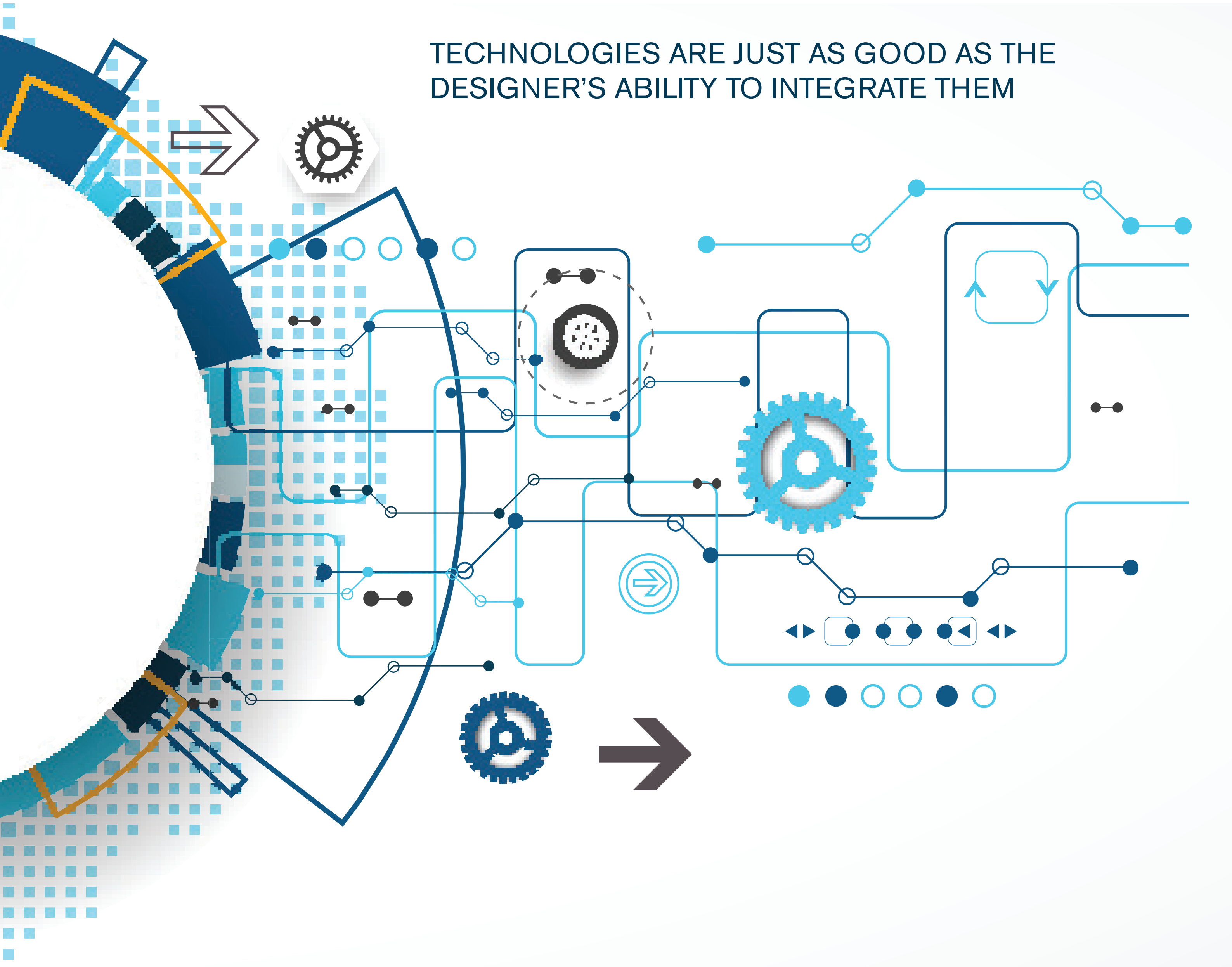
A Design Society Report September 2020

the Design Society
a worldwide community

# Product Development 2040

TECHNOLOGIES ARE JUST AS GOOD AS THE DESIGNER'S ABILITY TO INTEGRATE THEM



The Open University

CHALMERS UNIVERSITY OF TECHNOLOGY | Area of Advance PRODUCTION

Product Development Academy Sweden

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# The Authors

The future has a tendency to surprise anyone making predictions and trying to make sense of what is supposed to happen. So was the case also when compiling this report, where most of the data was gathered before the Corona / Covid-19 abruptly altered the conditions for nearly everyone.

Yet, we find that a report raising questions not only about what technology, society and environment will dominate in the next 20 years, but what consequences this has on design and product development research, education and practice.

In this report, we seek to raise questions and ideas, based on interaction with leading practitioners in industry and academia with a common passion for engineering design and product development.

We hope that the report encourages and inspire you to raise questions and reflect on what may remain and what may need to be, in terms of how we design and develop the products of our future.

*We are sincerely grateful for all contributions to this report!*

*Ola Isaksson and Claudia Eckert*

## Claudia Eckert

Claudia Eckert is Professor of Design at the Open University, the UK distance education university. Her background is mathematics and Philosophy. She has an MSC in Applied Artificial Intelligence from the University of Aberdeen and a PhD in design from the Open University. She spent nearly ten years in Cambridge in the engineering design before returning to the Open University. She carries out empirical studies of design processes in engineering, construction and fashion; and researches on understanding and supporting designers in industry. She also works on theoretical concepts underlying design practise. She has published over 250 papers in reviewed journal and conferences. She is a member of the board of management of the Design Society and a co-chair of the Design Process Special Interest Group of the Design Society.

## Ola Isaksson

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# Foreword from Industrial representative

Change is 'the new normal' and at the time of writing this the headwind seems particularly strong. However, it is therefore extra essential to both reflect and take action. We need to make use of the force in the wind of change instead of taking cover and hiding. New ways of interaction between people, industry and organisations accelerate as we are tested by a pandemic or by taking on challenges of climate change. Please join the quest to expand knowledge and ability that help us design better products and services helping individuals, companies and society as a whole.

Product Development 2040 is a report that illuminate important aspects related to the design of new products and services. The report addresses trends that impact both competitiveness and innovation. Trying to beat competitors only by cost cuts often mean to risk being sidestepped by disruptive innovations in terms of new business models or digitalisation. It is valuable to keep focus on design and actual product development processes in order to achieve sustainable progress. Furthermore, the importance of good design processes seems to increase with the exponential rise of sensors, networks and power to compute. Success often relate to a series of achievements, failures and attempts in a convergence of lessons learned which can be exploited yet leaving areas also to further exploration.

This foreword is humble and brief, encouraging you to move forward both by developing and implementing. Many thanks in advance to the authors and contributors as they are ready to connect in conversations and collaborate to make good products and services become part of our everyday reality. That way this report contributes to progress already now, on our journey towards 2040 and beyond.

*Let's engage for all the sustainable development that hasn't been done yet!*

*Dr. Magnus Kuschel*
*Principal for creating an IT Academy at SKF*
*SKF Group*

# Foreword from The Design Society

Technology like rapid manufacturing or machine learning have been around since the 1990s are only slowly reaching industrial practice now. One of the reasons is that the methods tools and techniques required to make the best use of these technological innovations, have only been developed over the last few years. Industry could not make use of them, because they did not have awareness and know-how to capitalise on them. Many of the trends that will dominate engineering design and product development over the next 20 years have already began and the engineering design and engineering system community is therefore called to develop the methods, process and tools required to give companies a competitive advantage in these uncertain times.

Design Society is an association of individuals across the world who deeply care about design: How we create new artefacts and systems, how we think about this creation process, and what is the impact of human-created artefacts on the world we live in and on ourselves. We express our caring for design through our efforts in research, education, practice, and outreach.

As such, we encourage initiatives that foster a critical and constructive dialogue on the evolution of design as a topic. As Design Society today celebrate its 20$^{th}$ anniversary as an organisation – this report stimulates the discussion on what might happen in the coming 20 years.

This report summarises trends in product development based on the analysis of a series of interviews with 13 experienced engineers from Sweden, the UK, Germany and Ireland and an international workshop with over 30 participants from industry and academia. The Interviews asked three simple questions: what trends do you see? What skills do you need? How can academia help? The answers to these questions were presented to the workshop participants, who were divided into groups to discuss technical trends (technology, modelling and simulation, computing) and social trends (ways of working, societal trends and lifelong learning). This report is a position paper of two highly experienced members of the Design Society community. Prof Ola Isaksson is now professor of system engineering design at Chalmers University, but spend over 20 years working in the aerospace industry. Prof Claudia Eckert is Professor of Design at the Open University and have over 25 years' experience of studying product development processes in industry and developing tools, methods and theoretical insights to support them. The topic was raised as a dialogue within two special interest groups (SIG's) in the design society, the Design Process SIG and the Design Practice SIG.

The report provides fascinating and useful insights into how industry may develop and what their needs will be over the next 20 years. For industry it draws attentions to the use they will need to address and the skills are required. For research it is a look forwards to the research that will be required in the future. It highlights that engineering practise in the future will be more systemic, interdisciplinary and virtual in which new groups of people will have to work together. The report will be a useful resource for planning and contextualising research as well as for curriculum planning.

*Professor John C Clarkson*
*EDC Cambridge*

# Contents

# The Design Society

*The Design Society is an interdisciplinary community of academics and industry practitioners with the goal of developing and promoting a robust, usable and scalable means of designing complex solutions that a sustainable and globalised society needs to thrive, in the 21st century.*

We see the development of Design Science, through design research, design teaching and design practice, as the enabler for maturing novel technologies into innovative solutions, as well as a way to engage diverse people in articulating their needs and challenges and to participate and even lead the creation of appropriate solutions. Our aim is to develop the innovative means that support designers in their practice. At the same time, we support the exchange of best practices to improve the routine design and conduct research to develop and maintain solid theoretical foundations of design.

The members of the Design Society are proud of the tools and methods that they have developed and introduced to industry for the development of better solutions. To this end, we combine rigorous technical knowledge with insights from different disciplines, to address specific problems. Our research is anchored in a deep understanding of the specific properties of the solutions we are designing, yet it is generalisable. It takes a process centred view in responding to the challenges of design practice across the product life cycle and embraces technical as well as human-centred approaches in combination of design and engineering expertise of our members. Our teaching, whether to students or to practitioners, impacts current and future product and process development.

The Design Society fosters a culture that combines scientific rigour with impact in industry. While a large portion of our members have a background in mechanical engineering and product development, researchers and practitioners from other fields who share our passion for design are contributing increasingly to the diversity of our community. As a mainly academic community, we seek to increase our industrial membership and influence policy makers and wider society. We see the Design Society as a dynamic forum for exchange among different groups.

The collaboration between industry and academia is a key feature to the endeavours of the Design Society. From the academic perspective, the challenge lies in carrying out research that makes a contribution, both to industry and to knowledge in general. At the same time, the Design Society is a platform for industry to pose its challenges and learn from the latest research. The Design Society offers a place of dissemination and exchange through our owned and endorsed conferences and journals. It argues the case for design research to funding agencies and other academic disciplines.

https://www.designsociety.org

# Executive Summary

*Based on a series of interviews carried out in 2018 with experienced European engineers and a workshop with Product development experts from over twenty leading Swedish company and academics researching and teaching product development, trends and their expected impact on engineering design can be identified. While engineering design practise in 2040 will in many ways be like today, several clear trends for the next 20 years are already visible and are likely to grow stronger.*

Over the next 20 years:

- The world will be changing rapidly to respond to the pressing challenges of a changing climate, a polluted planet, depleting resources, and a growing and increasingly-mobile world population.
- New technologies, such as quantum computing will emerge, while other technologies like rapid manufacturing and nanotechnologies, will be widely deployed.
- Digitalisation will permeate every aspect of our lives and the world around us.
- Data will always be captured about individual people and objects, giving rise to both ethical questions and unprecedented evidence-based engineering.
- Product development plays a vital part in creating a sustainable and prosperous future for all. Whilst at the same time, it will be profoundly affected by the wider changes in our society.
- Product designers will increasingly be empowered by advancements in simulation and AI to design the desired behaviour before defining the system structure.
- Products will involve much greater integration between mechanical parts and software as sensors become cheaper and more effective, and products are connected to user data through the internet.
- While the rate of change in technology is increasing, the need to reuse existing components and systems will also rise to conserve resources. Components and subsystems will be shared across multiple products as consumers demand integrated solutions.
- Principles of circularity will become mainstream and new materials will come to the market to replace those that become scarce.
- The ability to simulate product behaviour in multiple use contexts almost instantaneously will open up the possibility to design behaviour together or even before the structure is defined.

Modelling and simulation will become common throughout the development process and enable companies to simulate individual-use cases and product life cycles. This will be supported through analysis of user performance data. With rising computer power, simulations will become instantaneous. This leads to a gamification of product development where designers can try out options and build up product intuition through rapid feedback. This will bring about a new logic in product development, where product behaviour can be placed at the centre of the process. Instead of a process of transforming requirements through design and evaluation to produce verified products, desired behaviour can be explored with users, and created by combining existing solutions with novel technologies. Through simulation in combination with intelligent data processing, emerging solutions are formed and ultimately validated in its use context. Rapid evaluation cycles allow discovery of new applications and evolving designs.

To achieve this, engineers will need to work in tightly-coupled interdisciplinary teams which bring together people from different backgrounds, including generalists and highly specialised experts. Engineering teams will also include data scientists and mathematicians. They will become more diverse in gender and ethnicity, with many freelance experts working with closely-integrated core teams at the OEMs. As fewer engineers are looking at lifetime careers in one company, they will have to take ownership over developing their own skills.

Figure 1 illustrates how user needs are transformed into solutions. It also introduces the notion that product developers design a desired behaviour through matching needs in the targeted context with knowledge available in existing products, and develop the system design that realises the requirements.

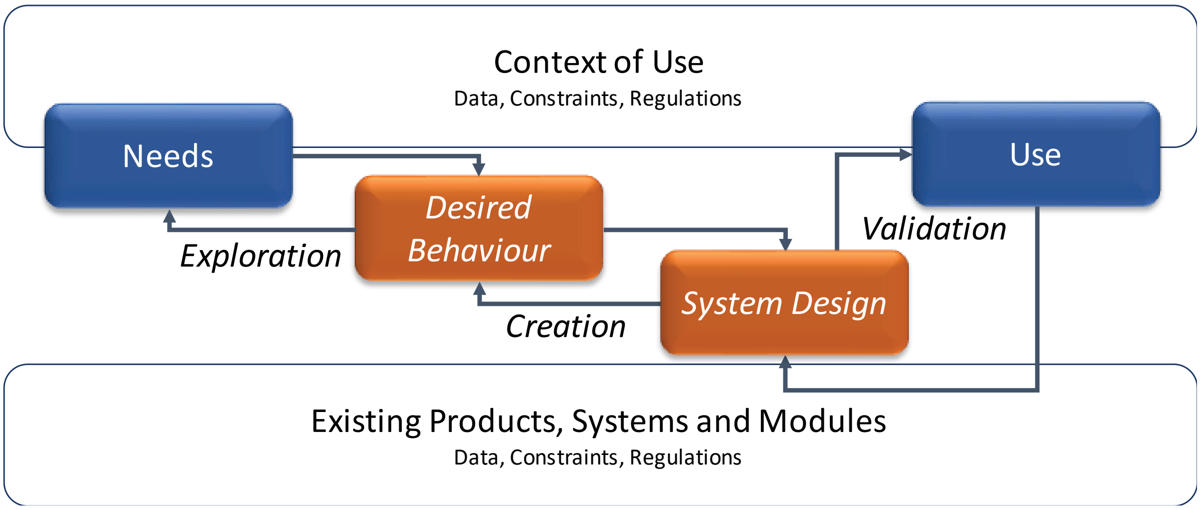



***Figure 1 Digital and Simulation driven design towards the 2040***

# 1 Introduction

*2040 may appear as though it's far into the future. However, comparing the lifetime career of a product developer with current trends in product technologies and aid/support for product developers gives a more graspable perspective. Engineers graduating in 2020 will be in the middle of their career by 2040 and will work until beyond 2060.*

Unlike most technology forecasts, the aim of this report is to present a view on how the practice of product development might be developing over the next 20 years. The work has therefore three interconnected objectives:

1. For industry – to provide a forum to reflect on future trends and enrich the dialogue on what knowledge is needed to prepare for, and meeting, the future.
2. For research – to identify research questions that need to be tackled in order to enable robust, innovative and effective means to develop the products and solutions of the future.
3. For education – to identify and implement the (new) skill sets necessary and improve the way to enable lifelong learning.

The data for the report was gathered before the Corona crisis which illustrates how un-predictable the future is. The trends are largely the rational responses to the emerging technology, so that many of the observations will still be valid, however what effects the likely recession and de-globalisation will have, have not been factored in. In contrast to several other surveys and reports this report is based on a qualitative analysis of data gained from interviews and a workshop in combination. The contributors come predominately from the Design Society network of researchers and practitioners with a bias on manufacturing industries and provide by necessity a limited, but not insignificant, breadth.

## 1.1 The changing nature of product and technology

Products introduced as radical and novel today, are likely to be around and evolve for decades to come. Also, larger and complex products and systems also tend to last for decades, although they are continuously refined and updated. Less expensive but technology-intensive products, such as mobile phones, have a much shorter life cycle. The observation is that by 2040, a large number of products will be recognised from today, but some of their technologies are likely to change. In relation to the career of a product developer, time scales of products are illustrated in figure 2 on page 12.

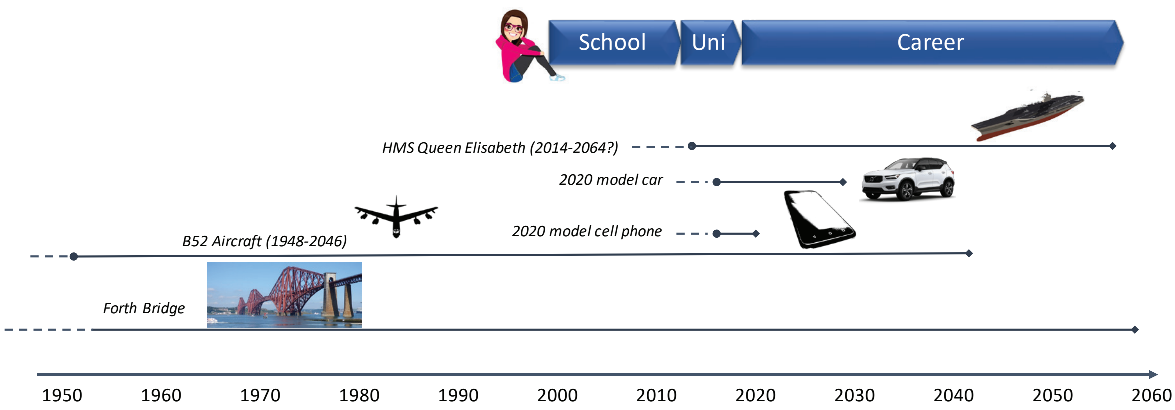



***Figure 2 Examples of life of products in relation to the career of a product developer***

Products rely on the underlying technologies and innovations must be seen in a longer time perspective. From discovery or first patented, they may evolve and have their breakthrough in products on the market many years after. Technologies and means that support product developers follow a similar route, enabling new design tools, software and work practices.

Some examples are shown in Figure 3.

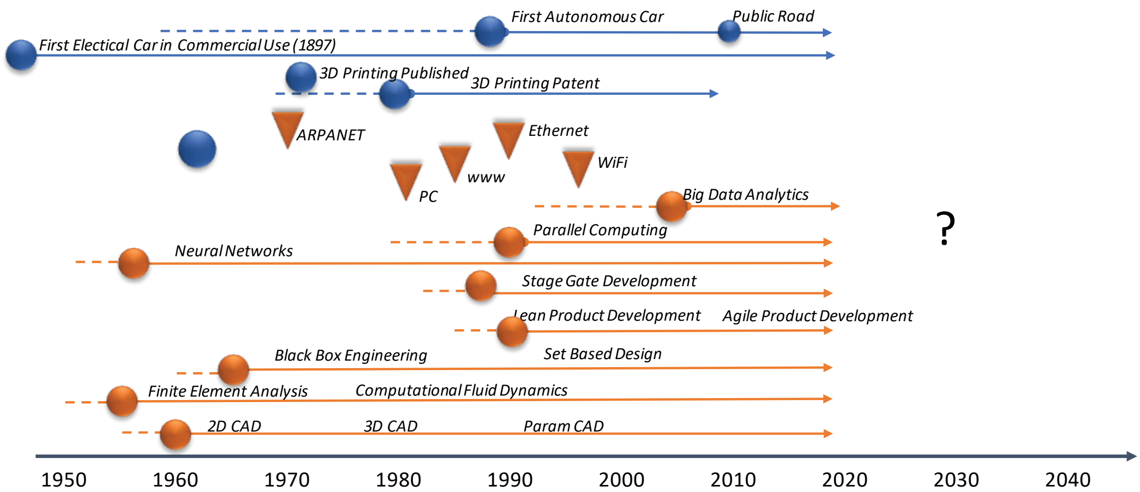



***Figure 3 Sense of time scales***

What is less intuitive are the disruptive technologies and dynamic changes that will appear in our society. Some are seen as opportunistic and visionary, others as risks and threats. The degree of uncertainty in such predictions is high, yet they are likely to have a strong influence over our everyday lives and work – particularly for product developers.

Products will still need to be designed and on a high level their development will follow the same generic logic, yet the means of designing will shift significantly, in particular when considering how technological aids can be utilised. Over time the means of designing changes significantly, see Figure 4.

*Figure 4 Evolving means of designing*

Over the next 20 years products must respond to increasingly urgent societal pressures, resource constraints and environmental concern.  This will have a profound impact on products and the way we develop them.

## 1.2 The perspective of the report

The study was motivated by the observation that one reason it takes a long time for new technology to be taken up by industry, is that industry must learn how to make use of technologies in an effective and efficient way.

For example, rapid prototyping, which has evolved into rapid manufacturing, or machine learning has been around since the end of the last century. These are typical examples where ideas and innovative technologies are available much earlier than their practical applications. Therefore, we assume that the important trends of 2040 will, to a certain extent, have already started.

Looking at the product development process gives this study a broad remit, as product development is affected by many factors. It considers the technologies deployed in the product, but also the enabling technologies that allow the engineers to design, test and develop it. Take the explosion of data as an example. The ability to capture and process large amounts of data impacts products as well as the engineers. During product development, they need to consider both what data to collect and how to collect it.

The report uses the term "product development" as the act to transform needs and expectations to defined products that can be produced and provided. Products are being defined based on the decisions that designers make, and what they know and understand. Further, the term "design" refers to the general act of creating solutions based on needs, but the focus lies on the engineering aspects of design. The designers understanding of needs and of available technologies, determines the technologies and products that surround us.

Academia is central to providing the necessary skill sets, competencies and means to enable designers to address needs and combine them with the most appropriate technologies. These abilities rarely reside in the same person, which is why training, tools and processes are needed to facilitate coordinated and efficient design.

**One of many challenges when trying to predict the future is the** *timescales involved.* Sometimes, new products set a new norm and replace existing products in a very short space of time. For example, horses being replaced by cars in cities within a decade about 100 years ago, the mobile phone replacing wired phones, the smart phone replacing keyboard phones etc.

If you would have asked a person in the late 1800s what they needed, the answer would in most cases be “a faster horse”. 20 years later, horses had disappeared from the street. Similarly, few had the need of a mobile phone 30 years ago. Such transitions created new norms during a period of a few years, or a decade.

Other technologies and products have taken much longer to fully implement. Often, seemingly radical breakthroughs are based on ideas and technologies that have appeared before, without obtaining such breakthrough status. Additive manufacturing has been in the pipeline for decades, artificial intelligence and automation as trends were intensively debated as transforming technologies already 50 years ago or more.

In other words, trends can appear and disappear unexpectedly, yet they often persist for many decades before they have a deep impact on practice.

## 1.3 Other studies on trends for the future

The interest in understanding, predicting and forming the future is of course immense and takes many forms. A sample of a variety of reports and their relevance to the central topic of design is provided in Table 1. Many strategies and agendas target a 20- or 30- year time horizon which is one reason to address the same in this report. The table highlights samples of reports of a different nature.

***Table 1 Sample of reports and their relation to design (see also reference list in the bibliography).***

| Report | Issued by | Type | Relation to design |
|---|---|---|---|
| Transforming our world: The 2030 Agenda for Sustainable Development (SDG’s) | UN (2015) | Global Goals | Defined goals for year 2030 needing to be addressed and a central reference for research and change programs globally. |
| A new Circular Economy Action Plan For a cleaner and more competitive Europe | EU(2020a) | Strategy | A European policy framework linked to the implementation of the UN 2030 SDG’s. Highlight the role of design to meet targets. |
| A New Industrial Strategy for Europe | EU(2020b) | Strategy | High level document, outlining the strategy for (i) global competitiveness, (ii) shaping Europe’s digital future and (iii) an industry that paves the way to climate-neutrality. |
| Shared Vision, Common Action: A Stronger Europe | EU (2016) | Strategy | Highlight the need to turn technology into solutions. |

| Report | Issued by | Type | Relation to design |
|---|---|---|---|
| Innovation in the Future of Engineering Design | Joseph F. Coates, 2000 | Paper | Agenda proposed for Engineering Design, 10-100 years ahead. |
| New approaches to engineering higher education | IET (UK) 2019 | Report | Engineering education including perceived "skill gaps" by employers. |
| The Roadmap Report: Towards 2040: A Guide to Automotive Propulsion Technologies | Advanced Propulsion Centre (2018) | Roadmap | Outlines critical technologies that need to be designed and integrated into solutions. |
| Vision 2040: A Roadmap for Integrated, Multiscale Modeling and Simulation of Materials and System | Xuan Liu et al, NASA (US), (2018) | Vision and roadmaps | Vision and recommendations for research and development of engineering tools. |
| Smart industry – a strategy for new industrialisation for Sweden | Swedish Government (2019) | Strategy | Identifies four areas of particular importance for manufacturing industry; digitalisation, sustainable development, competence and test beds. |
| Long-Term Trajectories of Human Civilization | Baum et al (2019) | Paper | Underlying scenarios for the long-term future, raising issues of action and ethics in societal development. |
| The Digital Revolution and Sustainable Development: Opportunities and Challenges | TWI2050 - The World in 2050 (2019) | Report | Analyses how digitalization transformation relate to the sustainable transformation needed |
| CDIO – Conceive, Design, Implement, Operated | CDIO | Educational Framework | An innovative educational framework for producing the next generation of engineers. |
| Report on the Future Role of Engineers in Society and the Skills and Competences Engineering will Require, A-STep 2030 - Report 1 Literature Review | Beagon, U., Tabas, B. & Kövesi, K. (2019) | Review | A recent literature study emphasizing the role engineering has to deal with societal (sustainability) driven challenges |
| The Design Economy 2018 | The Design Council (UK) (2018) | Strategy | National (UK) report on future Design and its impact on society. |

These, and many other reports and documents of the future **influence** the future of engineering and the competencies needed, whereas surprisingly few directly address design and product development as a discipline in its own right. The UN Sustainability Development Goals for 2030 targets will require new thinking in design and development, and the EU articulates the need to turn innovation into solutions that will require a new focus on design and development and so forth.

# 1.4 Methodology

The report is a result of a year-long study (see Figure 5) , comprising interviews with industry experts in the spring and summer of 2018, and a workshop with experts from industry and academia. The experts from the UK, France, Denmark and Serbia were thought-leaders and managers with experience and/or responsibilities for their organisation's capability to design and develop complex products.

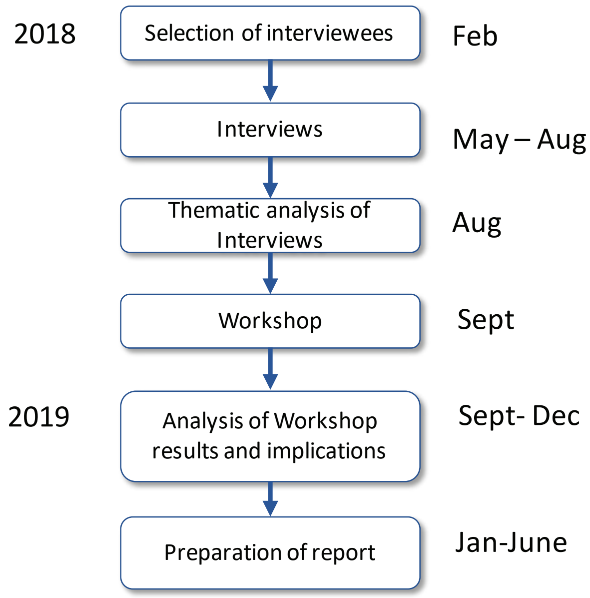



***Figure 5 Timeline of study***

The interviews were analysed and shared with the interviewees and the workshop participants. The findings were used to organise a two-day workshop where some 40 industrialists and academics came together in Gothenburg in September 2018. At the workshop, the attendees were first introduced to a summary of interview study findings and a keynote for inspiration, summarising challenges for a sustainable society. Afterwards the attendees worked in groups, spending about 30 minutes discussing the topics illustrated in Figure 5, that were facilitated by senior researchers. The findings were post-processed, summarised and compiled into a short paper for the ICED conference (Eckert et al., 2019). This analysis and compilation of the results was collated during the spring of 2019.

# 2 Industrial challenges to 2040

*Many of the challenges that companies face depend on the products and services they are offering, and the characteristics of the markets in which they operate. The interview participants were recruited from the research networks of the report authors and represented a range of different sectors, as indicated in Table 2, yet a number of common themes emerged.*

Most companies were large multi-national organisations (more than 250 employees), but medium (between 50 and 250 employees) and small (less than 50 employees) companies were also represented.

***Table 2 Companies participating in the interview study***

| Company | Country | Sector | Size | Product | Interview-ee's area of expertise |
|---|---|---|---|---|---|
| Volvo Trucks | SE | Automotive | Large | Trucks | Configura-tional Design |
| Husqvarna | SE | Consumer products | Large | Forestry and Gardening Equipment | R&D Strategy |
| Saab | SE | Aerospace | Large | Aircraft | Engineering Methods |
| Inocean | SE | Energy | Small | Off-shore turbines | Project Lead |
| AVL | DE | Automotive | Large | Electric powertrain | Batteries |
| Trumpf | DE | Manufactur-ing equip-ment | Large | Laser Cutters | Product plattforsm |
| MAN | DE | Automotive | Large | Trucks | Product strategy |
| EireCom-posites | IE | Manufact-uring | Medium | Composites | Business owner |
| Perkins | UK | Automotive | Large | Diesel Engines | Design Processes |

## 2.1 Thematic analysis of interviews

The interviews centred around three simple questions:

- What trend do you see for the next 20 years?
- What skills do you require to address them?
- How can academia support you in this?

This section reports on the topics arising from discussing the trends over the next 20 years with the interviewees. This reflects the interests and concerns of the interviewees rather than a general review of the topics. As automotive and aerospace companies are engaged in transport trends in transport was an obvious starting point for many of the discussion and broad up the trend to electric transport systems. Energy was also a major issue for Inocean and Eirecomposite who are both engaged in design and building turbines as well as the energy catapult. Product life cycle consideration affected each of the participants. Big data and simulation also concerned most of them directly in their jobs, as they had to understand how live cycle data could be used in design. In particular the interviewees from Volvo, SAAB and Energy catapult worked directly on the simulation of complex systems. The interviewees mainly had roles where they had direct or indirect responsibility for the system architecture, which is to some extend a reflection of the research interests of the report authors. The results from the interviews are summarised below.

### 2.1.1 Transport

The future of transport is intertwined with wider societal trends. It is heavily regulated, reflecting political and public concerns around the use of fossil fuels and air pollution. The social imperative over the next 20 years is the increasing decarbonisation of transport. All companies were working on minimising their carbon footprint and expected to step up their efforts for the future. All considered battery-operated vehicles and expected that by 2040 there will be battery-powered cars, trucks or off-highway vehicles. However, they felt that current battery technology does not yet have the capability to power trucks or off-highway vehicles, which are usually run continuously for many hours every day. The additional weight of current batteries would outweigh the benefit at present. Currently, no predominant battery technology or infrastructure has emerged. At the same time, they also expected other alternative fuels to be considered. It was expected that future transport solutions will rely on a greater mix of energy sources than was common in the last decades.

> *"We have mobility on the one hand, and we have the change of the energy system on the other hand. Both can be very interlinked partners but there are so different companies and industries involved that it seems not to be happening fast"* – AVL

The companies also saw autonomous driving as a trend. However, it is currently not clear whether cars developed for autonomous driving would occur before electric vehicles have been developed on a much larger scale. This is significant considering electric vehicles have simpler product architectures and are easier to control autonomously than heavy and complex hybrid or fuel cars.

> *"This is also a huge threat because the company wants to have a secure connection to the end users. We all know that there will always be a risk.*

*If someone – hackers – really specialise on this and threaten people in this new kind of car, not only electric but the autonomous functions in these cars. It again can be a big game changer and go back to a very early stage where we did not have any connectivity" - AVL*

Instead of thinking in terms of vehicles, the OEMs (Volvo, MAN, Airbus) were considering integrated transport solutions: getting passengers or goods to their destination involving a variety of different vehicles. For example, Airbus is looking at the feasibility of air taxis – possibly autonomous and electric – that collect passengers to take them to larger aircrafts at airports. Similarly, truck companies are thinking about trucks of different sizes that enable pooled journeys.

*"At the moment the transport system is not completely linked up so, for example, if I need to get to Heathrow, I need to take a bus from here or a train or a car. That's not in any way synchronised with when I get there. I then take a terminal bus, a local bus, that takes me to the terminal I want to be at, which again is not synchronised to when the aircraft needs to be ready, there are a number of aircrafts so it's not a simple problem. And then on the aircraft, I get to the other end and again I've got a disparity, a heterogenous set of transports I need to take. So, one thing being addressed is can we have door to door transport… if we had something that was capable of taking us from one door to another without necessarily leaving the vehicle, what would it look like? What would it benefit as far as society is concerned? Who would be interested in having such a product?" – Airbus.*

Integrated transport solutions are facilitated by considering alternative business models. A continued shift to selling services rather than products will keep the ownership of an increasing number of vehicles with the OEMs or transport providers, who then sell the capability across a number of vehicles to the customer. At the same time there is a trend away from personal to shared ownership of vehicles and their batteries. This has the implication that the use-load of vehicles is likely to increase significantly. In particular, cars are likely to be used to in a similar way to trucks or off-highway vehicles for many hours each day, which places higher demands on robustness and durability, but might decrease the overall time a vehicle is in operation.

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

## 2.1.2 Energy

Reliable energy provision was of great concern to all the companies, partly because they felt that provision of energy is largely outside their jurisdiction, being controlled by energy providers and national governance systems. The subsidies for particular technologies vary and influence the mix of energy sources. This is of concern to the two providers of underwater power generation equipment. Government subsidies and research play a role for these smaller businesses; however, despite technology development being funded, the investment of brining this technology to the market is too high for a small businesses to fund.

*“Larger renewable energy is driven by the incentives like feed-in-tariffs and government supports, and they set a lot of what happens in industry and in the UK. There have been reductions in the last few years so there isn’t as much of an incentive to do a lot of the renewable energy and it could be that some of these projects will go to other parts of the world where the incentives are better” – Eirecomposites.*

The participants were unsure whether the national grid will be able to handle the greater demand, in particular arising from charging a very large number of vehicles at roughly the same time.

Batteries used in transport are expected to play an increasingly role in energy provisions, as they can act as temporary storage for energy from the grid and thereby act as a buffer in peak times. When the batteries are no longer efficient enough to work in cars or trucks they could be used in domestic applications, for example as a buffer against electricity outages. The same battery could be used to power multiple products. This creates a significant increase in connectivity between products. This links the design of vehicles, houses and domestic appliances.

## 2.1.3 Product life cycle

The interviewees expected that over the next 20 years sustainability concerns will become mainstream and companies will regularly carry out sustainability assessments and embrace circularity principles.

As companies move from being manufacturers of products to solutions providers, greater emphasis will lie on integrated systems with flexibility boundaries, as the same product can be part of multiple systems, for example the car battery might be used for energy storage.

*“For the automotive application we will use the battery system until it has 80% of its capacity left, then it is not considered to be suitable for any more automotive application, but it is still safe and still good enough for home storage” – AVL.*

In these systems many products or elements will be legacy systems, that are already old now. However, in many systems new and fast-changing technology will have to be combined with legacy systems. There are currently two conflicting trends of products that have become highly reliable and durable through better material, better testing and the use of warranty data to improve products and, at the same time, very rapidly changing technology, in particular in electronics. This puts a great emphasis on design for upgradability both on the level of the product, but also for a product that is deployed in a specific context.

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

*"The lifecycle of the aircraft itself has changed. I mean typically we design a product that should be sustainable for 30/40 years. I mean there will be upgrades during the time, but it is not like a full new product… you do small design tasks during the long period but you will have no more people that have been involved with the full design from start to end. I think that is one of the difficulties I see" – SAAB.*

Companies will be able to understand the life cycles of their products through increased data gathered from those already in use. This will help them to understand the variability in use and misuse, as well as the performance of the individual components and systems. However, one challenge will be to maintain the link to the product over multiple ownerships. Truck companies who are already gathering significant amounts of data for their in-service products commented that they found it difficult to maintain contact as products are sold on to the developing world or have non-proprietary parts fitted. Maintenance of these proliferating systems might, however, be easier now as some replacement components will be possible to 3D print.

*"You are actually designing a car for two life cycles simultaneously. The first one, you try to optimise for optimum run time; on the second, you try to make it as flexible as possible because then it goes to Lebanon, Tunisia, India and the like" – MAN.*

## 2.1.4 System architecture

Changing life cycles also will have a huge effect on the system architecture of the products. Modularisation will play an important role in managing upgradability and meeting the needs of different applications and users. Duplication of functionality modules might be reduced to maintain production numbers, in spite to of an increasing number of use applications. The range of uses might also be increased by module sharing across competing products. This will require greater standardisation of interfaces and technologies. A counter-trend is constituted by manufacturers locking customers into proprietary infrastructures, for example plug in stations for electric cars with specific plugs.

*"How to describe the interfaces, what belongs to the interface, what belongs to the system, and what belongs maybe to another element of the system. I guess people haven't learnt how to make elements in a system explicit" – Trumpf.*

Another trend impacting system architecture is system design, where products are increasingly tangled with the environment they operate within (e.g. cars with traffic infrastructure, aircrafts with air traffic management and other flying products). The ability to represent the mix of software, electronics and hardware in common architecture was further addressed.

*"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.*

## 2.1.5 Big data

The companies are expecting a serious increase in product and component variants, as legacy systems will be maintained, and different markets and user groups demand different applications. One challenge will lie in managing and analysing the data associated with different applications.

For each product a much greater amount of data will be captured, as companies are expecting to monitor their products in real time. For example, manufacturing equipment will be monitored by the manufacturer to enable proactive and condition-based maintenance of the products.

*"Data analytics, but also good use of statistics and of course a domain knowledge, as well as having found some correlations – how can you be sure there's some causation behind it as well? Because at the end of the day, you want to be able to use that resource to be able to do something that matters to the business, so you want to be able to find those innovations that are translating to business practices" – Airbus.*

*"We are in the process of getting all this data but of course in the next 5–10 years we will use much more in order to make condition-based maintenance… of course if you look at consumer products you will use this data in order to develop both personalised products, but also in order to produce future product development" – InOcean.*

While it is clear that by 2040 companies will handle a huge amount of data, it is not clear how they will do so. At present data is often collected opportunistically according to what can be captured, rather than driven by an understanding of what ought to be captured. In the long run, data collection will have to be designed as part of the product development process; tools and techniques will need to be developed to aid engineers in analysing data in a way that can improve product quality and inform the design of similar systems. It is likely that a new discipline of data engineers will develop, who unlike current data scientists understand the engineering context.

Big data is currently discussed in conjunction with AI techniques. The engineers are very optimistic that machine learning approaches will help them in analysing and learning from the data.

*"I would say that we take data on face value and we do trust it, but of course we do the variants analysis and the other thing, as you know, is we use predictive techniques with AI where we pull in three quarters of that data set and we try and predict that other quarter, and so we do have a certain level of validation" – Perkins.*

## 2.1.6 Modelling and simulation

Modelling and simulation are large trends mentioned by all interviewees. Simulations will become more prominent throughout the product development process in order to understand the properties and behaviours of the product and system under different use conditions. Where products are currently tested through physical and virtual testing against a small number of test scenarios, future engineers can test an increased range of use scenarios and will be able to specify applications prior to selling them. The behaviour of entire systems, like the integrated transport solution will also be explored through simulations.

While engineers are already used to working with simulations, one of the challenges will lie in getting users, politicians and the public to trust in the results and to base fundamental decisions on them.

> *"Simulation is absolutely brilliant, if you understand your boundary conditions" – Perkins.*

> *"I think trust [in] the simulations… in general is increasing because more people, more of the engineers who would use it are familiar with it as a concept and that might literally be a generational change, that the new generation of engineers are more familiar with those sorts of techniques and they understand that the problems aren't solvable in other ways" – Energy Catapult.*

> *"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*

## 2.1.7 Engineering practice

The skills of engineers will also have to evolve over the coming 20 years. The need to handle big data and simulation results requires engineers to acquire skills and literacy in areas that are usually associated with mathematicians or statisticians.

> *"We are hiring for data analytics. We are looking for people who have much more of a mathematical background" – Perkins.*

The interviewees largely felt that the engineers of 2040 will have to be better system thinkers, more numerate and have a better understanding of different markets and modes of use. At the same time, they were aware that engineering specialists are still required, so that the need for generalists and for domain specialists will increase. However, several interviewees expressed the concern that young engineers currently do not stay long enough in a particular job to acquire this deep subject expertise.

*"We need to reshape the design engineer back to something similar to what they were in the past, taking a much broader responsibility… that will most likely make us more efficient because otherwise you have 10 different departments sitting around in the process of developing a new product" – Volvo.*

As products are developing into cyber physical systems, the division between engineering disciplines will diminish. By 2040 mechanical, electrical, software, and systems engineering will need to integrate with mathematics, statistics, data science and material science, as generalists will need to make trade-offs across the different disciplines. This will have a profound effect on the tools and methods used in product development processes as well as the organisational and power structure.

*"We are not any more faced just with challenges from one specific discipline but most of the topics are interdisciplinary and have a totally different type of project character or ways to work on the issues" – Trumpf.*

This cannot be accommodated by the current, somewhat rigid structure of the gateway processes. The engineers were therefore looking for a new process management paradigm. While many of them mentioned agile processes, they also did not believe that agile would be the dominant paradigm in 2040.

## 2.1.8 Conclusions from interviews

All interviews pointed to the increasing complexity of both the products are their development processes. As products are becoming more connected a systems approach becomes even more important. Engineers need system thinking skills as well as approaches to define, simulate and analyse the model. In particular, they need means to keep track of complexity at different levels of detail. Therefore, they need interconnected models at different levels of detail on which they can base their decisions and negotiate with others.

These negations involve a broader range to people, as different engineering disciplines will have to work together in new ways. Complex engineering products can no longer be thought of as mechanical systems with controls or software attached to them, but as cross-disciplinary systems where trade-offs need to be made. Rather than being able to do these as we do now – mainly in the early stages of product development – the different rates at which parts of a system will become obsolete will require an ongoing dialogue. Systems will need to be designed so that they can be changed or remain flexible. This requires a greater understanding of the product and its potential behaviour than companies currently have. Through simulation and use data the engineers will have the potential to assess margins and problems in ways that it is not currently possible. Companies are aware of the risk of introducing new technologies, and expressed several means to deal with this, such as a staged introduction of autonomous vehicles and the need to carefully understand the risks and consequences of new technologies before investing heavily in them.

However, the greatest challenge that the companies will be facing over the coming 20 years is how to manage and act on unprecedented volumes of data. Where they currently have results from simulation and testing for a small number of use scenarios, in the future they will have more data points over many more use scenarios. This will be combined with actual data from products already in use, generated at run time rather than from warranty cases. These volumes of data will need to be stored, organised and retrieved, and companies will need to consciously consider what needs to be archived. However, the challenge of analysing the data lies with engineers, who will be responsible for making changes or designing the next generation of the product. Traditionally much of this understanding has been encapsulated in the knowledge of engineering experts, who had an often-tacit understanding of what was possible and what was not. Now the nature of expertise is changing, as experts either specialise very deeply or are generalists. Companies are also reluctant to base their decision solely on expert judgements and want evidence-based decision making, however without having the methods and processes in place to access and analyse the data to base these decisions on.

# 3 Engineering practice in 2040

*The summary of the findings from each thematic station at the two-day workshop in Gothenburg is presented below. During the interviews, individuals talked about the challenges that their companies are likely to face, which revealed trends in specific sectors and for specific companies.*

Rather than discussing trends in specific products or sectors, the emphasis of the workshop lay on the visions of the future and the consequence of trends. The topic of system architecture was not pick up on explicitly, because it reflected the interests of interview participants. The themes that had emerged from the interviews are abstracted, as shown in Figure 6, and the social aspects, which were also touched on the in the interviews were given greater weight.

After analysis of the interviews, six balanced topics were formed for the purpose of facilitating the workshop. The station topics chosen for the workshop became:

1. Technology – including technologies related predominately to products, such as "transport", "energy" and "product life cycle"
2. Modelling and simulation – was broadly addressed in interviews and kept for workshop.
3. Digitalisation – to generalise the topic "Big Data".
4. Lifelong learning – addresses competence and skills development of "engineering practice".
5. Ways of working – that expected to capture aspects of work organisations, development processes etc.
6. Social trends – to encourage participants to reflect on the wider social aspects impacting the future of their particular interest.

"Product architecture," that emerged as a topic in interviews was omitted as a separate station, but have clear connection transverse the technology, modelling and simulation and digitalisation topics.

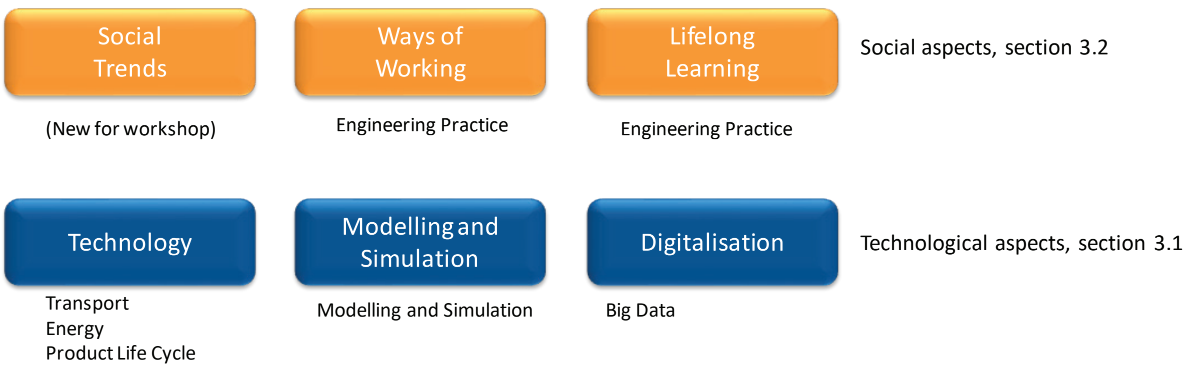



***Figure 6 Mapping of interview themes to workshop topics***

The workshop participants came from a broad range of organisations and had a broad range of expertise and responsibility, see Table 3

***Table 3 The organisations represented at the September Workshop in Gothenburg***

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

## 3.1 Technological aspects

Technologies already have a profound implication on practice and are likely to continue to heavily influence practices in the future. This relates both to the technologies used in products, and the means to develop and realise products. Digitalisation is a particular area of technology that will have a significant impact on both products and enabling tools for product developers. In particular modelling and simulation have already been rising in prominence and will have a profound effect on the way engineering design will be carried out.

### 3.1.1 Digitalisation

Digitalisation has been on the agenda for development of engineering processes for the last 50 years. The expert group identified some emerging capabilities and challenges in this area, including:

**Cyber-physical systems:** in the future "all" products will be to some extent cyber-physical systems based on an open architecture, which enables and requires both continuous product development, updates and customisation by users. Products will be "smart", with consciousness of space and time, as well as awareness of own state.

**Customisation based on data:** rather than relying on focus groups or other forms of user studies, data from actual use can be utilised to understand customer needs. However, the ability to discover new needs in this way is limited.

**Data capturing, storage and use:** with digital twin technologies supported by advanced sensor systems, massive amounts of use data can be captured. Storage is expected to be cheap, or even free. Data analytics will discover use patterns and drive adaptations of products as well as feedback to product developers, who will increasingly monitor the fleet of delivered products and continually launch fixes and upgrades. The experts further pointed to challenges such as respect for personal integrity, security and long-term data format robustness.

**Artificial intelligence (AI):** was described as a "future co-worker" helping with, for example, debugging and natural language-based programming. Still, there was no consensus of the impact of AI on creative or decision-making tasks. Some experts maintained that AI will be helpful in "reducing waste", but not for creative work. Other experts pointed out that AI techniques such as reinforcement learning have already been demonstrated to be able to carry out creative tasks, such as composing music.

**Virtual validation and verification:** future digital tools and computer hardware will enable many more iterations and thus verification and optimisation of product degree. The advances are particularly strong within disciplines, the classic "islands of automation" challenge. For validation and verification of future even more complex cyber-physical systems, more powerful tools for integrated multidisciplinary simulation are needed. Virtual validation of user experience also remains a challenging issue. AR/VR technology may address some aspects, much there is much work ahead.

## 3.1.2 Modelling and simulation

The importance and range of applications of modelling and simulation (M&S) is continuously increasing. Over decades, M&S has been seen as a way to analyse and predict phenomena, that are too costly, complex, dangerous or time consuming to understand through studying real conditions. For product development M&S enables an evaluation of the product before a physical prototype exists and can thereby support decision-making. The participants identified the following trends:

**M&S environments are becoming interlinked:** design decision-making requires taking different aspects, often originating from different domains, and trading them off against each other. Tools for M&S (e.g. structural mechanics) have evolved within their domain, but multi-disciplinarily design problems also drive the need for interlinking, different domains. The interlinking trend is justified by:

1. that goodness of design decisions, which rely on trade-offs
2. the increased ability to manage, combine and aggregate both data and methods, also mixing measured data with digitally generated data.

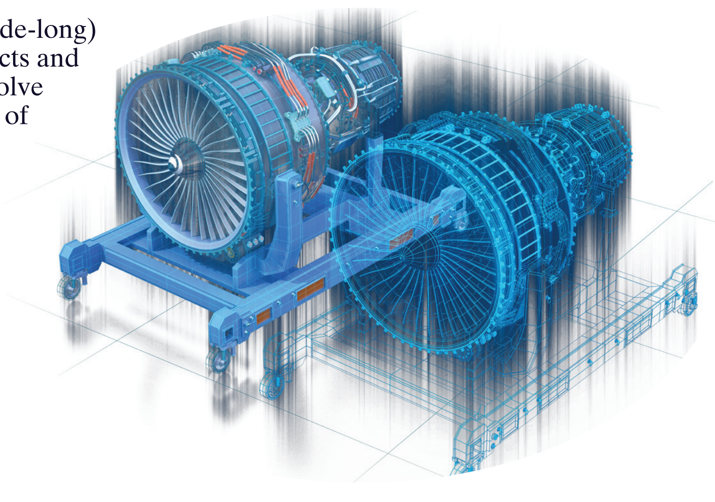
**M&S of entire life cycles:** since following circular economy and service orientation, products increasingly include behaviour through life with increasing responsibility for manufacturers. This is expected to drive the development of new and enhanced M&S tools for design and development support. This is further expected to support evolving designs, covering a range of life cycles to capture upgradeability and technology replacement strategies.

**M&S democratisation:** M&S has long been used by analysis specialists, whereas designers have had limited direct use of (advanced) M&S tools. It is expected that more roles in product development have M&S tools readily available "at their fingertips". Specialists are still needed, but increasingly for developing and validating the tools and their applicability and constraints.

**M&S trust increased:** it is anticipated that the increased sensing ability will (partly) be used to validate and train M&S methods and tools. Decision making will need to rely on M&S results, from guiding to ruling. Trust needs to increase and data availability needs to be used to achieve this.

**Multiple layers of M&S:** following systems logic, multiple layers are emerging which might affect trust in M&S of "systems of systems". M&S is used to predict and understand ever more complex physical or social phenomena, which maintains "advisory" status of M&S in decision making. Model validity remains an increased focus either way.

**Complete integrated digital twins:** the recent (decade-long) concept of digitally defined replicas of real products and processes – called Digital Twins – continues to evolve to include an even more complete representation of the existing reality. Advancements in sensing and computing power release many of the constraints from history. Digital Twins expect to evolve into variable designs behaviour in rich, real situations and as a means to validate simulation models.



**M&S blending with AI:** as AI is used more extensively in all synthesis and analysis along with the trends of the "exploding" capability to generate and measure data, the methods and tools to manage, visualise, interpret and operate on large and evolving datasets will bring AI closely integrated with M&S tools and methods.

**M&S becoming gamified:** both demographic effects and the speed of ICT development drive towards a more instant response functionality of M&S tools. Young people are brought up with "instant response" of queries from the game sector. ICT and AI advances will enable swifter analysis of designs options. It is expected that designers in 2040 will be able to assess the impact of alternative designs "instantly" and that underlying computational power is used to validate such tools.

In summary, M&S methods and tools will be blended with design tools, readily available for designers and developers, better enabling instant interaction for decision makers. ICT and AI will be used to enable such design aids. The countertrends can be the increased diversity and depth of specific studies, where specialists are needed. As the number of M&S applications grow, their integration across disciplines continues to be problematic. The ability to predict behaviour of "systems of systems" in real situations remains a challenge and will challenge design researchers with M&S interests.

## 3.1.3 Technology

The workshop took the shift in production and manufacturing systems from its analogue, carbon-oriented history into a connected, electrical and autonomous future as the baseline for discussion, and elaborated on the consequences and necessities for such transitions to become realised.

**Increase in computational power:** simulation combined with AI and AR will become a more realistic option for product development. In particular, quantum computing was stressed as a ground-breaking technology in increasing computational power, but the engineers were concerned by the difficulty in understanding the results from quantum computing.

**The maturation and evolution of Additive Manufacturing (AM):** will contribute to increased customisation and production on demand. Practitioners foresee AM as a "democratic technology". This will drive new business models and customer-manufacturer relationships. One participant pointed out: "what the company will sell to the customer is the knowledge to support the customer to design her own product, by suggesting what is doable and what is not".

The uptake of new smart materials will drive new practices in design: "there will be materials that are gradually changing over time, so that we will not design and change the product structures, but we will design and change the material properties of the product". The value of materials used in products will gain more attention from manufacturing industry, not only as means to realise functionality, but increasingly also as an asset for manufacturers. As such it complies with the principles of Circular Economy.

**New energy sources:** will drive new design practices, reducing consumption. The challenge in this context is to ensure the security of the supply. The uncertainty in society on cost, infrastructure and legislation was mentioned as an important factor where continuity is important for strategic investments.

Another aspect is that the robots have matured into being true "co-bots", that are nearly seen as colleagues. Their acceptance in all phases of the life cycle with far more ranging applications, and their everyday appearance will be influencing everyday life, as well as industrial practice. The current trend is to make them more flexible and applicable for multiple purposes. By 2040 these robots will have been accepted as a natural players.

In summary, technology plays an important role as an enabler, both for future products and their realisation processes such as design and manufacture. It is clear that many complex products truly rely on the combination of different technologies that work together, and as such this will impact methods, tools and practices for realising them. The perceived uncertainty of the future, in combination with many disruptive shifts in technology brings both opportunities and threats, since many manufacturing companies face large shifts in technology.

## 3.2 Social aspects

The future of engineering design is not only affected by the technology that is designed and the technical tools by which it is generated by also the human and societal changes. The ways in which engineering design processes in companies will be changing and the relationship that individuals have with organisations will also be affected. The individuals need to adapt to this and learning and training is a very important issue in this. Engineering designers will need to respond to many societal challenges, one that particularly concerns engineering companies is sustainability through the entire product life cycle.

### 3.2.1 Ways of working

The “ways of working” station addressed work practises in 2040. The ways of working are obviously affected by the other trends. The trends discussed below are consequently seen as responses to the other trends in the way companies choose to organise work.

> *“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*

**Working environments:** some experts argued that future working environments would assume a practice of working from anywhere – the home, on public transport, in the office etc. Digital engineering tools and AR/VR technology would need to support this practice. Other experts noted that the remote working trend may already have peaked and reversed, referring to IBM as an example. Personal digital assistants will be in place to structure and organise daily tasks.

**End of highly prescribed processes:** many felt that traditional gateway processes are too rigid and will be replaced by a more flexible approach to working. While several engineers mentioned agile scrums as an alternative to rigid processes, there was no expectation that agile will be the prevailing paradigm in 2040, even though many talked about working in intense scrums in the future.

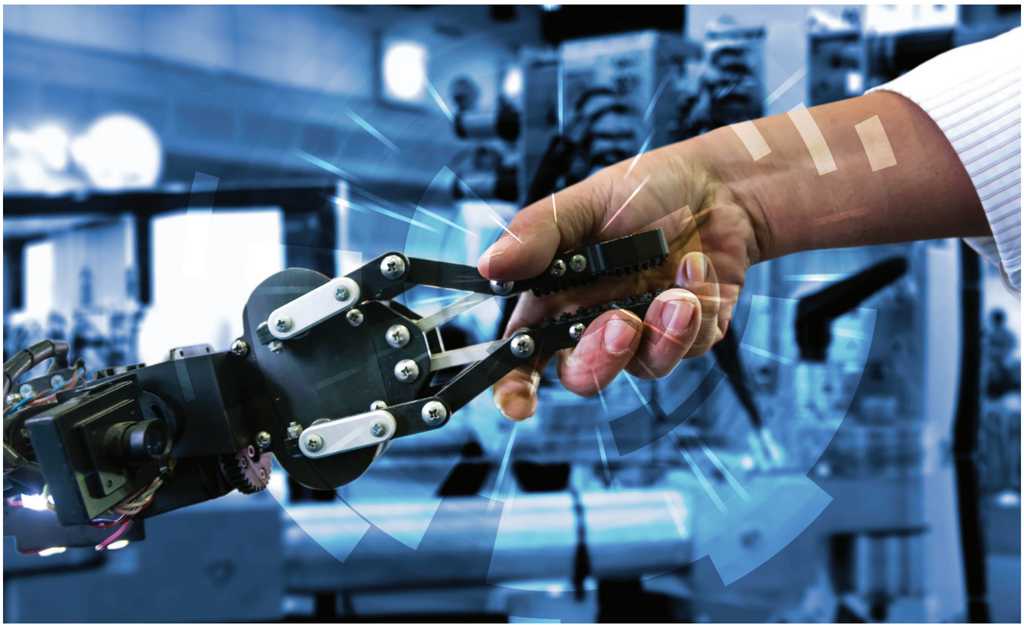
> *“Our whole process is based on agile and has always been in our factories, but it is never been that way in our research and new technology introduction. That’s been a very slow, steady process. What we’re saying now is, we need to jump on new technologies and try them very quickly and if it fails, 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.*

**Integration of disciplines:** as products are becoming more multidisciplinary, engineers from different backgrounds and experts from outside of engineering will have to work together more closely. Many participants voiced a need for better system thinking skills in engineering processes, which will enable system integrators to bring together the contributions of highly specialised experts.

**Flexible working around co-located core teams:** the participants felt that stable core teams will remain permanently located at central company sights, but they will be supported by a range of experts with specific skills, who will be hired for specific tasks and can be located anywhere. This could lead to a bifurcation of working practises with high standards for permanent employees and a gig economy for others.

> *"I think things will become more remote as well. I don't think you need to have – people need to meet up to do work, but I think a lot of stuff could be done just working from home and there's things like the work/ life balance" – Eirecomposites.*[1]

**More diverse teams:** diversity will increase not only in disciplinary backgrounds, but also in ethnicity and location as remote working will become more accepted. The participants, on the whole, did not expect gender balance in engineering. Despite increasing numbers of female students in classical engineering undergraduate programmes, participants did not perceive a strong upwards trend. The increased attention on interdisciplinary, sustainable and social aspects in design may attract more women into engineering.



**Collaboration with robots and AI systems:** is also going to increase and will be considered normal.

In summary, this raised interesting challenges for the product development community. The increased diversity in cultural and disciplinary backgrounds increases the need for effective and joint-up tools and methods to integrate across different disciplines. It also places a great emphasis on design representations that can be shared across different groups, which implies the need for a certain level of standardisation as well as increased literacy. The increased use of experts outside companies also has challenging implications for the protection of intellectual property.

1 Since this quote, the CORONA crisis has accelerated this trend and has brought a big shift in work pattern.

## 3.2.2 Lifelong learning

The "lifelong learning" station addressed continuous development and how engineers can stay updated throughout their professional career. This is increasingly important with the fast-developing technologies in industry, and the consequences this has on human behaviour, as well as increased awareness of engineering work on sustainability and ethics. The workshop discussions involved the ways this could be achieved rather than the content. Some suggestions from the workshop were:

**Technology innovation conferences:** this is not a new concept, but something that larger tech firms have applied over the years; "a very good experience for life-long learning so far, and is important to continue with". It was suggested that universities could offer such conferences to participants from several companies for experience exchange.

**Specialist vs generalist:** The longstanding generalist and specialist knowledge dichotomy was identified as being more important than ever, with the even wider variety of fields required in future product development work, and ever more knowledge available per field. Companies' investments in deep specialist knowledge were highlighted as "the key to success" in combination with specialists working together with generalists at the right times.

**Big data for learning:** with big data opportunities, tools need to be developed to:

- Collect data securely.
- Visualise this data in comprehensible ways in order to increase understanding and minimise risks of misinterpretations.

A critical regard as well as building trust in the results of simulations and data is needed.

**Learning with digital tools:** robots, AI systems, augmented, virtual and mixed reality (AR, VR, MR) will make it possible to move learning methods to new heights, in experimental ways. However, it is required that continuously developed specialist knowledge is built into the new technology tools, and there is an apparent risk if too static and simple, already known knowledge, is the only basis for these tech learning tools.

**The role of universities:** the societal trend of fast (and sometimes false) facts on social media was highlighted as a dangerous threat if spread to engineering work, i.e. it could lead to lost respect for deep specialist knowledge, if "go at intuition" is too much encouraged. Here, universities as platforms for knowledge and learning, and also for professionals along their careers were suggested to reduce this risk. Open boundaries in the educational system with inflow-outflow between professionals of different skills, and personalised programmes made available through digital solutions and online learning, were suggested. The role of universities as neutral places and knowledge hubs for education across companies and industries, regardless of commercial competition, was stressed as important in the future.

Some informal discussions among participants from larger companies touched upon a concern between HR (human relations) departments and product development, highlighting a risk of HR not being aware of the requirements of future knowledge needs. When planning long-term future training, the importance of technological foresight and applications was raised as a concern in the relation between engineering and HR in larger companies.

In summary, it was concluded that responsibility for lifelong learning lies with the individual but encouraging organisational structures and recourses for this need to be secured. The role of universities for education of practitioners after their graduation from university was highlighted.

## 3.2.3 Sustainability challenges in society

This station focussed predominately on sustainability and its implication on society, where resource issues impact the conditions for business, industry and citizens alike.

> *"You asked about trends, and recycling is another one and environmental policy generally. It's absolutely massive and it's driving almost everything" – Eirecomposites.*

As societal trends are comparatively well articulated, the participants chose to express five areas that required a global response:

**Social and administrative responsibilities:** the expert group saw a need for the authorities to better express clearly what is required. Business models should be established on a national level to accelerate adaption and implementation of more sustainable products and services. In this way, social institutions and industry can meet the future goals together. In addition, common global legislations, incentives and nudging for new, more sustainable solutions are needed to meet the societal challenges on the future market.

**Support to reach successful product development with future societal challenges:** they perceived a need for support tools that can increase the knowledge of the engineering teams in the early design phases regarding the product's lifecycle implications, including information about material and energy issues. There were also suggestions of tools and models (simulation and visualisation models) that can predict sustainability impact and circularity options by creating scenarios regarding product usage and social behaviour, societal needs, and policy changes. To quantify sustainability, to monetise sustainability, to asses social sustainability and to move from performance-based product requirements to impact-based product requirements is also needed.

**New development constellations:** there is a need for more multidisciplinary approaches and a collaboration within the value chain from local to global actors but also between different stakeholders (e.g. company, authorities and municipality). To share information, knowledge and to build capabilities across borders is therefore required.

**Long-term solutions:** describing future customer needs in a circular society – product resilience over time, multipurpose and modular products to be reused and maintained. Products with sustainability scores and soft digital certification standards to guide the customers of their choices.

**Education:** Engineers require knowledge and skills in the area of sustainability and engineering. "Sustainable development" is mandatory in public education in Sweden. Sustainable development" is mandatory in public education in Sweden.

In summary, the expert groups highlighted a clear need for tools, methods and models that can predict, simulate, and visualise sustainability impact and circularity options. Scenario creation regarding product usage, social behaviours, societal needs, and policy changes are also of importance. The engineers looked for ways to quantify and monetise sustainability as well as to asses social sustainability to enhance the decisions in product development. Support is also needed for how to move from performance-based product requirements to sustainability-impact-based product requirement.

## 3.3 Reflections and conflicting trends

The main impression from the workshop was the emerging awareness of simultaneously external challenges and their impact on business and technology, such as sustainable development, globalisation and demographic development on one side, and the enabling technologies on the other side.

Information technology and digitalisation are being developed faster than engineering companies are fully able to adapt their ways of working. They now generate very large data sets without being entirely sure how to use them, which may be why AI is a hot topic at present. During the workshop, specific advancements in areas such as AI were not extensively discussed other than that there emerges a need to develop new, and evolve existing, competences, methods and tools. The notion of mastering data was one thing, understanding products in their use contexts was another. In a sense, the participants largely extrapolated on what is already visible as trends but foresee that these will have a major impact on the future of engineering design and development.

The outcome of the workshop inspired to reflection, analysis and formulation of scenarios for the future. This will be presented in the reminder of the report.

Many of the trends discussed will occur simultaneously and need to be considered to successfully develop products of the future. For example, the rising trend towards customisation is conflicting with a trend towards a shared economy: new practices will be needed to effectively customise products that are actually going to be shared.

Some of the trends seem contradictory on the surface, as illustrated in Figure 7, where skill-sets (orange) grow in importance, and the views of the product (blue) expand what is possible. An electric car will need radical new technology and at the same time will reuse many existing parts. The organisations have to consider the entire transport system to understand and increase their role, but at the same time the organisation will need to optimise the subsystems to be as economical and resilient as possible. To design this, they will have to embrace holistic and multidisciplinary working modes, while nurturing and embedding deep expertise within disciplines. As the cars are likely to be operated under a shared ownership scheme, they need to be versatile and easily usable by a range of people. This requires visual and intuitive thinking from the engineers. At the same time the corresponding design will become more digital and more analytical.

The mix of skills required to develop future products will be critical, and rely on bringing together deep specialists with generalists, as well as expertise from different disciplines and intuitive and analytical thinking.

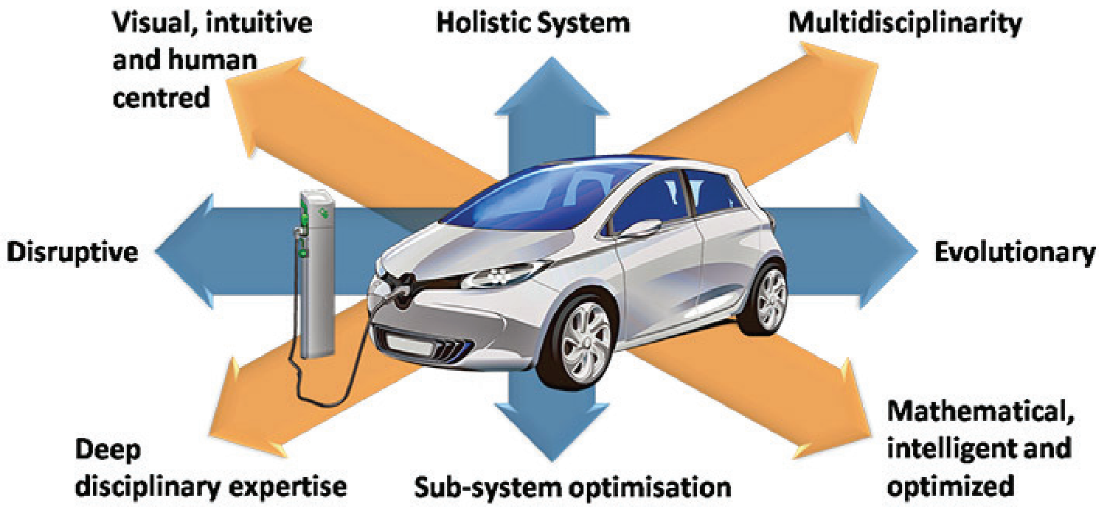



***Figure 7 Complementary dimensions of future product development***

The participants agreed that sustainability concerns and environmental assessments will become mainstream; the responses to the issues discussed largely pointed to a continuation of the current practice with optimising product performance as part of largely incremental design. Financial constraints and resource concerns will make it imperative to reuse as much of existing products as possible, but on the other hand radical new solutions are required to address the magnitude of the challenges we are facing. For systems with high capital investments, such as powerplants and infrastructure, it may make economic sense to prolong life, but a wider sustainability perspective would suggest decommissioning them. For many consumer products, the situation may be the inverse. Extending products life may be the sustainable option, whereas economic arguments and social aspiration call for replacement. Some expressed regret that in times of relative affluence, companies are not investing more in radical new technologies. The automotive companies explored both electric power and alternative fuels and expected these to be introduced gradually in parallel with current engine technology.

All agreed that there will be a greater proliferation of the product variants for different use profiles. The question is, however, how these use scenarios will be elicited. Some expect that user data would enable the company to build up a much clearer picture of user behaviour. The participants of the work made remarkable little reference to participatory design as a trend in the future to understand user needs, however this might be linked to few of them working in user-facing roles.

Similarly, the participants talked relatively little of "design thinking" approaches and expected the future of engineering design to be more mathematics- and model-based than with decisions based on facts. Where "design thinking" would advocate direct user interaction and physical prototyping, the workshop participants placed the emphasis on virtual modelling and data analysis.

Despite the prevailing belief in rational decision-making based on facts, the engineers placed remarkable faith into neural network-based algorithms as a basis for analysis. As these algorithms depend on pattern matching, they won't give the engineers a causal understanding, which makes it difficult to integrate the results into other decision-making processes.

# 4 The future of product development

*In this section, we propose a number of scenarios for 2040 that might impact the nature of engineering design and also some future roles (personas) of engineering designers. These scenarios are based on one or more trends that have been mentioned in the workshop, though many others might come into play.*

Now is a critical time from a sustainability perspective, when we determine much of the future of humankind. It is possible that a collective social and political will might lead to a totally different future. The scenarios reflect both the evolutionary nature of trends, already apparent now and the less predictable trends that could have significant impact. In our analysis we made the underlying assumptions that there will be a range of practices and services of today that will be there in 2040, such as medical doctors and draftsmen for physical prototyping, yet the way they act, and what support they use, may change. The purpose of the proposing these scenarios is challenge thinking and are therefore phrased in a slightly provocative way.

Over the next 20 years the values and literacy of consumers together with societal rules and legislative frameworks will change the expectations and realisation of new products. Generally, the younger generation is more aware of the impact of consumption and resource use and are adjusting their behaviour.

Product development cannot be seen in isolation of the wider cultural, social and political context, which itself has several contradictory trends, as Figure 8 illustrates. In many ways the world in the 2040 will be similar to the present as many of the products designed today will still be used at 2040. Still, in other ways we probably have not even began to imagine what the situation is in 2040. While more people than ever may afford a high material standard of living based on ownership of physical goods, the necessity and value of immaterial, experienced-based solutions increases. Examples are car sharing and users becoming electricity providers on the grid etc. As the patterns of wealth in the world are shifting and resources (materials, energy, water) become scarcer both the type of products, and the way products are being used, are likely to evolve. Bans on plastic products or incentives for carbon free solutions are evidence of changing attitudes in society that encourage shared or collectively owned products and re-used/re-manufactured goods whereas individualism, growing nationalism and prevailing materialism are norms in many parts of the world. Local solutions for products and services may “compete” with a nearly globalised and digitally instant economy, connecting customers and manufacturers.

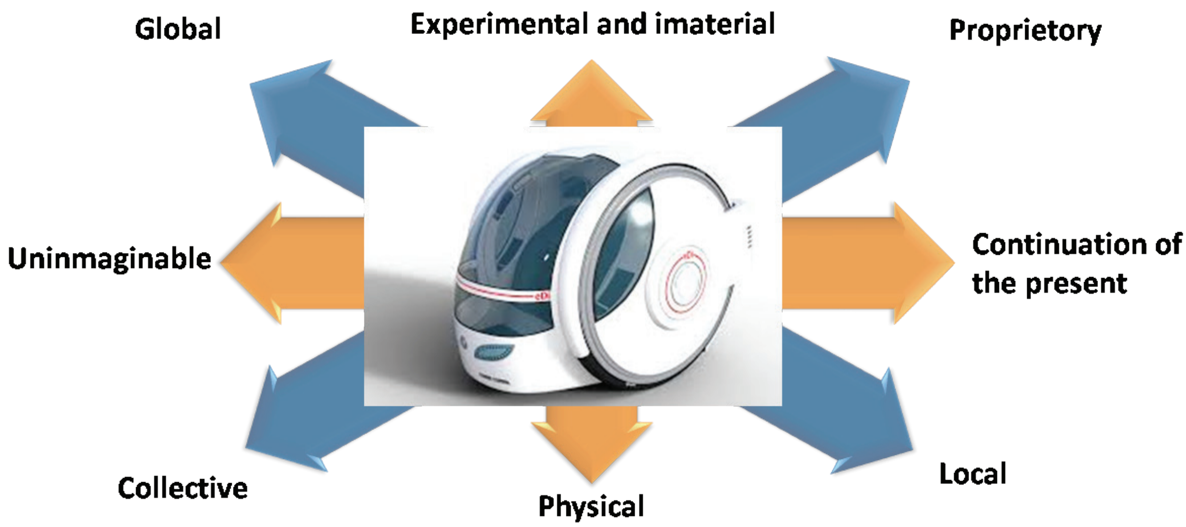



***Figure 8 the context of future product development***

20 years ago, mass customisation and economy of scale expected to be dominant in the manufacturing industry by now, while the present trend of individualisation has re-emphasised the need for flexibility and small scale solutions empowered through a global, digital and service oriented economy. “Mass customisation” has been quite influential but became more nuanced than predicted 20 years ago. However, the importance of “buzz words”, such as mass customisation, cannot be underestimated. Hence, todays societal focus on “digitalisation”, “Sustainable Development” etc. are likely to significantly influence the direction for the future.

It is difficult to foresee disruptive events and tipping points, which impact a global public and behavioural patterns. Some changes can come very quickly, like the recent ban on plastic in some products accelerated by the increased awareness of the pollution by plastic through television programmes, or the “the Greta Thunberg” effect, which brought climate change to the attentions of many and caused a change of attitude in the wider public.

During the workshop, few radically new trends emerged, rather a number of observations that add up to the impression that the future engineer will act differently compared to today. Clear trends were for example, the establishment of modelling and simulation as means to support engineering designers; the expectation is that wide spread availability, advanced performance and accessibility will call for new practices. 20 years ago, 3D representation of geometry was state of art and today we see 3D representations in much wider contexts, e.g. in gaming, training, instructions, “Digital Twins” etc.

## 4.1 The society of 2040

While studying the changes in detail was beyond the scope of this project, several assumptions or predictions about the world in 2040 were mentioned explicitly or alluded to in the workshop and the interviews. All the interviews and many of the workshop participants alluded to the great uncertainties that we are facing, but at the same time roughly assumed that the world would operate roughly in the same way as it does now. Attention to the availability of resources, both materials but even more so in energy was occasionally mentioned. The participants expected both evolutionary and more disruptive development due to societal changes, driven by political dynamics and environmental/ecological needs. Overall the Swedish participants saw the coming changes as an opportunity, while the British participants had a more dystopian outlook. This may show how people's views are much impacted by the political dynamics of their time, since the UK is in the middle of Brexit discussions. The following section covers several topics that were mentioned specifically in the context of emerging trends in product development.

The values according to which people act, follow their generation. In 2040 most of the engineers who are now in senior positions will have retired, along with the values they developed in the 1970s and 80s. The much more sustainably aware generation of currently young engineers will, by then, be in senior positions.

Current trends of raising economic inequality in many western countries could play out in different ways. A decrease in natural resources and loss of habitable land will add to political instability. This ambient uncertainty is the backdrop to following scenarios of 2040.

**The post materialistic society:** as segments of western society have realised the sustainability implication of consumption, they have taken a conscious decision to consume less. They do not define themselves through the products they own, but their ability to use less and make do with what they have. People value experiences very highly and therefore expect the product that they own to give them a good use experience while enabling them to have other positive experiences.

**The shared ownership world:** in some segments of the population, values and self-identity have shifted from personal to community ownership. This is relevant in the context of transport as the personal ownership of car has reduced and communally owned cars are used much more intensively. This has reduced the calendar lifetime of individual products, enabling a faster introduction of innovation into the market. Customers leasing or renting products has also given companies greater control over the life cycle of a product.

**Breakdown in globalisation:** for some products and commodities, the trend to unbridled globalisation has come to an end. While some products are still provided by highly specialised companies, others are sourced locally. The trend to local is driven both by the desire to reduce the environmental impact, but also by the fear of variability due to international politics.

**The rising middle class in the developing world**: the middle class in the developing world is still increasing. With increasing spending power, they consume more but consciousness for sustainability has still to become widespread. This has opened up new markets for conventional products in the developing world, while the different models of ownership have become prevalent in the western world. Diverging value systems have led to product proliferation across the world.

**The resource limited world:** the limits of resources (material, water, energy) have shifted from a concern to a reality, impacting the lives of many people and the conditions for both societies and industry. This raised the need (opportunity, threat) for new solutions, and seeded innovation efforts. Established products have become banned (plastics, CO2 generating) and have become reticent to use solutions based on scarce materials such as Lithium. Capability in Circular Economy has become a real success factor. Users, consumers and legislators have established resource use as a key metric of product success.

## 4.2 The products of 2040

**The Immortal product**: the time of products that are designed to be used and then discarded has come to an end. Complex products are upgraded and updated several times during their life time. Product repair and resale to different users is supported to increase their lifespan. If products reach the end of their life, components and materials are reused following principles of circularity. Legacy systems are incorporated with innovations, so that managing and designing of products blends together. Product maintenance is a core competence.

> *"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 the you can get functional requirements just to add to the fun" – Energy Catapult*

**The connected, the interconnected and shared product**: the manufacturers of products have taken ownership of maintaining the functionality and use on behalf of the users. The products monitor themselves and take active steps to be fuelled, supplied and available, supported by Industry 4.0 technology. Products are designed as seamless, interconnected solutions, e.g. door to door transport, interconnected production lines. Modular architectures allow the use of components, such as motors in multiple products. Therefore, the design of these products must consider a huge number of potential connections. Interfaces are more standardised than they are now. Components are flexible and reconfigurable. The complexity involved in optimising and controlling products for multiple and diverse conditions is far greater than it was in 2019. Digital twins and automatic failure recognition have made the service for the customer far more reliable and reduced the risk for the manufacturer.

**Robust products with locally produced replacement parts**: system architectures involve a mixture of locally repairable and of highly robust components. The emphasis in design for robustness lies in components, that are difficult to service or repair. These are designed and manufactured in a way that they can last for the life time of a product. Many spare parts are locally produced on demand using 3D printers. Therefore, design for reparability will become a key concern. The products and their logistics are designed together. Robust design tailored for local production and maintainability simplifies establishment on new, remote and urban locations with various levels of skill.

**Differentiated product platforms**: product platforms continue to play a vital role. However, the product platforms have evolved to be more structured to give companies a greater competitive edge. Standard parts are shared across competitors to ease maintenance and access to spare parts for users. Market differentiation is achieved through proprietary components and systems, which give the company a competitive advantage. Some components are highly optimised to assure robustness and cost efficiency. As rapid manufacturing has become more established the need for identical components in product platforms will diminish.

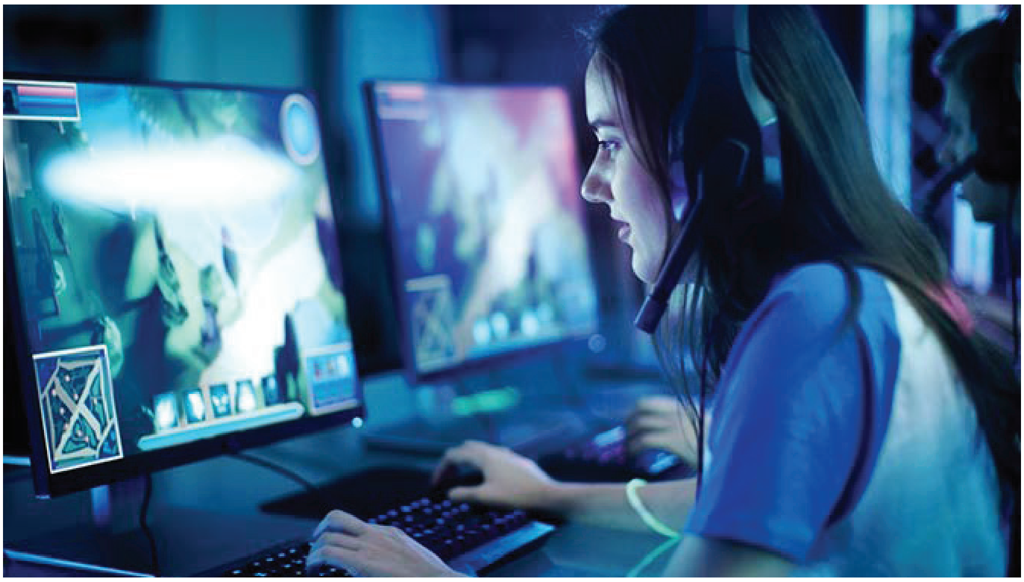
**Servitisation:** "classical" products are offered as services (product-service systems) and consumers pay per use, or availability. The perceived value relies increasingly in the services provided, which alter the requirements and constraints for manufactured products. This increases the proportion of time the product is in use and shortens the life cycles. Rather than piece by piece repair, the entire product is overhauled when it has identified a need for it. Traditional "consumer products" such as cars, irons, bikes, washing machines, telephones and furniture shift from a B2C to a B2B business model. This gives the customers access to higher quality products, as they are designed for much more intense use, but also enables products that deliver the tools to the consumer and assist them with using the products. This shifts the requirements on the products to increased performance, reliability and durability and aligns with the emerging "circular economy" models. Human machine interfaces have also become much more intuitive and products give feedback to the users on how they are used. The level of automation and the use of robotics has really improved the service experience. Design and manufacturing automation technology for service provision have become big business. The products are now optimised for their service models.

**The intangible product**: completely digital and intangible products, such as online games, rely on understanding of the underlying behaviour of the represented physical products. The "coding" of real world (physics based) products (and humans) in a game already exists. From being a niche business for many manufactures, this becomes a main revenue source subsidising the development of new models.

**The value of imperfection**: 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. Sustainability drives the appreciation of using and reusing more of the resources. Therefore, using old products that are still working is valued more. Current trends in reusing clothes spread to other areas of repair, restore and recondition products. Imperfection, as a means of individualisation, can be a feature of products. Long-term use has made it difficult to define use scenarios.

## 4.3 Product development processes in 2040

What is then the outlook for how product development is organised in the future? What will drive the development of new, and improved processes for product development? Influential scenarios that may drive the need for new and improved product development processes and practices are listed below.



**Gamification of Engineering Design**: the youth of today are brought up in a society with nearly instant access to whatever information is needed. "Interactiveness" is a key word, whether it is the feedback when using smart devises (touch screens etc.) or the expectation to instantly find out which movies are playing, where your friends are, if the bus or train is on time etc. By 2040 professional design requires instant response from their tools and techniques. It is possible to evaluate the goodness of a new concepts "instantly". The vision is that novel concepts and ideas can be embodied and tested without delay in different scenarios, much like what can be done today already in computer games. Decisions made on 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 is explored directly through simulation in real use scenarios derived from use data.

**Democratisation of Data:** we are already flooded with data. The ability to gain knowledge about the behaviour of existing products, processes and users through sensing and measuring behaviour in situ will continue to increase. The availability of data increases and that data will be shared (democratisation), whereas the interpretation of data will be a competitive skill of designers and decision-makers. Accessibility to data will become a pillar for new PD processes. Privacy and data access become a political battleground. The raised challenges of access to data in product development requires new processes to identify suitable data elicitation and storage. Data management inside organisations is now a core function.

**Design the behaviour of System of Systems:** the vast amount of innovation 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 of models in several steps. Validity of data, models and methods used in PD processes is critical. The complex methods and specific competence that is currently used in safety-critical systems like aerospace will become simpler and more intuitive. This has raised challenging ethical questions on whether the synthesis of these heterogenous data sources can be relinquished to machines or whether the systems need to be designed in a way that human agents can maintain control.

**Intelligent product development**: what we now think of as smart systems will play an important role in development processes as tools. Tasks that are currently carried out by people will be automated. Intelligent system will play take part in negotiations in the development processes.

The products themselves will also incorporate smart features. They will have greater autonomy and more adaptive control. The systems will also be able to diagnose their own problems and increasingly take control over the adaptations that will be required. 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, and how to cater for this already in the PD process.

**Outsourcing of non-core specialism**: OEMs increasingly become system integrators for multidisciplinary products. It is vital for them 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 will be increasingly outsourced. Such outsourcing raises the importance of active quality management interaction with “freelancing” partners and suppliers. Smart strategies to integrate disruptive technologies, developed by the “outsourced” partners into their systems becomes a competitive advantage; system architects need to be empowered to handle variability form suppliers.

**Structured and flexible processes**: the reign of the stage gate process seems to have come to an end. Agile processes are currently in fashion. By 2040 a new data-driven process structuring paradigm has emerged, but it is not yet clear what this will be. Flexibility of not only the product, but also the design, manufacturing and business process is a key competence to meet the specific needs of individuals and business models. Understanding the ranges of validity and trustworthiness of flexible processes is ensured through an underlying structure allowing manageable risk and quality convergence.
As multiple development processes are interacting, a structure needs to be found that allows automation of routine tasks and effective interaction, however a clear candidate for a future paradigm is to be seen.

# 4.4 The engineers of 2040

Engineering will remain a key expertise for design and development of products. Industry requires both deep specialists and generalists to design these new and integrated solutions. The ability to combine and integrate technologies across disciplines become even more central to product development. Companies need to manage the mix of expert skills in different disciplines. As data replaces expert judgement in many applications, the engineers will need to find new roles and new self-identities in companies and in society.

The engineering community emerging is already becoming more diverse with more women, and more people from ethnic minorities and different parts of the world taking engineering degrees. The skill set and range of interests they bring to engineering is becoming broader. There is a growing recognition that engineers need to address the social and environmental challenges of our time; meanwhile, deep specialists are vital for the technology that will be required. Many of the old roles will remain, but new ones are emerging:

**The gigging specialists:**

- Experts on particular software, materials or technologies.
- Expect to be given well defined problems or work closely with in-house experts.
- Might work through an agency for multiple companies and work from home.
- Are well paid for relatively few hours, and therefore can combine working with hobbies and care duties.
- Personally invest heavily in training and learning.
- Possess the deep and up-to-date knowledge necessary for innovation, that when integrated into products and systems is central to innovation.

These exist already, for example in software development, but the "gig economy" as a trend appears to be spreading to the deep specialism in other engineering fields.

**Core in-house engineers:**

- Generalist engineers, employed by a company, with long-term commitment to that company and the product.
- Work with large teams of remote experts and are responsible for integration and engineering continuity.
- Make strategic and trade-off decisions.
- Negotiate face-to-face with other in-house team members.
- Live locally to and have high emotional investment in the organisation they work for.
- Need to be good at system thinking and have the social and managerial skills to interact with outside players.

As the core teams will be smaller than they are now, they can work more informally and dynamically in working together but need to use formal procedures in the interaction with outsiders, such as suppliers and the gigging specialists.

The core in-house engineers play a decisive role for synthesis, integration and internal coordination and can embody the tacit heritage of core values of a company into designs.

**Legacy engineers:**

- Look after legacy systems, that will play in ever greater part in a world of resource shortages.
- Are able to use old software or understand old mechanical or electrical systems.
- Understand old representations and original manufacturing contexts.
- Nurture these old systems and repairs them with 3D-printed parts and software patches etc.
- Some of what they do, will be seen as a "black art".
- Have a real interest in a specific technology and enjoy their status as being "the expert".

The legacy engineers are central to ensuring the reliability of the industrial eco system of the company as "their" systems and tools are found increasingly valuable.

**Data engineers:**

- Take an active role in creation and use of data.
- Structure and analyse the huge amount of data generated during the product life cycle.
- Have a dual role of carrying out routine data analysis and help other engineers to design products in a way that suitable data can be collected.
- Support the design of suitable sensors as well as the touchpoints for life cycle data.
- Trained in recognising the quality and reliability of the data.
- Help design teams in setting up and analysing digital and physical experiments.
- Likely to have a background in data science, mathematics and statistics.

These engineers will often have a computing background and do not necessary understand other aspects of engineering. However, in the future this will become crucial in the discipline mix for which engineers will be trained.

Data engineers act as brokers with discipline experts to assure that suitable data is generated and can advise on how to analyse this data.

**Data custodians:**

- Have generic data management skills.
- Can handle data in different formats and different locations.
- Support their colleagues in retrieving data, as the 21st century librarian.

As increasing amounts of data are generated, this data needs to be gathered, curated and indexed.

The data custodians ensure that data is available and traceable and can provide the best view on any data when needed. Over time, multiple roles will be required.

**Engineering ethicists:**

- Are involved in key decision processes in the core team and assess ethical aspects of the decisions. This will become even more important as decisions will be based increasingly on the outcome at AI and deep learning. They will work with and challenge the data engineers.
- Are responsible for thinking of different aspects of use and misuse during product life and end of life phase.
- Their backgrounds combine technical, humanities and ecology training, and their aim will be to make sure ethical considerations are always prevailing in all engineering decisions, i.e. not only remains with this specialist.
- Advise on the Impact of decisions on brand, sustainability, business and external parties.

Engineering ethicists ensure compliance with regulations of integrity while managing risks and inform designers on consequences of design decisions.

**Interconnection engineers:**

- Handle interfaces and the data exchange between different products in an integrated system.
- Manage the data flow for different configurations of the system and assure that relevant information is passed on between collaborating products and organisations in a way that is both safe and convenient for the user.
- Design data exchange protocols and data privacy strategies.
- Likely to come from a computing background.

Interconnection engineers are critical members of the engineering teams to assure effective and efficient integration data flow into within and across teams.

**Extreme virtual testers:**

- Carry out virtual tests throughout the product development process and push the virtual design to its limits in unusual and extreme situations.
- As the gamification of engineering will enable nearly instant validation, they can develop virtual intuitions for product behaviour.
- Can look for new applications for products and new ways in which they are misused.
- Need to understand the actual behaviour of products as well as the users and their needs and habits.
- Highly skilled in virtual modelling and simulation software and come from a computing or gaming background.

Extreme virtual testers explore a products' behaviour to breaking point from a usage perspective, identify weaknesses of emerging products and inform the quality teams.

**Multi-disciplinary integration analysists:**

- Bring modelling and simulation skills from multiple domains (multi-domain experts).
- Symmetrically explore product behaviour to identify failure modes and potential areas of user dissatisfaction.
- Have an analysis mindset and pay attention to details.
- Possess skills to formulate and use abstract and disciplinary neutral descriptions and architect how contributions can be combined.

Multi-disciplinary integration analysists assure that trade-offs can be assessed, and products are optimised across multiple applications.

**Visual prototype designers:**

- Create visual models quickly and try out new ideas in a virtual or augmented world.
- Promptly adapt the visual design and explore its effect on users.
- Carry responsibility on the human-machine interface, which is critical for shared ownership products that are used by multiple users without introduction.
- Create different prototypes tailored to the needs to various audiences.
- Try out multiple options and explore the design space in a playful way.
- Have a background in product design.

Visual prototype designers assure that not only product behaviour meets the user needs, but also that the products have visual appeal. They have the ability to contextualise what is important to represent for different stakeholders and situations, using virtual prototyping for decision making and early information of tacit and emotional impact of products.

**Local application engineers:**

- Understand the needs of the target market and their local, social and cultural context to support the customisation of products to specific requirements.
- Skilled engineers who can customise the products, adhering to local conditions and legislation and input into the product development process from the perspective of these different markets.
- Oversee local servicing and repair, since spare parts are produced locally by 3D printing machines.
- Generate priorities for requirements arising in their area. They come together at critical points in the design to negotiate solutions that work for multiple markets or areas.
- Are local engineers who are trained remotely by companies to give them a presence in the market.

Local application engineers have an important role contributing to the design team, giving a voice to the communities they represent and negotiating requirements for product development amongst themselves.

**Repair and upgrade engineers:**

- Assure that products are maintainable, repairable and upgradable.
- Are responsible for design for reparability and upgradability as part of system architecture, work on instructions for repair components, create instructions for 3D printed spare parts and work out how to do repairs when unexpected problems arise.
- Their view is wider than traditional maintenance, which focuses on maintaining the status of already produced parts, towards continuous improving products and increasing their life and functionality.

Repair and upgrade engineers add a design view along the entire product life cycle. They will act as designers as the economy turns “circular”.

**User to product diagnostic interface developers:**

- Handle the development of tools and applications (apps) that inform the customer on the state of the product.
- Champions the knowledge extraction from products for the benefit of user and also back to the manufacturer.

As products are self-diagnosing their status to the users, the design of direct product-user interaction features is now absolutely central during development. This information will be available through increased system diagnostics but needs to be passed to the manufacturer as well as the customer. These applications provide information about the performance and state of repair of the product in an intuitive way, filtered by interest and expertise onto different platforms.

**Advanced material designers:**

- Assure that advances in material science are integrated into product development.
- Bridge the gap between material characteristics, design of functionality and manufacturing processes.
- Understand the repair, upgrade and reuse issues associated with the material.
- Understand the substitutability and sustainability issues associated the materials as well as economical and technical aspects.

Advanced material designers champion material questions, handle issues arising from scarcity of materials and contribute to designing solutions.

Many of these roles already exist in some form today, but are currently missing a clear design perspective. Since advancements in technology need to be integrated into future products, their roles need to be redirected to contribute effectively to product development and design processes.

# 5 Reflections

*The discussion of trends brings out very clearly how the products of the future are a response to societal needs and desires. In our rapidly changing world, companies need to understand which changes can be accepted and embraced by sectors of society, and they need to put active effort into positioning themselves. This is fundamentally a design challenge.*

Design can generate desirable new products and thereby create behavioural change, but it must also follow changing behaviour. Public and political rhetoric often argue that fundamental science leads to breakthrough technologies, which will then change lives or breathe new life into ailing industry sectors. However, this over-simplified view ignores the role of engineering and engineering design, which will become more, rather than less, important as it is needed to help people with embracing these new connected technologies.

It was remarkable during the workshop how much consensus there was amongst the participants. None of the groups argued amongst themselves and while they different arguments, they were complimentary rather than adversarial. This is may not be surprising in a workshop consisting largely of senior engineers in Sweden, where the national culture and the role put a premium on the ability to generate consensus. Most of the participants where long-standing collaborators of the authors from complex engineering firms, so that there might have been a bias towards like-minded people; however, because of the existing relations the participants were very open und willing to share their insights. GoCo, the workshop hosts also invited participants from a slightly broader range of companies, that the authors had not known before. To get industry people with a certain overview, the invited participants mainly had at least 10 years of experience. At the end of the workshop, the participants themselves were wondering whether a more heterogenous group would have come up with a broader range of answers. They were wondering whether a group including start-ups and entrepreneurs, or people in their 20s would have come up with different results. This emerged as a reflection from the participants, and of course it would be interesting to explore the views of a wider range of people.

The workshop was carried out in the autumn of 2018 under the darkening clouds of US import tariffs and a looming Brexit. This uncertainty was discussed or alluded to by the participants. The Swedish participants were fairly upbeat and saw the coming challenges as an opportunity for their businesses. The British participants had a fairly negative outlook with serious concerns over the future of product development in the UK. However, the participants did not break the likely development down into specific scenarios and largely ignored the implications of their current anxieties over the continued evolution of the developed world.

This report is being finalised in the spring on 2020 when Corona cases are rising all over the western world and much of public life has been shut down. Many of the companies that have participated in the workshop are also affected and had to suspend operations or reduce working hours. Some of the companies have long and illustrious histories and have withstood world wars and recessions, while some of the smaller companies only have the resources to be survive for a few months. Overall the prospects of the manufacturing sector are much better than for the service sector. The companies that are already embracing some of these trends will also be part of the solution to overcome the current crisis. From the perspective of the spring of 2020 it is difficult to say how individual engineers will be affected. For example, while we saw a clear trend towards gigging engineers, both individuals and companies might see the benefits of long term stabile employment relationships.

The participants largely assumed that trends to 2040 are a continuation of the trends that have already started, like an increase of modelling and simulation, or outsourcing of non-core competencies. Other trends they expected were responses to the problems they are currently confronted with. For example, they expected that current challenges around the integration of mechanical, electrical and software components would lead to better capabilities in cross-disciplinary working.

Some of the trends were current hypes, such as big data or machine learning. The participants reflected little about the backlashes to these technologies. For example, machine learning approaches are largely black box approaches. In the long run it might trouble engineers not to understand the underlying causes of correlations. This could also raise concern around the accountability of engineering companies, if they base decisions on the results of machine learning and analysis of big data. The current expectations in machine learning are so great that the probability is high that people will be disappointed. Therefore, machine learning might decline, and rise again when a greater skill levels and literacy is achieved across the engineering populations.

The engineers placed equally great hopes on big data without a clear understanding or plan of how to analyse it. Only a few mentioned concerns over cybersecurity and privacy. These issues will need to be resolved before these technologies can be rolled out on a large scale. These issues will have to be addressed outside of engineering by policy makers, lawyers and ethicists. However, the engineers need to input into the process in an active way.

This raises the question of whether the engineers are responding to changes that are happening in society or whether they are themselves the agents of change. In the design thinking community, is argued that design is an "action aimed at changing existing situations into preferred ones" (Simon, sciences of the artificial, 1969, p.130); designers therefore see themselves as change leaders. The self-understanding of the engineers who participated in the workshop was slightly different: they saw themselves as responding to changes, even though collectively they play a very important part in shaping the world.

# 6 Implications and recommendations

*Many of the products being designed and developed today will still be in service by 2040. Their components and sub-systems may have an ever longer life, as designs and physical components are re-used and legacy systems will need to be embraced. In that sense 2040 will be a lot like today, but with more complex, connected, "circular", interdisciplinary and more integrated products.*

More importantly, the people being trained and educated today will be the active generation of product developers by 2040. The 2040 perspective is not that far off. There are many possible recommendations and conclusions that can be drawn from this work. For education there are still noticeable differences between countries, organisation and disciplines, so that several recommendations do not necessarily apply to all.

## 6.1 Recommendation to Industry

The future of product development will involve greater connectivity, as technologies allow a greater connection between the product, the user and the manufacturer. Products themselves will be more connected, as the end customer increasingly buys an integrated service rather than a specific item. However, companies need to take a critical position on how much they specifically engage with any of these trends, such as connected products, resource limitation or life cycle approaches. Not all technologies and opportunities need to be followed by all companies.

Different industry sectors have already embraced many of the technological and societal trends, which are still some way off in other sectors. The various maturity of the business cycle in different sectors is also a great opportunity to learn from each (for example, the safety practice in aerospace would benefit the automotive industry and conversely efficiency practices of the automotive would benefit the aerospace industry). Therefore, industry would benefit from identifying these pockets of excellence and actively engaging with the practice of sectors with higher maturity by collaborating, hiring experts from different sectors or engaging with academic experts. The emerging skillsets needed in a particular industry sector can be more mature in other sectors.

Examples of important points for the future are:

Embrace complexity

- Invest effort to understand underlying complexities/phenomena; There are no "silver bullet solutions", but rather clever matchmaking between smart ideas and specific areas.
- Learn to work with other companies outside your sector in an egalitarian way, not the hierarchical supply chains, but networks of collaboration around specific issues
- Do not think in terms of optimising every single product, optimise systems in the long term, e.g. next generation, circular economy etc. Optimisation is increasingly important to find robust designs in a multidisciplinary context, rather than pointwise optima such as minimized weight. The risk of reduced margins can lead to other problems due to the integrated nature of systems.
- Push standardisation where it makes sense, to reduce the interfaces that need to be designed and managed; there are going to be many others as well.

Embrace new technology where it adds value

- Weigh up carefully where to engage in digital design and where physical solutions are needed. "Digital" is not always the solution, "just because we can". For example, much can still only be learned from physical tests.

Embrace news skills

- Understand the skills you need in the future and recruit new people in time to input into the product development. Encourage your existing workforce to evolve and incentivise them to engage in lifelong learning. In time of work mobility, the individual and not the company becomes the owner of learning.
- Think carefully about how to exploit/benefit from the new competences emerging. Anything that impacts people's way of working implies a change.

Overall, the capabilities required in the (near) future may need to be critically and strategically addressed, and investing in technologies may require investing also in how to design and integrate these into working products.

Companies have strategies for their future products, technologies and market position. It is equally important to have a strategy that ensures these products can be designed, integrated and maintained. This means proactive development of competences, tools, processes and methods to assure that the necessary experience and expertise is available for next generation products.

## 6.2 Recommendation to Research

Research is still often organised in a disciplinary way and engineering often priorities deep research on specific technologies or fundamental science over the interdisciplinary or multidisciplinary research. However, future engineering design research needs to become integrative, helping companies to bring different disciplines and perspectives together. This requires a change in which research is funded and how it is evaluated by outsiders, as well as a growing together and reaching out of different research communities.

Another topic is to understand the difference between data mastery and data literacy. Volumes of data are increasing, and there is a general need for designers, decision-makers and researchers to master situations where the sheer volume of data requires a different strategy than has been commonplace to date. "Mastery" is likely to require new expert skills, whereas literacy will be necessary for many generalists in engineering design.

There are a number of research areas that have become apparent:

Embrace disciplinary plurality

- Multidisciplinary, interdisciplinary and transdisciplinary research needs to be become the norm and not the exception. In particular, research is required on how to bring together the perspectives, tools, methods and models of the different disciplines.
- There is a need to better link data science and engineering design disciplines.
- Design is a subject matter that continuously needs to be revisited and questioned as the subject matter evolves. This is contrary to the traditional, disciplinary way to conduct research: "design cannot be solved, but needs to evolve".

Embrace the system context

- Systemic thinking – there is an increasing need to understand the impact of sub-systems and detail levels on the overarching system impact level, since success of products relies on their behaviour in a larger system context.
- How to maintain a critical view on systems of systems (also education) simulations. We increasingly rely on automated, simulated data of simulation results in multiple levels. What is valid?
- New products and technologies need to blend novel and legacy systems, where at present insufficient knowledge exists from a research perspective.
- Understand widening system boundaries: the systems of the future are likely to embrace multiple products and the services associated. Research is required on how these "softer" aspects can be modelled, analysed and integrated with the technical aspect production.

Embrace new ways of designing

- The means (methods and tools) to develop new products need to be co-developed together with the novel technologies used in these products.
- As engineering depends more on digital models and data, we need to think through implications for product development processes, legal implications, user, ethics and policies etc.
- The dynamic and multi-disciplinary nature of the future will require new processes and procedures for effective product development

Overall, research is needed on how to understand and master increasingly complex and tacit aspects from a design point of view. Advances in a range of disciplines are coming fast and in parallel, which means that designers need to deal with rich sets of evolving knowledge and condense these into products and services. The role for designers may be the same, whereas the nature of design problems changes, and with them the means to aid designers.

A challenge for research (and industry) is to build foundations for innovative ways of designing that leverage on interdisciplinary knowledge. The prevailing consumption paradigm is severely challenged, and there is a need to develop knowledge in how to design and develop products in a severely resource-constrained future.

## 6.3 Recommendation to Education

The education sector is now training the engineers who will be in senior positions by 2040. As products become more integrated and technically complex, industry needs technical specialists who can develop and apply these new technologies and deploy existing ones to maximum benefit. At the same time, it needs engineers who can think through the social and systematic aspects.

This raises the question of whether universities are recruiting the people who are most suited to meeting these challenges. Engineering degrees are, in general, still attracting predominately male students, although there are changes visible. For example, in Sweden the gender mix is slowly becoming a balanced situation at university level, but other countries like the UK fall behind. Several more recently adopted curricula make steps towards a cross disciplinary focus in the engineering programmes. For example, the widely adopted CDIO[2] curriculum still emphasises fundamental skills in maths and science, and also emphasises that these skills need to be set in a context.

2 http://www.cdio.org/

For the future, two clear sets of skills were requested in the interviews and workshop:

- Fundamental and general skills in maths, data science, statistics and programming are necessary to meet the needs of the increasingly data rich society.
- Systems thinking and integral skills, capable of bringing together specialists' contributions while keeping a focus on the customer and societal impact of solutions.

There is a risk that this causes a "gap" in mental capabilities between the specialised and generalised skills. The engineering organisations of the future, who are engaged in product development, will need to be capable of bridging and connecting these aspects, and employ people who either process both sets of skills or can act as a broker between them.

The challenge is to educate such engineers. One challenge for schools and universities will be to attract other groups with these diverse skills and interests in engineering. They need to find other entry points to the education system for system-related roles, which do not depend heavily on traditional technical skills. This is particularly a challenge in countries like the UK, where universities insist on students having selected maths and science at age 16.

The new disciplinary mix will require universities to look even further beyond the disciplinary boundaries and foster collaboration with mathematical subjects and social scientists, business and entrepreneurship development and physics/computing/material disciplines.

Empower new engineers:

- Recruitment of more diverse people in terms of gender, culture, age and background.
- Recruitment of people who are good at system thinking, rather than selecting purely on ability in maths and science.
- Recruitment of people into engineering as a second career, offering conversion courses or cross disciplinary masters courses.

Enable transferable skills:

- Training engineers, who can handle systems and details.
- Training engineers, who have the technical and social skills to work across disciplines.
- Training engineers, who can manage the interaction with the deep domain specialists.
- Training engineers, who can see solution for societal challenges such as sustainability of the future.

Embrace skills for technological trends:

- Digital engineering skills, such as Augmented Reality, Modelling Based Systems Engineering (MBSE) etc.
- Data science skills to meet the expanding amount and presence of data.
- Mix of physical (Measure and observe) and digital (Modelling and simulation) skills.

# 7 Concluding comments

*As L.P. Hartley's famous quote says: "the past is a foreign country; they do things differently there." The same can probably be said about the future. Many aspects of the working practice of engineers and the context in which they will be working cannot be foreseen. This is probably truer now than it had been before, as both political uncertainty and the climate emergency are posing many challenges that are both opportunities and threats to industry.*

In Section 3, this report listed a number of trends from the workshops and our interpretations in Section 4. What is harder to predict is the prominence of these trends in 20 years' time. In many ways practice will be very similar to now as people stick with what works for them; old technology has a tendency to linger as it fades out in niche applications.

Digitalisation, bringing an avalanche of data together with AI, is a cognitive challenge that brings fundamentally new aspects into design. The dynamics in society bring new and imminent challenges, such as the ongoing pandemic crisis, that require swift, broad and concurrent actions. Designers of the future are the ones responsible for creating solutions in situations where human cognition may be a limitation.

Designers need to remain the decision makers where "black box" approaches (AI, Machine learning, Big Data) become the norm. This challenges the ethics of design, and design decision making needs to be re-thought in both industry and academia. Rather than waiting for what the future will require, we need as designers to take a proactive role in shaping the future we desire.

The aim of this report was to alert industry to some of the potential changes, aiming to start a debate on the research and teaching requirements that arise. We are very interested in any feedback, and in generating and fostering this dialogue.

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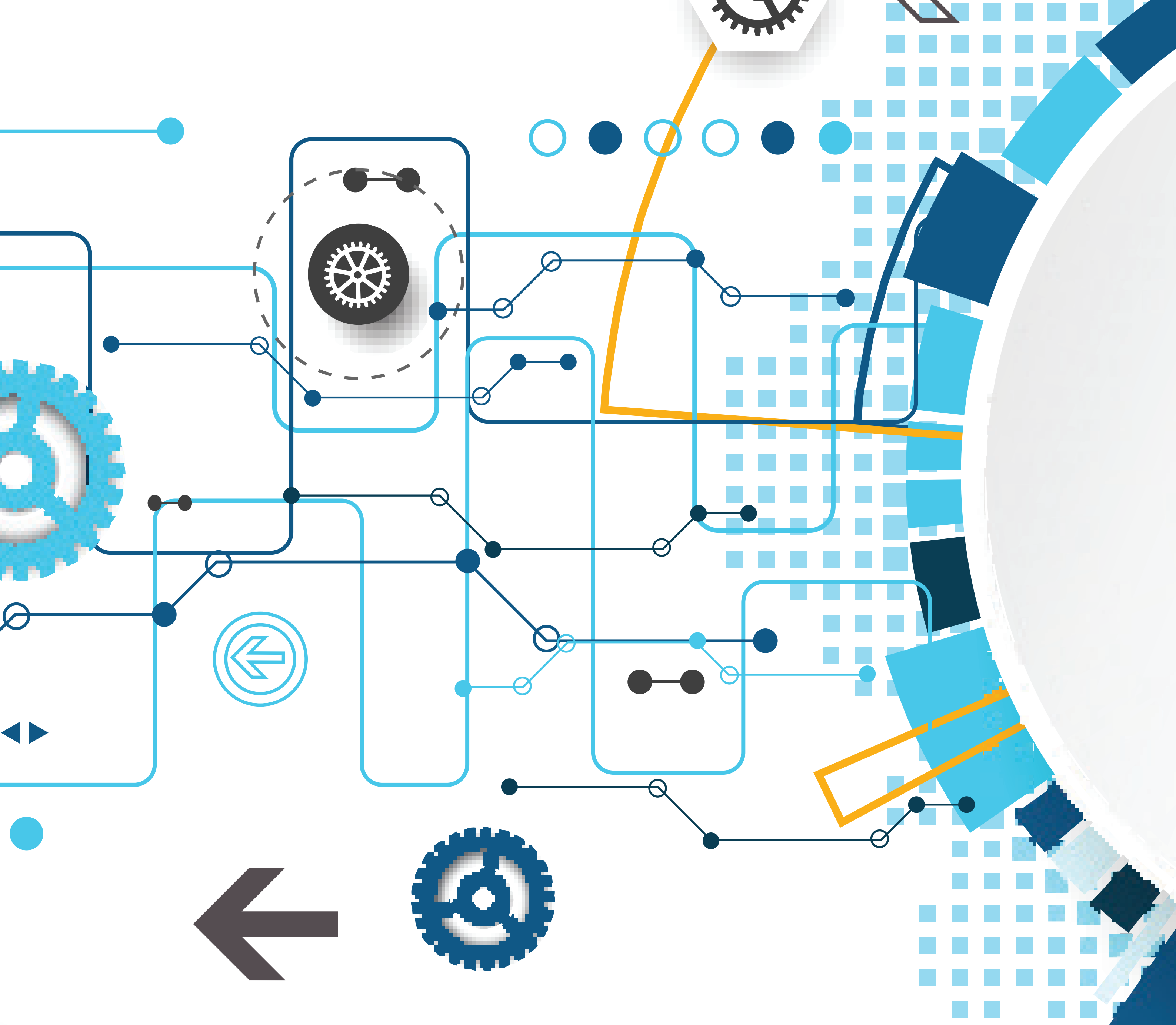

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