic research on design for Circular Economy is rapidly growing, but in 2020 still identified as a gap (see e.g. Da Costa Fernandes et al, 2020). Skill shortages have also raised awareness of the need for lifelong learning and political intervention to foster engineering education (Durazzi 2023).

Critical reflections on the participants understanding of trends

The participants of the study largely worked for or with established companies, who incrementally develop complex products. They come from a mindset of changing as much as necessary and as little as possible (see also Eckert et al. 2012) that was clearly apparent in 2018. By 2021, it was evident that several disruptive trends had shifted from strategically important to business critical, in particular in response to the climate crisis. For example, Environment and Social Governance (ESG) scores now directly affect companies' ability to raise capital. Reports on specific trends often focus on the business opportunities and general risks, associated with trends, whereas the participants of this study were also concerned with the specific risks and challenges to the way in which they realise the innovations in their own context.

In 2018 all the participants alluded to the great uncertainties we are facing in terms of climate change and globalisation. They expressed concern about the availability of raw materials and energy. However, at the same time they assumed that the world would operate in roughly the same way as it had. In consequence they looked at trends in isolation rather than from the perspective of how they would affect each other. Like the participants in the Heisig et al. (2010) study, they assumed that the trends are the responses to their present challenges.

Overall, the Swedish participants were more optimistic and saw the change to come as an opportunity for their businesses to create cutting edge products. The UK participants were highly concerned about the effects that Brexit negotiations and the outcomes of Brexit would have on their businesses, which was still echoed in the keynotes of the UK participants at the kick-off of the 2021 workshop. They were mainly concerned about losing international competitiveness and needing to deal with unreliable energy supplies.

There was no indication that particular trends were much more prevalent in particular countries, as most trends arise from internationally competing products, though it is worth remembering that our participants come from a small number of northern European countries. These countries have different ways in which industry-academia collaboration is funded and governed, which might have an effect on lifelong learning. Countries are also prioritising different fields of engineering with the Nordic countries placing a strong emphasis on sustainability and the UK on energy independence and mobility.

By the second workshop, all participants had gone through the shared Covid experience; however, the way in which governments regulated personal behaviour and industrial activities during the Covid years varied. The COVID-19 crisis has also demonstrated the resilience and adaptability of engineering companies in changing work practices, for example, by adopting more simulations for virtual testing or by working remotely.

Upcoming challenges for engineering design practice

None of the developments described in the previous section happen in isolation. They affect each other, both reinforcing some trends and counteracting others. This section picks out some of the challenges that industry needs to address over the coming decades, based on the trends discussed amongst the participants. While companies are already working on these issues and they have been pointed out in the literature, they will require different behaviours by companies and specific academic research to underpin this behaviour change.

Product offering

In the second half of the twentieth century established manufacturers focussed on making individual products more profitable, cheaper and better. Companies will now have to think beyond individual products to products integrated across platforms. The alignment of solutions over time, also with competitor solutions, need to be accounted for in product strategies.

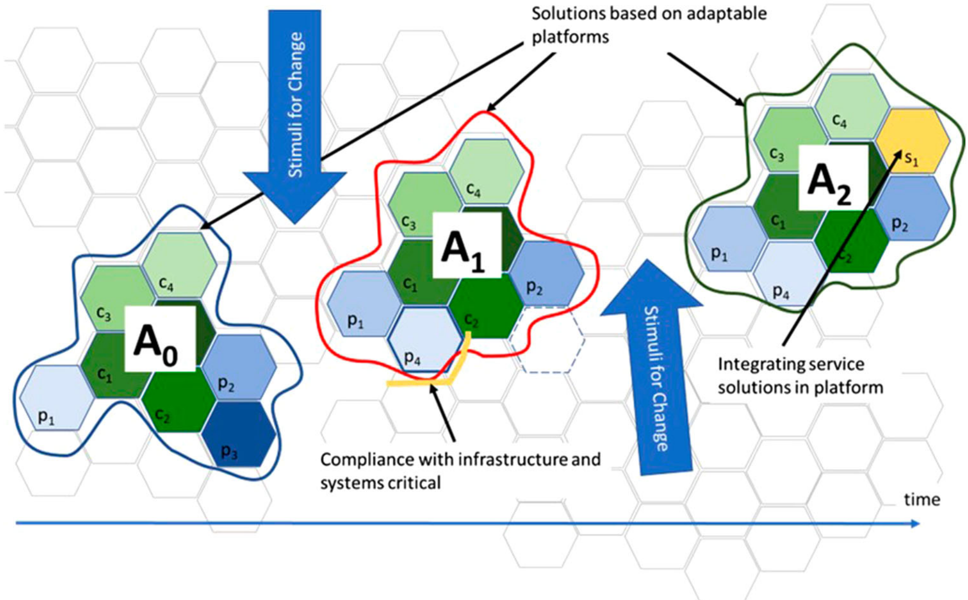

Figure 3. Illustration of the resilient, adaptable, modular and circular products evolving over time.

Figure 3 illustrate the transformable product A, that relies on retaining elements of a stable product core (c_1 to c_4) and reusing or adding other product elements (p_1 to p_4) or services (s_1) through multiple generations (A_0, A_1, A_2), motivated by interaction with its use context. The ability to transform in a resilient way in response to external stimuli in combination with a circular logic will ultimately create immortal products. These concepts are elaborated on as below.

Adaptable platforms

The idea of a product platform is well established (see Meyer and Lehnerd 1997; Simpson et al. 2001; Suh et al. 2007). Current platforms have often arisen out of the range of existing products and applications. Current product platforms have been driven by mass production and mass personalisation. Future platforms need to support life cycle services, such as repairability, upgradability and reuse (See e.g. Reike et al. 2018 for discussion on the 9R's). At the same time, they need to support both greater customisation and rely on common modules and standardised interfaces.

> That implies that when we talk about product platforms and the way we are working, we must at all times have the global dimension to it, since the platform is the foundation for everything and then we can have different types of adaptations or brand distinguishes because that is another thing that has taken place – Volvo.

Standard parts will be shared across competitors to ease use, maintenance and access to spare parts for users. These parts will be highly optimised to assure robustness and cost efficiency. Market differentiation can then be achieved through proprietary components and systems, which encapsulate the core functionality of the product. Many of these proprietary modules will be software, that are renewed more frequently than most physical modules.

Both software modules and hardware modules can have different ownership. For example, a battery for a vehicle can be owned by one company, the hardware platform by the user, and the user can subscribe to different software installed functionalities that are owned by yet another company (see, for example, Liao et al. 2019). The combination of strong platforms and local manufacturing will also allow a greater customisation of products both in the functional configuration of the product and the non-functional parts (see Novais et al. 2019). Additive manufacturing can support local customisation of products as it offers customised, low series print capacity. Realising this vision require both standardisation and flexibility in interfaces, and effective secure data handling across time and organisational barriers.

Recent global uncertainties have shown that companies need to change suppliers quickly or take production back into their own organisation. This will require further research on how to manage the relationship with suppliers. On the one hand, companies will strive to maintain their intellectual property, and on the other hand, companies need to be able to revalidate modules sourced from different suppliers.

Servitisation

In particular, in the transport sector, manufacturers of many products will retain ownership of maintaining the functionality on behalf of the users. The manufacturers have the responsibility to manage the increasing complexity of product-service systems. Many 'classical' products will largely be offered as services and consumers will pay per use, or for availability. The perceived value then relies increasingly on the services provided, which alters the requirements and constraints for manufactured products (Barnett et al. 2013; Mahut et al. 2017). This leads to a higher proportion of time in use, i.e. up-time, and shortens the overall life cycles of traditionally designed products following their more intense use.

Traditional 'consumer products' such as cars, bicycles, washing machines, telephones and furniture are increasingly shifting from a Business to Consumer (B2C) to a Business to Business (B2B) business model with manufacturers selling to service providers (see Kohtamäki et al. 2020, for a discussion of the challenges involved in this transition process). This gives the customers access to newer and higher-quality products without the responsibility and maintenance effort that come with ownership. This empowers consumer to value the results and experiences, while paying little attention to the actual means by which the services are performed. Such systems are also sometimes called Results Oriented Product Service Systems (see e.g. Tukker and Tischner 2006). Two factors are likely to determine the adoption of results oriented solutions; (1) the ability for the entire manufacturing enterprise, including suppliers, to provide viable solutions over time and (2) the willingness of clients and users to pay for pure services. The second factor is important as the cost of maintenance, repair, reuse and so on becomes visible up front for a customer, while the ability to provide an entire service is important for manufacturers as conditions may change and evolve over time, making pricing strategies difficult.

As products are shared between users, the individual products will be used more over shorter periods of time and the wear and tear of individual products increases. Users can access different products depending on their specific needs, as we already see with car share schemes enabling customer to select a size of car that meets the requirements of a specific trip, rather than their likely maximum requirement. Both the increased utility and flexibility will have to be addressed during design, requiring increased performance, reliability, durability and alignment with the emerging 'circular economy' models. As the Product-Service System literature reports (see e.g. Baines et al. 2009, Isaksson et al. 2009), ownership of products is a divider, where manufacturers gain more control – and responsibility – if ownership is retained (Bressanelli et al. 2019).

> To sell a result to the customer rather than selling the machine, and to know what the customer wants … three different machines may be even with a competitor machine in between depending on what he really needs – Trumpf

Human machine interfaces also need to become much more intuitive, and products might give feedback to the users on how they are used. The level of automation, use of robotics, and intelligent services will increase the perceived utility for the end user.

To provide a smooth service for users, products need to monitor themselves and take active steps to be fuelled, supplied and available. Industry 4.0 technology will make predictive maintenance easier (Zonta et al. 2020). Rather than being regularly inspected, the products will report their own state to the manufacturers, who will use data analysis techniques to analyse the state of the products and decide whether and when to upgrade a product.

Immortal products

As principles of circular design are be embraced more, products need to be designed to be upgraded, recycled, refurbished, and ideally become 'immortal' in the sense that they need to be up to date and satisfy their intended function as long as the need is there (Evrard et al. 2021). Products will also develop a degree of self-healing capability (Haines-Gadd et al. 2021). While simple products might be broken down and recycled, complex products will be upgraded and updated several times during their lifetime, so that different elements of the product come from different generations and individual products with the same functionality will be slightly different. This will widen the gap in lifetime between mechanical elements, which will be designed to be more long-lasting and robust; and software elements which will be updated frequently in the cause of a product lifetime. Many products will carry out roles in the later stages of their life cycle that was not anticipated by the original designers, either because they have been upgraded, or a secondary function is enacted. Functions typically need to be designed in from the beginning, but users can also discover new affordances. Dormant functions are a form of overdesign, which has a potentially high price.

This puts a huge emphasis on system architectures and interface designs to be sufficiently flexible to enable elements supporting new functions to be incorporated, unless the products can exploit unused or unexpected affordances (see Brown and Blessing 2005).

Repair and resale to different users' needs to be supported to increase their lifespan. We see this already in complex military equipment, like the Hawker Siddeley Nimrod aircraft that first went into service in 1969, based on the late 1940s design of the De Havilland Comet, and flew until 2011 with most of the parts upgraded over 40 years of service.

Legacy systems will need to be combined with new and upgraded systems that will need to be designed around them (Givehchi et al. 2017), so that managing and designing of products blends together.

> You just treat your legacy system as a requirement and then you end up with a messy definition of what is a requirement, almost as bad as what is a function, and then you can get functional requirements just to add to the fun – Energy Catapult

Due to longer life cycles and reuse in different parts of the world, the dependence on proprietary components needs to diminish. As OEMs specialise in producing robust parts that encapsulate their own core technology, other parts can be repaired and made locally, largely using 3D printers. This makes design for repairability a key concern (see De Fazio et al. 2021 or Bracquene et al. 2021). Design for robustness, focusses on components that are difficult to service or repair. These need to be designed and manufactured so that they can last for the lifetime of their product. The products and their logistics are increasingly designed together, while there is an increasing need for agile supply chains.

As public awareness of the need to make products last longer increases, more social kudos will be derived from using old products and being able to make products last (Hielscher and Jaeger-Erben 2021). Long-term use has made it difficult to define use scenarios. As a reaction to globalised production and perfection in products, the movement towards valuing the imperfect and often natural variation in handicraft and artistically created products rises. Current trends in reusing clothes will spread to repaired, restored and reconditioned products. Imperfection, as a means of individualisation, can be a feature of products.

This will increase the need to maintain product knowledge (Martins et al. 2019; Lim et al. 2020). Universities will also need to contribute to maintain an understanding of legacy techniques and methods, while at same time assuring that established principles don't stifle innovation. Research will be required on how to shift user attitudes and public values.

Engineering design practice

As products change, product development processes need to adapt. The range of skills that will be required to be a successful engineer is expanding, including the need to have a very high degree of computer and mathematical literacy. There is a growing awareness and willingness to tackle ethical and sustainability issues associated with manufacturing, using and disposing of the product and the way we increasingly rely on advanced data processing, including the use of AI. The right legislation and business models need to be in place and established design processes have to change. New theoretical views of design are emerging, incorporating products and use processes as well as governance issues too (see, for example, Reich and Subrahmanian 2022).

Globalisation will not only lead to a global use of products, but also to a global and distributed workforce working remotely and coming from different cultural and academic traditions. This workforce will also be more mobile, changing jobs and countries of residence throughout their careers.

Since the 2018 workshop, the COVID-19 crisis boosted the trends towards remote working in engineering. Studies of software engineers have shown that while productivity was maintained or improved, some engineers enjoyed the proximity to their family and the lack of commuting, but others often found it challenging because they did not have a suitable setup (Ford et al. 2022). Mechanical engineers also need to interact with physical products or prototypes and conduct physical testing, which proved to be challenging.

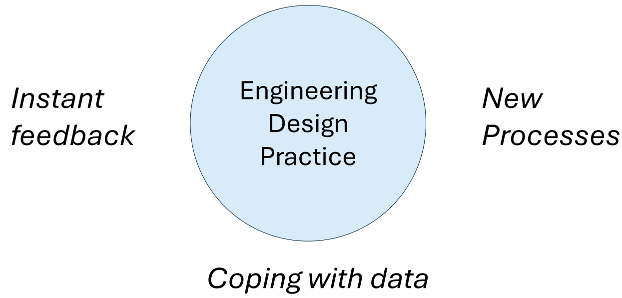

Figure 4. Three dimensions of new Engineering Design Practice.

However, distributed rapid prototyping and smart manufacturing technology, such as digital twin technology for manufacturing equipment, was able to fill some of the gaps (Shen 2020). During this Covid crisis working practises needed to change very rapidly. However, as hybrid working is becoming more prominent (Grzegorczyk et al. 2021), the processes to deal with it will also need be in place.

We chose to address three dimensions of Engineering Design Practice, that are expected to strongly influence emerging practices. These are illustrated in Figure 4 below and discussed in the following section.

Coping with data

Through digitalisation of both products and engineering processes, engineers are flooded with data, and design practices that can cope with data efficiently are clearly needed. Therefore, data analytics and AI are seen as necessary to harvest the information within huge datasets (see Brunton and Kutz 2019, for a description of currently used methods) and interpret the insights hidden in large datasets, which are often dispersed and ill-structured. Examples include the use of multiple engineering tools, CAD, CAE, etc., where databases are at least partially incompatible and difficult to access when needed. Increasingly AI techniques are tightly integrated into generative design systems forming 'grey boxes' where seemingly good designs are produced with limited input, and control by, the designer. The abrupt and somewhat chaotic breakthrough of Large Language Models, such as ChatGPT, during 2022 and 2023 could not have been foreseen in 2018 or even in 2021. It is a good example of how technology can impact practice at short notice. Designers' practical access to relevant and timely data is often limited, as understanding data sampled by sensors of products in use requires a clear understanding of the context where it was captured and to what extent this context represents the to-be-designed context.

An increasing portion of data will be shared (democratisation) amongst the multiple stakeholders of interconnected product offerings. This democratisation of data requires however, as Lefebvre et al. (2021) points out considerable skill development and a shift in the mindset of organisations. The interpretation of data is becoming a competitive skill for designers and decision-makers. Access to valid data will become a pillar for new PD processes. Filtering the data, and assuring that suitable data reaches engineers who need it, requires active planning and new processes of data identification, elicitation and storage. Engineering teams will be joined by data scientists, who clean, store, distribute and analyse data. Privacy and data access have become a political battleground, and ethics of data management is becoming a core competency of engineering companies. Data capture design will become a standard aspect of product development, as designers will need to identify at the beginning of design processes what data is needed, what sensors can provide it, and what interfaces need to be supported during operation.

Instant feedback

The enabling instant feedback on the behaviour of candidate designs during development provides enormous power. Increasing computational speed and better computer tools make the analysis of data easier and nearly instantaneous in most cases. In parallel, the ability to conduct physical tests using rapid manufacturing technologies can offer low-cost physical testing as a better alternative to advanced computational modelling. The engineers of 2040 will have grown up with instant access to information and interactivity with devices. This leads to a gamification of engineering, where it is expected that it is possible to evaluate the goodness of a new concept nearly instantly. The vision is that novel concepts and ideas can be embodied and tested without delay in different scenarios. Decision making using real-time testing of validated models of reality is likely to grow in importance. Rather than testing products against a fixed set of requirements derived from worst case scenarios, the behaviour of products will be explored directly through simulation in real use scenarios derived from use data. Such scenarios challenge the deterministic, controllable approach to valid designs, and open spaces for statistical, explorative approaches to design.

> And then suddenly it is not only engineering domains that we should include in our modelling, it is something a little bit more fuzzy – geopolitics, economics, societal change – how do you integrate that in the longer term perspective? – SAAB

Engineers can also play with design ideas much more and explore the design space both more systematically but also more playfully. This has long been discussed as an important element of computational design (see Woodbury and Burrow 2006); however, human engineers largely engage in satisficing activities (see Ball et al. 1998). A greater exploration of the design space can build up designers' intuitions for the behaviour of products and changes in behaviour in different situations. This possibility of exploring design spaces could also lead to a blurring of the differences between technical engineering designers and more artistic product designers.

The vast number of innovations becoming available in parallel in many disciplines requires engineering designers to combine technologies and components from different disciplines into functioning and integrated systems. Greater interactivity with the system context makes it more important to design the desired behaviour of systems. No single human has the capacity to understand the underlying functions and behaviour of all contributing technologies and concepts. As a consequence, decision makers need to trust the results of models building on other models, where they are rarely in control of the assumptions made in the first place. Since the workshops in 2021, the importance of interpretable – and transparent AI has gained significant attention in AI research. Attending to validity of data, models and methods used in product development processes will be even more critical.

> So, I think, innovation that we're looking at is all around customer experience and what the customer will see as benefit – Perkins.

New processes

What we now think of as smart systems will play an important role in development processes. Tasks that are currently carried out by people will be automated, and to a certain extent hidden in the gamification. Intelligent systems will take part in negotiations in the development processes and became partners rather than tools. The reduction of, or even lack of, human influence during decision making raises the need to actively include 'human intervention touch points' throughout the product life cycle.

As OEMs increasingly become system integrators for multidisciplinary products, they will attempt to maintain core competencies and to be leading experts in them in order to stay ahead of the innovation curve. Detailed design competence in non-core business is increasingly outsourced. Such outsourcing raises the importance of active quality management interaction with 'freelancing' partners and suppliers, which will be supported with online and electronic tools that support the sharing of complex product models. Companies are also bringing core manufacturing activities back to their own businesses and try to work more locally. Smart strategies to integrate disruptive technologies, developed by the 'outsourced' partners, into their systems becomes a competitive advantage. Technological advancements made by suppliers will force integrators and system developers to form strategic alliances with suppliers, something that may counteract the trend of 'low cost' outsourcing strategies. In intertwined and often outsourced processes, it is critical that companies hold on to their core expertise and protect their own IP as well as other aspects of collective corporate memory. This is important as there might be a high degree of staff fluctuation and individual engineers can't be relied on to maintain this corporate understanding.

The reign of the stage gate process seems to have come to an end. Agile processes are currently in fashion, as they support the flexibility and iteration that design processes require (see Siewert and Gericke 2024). Flexibility of the design, manufacturing and business process is a key competence to meeting the specific needs of individuals and to adapt to different business models. A common problem in practice is the dual role of a development process, being (1) a control and project management tool and (2) a guiding workflow that elucidates dependencies between tasks. As new technologies emerge and disciplines transform, both the management and sequencing of design tasks changes. For example, introducing 3D printing for manufacturing, or replacing hardware components by software, or changing the order in which decision are taken or tasks are carried out. It will require new competences, methods, tools, etc for design and verification.

> Our whole process is based on agile and has always been in our factories, but it is never been that way in our research and new technology introduction. That's been a very slow, steady process. What we're saying now is, we need to jump on new technologies and try them very quickly and if it fails, it fails and move on rather than feel you've got to follow something to the death and do it very carefully and keep trying – Perkins.

As different development processes need to co-exist, for example software design and hardware design, a structure needs to be established that allows automation of routine tasks and effective interaction. However, a clear candidate for a future paradigm is yet to be seen. Industry is in many ways ahead of established theory and educational practices, yet needs competences, methods and tools to be in place to work efficiently. Universities are expected to provide new engineers, literate in such – yet to be defined – development practices.

The product development processes of 2040 will be far more interdisciplinary than they are today, and will not only require the integration of different traditional engineering disciplines, but also require engineers to collaborate even more with experts from natural and social sciences and mathematics with no background in engineering. This will require serious progress in bringing together and integrating different perspectives, terminologies, and modelling approaches for complex engineering products. These are likely to be more abstract and domain neutral. Due to the greater integration of products and fluctuation of staff it will be necessary for companies to manage and curate their product knowledge. Human judgement will still play an important role in thinking holistically through problems and understanding the significance of big trends and small details; however, this will operate in conjunction with increasingly automatic design tools.

Concrete research areas arising from these challenges

With industrial practice, research effort will also have to shift. Table 6 provides a summary of the research areas, and examples of some of the many challenging questions that will need to be addressed.

Implications for engineering design research

This paper covers a broad range of technological trends and their implications for product development practice from the perspective of the industry experts working in product development processes.

The participants in our workshops largely assumed that solutions would be found to their current problems, which would then become the new prevailing way of working. New ways of working often take a very long time before they stop being seen as new and become mainstream. For example, artificial intelligence or additive manufacturing were seen as major trends by almost all the participants, but have been around for 30 or more years. Other trends, like servitisation, have been discussed for decades already, but are still to become mainstream. Broad adoption of new practices can be held back for a large variety of reasons, and design research has the role of analysing such factors and tackling barriers.

Nevertheless, there are a number of trends in product development, to which academia needs to adapt, that come through strongly from analysing the workshop and interview data:

- **Integration of Disciplines:** There was a near universal agreement that the future will bring a greater integration of disciplines as it is required to address many of the current challenges; nevertheless, no clear pathways to how to achieve this have been proposed. Companies are finding their own specific workarounds. However, systematic methodological support is still very partial, for example, around integrated models or standard translations between different types of models. Practices have largely been formed within organisation, or within separate disciplines. While interdisciplinary research is

Table 6. Research areas to the addressed.

	Future products
Adaptable platforms	• Standardisation of interfaces • Integration of suppliers / different ownership models • Management of redundancies in products • Acceleration of testing to explore more options • Platforms for life cycle, circular, and service components
Servitisation	• UX development enabling intuitive interaction with new and unfamiliar products • Establish user trust in service. • Design and manage digital twin solutions • Traceable, transparent and accessible life cycle data
Immortal products	• Design models and representations for Circular Products • System architecture design across product generations • Data generation and curation over generations of systems and technology • Knowledge management / rationale capture across product generations • Coexistence of obsolete and innovative technology
	Future processes
Product development practices	• Combining terminology in Product Development from different domains. • Ensuring coordinated qualifications in different countries • Learning and establishing practices for mixed modes of working (online, hybrid, co-located, asynchronous) • Supporting the evolving and circular mode of developing products
Coping with data	• Balancing decisions based on data and the expert knowledge of individual engineers. • Learning to master data quality, data wrangling and data volumes • Combining data from measurements and data from simulations (Digital Twins) • Ensuring secure, configurable, and smooth access to data when needed • Means of building trust and validity of data, and data from data
Instant feedback	• Rapid and trusted navigation of the design space • Combining new and evolving data with frozen data • Design systems supporting multi-level and multi-aspect data interaction and visualisation • Ensure interpretability and communication of interpreted data
New processes	• Efficiency in multi-domain and multidisciplinary design efforts • Paradigms for process management post stage-gate and lean • Development of solutions with a life cycle dimension (circular, sustainable) • Means of engaging and communication with stakeholders not traditionally actively engaged in design

called for, the research traditions and infrastructure (metrics, publication fora, career progression, methodology) are rarely in place.

- **Integration of Products:** There is a strong trend towards a greater integration of products through joined up user experiences, shared components and subsystems across different designs, reuse across the life cycle and a greater integration across the supply chain. This also requires a balance between engineers with good systems engineering skills and engineering specialists, which the participants thought of in terms of the old picture of the T-shaped engineer. Greater integration is likely to lead to greater complexity in products or systems, unless active approaches to managing and reducing complexity are developed.

- **Digital Modelling and Simulation:** Engineering is increasingly supported by multiple digital models from analysis and simulation models to digital twins, which requires generating trust in models and their results. A particularly interesting observation is that the data that some models are based on is generated by other models, where the engineer responsible for modelling will need to rely on other engineers' assumptions and simplifications. While the speed of feedback allows engineers to explore design spaces rapidly, this requires good data to calibrate the models. This carries the danger of locking companies into familiar solutions, where they have data. Methods to link high-quality data and novel designs are still sparse. At present, the paradigms of design are slightly in conflict: a bottom-up design thinking paradigm, that assumes fast iteration and prototyping in close interaction with users, and a top-down model-based system engineering approach. These paradigms are followed by researchers and practicing engineers with very different skill sets and outlooks. There are few signs of efforts to bring these different communities together. So far, the effort in modelling and digital twins has largely been focussed on the product; however, to control the design process more efficiently, there is also a need for a better representation of the state of the design process to allow for better planning and greater flexibility. In the long term, companies will also be aiming for a digital twin of the process.
- **Radical Change to Architecture:** Many advanced products, such as cars or aircraft, have had very similar architecture for the last 50 or so years, but companies are expecting big changes in the architecture in the near future. Electrification of powertrains is one such example, replacing decades of incremental design refinement and experience. At the same time, new manufacturing processes, like the different forms of additive manufacturing, cut lead times and require new designs for manufacturing practices, and therefore profoundly affect both the order and conditions in which design decisions are made. They also change the balance of supply chains, as on the one hand, companies begin to bring manufacturing back to OEMS to reduce vulnerability from disruptions within global trade; and on the other hand, the locus of innovation is moving from the OEMs to suppliers, for example, around electric power trains.

In summary, major trends in society and technology need to be seen over long periods of time, and their impact on design includes the establishment of new practices.

Some of the underlying technology can shift very quickly, as the example of the hype around nano engineering or graphene illustrate, strongly influenced by the ebbs and flows of different countries' research funding. However, the engineering design community is lagging behind industry as academia often responds to observable needs in industry and seldom anticipates them. At the same time when academia proposes tools and methods, it can be difficult to reach industry; while industry often adopts well-publicised approaches, such as lean production in the 2010s or agile processes now, without much reflection, and on the advice of consultants. Nevertheless, academia needs to be proactive and look at future trends and be ready to develop tools, methods and processes, and give industry the critical reflection it needs. However, academia also requires the support of flexible funding both from government and from industry, for example, through block grants for applied research.

Conclusion

Industry and society are rapidly adapting to huge challenges and are forced to operate in an uncertain future. Technologies, visions, and new solution strategies are being put forward. For these to make a difference, they need to be designed, developed, and integrated into complete products, systems and solutions. This is also an opportunity for design researchers to play a key role in industrial and societal development, if it is open to breaking out of the disciplinary boundaries and applying its ability to think as designers to the emerging problems.

This paper has reported from a deep interaction with experienced practitioners in – predominately European – manufacturing industry about how they foresee engineering design practice being impacted by ongoing trends. From 2018 to 2021, the trends – as likely scenarios of the future, remained largely the same over time, but the likelihood of these trends shifted. For example, the remote working trend was nearly instantly implemented (following Covid – 19 constraints) changing from being an evolving trend over decades to common practice. Similarly, the attention to sustainable development had suddenly become business critical from 'only' being strategically important in 2018. From hindsight, the relatively moderate attention given to AI topics at the two workshops is surprising, in comparison to what is apparent today following the rise of Large Language Models. AI was indeed mentioned in both 2018 and 2021, yet as one of several trends in e.g. autonomous driving, whereas its impact on design practice was not clear.

Following the analysis of these trends, it can be concluded that successful design ability in industry will rely on new competences and skills, both in particular technologies, but also in the ability to contextualise and adapt to change. A range of possible research challenges and areas has been compiled to foster a dialogue amongst researchers in design research, and an agenda for proactively interact with industrialists and government. Given the development in the world since the data was captured and analysed, the insights are still valid. The participants expected increased dynamic in society as a phenomenon to account for, yet the extend and speed of change have been beyond their expectations. They valued a dialogue on these matters, because it allowed them to articulate their impressions and to get a perspective on transformative processes.

Finally, the authors argue that the wider research community would benefit hugely from a regular forward-looking workshop with industry, where engineers and industry leaders can bring their problems and direction of travel, to which academics can comment and respond. These might be a means of breaking the cycle of largely responsive academic research and teaching, driven by the needs of the past. It is imperative that the engineers of the future can deal with unpredictable changes. Therefore, designing adaptiveness into educational curricula and lifelong learning strategies is important.

Notes

1. https://www.bbc.com/future/article/20180814-norways-plan-for-a-fleet-of-electric-planes
2. https://dictionary.cambridge.org/dictionary/english/trend

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