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Digitalisation, sustainability and servitisation: Consequences on product development capabilities in manufacturing firms

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Abstract

This paper investigates the impact of the three mega-trends (1) digitalisation (2) sustainability and (3) servitisation on design and development capabilities in manufacturing companies. First, technological advancements have created both product opportunities, and new aids, captured in e.g. the Industry 4.0 paradigm, and intensively driving digitalisation of businesses, that, besides the technological challenges, cause new challenges and problem areas, such as information ownership and shared long-term responsibilities. Second, the need for sustainable solutions increases the focus on the design of circular, resource efficient and radically new technological solutions to be designed with a total life cycle perspective in mind, through use phase, repair and overhaul, until recycling and end-of-life. Third, and finally, the classical roles for suppliers, integrators and users are being changed as servitisation and Product-Service Systems (PSS) offerings affect both products and businesses, and ultimately entire value networks with new constellations of business partners contributing to the realization of solutions for customers.
This paper builds on a conceptual literature review to identify relevant information about the three trends regarding their impact on design and societal development. In addition, a semi-structured interview study was conducted to investigate possibilities and challenges that four different types of manufacturing companies perceive today with respect to the mega-trends, and more specifically how these trends impact the design and development capabilities in the studied companies.
Results from this empirical study show that digitalisation is viewed as an opportunity to find new solutions to meet customer needs and be competitive at the future market. Sustainable Product Development (SPD) was instead primarily to fulfil requirements and legislation. However, it was clear that some manufacturers start to see market forces as a driver. PSS can be seen as a means to create new solutions, often with digital tools as facilitator. Altogether, the literature study and the empirical data show that increasingly, designers are expected to design entire solutions, as opposed to merely artefacts. This implies that designers need to consider not only the product performance and cost, but products' and solutions' behaviour and impact over complete life cycles, developed and organized by business networks together with several suppliers and other partners with different capabilities. The basis for the designer is a technology mix comprising services, software, electronics and hardware, bundled into offerings in new business models, interlinked with new digital opportunities. Moreover, it is clear that the three trends do not represent stand-alone perspectives but affect one another in an

intertwined way. To achieve long-term effects, the sustainability issues need to be integrated with many other subject areas, and implemented simultaneously as digital solutions, e.g. digital twins to physical artefacts are conceived, and value creating networks are being built up. Obviously, these three trends affect the need for change in product design capabilities and escalate the challenges of the integrated product development viewpoint, in a way that is difficult to master for individual engineers. Support for design and development work is needed that takes into account the mega-trends digitalisation, sustainability, and servitisation.

Keywords: Design Methods, Sustainable Product Development, Product-Service Systems, Value Constellations, Design capabilities

1. Introduction

It is expected that many manufacturers' traditional physical products produced by today have to be replaced by novel solutions for a sustainable society, and take advantage of the new technologies and business models emerging in society. Similar to the societal transition that has a profound impact on our daily life, the methods, tools, and processes used to develop products, need to be adapted and evolved to realize expected innovations. Competitiveness of manufacturers lie within their ability to adapt and develop efficient and effective practices to develop the needed solutions. Many manufacturing companies use methods, processes and tools that have been developed to handle predominately mechanical or electrical products, and the question is if this is sufficient for the management of a more diverse scenario. We have selected three product development capabilities; digitalisation, sustainable product development (SPD) and product-service system (PSS), that mirror how manufacturers can address the three mega-trends: digitalisation, sustainable development and servitisation.

The purpose of this study is to investigate possibilities and challenges that companies perceive today with respect to the mega-trends in digitalisation, sustainable development and servitisation, and more specifically how these trends impact the design and development capabilities in product development companies. The particular focus is to answer the research questions: How are the manufacturing industry capabilities for product development affected by these three trends in society? What are some potentials in combining digitalisation, SPD, PSS to develop innovative and valuable solutions?

Numerous studies exist that analyze each of these mega-trends individually (e.g. Lazl, et al., 2014; Robèrt and Broman, 2017; Willrd, 2012; Davis et. al., 2015) and their impact on society and industry. What is less clear, is the impact on design and product development, and in what way design and development capabilities are impacted by these mega-trends. Design and development, which are the early stages in the product innovation process, are good examples of "integrative" business processes that later can be produced and offered. The three trends have in common their broad and overarching impact on the development of society, as well as detailed impact on companies' business models and solutions to meet the needs in society. As the variables of such solutions is likely to influence not only the artefact, but also life cycle dimensions, product-service system interactions, value constellations etc., the established design capabilities are likely to be impacted.
The paper is organised as follows: i) in the remaining of the introduction, three product development capabilities, digitalisation, SPD, and PSS that address the three mega-trends are described; followed by ii) method description in section 2; and, then finalized with iii) result and discussion in section 3.

1.1 Product development in Industry 4.0 – digitalisation

The digital economy is central to development and growth in Europe, as outlined by the European president-elect Juncker in 2014 (Juncker, 2014). In the 2017 version of the scoreboard (European Union, 2017) monitoring the progress of digital transformation in Europe, it was stated that 75% of respondents from Automotive, Mechanical and Healthcare and pharmaceutical industries regarded digital technologies as an opportunity, and 44% of the companies investing in digital technologies had generated a positive outcome. Still only 47% considered that they had the necessary skills over the last three years to adopt new technologies. It seems evident that the digital transformation has a broad impact on society in general and is a fundament for – what is often called the fourth industrial revolution.

Digitalisation is the term commonly used to denote the use of digital data, and for product development we here refer to the use of digitized information to support and enable product development. In this way, the product development is a part of the concept of Industry 4.0 (Lasl et al, 2014). In the present report, we use the term Product Development 4.0 as a term to emphasise the product development view in the wider Industry 4.0 domain. Practical examples include the use of digital guidelines, capturing and using data generated in all phases of the life cycle for the purpose of product development, as well as capabilities to manage and process the increasing amount of data generated.

One characteristic of digitalisation is the explosion of data being generated in all phases of the life cycle. Engineers in product development have the ability to benefit from the vast amount of information measured in both production processes and when products are in use using so called “digital twins” (Tao et al. 2017). Less evident is how companies benefit from the data being generated within design iterations. Theoretically, and practically, data can be communicated nearly instantly independent of geographical location, yet the work practices for designers, focusing synthesis in design decisions have not established and gained sufficient experience in the new way of working. One problem is the experience, trust and set of practices that have been matured over decades of less digitalized work practices and to what extend these are helpful as an experience base or as conditions that hamper a transition into a more digital context. Hence, it is important to understand the needs and opportunities that industry faces, and how these are tackled in practice.

From a digitalisation perspective, the interest in this study is to identify both challenges and opportunities arising from digitalisation, both directly as products increasingly use digital technologies, and indirectly as a consequence of new offerings. Other aspects are the new and enhanced capabilities for digitally aided design tools and methods.

1.2 Sustainable Product Development

Many product development companies are affected today by sustainability challenges such as climate change, increased costs for critical materials and stricter regulatory requirements, which are a consequence of a linear resource society. To steer into a more sustainable development path not only requires small changes in line with tougher legislation but also radical improvements and innovations. Sustainability-driven innovations are profitable (Willard, 2012) and empirical studies indicate a positive effect of sustainable product innovation on overall company performance (Chen et al., 2006; Küçükoğlu and Pınar, 2015). A way for manufacturing and product development companies to respond to the sustainable development trend is to apply Sustainable Product Development (SPD). This means that a strategic sustainability perspective is integrated and implemented into the early phases of the product innovation process, including life-cycle thinking (Hallstedt and Isaksson, 2017). Working strategically with corporate sustainable development means that efforts are guided by a unifying vision of what sustainability means for the company. At the same time, it is crucial that a

complete socio-ecological sustainability perspective is applied, rather than focusing only on a few sustainability aspects, which leads to a risk of sub-optimization and long-term sustainability consequences (Byggeth et al., 2007). To explain sustainability a principled definition of sustainability that describes the boundary conditions within which a sustainable society has to operate is therefore used here. These principles can also be regarded as the root causes of unsustainability for the ecological and social systems. The current phrasing of the sustainability principles is as follows (Missimer, 2015; Robèrt et al., 2013):

> "In a sustainable society, nature is not subject to systematically increasing…
> 1. … concentrations of substances extracted from the Earth's crust.
> 2. … concentrations of substances produced by society.
> 3. … degradation by physical means.
>
> and people are not subject to structural obstacles to…
> 4. … health.
> 5. … influence.
> 6. … competence.
> 7. … impartiality.
> 8. … meaning-making."

These sustainability principles clarify what is required for sustaining the social and ecological systems so that their potential to support the fulfillment of human needs are not systematically degraded.

Businesses clearly expresses a need to be able to increase their abilities to work with sustainability (Schulte and Hallstedt, 2017) and the main company driving forces for investing in building capabilities for sustainable product development and innovation are increased competitiveness, legal requirements, brand and reputation, and employee motivation (Bansal and Roth, 2000; Dangelico and Pujari, 2010). The problem today is that few companies have succeeded in integrating and implementing sustainability, especially at the more operational level because it is not concretized and integrated with other technical parameters (Knight and Jenkins, 2009). Today there are several examples of more sustainable solutions from manufacturing companies, such as, reduced need of lubricating oils in the usage phase, improved hydraulics that optimizes and makes the machines more energy efficient, lower weight which reduces the material usage and makes the machines more energy efficient in the usage phase, and longer service life that also is a more material and energy efficient solution. In total, these are typical examples of solutions that can give a better sustainability profile of a product. However, many of these solutions are more of a coincidence than a conscious and systematic approach of sustainable product development. Previous studies have shown that there is a potential to adopt a more systematic approach for sustainable product development (Hallstedt, 2017; Hallstedt et. al., 2013; Pigosso, 2013).

From a sustainable product development perspective, the interest in this study is to investigate the potential of creating more sustainable solutions, and particularly in combination with digitalised PSS solutions. The aim is to learn from some current examples how sustainability aspects have been integrated in products, services and processes. From these suggest, in future studies, a more deliberate and systematic approach for sustainability integration and implementation.

1.3 Product–Service Systems

Product-Service Systems (PSS) is commonly used to give manufactures a framework to articulate business offers in the servitisation economy (Davies 2015, Neely 2008). It can be considered to be a solution or a strategy where value is provided by combining the artefact, its services and enabling infrastructure, often delivered at an already installed resource base (Oliva and Kallenberg 2003). The portion of service sales for manufacturing industries is increasing (e.g., Dachs et al, 2012) and is clearly connected to innovation. It is also reported that the revenue from services versus product sales is increasing (Neely, 2011).
The PSS demands call for organisational transformations and manufacturers therefore need to develop new competencies and capabilities to become providers of integrated solutions (Antonacopoulou and Konstantinou 2008, Raja et al. 2013). The development of PSS is challenged by the different characteristics of its constituting parts, i.e. mainly the tangible product and the intangible service components. Generally, PSS offering integrates the business model as a part of the solution, which means that the design and development of both tangible products and services are strongly linked to how the manufacturer chose to provide the PSS. A concrete example is to understand and design the PSS taking into account who has the responsibility for e.g. availability and "up-time". Service innovation follows a different logic than product innovation (Janssen, Castaldi, and Alexiev 2015) than product innovation, and manufactures need to find ways to combine product and service innovation effectively.

From a PSS perspective, the interest in this study is to investigate the what extent the industrial manufacturers combine and create PSS solutions that are contributing to solve customer needs for integrated solutions. The aim is to learn from some current examples how PSS aspects have been integrated in product development work, and from these suggest, in future studies, a more deliberate and systematic approach for integration and implementation of PSS solutions.

2. Research methods

The aims of this study were addressed with applying a brief literature review (Thomas and Hodges, 2010), and a semi-structured interview study (questions in Appendix 1). The literature review had the purpose to identify relevant information about the three trends regarding their impact on design and societal development. The review was also used to form research questions, and organize a descriptive interview study. The brief review is presented in the introduction.

The interview study had the main purpose to investigate and give an initial view on what possibilities and challenges companies perceive today with respect to the mega-trends and more specifically how these trends and means impact the design and development capabilities in companies. In addition, the interview study gave indications of how these can be combined in a way that result in innovative and more sustainable solutions that gives added value in the functionality. The industries selected for this study are all Swedish manufacturing companies within the transportation and logistics area that develop and produce products and product-service solutions. The selected business-to-business companies develop and sell advanced and complex products and their technology, business, and collaboration with customer and suppliers, are possibly affected by changes due to these trends. The group of selected companies were broad in the sense that they covered: i) small and large companies, ii) original equipment manufacturer (OEM), and iii) component and sub-system manufacturers. The ambition was to gather information from a representative set of companies to give a first indication of the results. Therefore, four different companies (three large and one small) were selected in this initial study and one to two persons in each company were selected for the interviews. The roles selected for the interview were R&D manager or business development manager, and a project

leader with engineering role or design leader and specialist for technical development. In the small firm the managing director was interviewed covering these roles,

Company A is a manufacturer of aerospace components with about 2000 employees, company B and C manufacture products and provide services in the transportation domain as OEM's with about 2000 and about 4000 employees respectively, and Company D is a vehicle manufacturer with about 30 employees. These four companies were all considered interesting as the roles of the company may change, e.g. expanding its offering to customers with services as opposed to product manufacturing "only".

One of the authors were present for each interview, and an audio recording was made for each interview. After a short standardized introduction to megatrends where the three views of mega trends were introduce, the interviews were guided by a set of semi-structured interview questions divided into three blocks of open questions, around eight in total, see Appendix 1. The employees at the large companies and the owner-manager of the small firm had an average of 18 years of working experience at these firms. The result was analysed using a thematic analysis approach (Guest, 2012).

3. Results and discussions

3.1 General interpretation of these trends and measures

Digitalisation is viewed as an opportunity to find new solutions to meet customer needs and be competitive at the future market. It was expressed as a must – *"as you have to work with this trend and find digitalisation solutions otherwise the company will not be competitive at the market*". SPD seems to be viewed as something that is primarily done to fulfil requirements and legislation, although some manufacturers reported that market forces for more sustainable solutions start to replace legislation as a driver. Here, a difference can be observed between the small owner-managed company, where the respondent expressed a value-driven view on SPD, with prevalent conscious choices made regarding both internal processes and product development, e.g. construction material choices. However, there is perceived limitations in the supply chain that restrains the possibilities to accomplish SPD. In other words, only few interviewees report that SPD is used for innovation and satisfaction of requirements. Instead compliance with legislation still dominate in these companies. On the contrary, PSS can be seen as a means to create new solutions – but these are voluntary in the sense that the customer might not ask for it. The companies can choose to offer PSS solutions and have that in their portfolio if they decide so and see a clear connection to innovations building on digitalisation. This connection is reported also from the small firm, but a difference in PSS development with e.g. software platform solutions is that due to its smallness it supports its larger partners' PSS offerings rather than leading the development on its own. The interest in PSS is more related to whether the manufacturers are close to their end-customers and users or not. PSS is not as strong trend as digitalisation and the emphasis differs between the companies due to where they are in the value chain.

3.2 What are the expected potentials and changes

There are potentials in combining all three areas, as a digitalized service solution is considered to be beneficial from a sustainability point of view. These solutions have a clear customer value such as less fuel cost, less maintenance cost, better working environment, better information to be able to work more efficiently, customized and optimized solutions for the user. Most of the interviewees gave examples of how the trends impacted their products and business offers, and less on its impact on work procedures and processes. But also, it was mentioned that

digitalisation is an opportunity to collaborate in a new way in the value chain or make the internal product development work more efficiently, or even to learn more about the machines they develop. Companies working directly with societal customers, such as cities, see digitalisation already as a fundamental mechanism to understand customer needs and develop their solutions to match these needs. Typically, such solutions are based on digitalized data, provided as services and tailoring of a mixed hardware and software offering.

A digitalised and/or a PSS solution is clear and cannot be questioned in contrast to if it is a more sustainable solution. The interviewees assumed that it is a more sustainable solution if there is an improvement in one of the life cycle phases. However, because it might be more sustainable in one life cycle phase it might not be more sustainable in total. To be certain it has to be supported somehow for example from using defined sustainability criteria, or measure sustainability indicators. The small firm expressed a clear preference for traditional, tested supply chains for life-cycle management and recycling, instead of rushing into new materials and equipment without fully controlling the long-term consequences, and the risks of environmentally worsening solutions compared to the prevalent. Also, the risks of complex configurations risk less controlled sustainability impact. Only when the customers are clearly articulating needs for more sustainable solutions for their operations, the focus of manufacturers shift.

Digital twins, autonomous electrical machines, or co-pilots can all be seen as solutions with a combination of all these three areas. The customer values are expressed as e.g. customized solutions dependent on usage patterns, optimized maintenance program and reparation only when it is needed etc, possibility for the user to optimize the usage of the machine, the time for the staff and also possible to have a cleaner environment and operate from distance. When machines and vehicles are operated in a context where humans and citizens are directly affected, such as in a city environment, digital services for e.g. monitoring, control and optimization of services become directly linked to end-user operations.

3.3 Company engagements regarding the three areas

The engagement in the area of digitalisation is high in all interviewed companies and prioritized. However, the OEM companies are more solution focused, while the component manufacturer also tries to use digitalisation in optimizing their development processes and improve their efficiency. The small firm, with inhouse production, also mentions the ambition of using digital (or Industry 4.0) solutions for more efficient production, such as cobots (collaborative robots) to improve ergonomics and precision in manufacturing operations.
SPD is mainly about keeping it on a level where the technical and legislation requirements or expectations are met, whereas the OEM interacting directly with cities as customers recognize a shift in that innovations are needed to deal with e.g. health issued and quality of living.
PSS is more focused and prioritized in the OEMs than in the component supplier company. The freedom to suggest PSS offer differs depending on where the company is situated in the value chain. There may therefore be a risk that the component supplier company will lose market opportunities as many new digitalised solutions offered at the market are service-oriented. This readiness is clearly expressed by the small firm; although it cannot lead the development of PSS in its field of business it is attentive to be able to provide requested services through its re-selling network and partners. Several manufacturers agree on that the digitalised solutions developed for their product and offer naturally are combined with a PSS model, and one interview emphasized the need to build digitalized solutions that have a tight link to their product and process knowledge, to avoid being copied by competitors.

3.4 Changes in focus and interests

Digitalisation is prioritized and the interest has increased the last three years in all interviewed companies. The difference is that the OEM focuses and combines digitalisation with PSS while the component supplier company have focused on using digitalisation in their internal development processes to optimize and make it more efficient. As the suppliers have less opportunities to provide PSS solutions, the interest has been weak in the supplier company. One OEM identified though the need emerging where they need to build tight and strategic relations with suppliers in order to integrate effectively new technologies. The other reason was the insight that they need to focus much more on understanding their customers underlying needs and cannot keep the necessary expertise in-house for all critical technology domains.

3.5 Future perceived changes in product development

Digitalisation will gradually change the working process. More data need to be analyzed and several sources and types of data need to be analyzed at the same time. To be a strong player in future the efforts in integrating digitalisation are important. New solutions to offer are expected to meet the future needs and new competences and skills is needed. For example, there will be a need of engineers that can do programming, create new platforms, develop new software, and understand new business models.

Sustainability has an influence on the decisions and the solutions that are generated and offered at the market. This is a big challenge in the future and there is a need to be proactive in order to keep the freedom and not have to adapt to even more regulations and restrictions. Awareness, understanding and some on-going learning is needed.

Time aspect is important for digitalised solutions. New digitalised solutions will need to be exchanged sooner than traditional product life-cycles today, especially compared with physical products (every other 8th year or so). Digital (software) solutions are developed with much higher iteration frequency than hardware solutions, and a challenge for product development is to combine the "traditional" product development of hardware dominated products with a continuously increasing electronics and software content. Respondents mentioned the downside on sustainability with a multitude of configurations, as far as individually customized, when it concerns maintenance and recycling, and there is a need to be able to combine these development principles.

3.6 Product development capabilities influenced by the three trends

There has been new learnings and new approaches in the development and design due to real-data information. Instead of an instant change this has come gradually. For example, new solutions when data is transferred between different machines require more advanced computers. The increased software content in products and services is already influencing the product development work practice, and agile methodologies as have been prevalent in the software industries during more than a decade are being introduced also in equipment manufacturers' development processes. It is not clear how SPD actually has influenced and affected the design process. However, it is considered to be important and something that comes more and more, and conscious choices are needed which require skilled engineers regarding sustainability.

3.7 Challenges for realizing the potentials for expanding digitalisation, SPD and PSS in industry

A clear barrier for expanding in the digitalisation field is lack of competence and resources in terms of money for development and investments. There is a risk that top managers do not have

the awareness and competence in this field and therefore do not see the potentials and make the necessary priorities. Another challenge is to change into a more agile approach. In order to keep up with the development potentials in the area of digitalisation, new collaboration forms are needed or to buy competences and key businesses that already have the right competence and can develop solutions and, if so, manage successful merger and acquisition. A major challenge is also to have the ability to invest in the introduction of novel, disruptive, technologies meanwhile keeping efficiency in "classical" product offers.

Other challenges related to digitalisation is intellectual property rights and how to collaborate around data, revolving questions such as – who owns the data? Can a new business model be created based on important data? How to deal with the increased exposure of data raises questions on cybersecurity. What will the data storage and analysis cost in future, considering the energy need and sustainability demands related to that (Garcia-Martin et al. (2017). Answers to these questions are not solved and in a long value chain (such as the aerospace industry) it can delay the development. A common goal and clear road map is probably needed to be developed by supply chain players in an international forum.

For the SPD area, it is an internal company priority to focus more on sustainability aspects. To make it become a selling point it needs to be connected with a customer need that impacts some key requirements, e.g. safety issues, select some indicators and monitor those. Also, awareness, dissemination, and internal communication are important to expand in this area. Need champions that lead the area and have a position in which they can influence decisions. For PSS, it also depends on the company's priority and customer needs. If there is a clearly expressed customer need – then a company interest will be developed.

3.8 Beneficial to combine digitalisation, SPD and PSS to meet future expectations

It is clear that there is a benefit from combining the three areas to meet future expectations. Today there are good examples of how sustainability advantages can be achieved from tracking real-time data during usage phases to avoid extra repairs or to optimize the maintenance. These more resource efficient and sustainable service oriented and digitalized solutions are not developed to purposely develop more sustainable solutions. Profitability and customer needs are the drivers. However, there are potentials to deliberately create such solutions that could give the company a business advantage and at the same time contribute to a more sustainable society.

> *"The main target is to do more sustainable solutions and to do that, PSS can be used. Digitalisation is then a tool and a way to develop PSS solutions" (System responsible in service systems in company B)*

4. Conclusion and Further work

In this study digitalisation is viewed as an opportunity to find new solutions to meet customer needs and be competitive at the future market. The view on Sustainable Product Development was instead viewed as something that is primarily done to fulfil requirements and legislation in some companies. However, it was clear that some manufacturers start to see market forces replacing legislation as a driver. PSS can be seen as a means to create new solutions and the companies can choose to offer PSS solutions and have that in their portfolio if they decide so.

It is clear that there is a benefit from combining the three areas to meet future expectations. There are examples of resource efficient and sustainable service oriented and digitalized solutions where profitability and customer needs are the drivers. It was found that there are

potentials to deliberately create more sustainable solutions that could give the company a business advantage and at the same time contribute to a more sustainable society.

The result also showed that digitalisation will gradually change the working processes in the companies. More data need to be analysed in the early innovation process and several sources and types of data need to be analysed at the same time. New solutions to offer are expected, to meet the future needs, which will require new competences and skills. Sustainability has an influence on the decisions and the solutions that are generated and offered at the market. This is a big challenge in the future and there is a need to be proactive in order to keep the freedom and not have to adapt to even more regulations and restrictions. Awareness, understanding and on-going learning is needed.

To be a strong player in future the efforts in integrating digitalisation are important. A clear barrier for expanding in the digitalisation field is lack of competence and resources in terms of money for development and investments. There is a risk that the top managers do not have the awareness and competence in this field and therefore do not see the potentials and make the necessary priorities. Another challenge is to change into a more agile approach. In order to keep up with the development potentials in the area of digitalisation new collaboration forms are needed or to buy competences or key businesses that already have the right competence and can develop solutions. For the SPD area it is an internal company priority to focus more on sustainability aspects. To make it become a selling point it needs to be connected with a customer need that impact some key requirements, e.g. safety issues, select some indicators and monitor those. Also, awareness, dissemination, and internal communication are important to expand in this area. Therefore, it is needed to be able to identify more specifically why a digital solution is more sustainable than an alternative solution. This can enhance the development and investment for such solutions and also inspire further development of more sustainable digital solutions. For PSS it also depends on the company's priority and customer needs. If there is a clearly expressed customer need – then a company interest will be developed.

This intitial study points clearly at the need for change in product design capabilities as a consequence of these three trends, in a way that increases the complexity to master for individual engineers. The main challenge is to empower engineers and development teams to model, present, evaluate and develop these expected and smart digitalized solutions in a time limited environment and prioritise the most resources and sustainable solution. In continues research studies a systematic literature review and an in-depth investigation will take part to build a framework and a suggested road map to improve the design and development capabilities in manufacturing companies.

For future studies, more manufacturing companies will be included, together with a systematic literature review. Future questions could focus on: How can classical design strategies, with concept search, modelling, simulation, test and evaluation, refining and detailing of concepts stage, to a final, producible and functionally verified product solution definition, address this increasingly complex demand picture, with uncertain and often unknown long-term consequences? How can complex requirements be simplified in a convincingly sound manner securing future reliability of developed solutions? What are the demands on future product development engineering work, methodologies, and supporting tools? What are the implications for engineering education and life-long learning for product development practitioners?

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Appendix 1: Semi-structured interview questions

A Potentials: A1. What /which possibilities and potentials do you see with:
i) Digitalisation, ii) Sustainable Product Development; iii) Product-and Service Systems (PSS)
A2. For each of these areas, on a scale 1 to 5, estimate your organization's current engagement, rated from 1 *not relevant,* to 5 *a key area* for priorities and investment.
A3. Do you consider that the interest has increased or decreased within the latest 3-4 years within your company for: i) Digitalisation, ii) Sustainable Product Development; iii) Product-and Service Systems (PSS). Give examples.
B Impact on product development capabilities: B1) In which way do you think your organisation's ability on product development will be impacted on: i) Digitalisation, ii) Sustainable Product Development; iii) Product-and Service Systems (PSS). Give examples.
B2) In which way have your organisation's ability on product development already been impacted on: i) Digitalisation, ii) Sustainable Product Development; iii) Product-and Service Systems (PSS). Give examples.
C Future challenges: C1) What do you think preventing you from realizing your potentials already today? Give examples.
C2) Can you benefit from combining these three areas to meet future expectations?
C2.1 If yes --- and if so, how can you benefit from combining these three areas?
C2.2 If no - why?