
# BARRIERS FROM A SOCIO-TECHNICAL PERSPECTIVE TO IMPLEMENT DIGITALISATION IN INDUSTRIAL ENGINEERING

# BARRIERS FROM A SOCIO-TECHNICAL PERSPECTIVE TO IMPLEMENT DIGITALISATION IN INDUSTRIAL ENGINEERING PROCESSES – A LITERATURE REVIEW

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## ABSTRACT

With the paradigm shift towards Industry 4.0 and digitalisation, manufacturing engineers face several unexplored challenges; in the products for which they are designing production, in the equipment they are designing to realise production systems and in the digitalisation impact on engineering processes. Today's manufacturing system design processes are still based on traditional engineering methods and have difficulties to cope with increased complexity. The aim of this systematic literature review is to explore drivers and barriers to implement digitalisation in engineering processes from a socio-technical perspective. The identified general barriers were cyber security, lack of competence, lack of standards, large investments and resistance to change. For the engineering processes the main drivers were increased product complexity, servitisation, data driven design and engineering productivity, with the main barriers culture, excess amount of data, integration of tools. cyber security and data quality. The study shows the complexity of the challenge, and that it is not only the technology that is the top barrier. Further research is recommended to develop approaches of successful engineering digitalisation implementations.

**Keywords**: Design methods, Industrial design, Human behaviour in design, Industry 4.0, Manufacturing engineering digitalization

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## 1 INTRODUCTION

The purpose of the design of production systems is to create systems that perform according to set targets. To design and realise the production system is often the task of industrial or manufacturing engineers in manufacturing companies, With the paradigm shift towards Industry 4.0 and digitalisation, industrial engineers face several unexplored challenges; in the products for which they are designing production, in the equipment they are purchasing to realise production systems, and finally, in the digitalisation impact on engineering processes. Lasi et al. (2014) state that “Industry 4.0 describes different, primarily IT driven, changes in manufacturing systems. These developments do not only have technological but also versatile organizational implications". Today's industrial system design processes and architecture are still based on traditional engineering methods and can hardly cope with increased system complexity (Stark et al., 2017). “In reality, the manufacturing system design barely follow a systematic design approach: it is still common practice to let each design engineer work within his or her own discipline by using specific design and engineering models (…) without any true systems engineering design opportunity”. Digitalisation enables several important benefits to manufacturing companies, however, there are barriers which impose challenges for companies wanting to adopt digital solutions. It is vital that companies planning to digitalise acknowledge those barriers for effective mitigation. The concept of this study is to investigate how literature describes the barriers which are hindering the industrial engineering community to implement and adopt digitalisation for their own processes, with a perspective of viewing engineers as humans, hence the socio-technical aspect of engineering. To frame the context, an initial study was performed to understand general barriers to implement digitalisation for industrial companies, and as the next step go deeper in the engineering processes. Realising the full potential of new technologies often requires greater collaboration across disciplinary knowledge boundaries. Engineers are used to working in their own object worlds i.e., the concepts, terminology, and domain of their own field, and can find it difficult to collaborate with others who have different ways of thinking and use a different vocabulary (Bucciarelli, 1994) (Stark, 2017). To work together, engineers depend on boundary objects which are understood by all the groups that are relevant (Star, 2010). Hence, the socio-technological aspects are relevant to understand further in a literature review. Buckl et al (2011)) stated that "Enterprises are complex socio-technical system, whose management can be considered a challenging task. Especially against the background of intricate relationships, dependencies, and contributions that link social actors and technical components". De Weck et al (2016) point out that "Today, working in an engineering system, the same engineer has to interact with a host of socio-economic complexities and 'externalities' - impacts, either positive or negative, that are not a direct part of the artifact or even a self-contained system or process under consideration". The research questions are formulated as below, focusing on the current literature:

RQ1: Which are the barriers to implement digitalisation for industrial companies?
RQ2: Which are the barriers to digitalise industrial engineering processes from a socio-technical perspective?

## 2 FRAME OF REFERENCE

The term Industry 4.0 was introduced in 2011 during the Hanover Fair. Despite its widespread adoption there is no formal definition of this concept. Glass et al. (2018) attempts to describe Industry 4.0 as “an initiative of transforming the value chain of a company to becoming digitalised and to integrate the components in the value chain by utilising modern technology”. This definition shows that digitalisation and Industry 4.0 are closely connected to each other. Huang et al. (2020) describes digitalisation as “the process of adopting digital technology with the aim of improving a company's performance across a multiple of factors and to gain access to new business opportunities”. Kumar et al. (2021) states that “Industry 4.0 is the practical application of digitalisation in the manufacturing industry” which suggests that digitalisation is the broader term which is more well-known and will therefore be predominantly used in this study. As described by Bakhtari et al. (2021), a successful digitalisation can bring great benefits to a manufacturing company in terms of increased productivity, quality, and flexibility. Decisions based on data can enable decentralisation of decision making as well as real-time decision making conducted by technology instead of humans (Kumar et al., 2021). When basing decisions on real-time Big Data, decisions have the potential of being more accurate, less



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biased and because of the automation, the employees are relieved. When digitalising it is vital that the company addresses their business model and aligns it with the new conditions caused by the digitalisation. Digitalisation can foster either new and disruptive business model as can be seen for example in companies utilising sharing economy, or incremental improvements like shorter time to market, enhanced products and services, decreased costs and increased ability of customization and personalization (Fonseca, 2018). Furthermore, digital solutions can support the current trend of servitisation by offering bundles of products and digital services. A product-service offering naturally needs to be integrated into the business model and this needs to be carefully executed since service logic is different to product logic (Isaksson et al., 2018). There seems to exist some ambiguity regarding the nature of the change that digitalisation introduces to a company. Many of the technologies have been available for a long time and applied in industry but more as incremental changes. The potential the integration of these technologies can achieve in terms of new business models and large increases in productivity and efficiency would suggest more radical changes (Calabrese et al., 2020).

## 3 RESEARCH APPROACH

For this literature study the systematic review approach was selected. As stated by Petticrew and Roberts (2006), a systematic review reduces bias often inherent in traditional reviews. and reduces the risk of missing out important literature. Another benefit of the systematic review is that the methodology can be described in detail which means that the transparency of the study can be greater compared to a traditional review (Snyder, 2019). Since transparency is increased, the ability to reproduce the findings is also increased. To further reduce bias and provide transparency when conducting the literature review, the PRISMA reporting system by (Page et al., 2021) was used as an overall guide. As mentioned by its authors, PRISMA was initially developed for medical science research but has through development become more general and is deemed suitable for most mixed-methods and qualitative research. Three databases were used; Scopus, Web of Science and Access Science. The keywords were selected to reflect the scope of the research, and the string "engineer 4.0" was included as this was a specific interest of one supervisor. The keywords were combined into search strings with Boolean operators together with a summary of the quantity of records each search string resulted in. When searching, the search was limited to title, abstract and keywords of the records as presented in Table 1.

*Table 1. Search strings for literature review with summary of quantity of records results.*

| **Search strings:** | **Number of hits:** |
|---|---|
| Barriers AND (“Industry 4.0” OR digitalisation) | 812 |
| (“Industry 4.0” OR digitalisation) AND (sociotechnical OR socio-technical) | 222 |
| (“Industry 4.0” OR digitalisation) AND (sociotechnical OR socio-technical) AND barriers | 3 |
| (“Industry 4.0” OR digitalisation) AND (engineer) | 1004 |
| “engineer 4.0” | 10 |
| (“Industry 4.0” OR digitalisation) AND (“design management”) | 20 |

Since several databases were used applying the same search strings, duplicates occurred between the searches in the different databases. To remove these duplicates and ease the process of screening, all results lists were imported to the software EndNote to remove duplicates. After removing duplicates, the papers were screened by reading title, abstract and keywords. If the titles were considered irrelevant already at this stage these were screened out. For relevant titles, abstract and keywords were read and added to the list of papers to be read in full. Criteria for exclusion and inclusion were connection to the manufacturing industry or engineering, only published articles, conference papers, books and book chapters were included, and the included papers needed to be clearly connected to the research questions. An important note is that the latter criterion involves a risk of bias in terms of subjectivity since it relies on the interpretation of the researcher whether a paper is connected to the research question or not. In addition, this screening was performed by one researcher only and no criteria regarding type of paper were applied when screening, only the type of document as described. Few papers were identified addressing the digitalisation effect of engineering. This fact indicates a



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potential research gap on the topic which also Hallstedt et al. (2020) have identified. As a means of finding more papers on this topic, searches were done in other databases and snowballing was utilised. Snowballing is a method in which the reference lists of relevant papers are scrutinised with the goal of finding additional papers to include in the review (Hiebl, 2021). From this approach additional papers were found but as mentioned by Hiebl (2021), the transparency of the literature review is decreased since it is less structured and outspoken. Furthermore, snowballing is a backward search, meaning that only older studies are found. The process of reviewing the existing literature is summarised below in Figure 1.

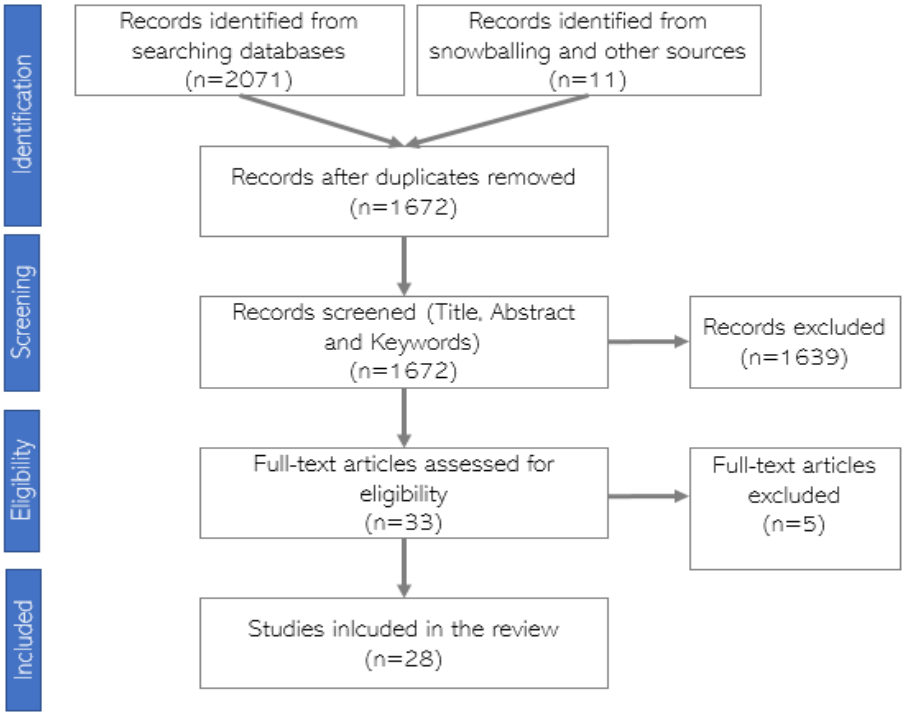


*Figure 1. Literature review process including number of papers found per each step*

Twenty-eight papers were considered relevant and of sufficient quality for further analysis. These papers were analysed qualitatively and quantitatively in the software NVivo. The papers were imported to NVivo, they were read in full, and to structure the information from the papers, coding was used. Each identified barrier was assigned a code which was used in analysis so that barriers with the same meaning but different phrasing were grouped together. In addition, themes were identified, barriers that were connected were assigned a theme, and the frequency of mentioning was counted. The information from the papers was synthetised to provide a summary of the meaning of digitalisation and Industry 4.0 in the introduction section. To visualise the areas of relevance and contribution (ARC), a diagram of the research area was created based on the layout proposed by Blessing and Chakrabati (2009) in Figure 2 below.



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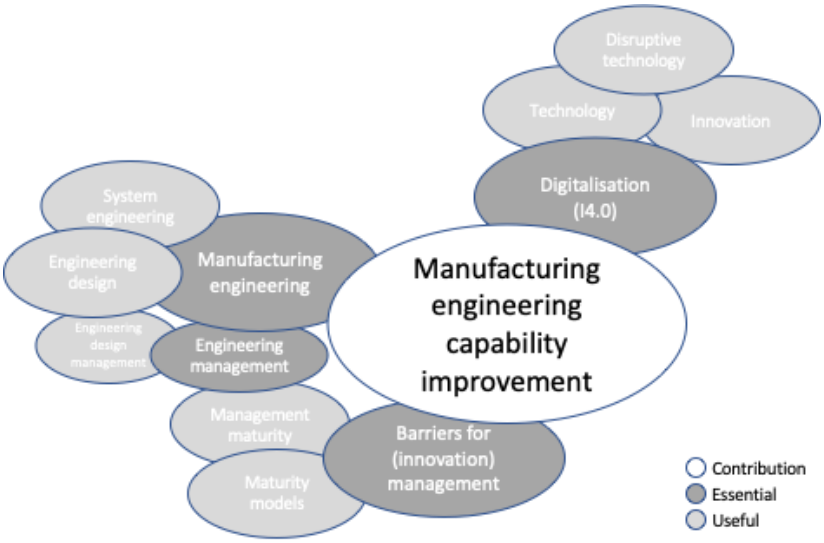


*Figure 2. Arc diagram of research topics with the categorisation from the most significant influence of direct contribution, essential to the research context and useful for orientation purpose.*

# 4 RESULTS

## 4.1 Results RQ1: Which are the barriers to implement digitalisation for industrial companies?

A total of 26 unique barriers were identified and with the aim of creating an understanding of the relative importance of these barriers, the frequency of mentions across the papers was noted in Figure 3 below.

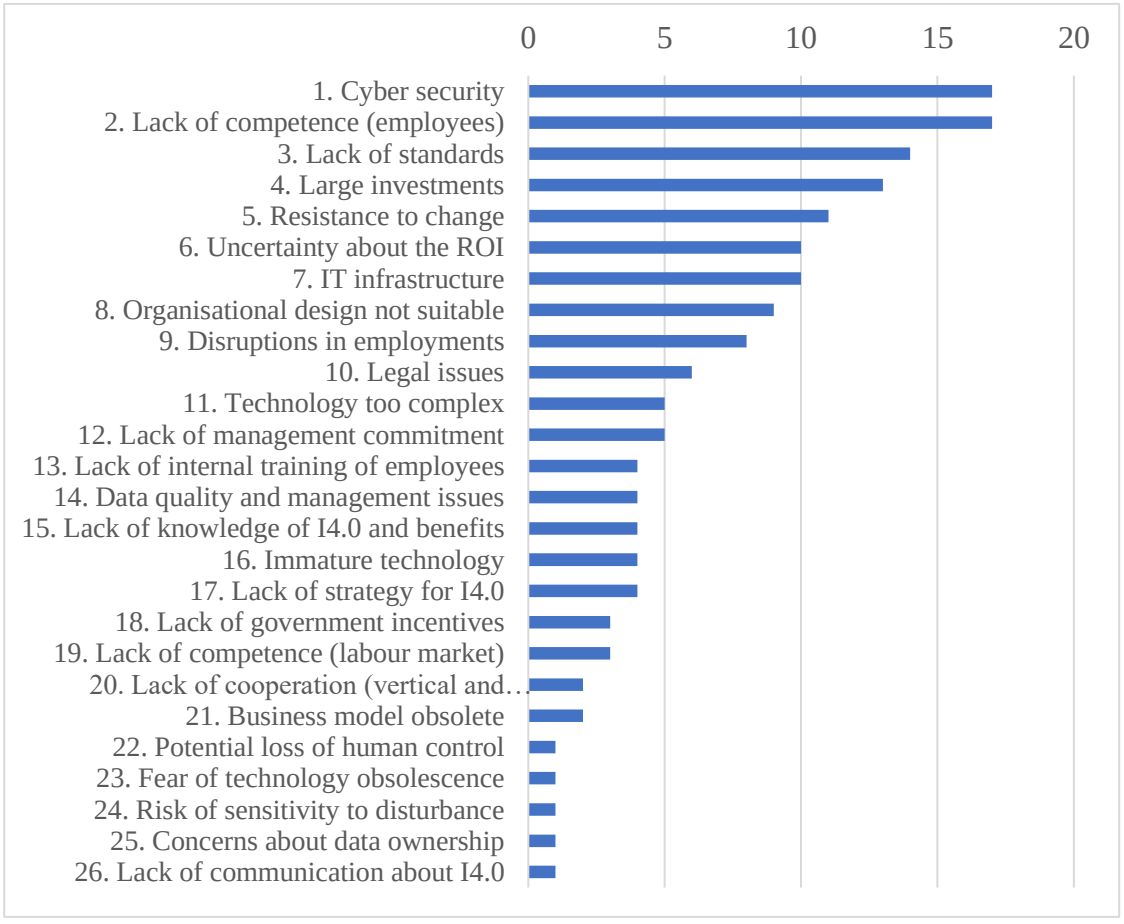


*Figure 3. Frequency of mentioning of the identified barriers from the selected 28 papers.*



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Of the 26 barriers identified, the five most frequently mentioned barriers were “cyber security”, “lack of competence by employees”, “lack of standards”, “large investments” and “resistance to change”. This result was cross-checked to validate its credibility by comparison to the study by Kumar et al. (2020). The Kumar et al study identifies barriers to digitalisation and uses K-means clustering to assess the importance of each barrier. Four of the five barriers that Kumar et al. (2020) considered most influential are present among the five most frequently mentioned barriers according to this review. The barrier that differed (“resistance to change”) was however mentioned as well, hence this result is considered trustworthy.

- **Cyber security**

The threat of cyber security comes with an increased use and gathering of data which is transferred wirelessly. This practice imposes several types of risks like theft of intellectual property, sensitivity to cyber-attacks and the dilemma of data ownership when integrating vertically and horizontally and including third party actors (Raj et al., 2020). There are measures that companies can take to address this risk, for example Blockchain-based security technology and encryption (Cugno et al., 2021).

- **Lack of competence (employees)**

As described by Bakhtari et al. (2021), new skills and competence are needed for both operating, installing and maintaining the new technology. The technology enables more automatisation, but human-machine interaction is still needed, and the interaction differs from traditional manufacturing. There is a consensus that existing staff can be trained to gain this competence and when needed, specialists can be recruited or consulted (Calabrese et al., 2020). In addition to competence to handle the modern technology, employees that are creative, innovative, and willing to continuously learn and develop are important for successful implementation of digitalisation (Cugno et al., 2021).

- **Lack of standards**

Several studies state that companies experience a lack of standards regarding aspects of digitalisation. The horisontal and vertical integration of the value chain requires sharing and collaborating throughout the value chain and for this to work, standards regarding ways of working, system architecture and data formats needs to be in place (Bakhtari et al., 2021). A lack of industrial standards regarding digital technologies becomes a barrier for companies that do not possess sufficient knowledge about the adoption process (Stornelli et al., 2021).

- **Large investments**

In general, companies need to increase their investments by 50% for at least five years to cover the costs of digitalisation implementation (Raj et al., 2020). This fact combined with an experienced uncertainty regarding the return on these investments imposes a critical barrier since companies often hesitate to make the investments (Marques et al., 2017). This barrier is most prominent in small and medium-sized enterprises, since these companies more often lack the required capital or become exposed to a larger risk if making the investment. Larger companies often have more excess capacity, more competences and capability to run smaller pilot projects which can be scaled up if successful thereby decreasing the risk of unsuccessful large investments (Horváth & Szabó, 2019).

- **Resistance to change**

This term is a very generic term and does not fully describe all the underlying aspects of why often management perceive that their organisation is not willing to change. Often there are very good reasons why people working with activities daily does not view the change as an improvement or a support in their work. There can be several reasons for employees resisting the change that digitalisation entails. Employees are afraid that they will not be able to learn new required skills and feel overwhelmed by technology. Furthermore, employees might be afraid that their core competences will no longer be needed and thus feel less valuable for the company (Horváth & Szabó, 2019). In addition, both the increased level of automation and the increase in productivity that digitalisation potentially results in could cause a disruption which can lead to some jobs becoming redundant (Calabrese et al., 2020). To overcome this barrier, it is vital to establish employee motivation through training and education to achieve sufficient knowledge about digitalisation and mutual understanding and sense of the topic. Furthermore, management commitment and agreement are important (Kumar et al., 2021).

### 4.2 Results RQ2: Which are the barriers to digitalise industrial engineering processes from a socio-technical perspective?

When zooming in on the digitalisation of the engineering processes in themselves, there are fewer sources found. In their study of digital visual management tools, Pedó et al. (2020), identified a need



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of a substantial change in company culture when introducing digital tools since it profoundly alters the way of working and sharing information. The authors identified a downside of an increased use of data in terms of difficulty of prioritising data and risk of slowing down the process because of excess amounts of data. Furthermore, Kügler et al. (2018), points out the challenge of integrating new digital tools in the existing IT infrastructure in the company. Huang et al. (2020) identifies Cyber Security risks in terms of theft of intellectual property and disturbances, the difficulty of ensuring data quality in Big Data applications and the need of a central standard format of the data. In their literature review, Hallstedt et al. (2020), names additional barriers in terms of the difficulty of combining Agile and Waterfall methods, the large investments needed to succeed with these technologies, a lack of competence to handle new technology in combination with a need for competence that is growing faster than the rate of people being educated. Furthermore, the ethical aspect needs to be considered when collecting data from customers, there is the question of who owns the data and what data can be collected. In addition, Eckert et al. (2020) mention ethical implications that can arise when data is used for decision making and points out the fact that the analysis of personal data places these people in a vulnerable position. Similar to implementing digitalisation in a production context, some engineering jobs can ultimately become redundant which can lead to a resistance to change among employees. However, Peetz (2019), proposes two reasons to why the technological development might not affect the number of jobs significantly. First, new jobs will be created to handle the new technology and second, as processes become more streamlined, products become cheaper, and consumers can spend money on additional products which will result in new job opportunities connected to the production of these additional products. Summarising these studies, a list of barriers to digitalise the engineering processes is described in Table 2 below:

*Table 2. Identified barriers in literature to digitalise engineering processes*

| # | **Barrier** |
|---|---|
| 1 | Change in company culture and ways of working |
| 2 | Excess amounts of data slowing down the work |
| 3 | Integration of new tools into existing infra structure |
| 4 | Cyber security risks |
| 5 | Data quality |
| 6 | Challenges to combine agile and waterfall ways of working |
| 7 | Large investments |
| 8 | Lack of competence and training capabilities |
| 9 | Data ethics |
| 10 | Risk of people becoming redundant and hence hesitant to take full use of the new technology |

## 5 CONCLUSION

The concept of this literature study is to investigate how literature describes the barriers which are hindering the industrial engineering community to implement and adopt digitalisation for their own processes, with a perspective of viewing engineers as humans, hence the socio-technical aspect of engineering. To frame the context, an initial study was performed to understand general barriers to implement digitalisation for industrial companies, and as the next step go deeper in the engineering processes. Regarding the first research question, which are the barrier to implement digitalisation for industrial companies, the literature study shows a large diversity of barriers, and on very different abstraction levels. The barriers range from technology too complex to concern about data ownership. This could show an immaturity in the topic, that people interviewed in the papers where not fully aware of the difference in magnitude of the aspects they mentioned. The difference in abstraction level is also a concern for the reliability of this study. Taking this into account, the study shows that the main barriers for industrial companies to implement digitalisation are cyber security, lack of competence among the employees, lack of standards, large investments and resistance to change. The collection of barriers is diverse, which shows that industrial companies see several dimensions to digitalisation could be problematic. These top five barriers are part of technical, organisational, quality, financial and social dimensions which clarify that the digital transformation is not only a technical one. For the second research question, the barriers to implement digitalisation in industrial engineering processes, one finding from the literature study is the relatively small amount if papers



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that touched on the digitalisation impact on engineers. Several papers were identified where both the key words “engineer” and “digitalisation” but when reading the papers not many covered this aspect. The barriers of digitalisation of the engineering processes reflects the general barriers, but unique barriers are also mentioned, such as excess amount of data slowing down the work, integrating new ways of working into existing structures and data ethics. The conclusions are that within industrial engineering, which is today a socio-technical discipline, the barriers are a mix of technical, cultural, quality, organisational and competency aspects and not only a technical one.

## 6 DISCUSSION AND FURTHER RESEARCH

For the industrial workers the production line has more and more transformed to automation, with the primary focus to improve safety, quality and productivity. This shift has not been unproblematic for sure but is now established as a way of working. From this perspective it is interesting that the engineers and technicians in the manufacturing industry have been rather unaffected by automisation during the same time period. Often the same arguments are raised by the engineers as the industrial workers have risen when discussing automisation of the engineering processes such as “my job is too complex for a robot” and “my job will be less interesting with digitalisation”. Additionally, engineers seldom talk about the productivity in their work; how effective and efficient the engineering processes are. Safety, quality and productivity should be interesting also for the engineering community. As an industrial PhD student this distinction between the industrial workers and the engineer’s approach to digitalisation is striking. The industrial workers see very quickly the benefits and potentials of automation and digitalisation, while the engineers have more difficulties to see the same potentials in their own daily work. From this perspective this literature study was relevant to perform to see if the academic world reflected this impression. It was important to have the socio-technical perspective as this will be more and more relevant in the engineering context. The proposed next steps for research is to explore further the drivers for digitalisation of engineering processes, the barriers to implement digitalisation and also see how both the drivers and the barriers can be used to develop approaches of successful implementations.

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