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Participatory Design for Digital Transformation of Manufacturing Enterprises

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1. Introduction

The digital transformation holds various promises for improvements in terms of productivity and quality in manufacturing (Neugebauer, 2019). With Industrie 4.0 and the Industrial Internet of Things, technological solutions are available and beginning to be implemented in today's smart factories (Frank *et al.*, 2019; Niewöhner *et al.*, 2020). Nonetheless, recent studies and applied research imply that the digital transformation of whole manufacturing enterprises is stagnating in terms of innovation and organizational business development. Manufacturing companies are prone to get stuck in the differentiation phase when trying to evolve with the individual digital transformation of their businesses. Over 70 percent of digital transformation initiatives fail, cumulating an overall loss of 900 bn. USD (Tabrizi *et al.*, 2019). Reasons for failing digital transformation initiatives range from mainly technology-focused, socio-organizational approaches, inadequate management of organizational growth, centralized knowledge and innovation management to a widespread lack of user acceptance in the workforce (ZoBell, 2018). The organizational and methodical approach for digital transformation in manufacturing systems has to change.

Participatory design aims to actively involve all stakeholders in the design process to help ensure the result meets their needs and is usable. In manufacturing companies, the workforce often accumulates valuable knowledge on processes and internal problems. By introducing participatory design to the digital transformation of manufacturing enterprises, workers in their role as the central (end-)users of the system are integrated into important innovation processes (Issa *et al.*, 2018). Thus, new types of manufacturing organization with bottom-up innovation from within the workforce can be realized.

Our aim is to benefit the digital transformation of manufacturing enterprises by introducing human-centered methods and technologies through participatory design. Our research intends to involve relevant case studies from manufacturing enterprises and provides significant industrial impact by enabling an innovation capability shift towards individuals, including the manufacturing workforce. When implemented systematically and holistically, manufacturing enterprises, unions, and individuals will benefit from the improvements made possible by participatory design for digital transformation.

This working paper is structured as follows. Section 2 provides the relevant related work and background information from manufacturing organizations, digital transformation and participatory design. Section 3 describes feasible opportunity areas for participatory design in manufacturing. Section 4 consists of the conclusion.

2. Related works & background

This section provides a summary of relevant related works for participation in context with the digital transformation of manufacturing enterprises. First, manufacturing organizations and their evolution stages are characterized, highlighting historical and modern organizational models targeting mainly white-collar workers. Second, technological developments of smart manufacturing and corresponding work scenarios with regard to the human-tech-frontier are presented. Third, the role of workers in the digital transformation and organizational implications are shown. Fourth, the related literature regarding participation and participatory design is discussed. At the end of this section, an overview of related design methods is given, including the description of the worker's voice in manufacturing. Each subsection is summarized in a concluding box with regard to this research activity.

2.1 Manufacturing organizations

The possibility for participation by workers is dependent on the organizational model, culture and leadership mindset of an organization. In manufacturing companies, raw materials or unfinished goods are converted into consumer or capital goods with the help of production resources, such as machines and tools, as well as, human workforce and energy. Production management is responsible for the planning, execution, management and control of the manufacturing processes. Strategic corporate planning, which is the responsibility of the management, defines the goals to be achieved in advance. These are usually quantity targets for the products to be manufactured within a certain period. Porter (1985) defines the manufacturing value chain as a sequence of five primary activities, i.e. inbound logistics, operations, outbound logistics, marketing/sales, and service, as shown in Figure 1. In addition to the primary manufacturing activities, there are different support activities in centralized functions, such as firm infrastructure, human resource management, technology management, and procurement (Porter, 1985).

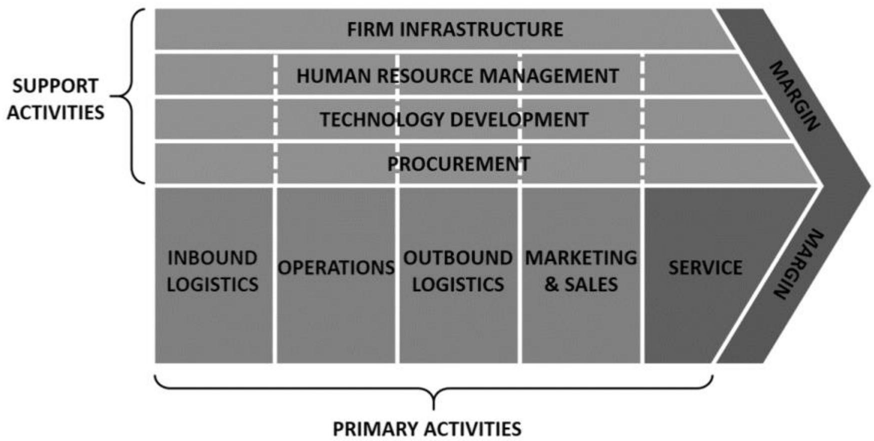

Figure 1: Generic value stream of a manufacturing enterprise (Porter, 1985)

Factory design over the years

Along with industrial revolutions, market changes and technological leaps have always changed the respective organizational form of manufacturing enterprises. Only the appropriate form of organization makes the use of technological potential possible. Taylorism and Fordism led to strong specialization and productivity gains. In the course of industrialization after World War II, the Toyota production system was developed and resulted in faster throughput times, better quality indicators and further productivity gains (Valentin, 2019; Kochan *et al.*, 2020).

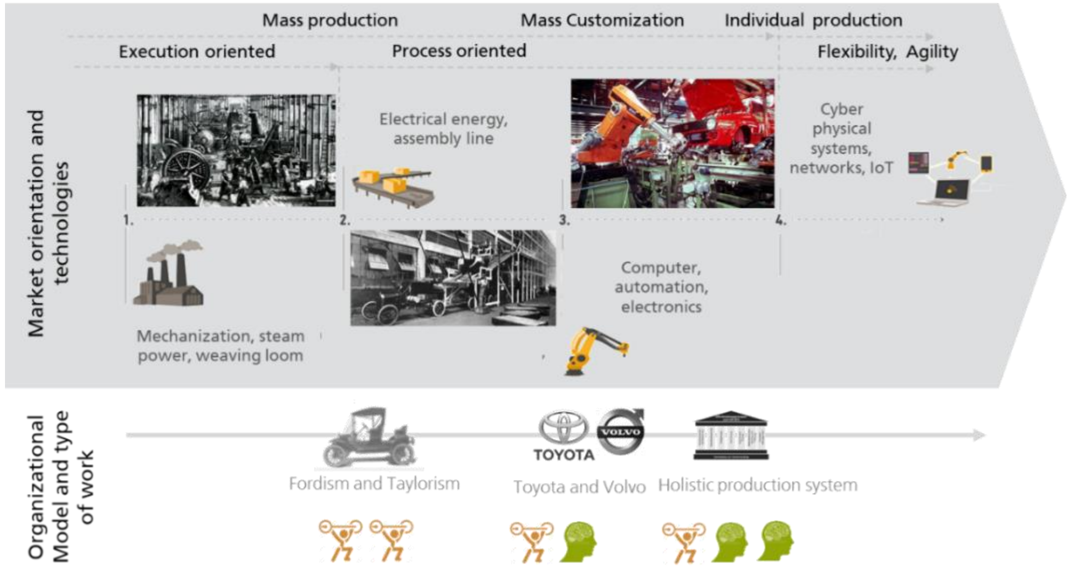

Figure 2: Correspondence between market demands, technologies and organizational model in manufacturing

Nevertheless, current developments are still based on the principle of line production according to Fordism. The organizations are rather centralized and based on continuous improvement, whereby Toyota supports the involvement of employees in improvement processes and decentralizes group work models. However, in most companies, this is not applied (Valentin, 2019). There have been repeated attempts to empower production employees. For example, Stahl (2013) presents models and examples of how productivity and innovation can be increased on the basis of lean production and empowerment (Stahl, 2013). Volvo demonstrated how team-based work can be realized in automotive manufacturing at the now closed Uddevalla plant (Mohr & van Amelsvoort, 2016). Figure 2 gives an overview of some of these developments in factory design and organization.

Organizational evolution

The development phases of an organization according to Lievegoed and Collis (1973) and Glasl and Lievegoed (2004) detail how the organization of companies evolves throughout time of existence. The development phases were derived on the basis of dialectics (Lievegoed & Collis, 1973; Glasl & Lievegoed, 2004). According to Glasl and Lievegoed (2004), each evolutionary phase is determined by a dominant principle. When transitioning to the next phase, a counter principle emerges and becomes dominant. In further phases, both principles are then integrated.

Often existing there for decades, manufacturing companies are located in the differentiation phase. The dominant principle in the differentiation phase is to design and operate the company as a controllable, rational apparatus with efficient mechanisms. Functional divisions based on the division of labor differentiate themselves. A hierarchical organization with centralized management is created. The management tries to control all processes centrally and pays attention to functional limits. People must subordinate themselves to constraints and formalisms. Companies in the differentiation phase can coordinate a large number of employees. This puts them in a position to produce and market complex services in large quantities, as is impressively demonstrated by the automotive industry. Side effects of the differentiation phase are complex and slow information and communication flows and rigid demarcation and overregulation. As a result of this, customer needs move out of sight.

Purpose and team spirit are lost and humanity, motivation, and commitment suffer, while agility decreases (Lievegoed & Collis, 1973; Glasl & Lievegoed, 2004).

White-collar agile organizations

With regard to white-collar work, flexible and agile forms of organization have been known and used in practice for many years. Agile forms of organization have existed since the 1950s and can be traced back to the sociologist Talcott Parsons. These forms of organization are becoming an important transformation issue in the so called VUCA era, standing for an increase in volatility, uncertainty, complexity, and ambiguity of labor systems (Peters, 1992; Laloux, 2014).

Agile forms of organization are based on self-management, iterative procedures, the creation of meaning, small teams, decentralized decision-making structures, and high transparency and flexibility. These types of organizations (1) can handle unforeseen events; (2) have the ability for continuous adaptations to permanently changed boundary conditions with the aim of achieving a new state instead of restoring the original state; and (3) deal offensively with changes, instead of engaging in reactive behavior and very rapid implementations of actions.

Working methods, such as design thinking, scrum and beyond budgeting, have proven beneficial to agility in organizations. Today, these methods are applied throughout the whole organization, mostly in centralized functions (e.g. new product/software development and engineering processes). These methods result in increases in productivity, job satisfaction, motivation, customer centricity and the development of more innovative products (Aghina *et al.*, 2018).

Even though many companies already use this type of methods, many focus on the pure application of these tools and do not restructure the entire organization. While agile and flexible organizational models and work methods have been successfully introduced into white-collar work, the same introduction into blue-collar work lags behind.

Conclusion 2.1: ***Manufacturing organization***
The existing forms of manufacturing organizations no longer meet the requirements of society and the market. Centralization, a high degree of division of labor and a low level of worker participation are main characteristics of these organizational models. Industry needs an empowered, agile and self-directed workforce to master future challenges. Direct information flows, decentralized decision making and innovation processes are crucial for overcoming fuzzy digital transformation. The organization of blue-collar work needs to be reimagined, using the agile organization of white-collar work as a model.

2.2 Smart manufacturing

According to a recent study by the Capgemini Research Institute, only 30 percent of factories can be described as smart (Petit *et al.*, 2019). Striving for a successful digital transformation of their factories, companies face various challenges. Besides technological challenges, there are increasing challenges and concerns with regard to the adequate integration of the human workforce.

Smart manufacturing technologies

Smart manufacturing (Industrie 4.0) refers to the realization of highly flexible and resilient factories with high interconnection through the use of information and communications technology (Vogel-Heuser *et al.*, 2017; Neugebauer, 2019; Schumacher & Bildstein *et al.*, 2020). Due to this reason, smart manufacturing includes a wide range of technologies. Technologies and applications like advanced data (incl. big data, smart data and artificial intelligence), cloud and edge computing, cyber physical systems and the internet of things, smart sensors, additive manufacturing, virtual reality, augmented and mixed reality, real-time data and simulation, digital twins, traceability, flexible automation, co-bots and exoskeletons, digital assistance systems, blockchain, cyber security, plug and produce machines, flexible logistics systems and autonomously guided vehicles, 5G, etc. are discussed in this field of transformation (Saturno *et al.*, 2017; Vogel-Heuser *et al.*, 2017; Frank *et al.*, 2019; Neugebauer, 2019). The automotive industry is already piloting post-Fordism factories based on reconfigurable manufacturing systems breaking loose sequential, coupled assembly line cycles and rigid systems based on smart manufacturing technologies (Fechter *et al.*, 2016; Foith-Förster *et al.*, 2016; Siegert *et al.*, 2018; ElMaraghy, 2019; Foith-Förster & Bauernhansl, 2019; Fries *et al.*, 2020). In these concepts, it remains unclear how the organization looks and how the factory is structured according to beyond-lean approaches.

These technologies and fields of application, such as automotive and machinery engineering, enable the near-real-time connectivity of all humans and objects inside and outside the factory (vertical and horizontal integration) via internet protocols and the virtual representation of the reality. The basic concept is technology-focused and represents the continuation of automation.

Human-Tech-Frontier

Many current and future applications in the field of smart manufacturing will further reduce the distance (distance in terms of physical and work content) between humans and technologies. In many cases, the intention is not to replace human work with technology, but to achieve meaningful cooperation and collaboration between people and technology to enhance human capabilities. Many of the applications in the field of human-robot collaboration, such as wearable robotics, and human-AI collaboration will enhance dynamic collaboration (Li, 2018). Figure 3 illustrates different types of co-existence of humans and technology.

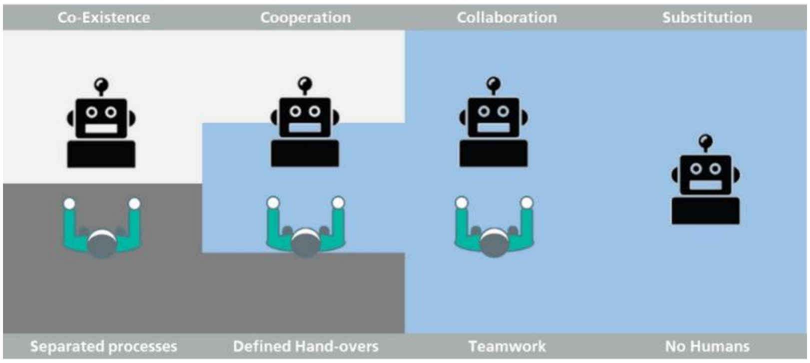

Figure 3: Co-existence-levels of Human-Tech

Machines will be able to anticipate how to react in each situation. Humans will partly put themselves in the role of the teacher and provide the machine with necessary contextual information and vice versa. Therefore, there will be a teaming between machines and workers (see Figure 4 for human-AI assistant example in the of failure management processes – grey box indicates leader for each step).

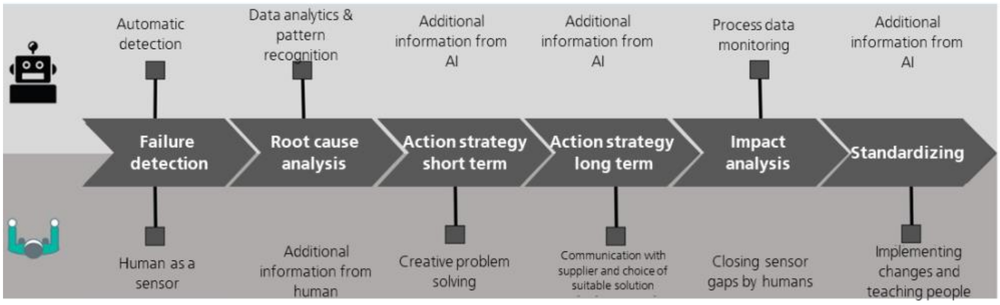

Figure 4: Example of a shared work process in Human-Tech-teams

In a human-machine relationship, there is a so called missing middle field where humans and machine are working cooperatively (Daugherty & Wilson, 2018). In hybrid activities, man and machine work within a common task. Each of the participating parties perform the task that is best suited for them (see Figure 5). The role of humans is to develop, train and organize different applications. This enables the system to act as a collaboration partner. At the same time, machines support human capabilities by providing analysis and inference and preparing decisions. This represents a symbiotic collaboration in which humans support machines in learning processes and, vice versa, machines assist humans through an alternating teacher-student model (Daugherty & Wilson, 2018).

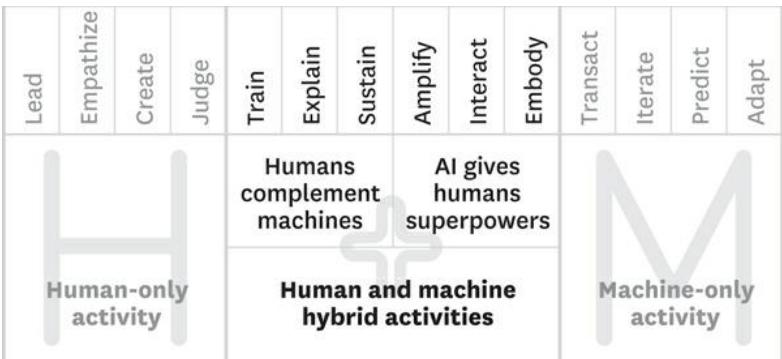

Figure 5 Spectrum of activities with human-machine relationship (Daugherty & Wilson, 2018)

This results in physically demanding work becoming increasingly automated and some of the thinking being done by machines. The people in production will therefore be more likely to take the role of conductor and/or coordinator. The production worker of the future will increasingly take on engineering-like tasks (Schumacher & Pokorni *et al.*, 2020). Operating the traditional blue-collar machine is complemented by tasks that white-collar workers do today, such as programming robots, locating errors and supervising artificial intelligence algorithms, as well as, doing small programming and inspection tasks. Thus, it is important to train blue-collar workers in these systematic skills in order to use existing creativity as efficiently as possible. The mixture of blue-collar and white-collar work will shape a new type of production worker, the so-called grey-collar worker.

Technology acceptance

Smart manufacturing leads to complex socio-technical systems with a symbiosis of physical and cognitive capabilities of humans and technology. In order to do this, system designers need to be critical of technology acceptance in the workplace, a major aspect of and potential barrier in socio-technical systems. Due to the large amount and variety of technologies used in Smart Manufacturing and Industry 4.0, it is difficult for companies to analyze the acceptance-promoting effects of each technology for a practical application. Regarding the decreasing distance in terms of content and physical distance, the acceptability of such systems becomes of crucial importance. This becomes even more important because many of these future systems use personal data and some decisions are generated from a black box behavior of autonomous systems (Bengel, 2020), potentially providing less information about functions to the user.

Designers need to consider how Industry 4.0-technologies and human-technology-teaming could look like to improve work processes in terms of better ergonomics, more productivity and more attractive work places in manufacturing. This is critical as manufacturing will be confronted with a shortage of qualified personnel and an aging workforce. In the same time, new generations with new preferences and flexibility requirements will enter manufacturing as the workforce gets more diverse. Therefore, the technology needs to be more adjustable for each person and each particular work situation. Robots, for example, will need to anticipate human behaviour and they need to know workers' preferences to react faster, slower or in completely different way. Digital assistance systems on the other hand need to know the qualification level of the worker so it can adjust the level of support according to their needs. This new era of designing work technology will lead to huge challenges for designers away from standardization towards individualization.

Conclusion 2.2: ***Smart manufacturing technologies and Human-Tech-Frontier***
There is a large number of different technologies and use cases emerging in the factories of the future. Cooperative and collaborative technologies are especially creating new forms of interrelation between humans and technology. Technology acceptance will be a major success factor. The question will be how such socio-technical systems can be designed with or by users themselves.

2.3 Digital transformation towards a Smart Factory

Human role in the Future of Work

The application of technologies and the choice of the organizational form are strongly dependent on the transformation objectives, visions and culture of the individual companies. Industrial blue-collar work will be influenced by technology, used as an assistance or substitution for humans and the job content will either be narrowed (polarization) or enhanced by other skill-demanding tasks (upgrading). These developments form four different idealistic types of work in the future: (1) low qualified work, (2) knowledge work, (3) full automation, and (4) process support. Any work system in the office or in production can develop into one of these future work types shown in Figure 6. There are already decisive differences today, distinguishing whether digitalization aims to replace (substitute) human work or to support the working person (assistance). The second discussion deals with the development of task complexity and qualifications among employees. A distinction is made between upgrading (upgrading) and splitting (polarization) (Korge & Marrenbach, 2018).

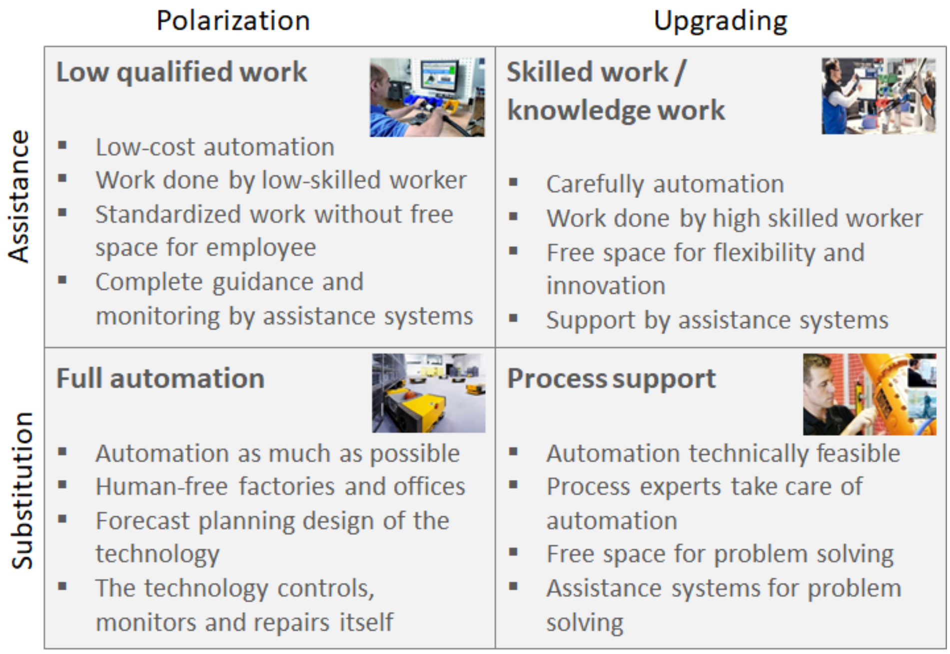

Figure 6 Transformative scenarios for the future of work in manufacturing (Korge & Marrenbach, 2018)

Success factors for the digital transformation

The digital transformation is the change and innovation process of companies, business models, products, and business processes through digital technologies (Schallmo *et al.*, 2018). In many cases, the digital transformation represents a top-down initiative led by dedicated departments and experts. At the same time, the use of certain technologies is of high priority for many companies (Brown, 2019). Kane *et al.* (2019) attempted to define a linear step-by-step process for the introduction of individual or several technologies and advancement through this process (Kane *et al.*, 2019).

There is no standard process for implementing a Smart Factory. Nevertheless, numerous process models for the introduction of the technologies have been introduced in the past. The majority of process models is focused on technological or strategic top-down aspects.

Involvement and participation of employees are not included in most of these process models (Terstegen *et al.*, 2019). During the implementation process, industrial practice is facing various technological and organizational challenges with regard to the digital transformation, which are listed below.

Technological challenges

- Too slow in implementation (often longer than 12 months)
- Too high demands regarding IT security
- Lack of technical requirements in general
- Personal data protection challenges
- No prototyping possibilities (Schlund & Pokorni, 2016; Horváth & Szabó, 2019; Kane *et al.*, 2019)

Organizational challenges

- Know-how transfer and the integration of the diverse departments and actors
- Transformation process is not only a matter of IT, but is equivalent to a cultural change
- Previously valid management methods are becoming less important in the digital world
- Lack of skills and expertise
- Lack of willingness to change within organizations
- Late user involvement (Schlund & Pokorni, 2016; Horváth & Szabó, 2019; Kane *et al.*, 2019)

In contrast to these challenges, success factors according to current research are supportive and agile organizational culture, cross-functional collaborations, well-managed transformation activities, leverage knowledge, engage managers and employees, capabilities, digital business strategy, change management, and top management support (Martin, 2018; Osmundsen *et al.*, 2018; Morakanyane *et al.*, 2020).

Conclusion 2.3: *Digital transformation*
Digital Transformation is not only about technology. It is about the organization and culture. We can see that in many organizational challenges within manufacturing companies. At the same time, it must be taken into account that there is no linear process, but, instead, a fuzzy, ill constrained process. Companies need to experiment, iterate and involve employees, beginning with a clear understanding of what the manufacturing company wants or needs to be in terms of different scenarios.

2.4 Participation and participatory design

In order for successful digital transformation, employees must be enveloped in the process of organizational changes and technology introduction. We believe participatory design offers a model for how organizations can achieve digital transformation.

The history of participation & participatory design

The beginnings of participatory design emerged in Scandinavia in the early 1970s with the Norwegian Industrial Democracy program (Asaro, 2000; Bannon & Ehn, 2012). The program's goal was to understand "how social groups formed around production technologies and sought to reform job distribution and wage systems for workers" (Asaro, 2000). The researchers were largely trying to find "alternatives to the Tayloristic rationalization of work'' (Asaro, 2000). Initially, participatory design focused on working with unions around technology implementation and policies in the workplace. At this point, worker participation was not common because management feared that workers may become experts through the process and threaten management positions, that management would gain too much knowledge of the shop-floor, that union participant would be affected, and that management could use workers' engagement to manipulate workers (Ehn & Kyng, 1987, p.40; Asaro, 2000).
In parallel to Scandinavian participatory design, IBM was creating a new methodology, Joint Application Design. To improve hierarchal communication struggles, joint application design aimed to reduce time spent in the System Development Life Cycle, thereby, increasing quality and decreasing overall costs (Asaro, 2000). However, in this methodology, employees were "overlooked as participants", limiting the knowledge of everyday operations to management, resulting in failure (Carmel *et al.*, 1993, p.46). Management viewed themselves as the beholders of knowledge and technical experts. Because managements lacked confidence in workers being able to meaningfully contribute to the project, these initiatives organizationally failed (Carmel *et al.*, 1993, p.46).
What we consider as participatory design today began to take shape in the 1980s, starting with the Swedish-Danish UTOPIA project (Bannon & Ehn, 2012). At this time, technology was attributed to dehumanizing work, causing divisions within the work place, increasingly creating rigid and routine tasks, and shifting power to management and the top of companies (Asaro, 2000). In this environment, designers sought to empower workers through creating technologies around worker interests (Greenbaum, 1991, p.11; Asaro, 2000). Therefore, the UTOPIA project sought to include graphic workers and their unions with computer scientists, social scientists, industrial designers, and graphic designers in the design of "tools for skilled work" (Bødker *et al.*, 1987; Bannon & Ehn, 2012) so that the unions could leverage a preferred technology for the workplace (Asaro, 2000). While the UTOPIA project was unsuccessful, it demonstrated a roadmap for how workers could be included in technology design, introducing methods such as "design-by-doing" and "design-by-playing" (Bannon & Ehn, 2012). Participatory approaches were also beginning to be glimpsed in the United Kingdom after World War II with work reorganization focused on optimizing social subsystems and technical subsystems together (Bannon & Ehn, 2012). Developed by the Tavistock Institute in London, this became known as "socio-technical systems" (Trist & Bamforth, 1951; Bannon & Ehn, 2012).
Participatory design has grown since 1980 working in multiple areas including urban planning and community development (Bannon & Ehn, 2012). Due to its increasing use, it is important to understand the approaches that merged together to create participatory design. Participation in design can be considered as an ideology but it is also surrounded by "ethics,

politics, democracy, and empowerment" (Bannon & Ehn, 2012). (Asaro, 2000) identifies participatory design as emerging from "(1) a critical project which sought to rectify political imbalances caused by technologies in the workplace and to protect workers from technological change, and (2) the evolution of a technological rationalism which sought to increase the success and efficiency of new systems. Therefore, participatory design holds promise in successful technology development as it builds technology while considering "material, practical, and political consequences of a system" (Asaro, 2000). In order for success, participatory design seeks to empower users in the design process through "democratic participation in technological choice" (Asaro, 2000). As Asaro notes:

> "The point is not that everyone gets a voice, but that *everyone who has engaged the technology and is in a position to assess its usefulness in their daily practices has the ear of those who have the power to alter its potential usefulness*. Participatory design researchers themselves stress the virtue of participation, but much of the value of their contribution lies in the consequences of realizing participation—the confrontation of the material and practical implications of their technological artifacts." (Asaro, 2000)

Participatory design is nestled within the socio-technical systems of the world, enabling it to be used as a tool to provide a voice to workers for more successful implementation in organizations.

Organizations & participatory design

New information systems are constantly being introduced into the workplace. Organizations often struggle with modifying these technologies for particular scenarios and its subsequent cost (Bannon & Ehn, 2012). There are several participatory design projects that are seeking to address these cases including the Danish MUST team (Bødker *et al.*, 1987). Bannon and Ehn (2012) highlight their work, emphasizing how their approach "supports the work involved in preparing visions for competitive bids and a later implementation project" and "addresses outsourcing situations, and the use of configurable standard solutions in various customer–supplier relations." Their approach provides a deviation from the traditional design paradigm, more so, demonstrating how participatory design can be integrated into large-scale commercial infrastructures. Bannon and Ehn (2012) emphasize a need for more participatory design methods and techniques to be developed to address infrastructure issues including globalization, generification, and personalization.

Increasingly as user-driven design and innovation have gained popularity, participatory design can be investigated as a model for business innovation (Bannon & Ehn, 2012) as more and more companies seek to implement "open" innovation models and "co-creation of value" often focusing at managerial levels (Chesbrough, 2003; Bannon & Ehn, 2012). Participatory design methods can be integrated across the design process in early and later stages, ranging from the designers participating in the user's world to users engaging in design activities (Muller & Kuhn, 1993; Schuler *et al.*, 1993). Within commercial projects, participatory design activities have been applied in numerous contexts, deploying activities across the spectrum of engagement and design process stage such as ethnographic methods (Bjerknes *et al.*, 1987; Floyd *et al.*, 1989; Turner & Kraut, 1992; Schuler *et al.*, 1993), low-tech prototyping (Muller *et al.*, 1992), collaborative prototyping for design (Mumford & Henshall, 1979; Floyd *et al.*, 1989; Turner & Kraut, 1992; Schuler *et al.*, 1993), theater (Docherty, 1987; Floyd *et al.*, 1989), and participatory analysis of usability data (Mumford & Henshall, 1979). These techniques and the many other participatory design techniques can be applied to open innovation (Colin &

Chavez, 2015; Tawalbeh *et al.*, 2017), integrating stakeholders, including workers, to represent their needs for functional designs (Tawalbeh *et al.*, 2017). Participatory design projects including SPIRE in Denmark (Buur & Matthews, 2008; Buur & Larsen, 2010), the Danish Design School (Halse *et al.*, 2010) and Malmö Living Labs (Björgvinsson *et al.*, 2010; Hillgren *et al.*, 2011; Bannon & Ehn, 2012) demonstrate how these techniques can be incorporated. Within factories, projects including the German Federal Cluster of Excellence MERGE studies, German promotion initiative "Mittelstand 4.0 – Agentur Prozesse", and the Methods of System Engineering course at the Chemnitz University of Technology have explored participatory design methods to integrate users in the innovation process (Tawalbeh *et al.*, 2017). These examples further strengthen the potential for participatory design in today's organizations as we press towards digital transformation.

2.5 Design methods and worker's voice

Design methods are procedures, techniques, aids, or tools for designing (Schön, 1983). The goal of every design is the satisfaction of the human being. Design methods can be divided into different areas, such as participatory design as discussed in the previous section. Engineering design is the use of scientific principles, technical information and imagination in the sense of a mechanical structure, machine or system to realize predefined functions and specifications with maximum productivity, safety and efficiency (Fraser, 2019). In the industrial sector, different methods are used to design technologies. In industrial engineering, methods from the field of human factor engineering and systems thinking for engineering are favored, whereas in the design of (consumer) products and services, innovation approaches such as human-centered design, design thinking and UX are used.
Design methods increasingly focus on the future user and their needs with regard to the new service to be developed or adapted. Therefore, in addition to the pure methodological view, the mindset within the organization and its mindsets is the key to agile and user-centered development. These approaches are mainly based on the following principles:

- Mindset: Empathy, courage, positivity, human-centered (Greene *et al.*, 2017; Fraser, 2019)
- Thinking: Understanding, generating, synthesizing and deciding (Greene *et al.*, 2017; Fraser, 2019)
- Methods: Divergent and convergent thinking, prototyping-driven, visualization, multidisciplinary collaboration, co-creation, storytelling, experimentation, participatory (Greene *et al.*, 2017; Fraser, 2019)

Each principle and the linked methods represent valuable improvement potential. Single efforts and separate analysis do not lead to significant organizational change. For a successful digital transformation, a configuration of the principles and various corresponding design methods needs to be used in a holistic manner to make use of their full potential.

Worker's voice in the design of socio-technical systems[1] and workplaces

With regard to the implementation of lean manufacturing, it has been repeatedly shown that involving employees in the introduction and design of technological solutions has led to higher employee satisfaction, more sustainable implementations and higher productivity (Kane *et al.*,

[1] A socio-technical system is an organized set of people and associated technologies that are structured in a certain way to produce a specific outcome

2019). Successful lean implementation “depends on employees’ involvement in lean activities, which is produced by giving them more empowerment, training, information and new forms of compensation.” (Marin-Garcia & Bonavia, 2015)

In the case of socio-technical system design, there are already procedures and experiences that can be leveraged. Here, human-centered design approaches are transferred to the design of industrial technologies and processes, such as the use of design sprints in the design of digital assistance systems in production. The acceptance of the systems especially in the industrial environment is partly limited due to the lack of integration of the workers. Nevertheless, the transfer is difficult due to the different and sometimes conflicting interests between companies and users (Pokorni *et al.*, 2020).

According to Emery, different levels of engagement can be distinguished in the Worker Voice area:

- No active involvement of employees. Everything is decided by the management
- Direct participation: employees are involved at workplace or organizational level
- Representative participation: employees are represented by trade unions
- Indirect participation: employees are represented at national and regional level (Mohr & van Amelsvoort, 2016).

Despite trade union policies that represent basic rights of workers to be heard, there is an essential need for participation at the inter-organizational level. Mohr and van Amelsvoort (2016) call for new design processes, strategies and tools for participation within and even beyond the boundaries of the company. Thus, trade unions become important participation partners within these structures (Mohr & van Amelsvoort, 2016).

Conclusion 2.5: ***Design methods and worker’s voice***
We see different mindsets, thinking and methods from the field of human-centered design and associated successes. We need to bring those “mechanics” to industrial design processes in a suitable way. It can be the key factor for higher involvement levels of the employee in change/transformation processes.

3. Opportunity areas

At present, various obstacles and growth barriers are once again exerting powerful pressure on the economy and companies to change. For manufacturing companies, the digital transformation to the Smart Factory represents a major challenge. Preparation for the uncertain future is necessary for competitive reasons. Neither people nor companies are capable of abrupt and radical changes without problems. The current coronavirus pandemic is expected to accelerate these developments. Nobody can yet foresee exactly where this upheaval will lead.

Digital transformation not only requires the implementation of technologies in the factory but rather a sustainable cultural change of the entire company. In other words, on the levels of organization, culture, leadership, processes, technologies, and people. The digital transformation based on cyber-physical systems brings innovative technological improvements, such as human-centered assistance systems to smart factories. Despite technological advances, manufacturing companies often have not been successful using digital solutions comprehensively throughout the organization. The lack in consideration of workers' needs causes a low acceptance rate of new technologies. As of today, the digital transformation does not offer adequate opportunities for the participation of employees in innovation and decision making with their implicit decentralized expert knowledge.

In the following, opportunity areas are summarized which the current state of technology and science has yet to sufficiently answer:

- *The Company:* Manufacturing companies are mostly in the differentiation phase and stagnating. Bureaucratic process and structures are responsible for preventing innovation and speed due to top-down approaches and centralized implementations reducing speeds. Therefore, it is very difficult to quickly adapt to new types of factory concepts such as the digital transformation towards a Smart Factory.
- *The Socio-Technical:* Digital transformation is understood as a technology issue. This perspective ignores that cultural changes are required in order to successfully implement technology into companies. Micro social and human resource aspects in socio-technical work systems are key success factors (Kochan *et al.*, 2020).
- *The Workers:* Employees are less involved in transformation processes with manufacturing companies favoring external consultation to decentralize knowledge. However, new technology applications are directly affecting workers as the interface between man and machine in manufacturing is shrinking. Top-down decisions can devalue approaches that seek to empower employees in the implementation of these technologies in the workplace. Top-down approaches tend to ignore employee's fears (i.e. replacement, substitution), decrease transparency in the process, and do not ensure worker's perspectives and values are considered in the design process. By not involving workers in the early stages, it ensures that participation will not become a central part of the organization. Though manufacturing companies may argue that workers are unqualified to participate in such process, we argue that worker's lived, learned experience in manufacturing companies are critical sources of information to promote successful digital transformation.

The digital transformation creates new opportunities for a participation-oriented corporate culture in both the production and indirect employee areas. Teamwork is becoming increasingly important and opens up new opportunities for self-organized work and bottom-up innovations. Design methods and digital tools make it possible to involve employees directly in decision-making processes. This development poses new challenges not only for employees, but also for co-determination and trade unions. Participation will play a key role to evolve companies for the future and create human-centered technology for sustainable transformation.

4. Conclusion

When trying to digitally transform, manufacturing companies mainly focus on the integration of new technologies without adequate consideration of organizational and workforce-related issues. As a result, organizations stagnate in the differentiation phase, fail with digital transformation initiatives, and workers are less inclined to adopt and adapt to new technologies in manufacturing settings. A successful digital transformation needs to involve organizational development, change and innovation management, participation of all employees, and, accordingly, participatory design methods. With a participatory design framework for the digital transformation of manufacturing enterprises, our aim is to promote successful organization of work in the future.

Throughout this working paper, we have identified potentials for organizational improvements with regards to innovation and participation. There are multiple benefits directly associated with including participation in digital transformation and innovation. Worker participation leads to the externalization of expert knowledge and promises valuable ideas for organizational innovation. Technology acceptance rates can be raised by worker participation, leveraging the use of technological improvements. The recognition of workers by integrating them with participatory design methods is highly beneficial as well. As a result of workers being involved in the design process, they may feel more empowered as a member of the organization and feel their voice has been heard in technological improvement decisions. Furthermore, the use of modern organizational structures and measures leads to additional innovation effects. Overall, the digital transformation of manufacturing enterprises can benefit from the already existing structures and methods from participatory design, as applications from other fields have already shown.

5. References

Aghina, W., Ahlback, K., Smet, A. de, Lackey, G., Lurie, M., Murarka, M. & Handscomb, C. (2018) *The five trademarks of agile organizations*. Available from: https://www.mckinsey.com/business-functions/organization/our-insights/the-five-trademarks-of-agile-organizations [Accessed 29 August 2020].

Asaro, P.M. (2000) Transforming society by transforming technology: the science and politics of participatory design. *Accounting, Management and Information Technologies*, 10(4), 257–290. Available from: doi:10.1016/S0959-8022(00)00004-7.

Bannon, L.J. & Ehn, P. (2012) Design matters in participatory design. In: Simonsen, J. & Robertson, T. (Eds.) *Routledge International Handbook of Participatory Design*.

Bengel, D. (2020) *Organizational acceptance of artificial intelligence: Identification of AI acceptance factors tailored to the German financial services sector*. Springer Gabler: Wiesbaden, Germany.

Bjerknes, G., Ehn, P., Kyng, M. & Nygaard, K. (Eds.) (1987) *Computers and democracy: A Scandinavien challenge*. Aldershot: Avebury.

Björgvinsson, E., Ehn, P. & Hillgren, P.-A. (2010) Participatory design and "democratizing innovation". In: Robertson, T., Bødker, K., Bratteteig, T. & Loi, D. (Eds.) *Proceedings of the 11th Biennial Participatory Design Conference on - PDC '10, the 11th Biennial Participatory Design Conference,* 29 November - 3 December, Sydney, Australia. ACM Press: New York, New York, USA, p. 41.

Bødker, K., Kensing, F. & Simonsen, J. (1987) *Participatory IT design: Designing for business and workplace realities*. MIT Press: Cambridge, Mass.

Brown, A.W. (2019) *Delivering digital transformation: A manager's guide to the digital revolution*.

Buur, J. & Larsen, H. (2010) Crossing intentions in participatory innovation. In: Robertson, T., Bødker, K., Bratteteig, T. & Loi, D. (Eds.) *Proceedings of the 11th Biennial Participatory Design Conference on - PDC '10, the 11th Biennial Participatory Design Conference,* 29 November - 3 December, Sydney, Australia. ACM Press: New York, New York, USA, p. 251.

Buur, J. & Matthews, B. (2008) Participatory Innovation. *International Journal of Innovation Management*, 12(03), 255–273. Available from: doi:10.1142/S1363919608001996.

Carmel, E., Whitaker, R.D. & George, J.F. (1993) PD and joint application design: a transatlantic comparison. *Communications of the ACM*, 36(6), 40–48. Available from: doi:10.1145/153571.163265.

Chesbrough, H.W. (2003) *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business School Press: Boston, Mass.

Colin, L.M. & Chavez, A.R. (2015) User's Typology for Designing. *Procedia Manufacturing*, 3, 6005–6012. Available from: doi:10.1016/j.promfg.2015.07.708.

Daugherty, P.R. & Wilson, H.J. (2018) *Human + Machine: Reimagining Work in the Age of AI*. Harvard Business Review Press: La Vergne.

Docherty, P. (Ed.) (1987) *System design for human development and productivity: Participation and beyond ; proceedings of the IFIP TC 9/WG 9.1 Working Conference on System Design for Human Development and Productivity, … Berlin, GDR, 12-15 May, 1986*. North-Holland: Amsterdam.

Ehn, P. & Kyng, M. (1987) The collective resource approach to systems design. In: Bjerknes, G., Ehn, P., Kyng, M. & Nygaard, K. (Eds.) *Computers and democracy: A Scandinavien challenge.* Aldershot: Avebury, pp. 17–57.

ElMaraghy, H. (2019) Smart changeable manufacturing systems. *Procedia Manufacturing*, 28, 3–9. Available from: doi:10.1016/j.promfg.2018.12.002.

Fechter, M., Foith-Förster, P., Pfeiffer, M.S. & Bauernhansl, T. (2016) Axiomatic Design Approach for Human-robot Collaboration in Flexibly Linked Assembly Layouts. *Procedia CIRP*, 50, 629–634. Available from: doi:10.1016/j.procir.2016.04.186.

Floyd, C., Mehl, W.-M., Resin, F.-M., Schmidt, G. & Wolf, G. (1989) Out of Scandinavia: Alternative Approaches to Software Design and System Development. *Human–Computer Interaction*, 4(4), 253–350. Available from: doi:10.1207/s15327051hci0404_1.

Foith-Förster, P. & Bauernhansl, T. (2019) Generic Production System Model of Personalized Production. *MATEC Web of Conferences*, 301, 19. Available from: doi:10.1051/matecconf/201930100019.

Foith-Förster, P., Wiedenmann, M., Seichter, D. & Bauernhansl, T. (2016) Axiomatic Approach to Flexible and Changeable Production System Design. *Procedia CIRP*, 53, 8–14. Available from: doi:10.1016/j.procir.2016.05.001.

Frank, A.G., Dalenogare, L.S. & Ayala, N.F. (2019) Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, 210, 15–26. Available from: doi:10.1016/j.ijpe.2019.01.004.

Fraser, H.M.A. (2019) *Design Works: A Guide to Creating and Sustaining Value through Business Design, Revised and Expanded Edition*. University of Toronto Press: Toronto.

Fries, C., Wiendahl, H.-H. & Foith-Förster, P. (2020) Planung zukünftiger Automobilproduktionen. In: Bauernhansl, T., Fechter, M. & Dietz, T. (Eds.) *Entwicklung, Aufbau und Demonstration einer wandlungsfähigen (Fahrzeug-) Forschungsproduktion.* Springer Berlin Heidelberg: Berlin, Heidelberg, pp. 19–43.

Glasl, F. & Lievegoed, B.C.J. (2004) *Dynamische Unternehmensentwicklung: Grundlagen für nachhaltiges Change Management*. Haupt: Bern.

Greenbaum, J. (Ed.) (1991) *Design at work: Cooperative design of computer systems*. Erlbaum: Hillsdale, NJ.

Greene, M.T., Gonzalez, R., Papalambros, P. & Mcgowan, A.-M. (2017) Design Thinking vs. Systems Thinking for Engineering Design: What's the Difference? *21st International Conference on Engineering Design*.

Halse, J., Brandt, E., Clark, B. & Binder, T. (Eds.) (2010) *Rehearsing the Future*. The Danish Design School Press: Copenhagen.

Hillgren, P.-A., Seravalli, A. & Emilson, A. (2011) Prototyping and infrastructuring in design for social innovation. *CoDesign*, 7(3-4), 169–183. Available from: doi:10.1080/15710882.2011.630474.

Horváth, D. & Szabó, R.Z. (2019) Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? *Technological Forecasting and Social Change*, 146, 119–132. Available from: doi:10.1016/j.techfore.2019.05.021.

Issa, A., Schumacher, S., Hatiboglu, B., Groß, E. & Bauernhansl, T. (2018) Open Innovation in the Workplace: Future Work Lab as a Living Lab. *Procedia CIRP*, 72, 629–634. Available from: doi:10.1016/j.procir.2018.03.149.

Kane, G.C., Phillips, A.N. & Copulsky, J.R. (2019) *The technology fallacy: How people are the real key to digital transformation*.

Kochan, T., Helper, S., Kowalski, A. & van Reenen, J. (2020) *Interdependence of Technology and Work Systems*. Working Paper Series. Available from: https://workofthefuture.mit.edu/research-post/independence-of-technology-and-work-systems/ [Accessed 1 October 2020].

Korge, A. & Marrenbach, D. (2018) *Wege zur Arbeit 4.0: Zukunftsbilder – Entwicklungspfade – Transformationen*. Fraunhofer IAO: Stuttgart.

Laloux, F. (2014) *Reinventing organizations: A guide to creating organizations inspired by the next stage of human consciousness*. Nelson Parker: Brussels.

Li, K. (2018) *AI superpowers: China, Silicon Valley, and the new world order*. Houghton Mifflin Harcourt: Boston.

Lievegoed, B.C.J. & Collis, J. (Eds.) (1973) *The developing organization*. Tavistock: London.

Marin-Garcia, J.A. & Bonavia, T. (2015) Relationship between employee involvement and lean manufacturing and its effect on performance in a rigid continuous process industry. *International Journal of Production Research*, 53(11), 3260–3275. Available from: doi:10.1080/00207543.2014.975852.

Martin, J.-F. (2018) *Unlocking success in digital transformations*. Available from: https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Organization/Our%20Insights/Unlocking%20success%20in%20digital%20transformations/Unlocking-success-in-digital-transformations.ashx [Accessed 29 August 2020].

Mohr, B.J. & van Amelsvoort, P.J.L.M. (Eds.) (2016) *Co-creating humane and innovative organizations: Evolutions in the practice of socio-technical system design*. Global STS-D Network Press: Portland ME.

Morakanyane, R., O'Reilly, P., Mcavoy, J. & Grace, A. (2020) Determining Digital Transformation Success Factors. In: Bui, T. (Ed.) *Proceedings of the 53rd Hawaii International Conference on System Sciences, Hawaii International Conference on System Sciences.* Hawaii International Conference on System Sciences.

Muller, M.J. & Kuhn, S. (1993) Participatory design. *Communications of the ACM*, 36(6), 24–28. Available from: doi:10.1145/153571.255960.

Muller, M.J., Wildman, D.M. & White, E.A. (1992) *Games and other techniques for group design of user interfaces*.

Mumford, E. & Henshall, D. (1979) *A participative approach to computer systems design: A case study of the introduction of a new computer system*. Wiley & Sons: New York NY u.a.

Neugebauer, R. (Ed.) (2019) *Digital Transformation*. Springer Vieweg: Berlin.

Niewöhner, N., Asmar, L., Röltgen, D., Kühn, A. & Dumitrescu, R. (2020) The impact of the 4th industrial revolution on the design fields of innovation management. *Procedia CIRP*, 91, 43–48. Available from: doi:10.1016/j.procir.2020.02.149.

Osmundsen, K., Iden, J. & Bygstad, B. (2018) DIGITAL TRANSFORMATION DRIVERS, SUCCESS FACTORS, AND IMPLICATIONS. *The 12th Mediterranean Conference on Information Systems (MCIS)*.

Peters, T.J. (1992) *Liberation management: Necessary disorganization for the nanosecond nineties*.

Petit, J.-P., Brosset, P., Puttur, R.K., Ghosh, A., Bagnon, P., Capone, A. & Buvat, J. *et al.* (2019) *Smart factories @ scale: Seizing the trillion-dollar prize through efficiency by design and closed-loop operations*. Available from: https://www.capgemini.com/de-de/wp-content/uploads/sites/5/2019/11/Report-%E2%80%93-Smart-Factories.pdf [Accessed 29 August 2020].

Pokorni, B., Zwerina, J. & Hämmerle, M. (2020) Human-centered design approach for manufacturing assistance systems based on Design Sprints. *Procedia CIRP*, 91, 312–318. Available from: doi:10.1016/j.procir.2020.02.181.

Porter, M.E. (1985) *Competitive advantage: Creating and sustaining superior performance*. Free Press: New York.

Saturno, M., Moura Pertel, V., Deschamps, F. & de Freitas Rocha Loures, Eduardo (2017) Proposal of an automation solutions architecture for Industry 4.0. *24th International Conference on Production Research*.

Schallmo, D.R.A., Reinhart, J. & Kuntz, E. (2018) *Digitale Transformation Von Geschäftsmodellen Erfolgreich Gestalten: Trends, Auswirkungen und Roadmap*. Gabler: Wiesbaden.

Schlund, S. & Pokorni, B. (2016) *Industrie 4.0 - wo steht die Revolution der Arbeitsgestaltung? Ergebnisse einer Befragung von Produktionsverantwortlichen deutscher Unternehmen*. Fraunhofer IAO: Stuttgart.

Schön, D.A. (1983) *The reflective practitioner: How professionals think in action*. Basic Books: New York.

Schuler, D., Namioka, A. & Suchman, L.A. (1993) *Participatory Design: Principles and Practices*. CRC Press: Mahwah.

Schumacher, S., Bildstein, A. & Bauernhansl, T. (2020) The Impact of the Digital Transformation on Lean Production Systems. *Procedia CIRP*.

Schumacher, S., Pokorni, B., Himmelstoß, H. & Bauernhansl, T. (2020) Conceptualization of a Framework for the Design of Production Systems and Industrial Workplaces. *Procedia CIRP*, 91, 176–181. Available from: doi:10.1016/j.procir.2020.02.165.

Siegert, J., Schlegel, T. & Bauernhansl, T. (2018) Matrix Fusion Factory. *Procedia Manufacturing*, 23, 177–182. Available from: doi:10.1016/j.promfg.2018.04.013.

Stahl, F. (2013) *Worker leadership: America's secret weapon in the battle for industrial competitiveness*. MIT Press: Cambridge, Massachusetts.

Tabrizi, B., Lam, E., Girard, K. & Irvin, V. (2019) *Digital Transformation Is Not About Technology*. Available from: https://hbr.org/2019/03/digital-transformation-is-not-about-technology [Accessed 27 August 2020].

Tawalbeh, M., Riedel, R., Horler, S. & Müller, E. (2017) Case Studies of Participatory Design. In: Lödding, H., Riedel, R., Thoben, K.-D., Cieminski, G. von & Kiritsis, D. (Eds.) *Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing.* Springer International Publishing: Cham, pp. 159–167.

Terstegen, S., Hennegriff, S., Dander, H. & Adler, P. (2019) Vergleichsstudie über Vorgehensmodelle zur Einführung und Umsetzung von Digitalisierungsmaßnahmen in der produzierenden Industrie. *65. Kongress der Gesellschaft für Arbeitswissenschaft*.

Trist, E.L. & Bamforth, K.W. (1951) Some Social and Psychological Consequences of the Longwall Method of Coal-Getting. *Human Relations*, 4(1), 3–38. Available from: doi:10.1177/001872675100400101.

Turner, J. & Kraut, R. (1992) *Proceedings of the 1992 ACM conference on Computer-supported cooperative work*. ACM: New York, NY.

Valentin, M. (2019) *The Tesla way: The disruptive strategies and models of Teslismn*.

Vogel-Heuser, B., Bauernhansl, T. & Hompel, M. ten (Eds.) (2017) *Handbuch Industrie 4.0: Bd. 1: Produktion*, 2nd edn. Springer Vieweg: Berlin.

ZoBell, S. (2018) *Why Digital Transformations Fail: Closing The $900 Billion Hole In Enterprise Strategy*. Available from: https://www.forbes.com/sites/forbestechcouncil/2018/03/13/why-digital-transformations-fail-closing-the-900-billion-hole-in-enterprise-strategy/ [Accessed 27 August 2020].