Recent trends in industrial transformation: A literature review on skills and the future of work

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Suggested citation

Schartinger, D.; Rhomberg, W. (2024) Recent trends in industrial transformation: A literature review on skills and the future of work. Paper presented at the R&D Management Conference, Stockholm/ Sweden, June 17-19, 2024.

Abstract

This paper sets out to identify developments and trends around industrial transformation stemming from digital technology adoption and environmental aspirations, and how these transformations impact on the future of work until 2035. Thereby our guiding question is: How do recent digital and environmental developments shape industrial firm and work practices, thereby changing the nature of jobs and the demand for skills? The method applied is a systematic literature survey following the PRISMA method. We started with broad search terms around “digital” and “green” in Sciencedirect and the Web of Science in February 2024. This literature study is part of a wider European research project on industrial transformation. It will eventually serve the development of explorative scenarios of future developments relating to new jobs and emerging skill needs.

Key words: industrial transformation; digitalisation; skills; future work, literature survey

Introduction

Digital technologies are key technologies, broad applications of e.g., cyber-physical systems, ERP/CRM, VR/XR, have led and will lead to broad transformations of industry and society. As the nature of jobs and of work changes , this leads to vast uncertainties on part of firms and on part of employees (Ghobakhloo 2020). Firms may not be able to adopt technologies fast enough due to lack of managerial or workforce skills (Zangiacomi et al. 2020; Cirillo et al. 2023; Delias and Kitsios 2023) and employees are faced with major uncertainties related to the ways they live and work (Trzaska et al. 2021; Lima et al. 2023). This leads to increased analysis of competences and skill sets including the attempts to scrutinise their importance (Jiang et al. 2021). More recently, policy attempts to reconcile the tensions between opportunities stemming from digital technologies also to solve societal challenges, and their risks if implemented and pursued with shortsightedness, like inequality, poverty and lack of purpose and meaning within society. The debate around Industry 5.0 places firms and industry as employers and suppliers as a part of society. (Breque et al. 2021; Dalvit et al. 2023)

The purpose of this paper is to uncarve trends in industrial transformation. These trends come from various directions, on the one hand through technological developments particularly around digitalisation, automation and connection normally termed as the fourth industrial revolution (Kagermann et al. 2013; Brynjolfsson and McAfee 2016). Furthermore, through political and societal debates, e.g. in Europe the industrial strategy aiming for twin transition where industry is "embarking on a transition towards climate neutrality and digital leadership" [1] or in Japan the debate around Society 5.0 (Fukuyama 2018) where at the same time through the adoption of super-smart technologies economic prosperity and the resolution of societal challenges including climate change and other environmental challenges are achieved. Moreover, the concept of Industry 5.0 (Breque et al. 2021) reflects on the role of human-centricity thereby adding a perspective on work and jobs for people and society.

Hence, we set out to identify trends around industrial transformation stemming from digital technology adoption and environmental aspirations, and how these transformations impact on the future of work until 2035. Thereby our guiding question is: How do recent digital and environmental developments shape industrial firm and work practices, thereby changing the nature of jobs and the demand for skills?

The method applied is a systematic literature survey following the PRISMA method. We started with broad search terms around "digital" and "green" in Sciencedirect and the Web of Science in February 2024. A first set of exclusion criteria mainly based on title and abstract reduced the number papers. We excluded papers that are first) too technical, mainly piloting a technology in a laboratory setting and hence technology testing without relevance for work or skills, second) too alien to the European context, or third) too COVID crisis-focussed. Furthermore, we maintain a focus close to manufacturing, therefore excluding some service sectors like military, hospitals and healthcare, schools and education, films and Hollywood. In screening the full-text of the papers, we reduced their number further.

This literature study is part of a wider European research project on industrial transformation. It will eventually serve the development of explorative scenarios of future developments relating to new jobs and emerging skill needs. Hence, as a first step we want to identify dominant trends, as well as weak signals, potential disruption, and "wild cards". These will be further assessed in a workshop setting with experts from industry and academia, before translating them to scenarios. The explorative scenarios will be the basis for identifying opportunities and risks, and tracing back possible options and necessary action from today into the future, examining milestones, trigger events, and innovative strategies. In the current phase, it is important to identify trends and development of suitable granularity. For our

[1] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy_en,

purposes, trends must not be of a macro level or too local and context-specific in order to be meaningful for the further study. The timeframe of industrial transformation until 2035 directs our attention to the very recent literature in order to shed light particularly on developments that continue in the not-too-distant future.

Methods applied

Systematic literature review, PRISMA. (References)

Following our aims specified above we applied the search terms in Table 1. The search string had first, terms relating to "industrial transformation", second, terms relating to the twin aims of either "digital" or "green" developments, and third, terms relating to jobs or skills. We tried several versions of search terms, particularly also "work" or "education and training". However, the latter proved unfit for our purposes because the term "work" is extensively used also in the context of "in this work we tackle" or "our work" referring to the whole study. In contrast, terms like education and training often resulted in studies on concrete (university) curricula which were mostly beyond our aims.

We conducted our search in both the Web of Science and Sciencedirect. Although these data bases partly overlap, they produce also different results which is due to their different sets of sources and differences in search features. Whereas the Web of Science supports proximity operators, Sciencedirect works with semantic search features. Roughly one third of the resulting papers were dublettes which we eliminated as part of the systematic selection procedure.

Table 1: The search strategy

Query	Number of articles	Number of articles after screening for European countries, articles (no book chapters), in English	After screening abstracts
Job or skills			
Year(2020-2024) Title, abstract, keywords((industry OR industrial) AND (sustainability OR green OR environment) AND transformation AND (job OR skills)) - Search | ScienceDirect.com	64	28 (only articles, screened **title**, European countries, down to 28)	**83**, after reading abstracts; **81**, after reading (group of) full papers
Year(2020-2024) Title, abstract, keywords((industry OR industrial) AND digital AND transformation AND (job OR skills)) - Search | ScienceDirect.comcv	101	53 (only articles, screened **title**, European countries, down to 53)	
industr* AND (sustainab* OR green OR environment*) AND transformation AND (job	147	34 (only articles,	

OR skill*) in Title, Abstract or Keywords AND 2020-2024 (Year Published) Web of Science		screened **title**, European countries)	
industr* AND digital* AND transformation AND (job OR skill*) in Title, Abstract or Keywords AND 2020-2024 (Year Published) Web of Science	175	58 (only articles, screened **title**, European countries)	
	487	**173, 121 after eliminating dublettes**	

Exclusion criteria

We excluded papers first) that did not have an empirical focus but rather conceptually elaborated on a desired state of industry; second) that focussed on the potential of a technology in a laboratory setting; third) where the COVID- focus was too dominant; and forth) that rather focussed on the design of a curriculum without empirical data.

Inclusion criteria

We included papers first) that are a primary empirical source OR apply a systematic meta-level method, second) that provide a real-life industry setting, e.g. in the form of firm-level cases or employee surveys within or across firms. These are often related to skills profiles of occupational groups or sectors. Third, we included paper with a sectoral sectoral perspective on skills demands and shortages, either based on sector employee surveys or wider on a stakeholder perspective. Fourth, we kept to papers close to manufacturing, but not exclusively to manufacturing (e.g. also KIBS, banking, transport, but not tourism or films).

Table 2: Search results

Types of empirical studies	**Number of papers**	**Comment**
Firm level (case studies/employee surveys)	23	
Sectoral level (case studies/employee or stakeholder surveys)	14	(Steel, automotive, oil and gas, construction, energy, mineral ind., process ind., KIBS, transport, banking)
Occupational level (employee or stakeholder surveys)	14	(engineers, leaders/managers, purchasing/supply, QM professions, data scientists, plus youth, sustainable I4.0)
Sub-total I	**51**	
Conceptual (meta studies literature), macro trends (empirical)	24	
Sub-total II	**75**	

Scenarios	2	(circular economy, occupations/employment)
Frameworks	4	
Overall	**81**	

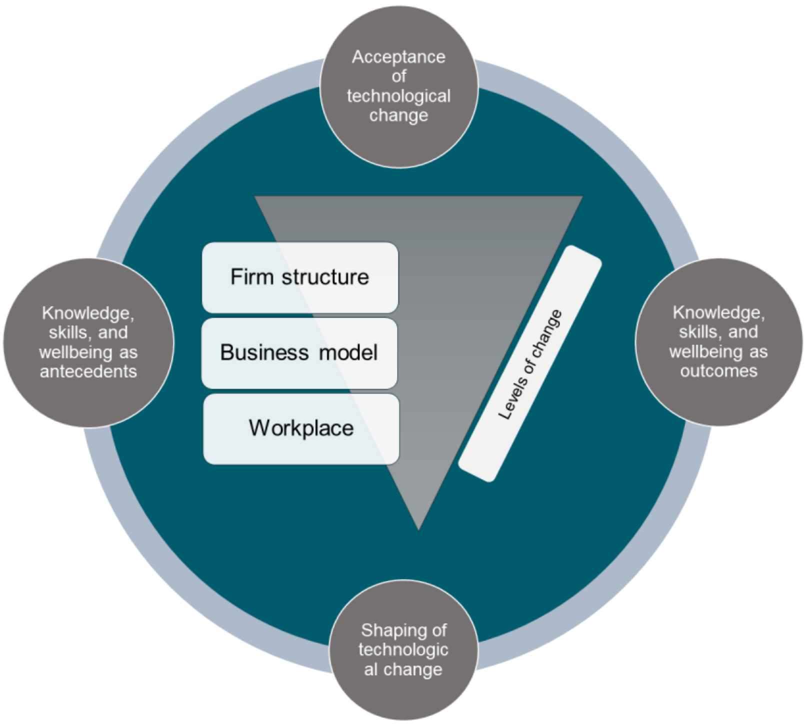
This current version of the paper focusses on the 23 firm level papers which are also listed in the annex.

Resulting themes

Figure 1 presents the resulting themes coming out of 23 academic articles incorporating a firm level perspective. As a basic framing, technology adoption can take place on any level of the firms and accordingly has different effects in terms of skills. The consequences of technology adoption in general refer to either the level of the workplace, the business model, or the overall firm structure. Empirical research can also focus on specific technologies and the particular consequences of their adoption, e.g. for AI (Malik et al. 2022), IoT and edge computing (Stadnicka et al. 2022), or robots (Pérez et al. 2020; Gualtieri et al. 2020).

On the level of the workplace, (Gualtieri et al. 2020) show how purely manual workstations are transformed into assemblies involving collaborative robotics where then the work station is reorganised in a way that two parallel panels are operated by one worker. The collaborative robot takes over repetitive tasks (Pérez et al. 2020), or the tasks that were the cause for biomechanical overload, resulting in reduced repetition in awkward postures (Gualtieri et al. 2020), but not necessarily in increased autonomy of work as such (Cirillo et al. 2021).

Figure 1: Themes derived from the literature review



Conversely, (Simsek et al. 2022) in a very interesting paper show how a product and manufacturing-oriented business model over years turned into a platform as a service (PaaS) business model. Whereas the established multi-national enterprise with production plants around the world was traditionally oriented towards producing equipment, it consequently changed its organisational structure to a networked form now selling not only equipment, but 24/7 availability of equipment systems. Revenue streams consequently changed from one-off sales and service agreements to contract-based revenue streams with subscriptions according to pay-as you-use policies. The change process lasted for more than a decade with first smaller changes resulting from technological opportunities from early-on remote condition monitoring and remote diagnostic technologies, extending to predictive maintenance data and technologies, and moreover asset and energy management technologies, to cloud-based Internet of Things, open access platform with membership, and customer-specific apps. The stepwise adoption of technologies meant a strategic shift in firm structure around the globe, the re-organisation process meant the parallel operation of the traditional and the new business model in phases. The biggest driver apart from technological opportunities was market structure, with the main competitor announcing their platform. (Simsek et al. 2022)

In between these two lie levels of limited business model innovation as suggested by (Kirklikçi 2024) and (Giacosa et al. 2022). Here parts of the enterprise or specific functions are reorganised due to increased needs for agility (Giacosa et al. 2022) indicating a change in firm practices. (Cirillo et al. 2021) observe here that I4.0 implementation generally fosters the leanness of the production system, although implementation my be scattered across and even within firms.

The conceptual relation to knowledge, skills and competences

Levels of change through technology frame the whole discussion on competences and skills because from the granularity of change it is obvious that the relation between skills/competences and technological adoption is bi-directional: Competences are an important antecedent for the adoption of new technology and needs strategic and large-frame decisions along the way of its implementation. While changing the value propositions and structure of the firm it also has an effect on the level of work organisation/workplaces, firm practices and thus on the nature of jobs and work and on concrete workstations and tasks. These changes then impact on the knowledge and skillsets needed there, and on job satisfaction, job-related health outcomes, or technostress (Kwiotkowska and Gebczynska 2022; Malik et al. 2022; Abeliansky et al. 2024).

The concepts used to argue knowledge and skills as antecedents of industrial transformation are absorptive capacity (Cohen and Levinthal 1990) and the dynamic capabilities approach (Teece and Pisano 1994).

Shaping of technological change

A number of papers broach the issue of organising the change processes due to technology adoption under the lens of active participation of all actors concerned. Empowerment and the notion of shaping technology to support people where people want to be supported is an entry point for analysis here.

(Kaasinen et al. 2020) argue that if human-centricity shall be an important element of industrial transformation, smart factories of the future shall be able to accommodate workers with different skills, capabilities and preferences. In their case study work in different firms, they contribute to the operator 4.0 concept in identifying the viewpoint of workers and the works council. They argue that for the organisation of the change process, it will be crucial to involve workers in order to be able to develop the work practices in parallel with the technical solution. In their empirical investigation, many concerns were raised concerning work practices at the workplace and "production-centered shift plans" (p9) that challenge the social and private lives of workers. In turn, health performance-related measurements are seen as critical by the works council in case they are laid open to higher hierarchical levels on the individual worker level. Related to skills, workers noted that they often have limited possibilities to apply newly gained knowledge or competences after trainings, which points to non-use and forgetting or de-skilling. This has also been mentioned by (Cirillo et al. 2021) who note that in case that discretion is also reduced on top of autonomy, because e.g. interventions are not necessary although people are trained for them – this reduces jobs to simply monitoring cyber-physical systems, resulting in de-skilling. Following (Kaasinen et al. 2020), a participatory design of technology adoption investigating different viewpoints by stakeholders, will be necessary in order to achieve workplaces and work practices that appeal to the workforce and make them want to be part of industrial firms.

The approach of participatory technology design points to different skills and mindsets also on the level of leaders and managers. Participatory design to shape technology adoption needs different firm and leadership practices from making workforce accepting technology investments already accomplished. Contrastingly, (Reljic et al. 2023) find that robot adoption is associated with higher demand for managers who are the ones responsible for making the decisions and governing the processes of implementing new technologies in the workplace. Instead, all other occupational categories have negative coefficients, although statistically significant only for manual workers. They conclude that employment gains are asymmetrically distributed across occupations. This in turn indicates that the decisions by managers shaping the technological solutions implemented in a firms need not necessarily harm on the level of management but on the levels below.

Skills and competences are an antecedent as well as their change may be an outcome of technology adoption. This is often difficult to disentangle. (Cirillo et al. 2023) find that firms with skilled employees are more likely to invest in new digital technologies. "It is nevertheless possible to ask which skill sets are more suitable for the adoption of new digital technologies as part of firm-specific strategies. Firms have to anticipate skills needs in preparation for particular technology choices and are bound in their technology choices by path-dependent human capital endowments." (p91)

In this respect, there are of course opportunities in proactive skill developments (PSD) by employees themselves. (Ostmeier and Strobel 2022) define PSD as self-initiated future and change oriented development of one's own competences directed towards tasks of occupation creation of career. However, they found that it does not suffice that digital maturity rises in general in order for employees to engage in PSD, but PSD is hinged to employees' perception of digitalisation. If people see digitalisation as an opportunity or at least as controllable, they raise their engagement in PSD. If they see digitalisation as a threat, no significant results are obtained. (Ostmeier and Strobel 2022) recommend to actively self-initiated skill development among employees by deliberately designing communications on macro-level trends and their effects on the organisation.

Acceptance of technological change

Acceptance of technology and of technological change process on the organisational level has passive elements in that some actors are on the receiving end of work solutions designed by someone other than themselves.

There are different narratives of how the change comes about that is then pressed upon firms and firms' employees. For (Herceg et al. 2020), Industry 4.0 technology adoption is mainly something that is forced upon firms from external partners or customers. Market competition and the necessity to reduce costs and increase efficiency are strong drivers in their study in the manufacturing sector. Consequently, as the pressures come from outside the firm, also managers are on the receiving end and consequently lack of managerial competences are seen as barrier of technology adoption as well as the lack of skilled workforce. This is followed by barriers as financial resources, lack of standards and conscious planning, and lastly resistance to change.

Other papers frame the change process from an internal perspective where the management level steers the change processes among employees. (Heim and Sardar-Drenda 2020) argue that in their study, they consider "a topdown approach to change management because this change dynamic is the most typical for digitalisation-induced organisational transformations, which are often the results of the new strategy implementation at the organisational level." (p2) However, they also recommend to involve employees to solve issues and build on employees' prior experience. They contend that "employees would like to be involved and have control over the upcoming change events at the earliest stages." (p18)

(Porfírio et al. 2024) point to combinations of people and process characteristics that make employees more likely to accept change. They point out that it is not necessarily a person's age that determines the openness to change processes, rather it is the level of education and the communication procedures associated with the organisation of change. When employees understand the necessities, context and elements of digital transformation they are more likely to accept the changes. They emphasise "it is "possible to bypass budget constraints on DT processes either with an adequate combination of the level of employees' education or with an adequate level of communication and understanding of the processes by the employees." (p7) Thus, it is not specific skills that are the basis for technological change, but a general level of knowledge and competences in the vein of absorptive capacity. (Cohen and Levinthal 1990)

The level of workstations/workplaces

Various papers show how the workstation is reorganised in a way to accommodate some new technology. These papers have a limited empirical setting in the form of a "use case", a "realistic use case scenario" etc. They include technical KPIs and sometimes firm expert opinion, and they are mostly directed towards managers who make decision to invest in these technologies.

(Gualtieri et al. 2020) provide insights on the conversion of a workstation with collaborative robotics. Although they argue general process sustainability - meaning the three-pillar concept based on environmental, social and economic aspects - as the driver for this conversion, their paper focus is on physical ergonomics in terms of reducing biomechanical overload, and on economic productivity. Their key performance indicators show that the work cycle is accelerated, and the production time shortened. The set-up of their workstation is tested to similar anthropomorphic feature in terms of age, gender and work skills of candidates. And only future research will focus on autonomously and dynamically adapting workstations.

(Konstantinidis et al. 2020) target a different production function, not workstation in routine production but maintenance operations. They argue that when in general human intervention in production will drop off due to the introduction of cyber-physical systems, operators will become fewer, but still maintenance will be carried out by operators. Hence, they introduce a supportive system "which can be used by unskilled operators to perform maintenance operations in night shifts." (p2) In an experimental process they collaborate with a potential user firm. The authors from an engineering department argue directly towards the managers of the experimental user firm (p11): "exploiting the application as a means of training new and unskilled maintenance operators, reducing both the required training, as well as the total repair time. Eventually, the integration of exponential digital technologies, like [X], in small–medium enterprises can strengthen the industrial competitiveness in the global landscape." Operators and human-centricity are captured in one sentence (p11) "Considering the current applications, the system is designed in a user-friendly way to be effectively controlled in fast-track repair procedures by shop-floor operators and capable to be correlated with ubiquitous maintenance system that can reduce the mean time to repair (MTR) in production's availability."

Similarly, (Pérez et al. 2020) present a technical use directed towards managers. Generally, in papers with a technical use case and experimentation, the length of the testing period is often unclear. However, this is crucial as job-and work-related issues may only arise after some time of application and repeated interaction between humans and machines. The general danger is that managers base their decisions on limited technical and economic criteria, and invest in premature settings – when these settings cannot be easily converted in a flexible manner to accommodate different anthropomorphic features (e.g. size), gender, age etc – these investments stick as they would otherwise be sunk costs.

Before this background, (Cirillo et al. 2021) provide insights into how the introduction of Industry 4.0 technologies has an impact on workers' roles in the work process in Italian automotive firms. They distinguish between "autonomy" and "discretion". Whereas discretion in the form of intervention authority during the work process as increased, autonomy has decreased. Workers cannot establish own rules or ways of executing a task, instead the implementation of many technologies results in increased standardisation of work processes meaning that work processes can only be executed according to a "unique admissible combination of steps, otherwise errors are raised." (p167) They conclude that "the organisational practices that have accompanied the introduction of I4.0 technology in general do not create the conditions for an increase in the autonomy of workers, especially in terms of the ability of establishing their own rules in the organisational and production process. Indeed, the reduction of the space of autonomy is the combined result of new technology in use and of hierarchical structure of the organisation." (p182)

In a similar vein, (Kaasinen et al. 2020) observe that when firm environments are highly automated the operators work consists mainly of monitoring the machines and discretionary action in terms of problem-solving.

The level of firm structure and business model

What starts with technology adoption e.g. in order to be compliant with external regulation, may over time result in a change of the core business model and consequently of the structure of the business firm as a whole. (Porfírio et al. 2024)

Often, studies situated on this level of analysis are not specific as to which types of skills or other barriers are in contrast with changes deemed necessary. (Kirklikçi 2024) On a general level, they point out the high costs of technology and the lack of skilled workers as the main obstacles to I4.0 technology adoption in the forest product sectors. However, their practical recommendations indicate that it is more the general high levels of knowledge and skills that they see as necessary antecedents of technology adoption. Therefore, they advise that businesses collaborate with educational institutions in order to "ensure that there is a pipeline of skilled workers available to industry." (p6) They conclude that a general lack of a high level of education leads to employees [different levels, managers, engineers, foreman, workers] being unaware of the full spectrum of advantages of digital transformation, including its cost-reducing effects.

(Simsek et al. 2022) reflect on the different types of skills related to a comprehensive transformation process on the level of the whole firm structure. On the one hand, transformational leadership is necessary which is different from effective change management but embraces uncertainties and the needs to govern along a more general vision of the future. Transformational leaders do not only watch market signals and interpret them but sense the weaknesses, perceive trends, and transform them into opportunities for the company. The decisions that are associated with such a mindset are by their very nature riskier, need a trial-and-error approach and have to tolerate low revenues in initial phases. At the same time, they may need the ability to weather the cannibalisation of the traditional business model.

Conversely, the total restructuring of the firm into new practices and processes needs new skills on different other levels. Operating a cloud-based ecosystems requires different skills in terms of R&D and sales processes. When production is outsourced to a network partner and the business model changed from sales of equipment to platform as a service (PaaS), the focus is not on technical sales anymore but on customer-value co-creation which needs more consultative sales approaches. Logistics and procurement changed to mainly web-based, which also need different approaches from the traditional ones. Rather than a taxative list of skills necessary, the article emphasises that the approach was more on iterative moves during the adaptation processes. Experimentation, trial-and-error based deployments, and discovery-driven decision making were part of the journey. (p12) Long-term customers served as pilot sites and supported with cooperation and feedback. Also in this case, a general high level of education is emphasized where knowledge is seen as a reservoir and unevenly and in an often tacit form influences technology adoption. This is obvious in statements like “Cloud business and surrounding technologies were new to the company; however, as a sustainable learning organization, the company achieved to ramp up more than 900 global research and development engineers around the world.” (Simsek et al., p12) Furthermore, as quality has been a hallmark for many decades, a new firm structure and value proposition needs new quality management practices and processes with different priorities.

Digital skills and talent

(Ghobakhloo and Fathi 2020) analyse digital transformation from the viewpoint of SMEs. SMEs can often only digitise certain areas of their operations, like customer relationship management or production planning and control, they are mostly driven by their supply chain partners but can be met with resistance from employees and be significantly limited regarding their financial and human resources. The transformation involves many steps and is unfathomable in advance in terms of related costs and know-how and competences necessary when the single steps unfold. On top of new digital hardware, software applications and cybersecurity, the dismantling of outdated physical infrastructure and equipping existing machines with smart industrial sensors is characterised by a myriad of challenges and including debugging, until a seamless stream of data becomes possible. The need for skills and competences to meet the manifold challenges is thereby sourced in various ways: On the one hand they significantly invest in new hires and technological partnerships, consultation of external experts and training of in-house employees. But at the same time they mention lay-offs as occasionally necessary in case employees are resistant too change, as well as cooperation with engineering departments at universities in spatial proximity, for internships and potential future hires.

(Ghobakhloo and Fathi 2020; Pérez et al. 2020) and (Stadnicka et al. 2022) provide insights into why it is so hard to define the skills needed for digital transformation. Digital transformation always means a combination of different technical systems causing issues in connectivity and interoperability, where seamless streams of data are hence a painstaking process. Whether firms do not replace all equipment at once because it is economically unmanageable or because their equipment is too idiosyncratic to replace entirely it means integration of old appliances and interconnection of different industrial units into a modern production system. This requires what (Stadnicka et al. 2022) term “a latent need regarding training and soft skills (e.g. involvement, logical thinking, teamwork, interpersonal and interdisciplinary communication, self-motivation and self-organisation)”. (p39)

The above entails that the problems caused by integrating different systems are insurmountable when the process starts and can only be solved in an iterative way while going. At the same time this entails that the precise skills can hardly be named beyond general notions like “problem solving” once they arise, or “communication skills” between units and hierarchies to determine the functionalities that are impaired and have to be re-established, or “negotiation skills” when it comes down to securing services with and among (different) vendors when it is still not clear which system causes the disruptions. Apparently, these skills can also be hardly named ex post because of their ad hoc nature that often involves the cumulation of different ad hoc inputs and hence interaction (which needs soft skills).

To narrow down what new skills become more important with digital transformation or how skillsets of the future will be different from current ones is extremely difficult and often tied to the same phrasings. These phrasings then become stereotypes and prevent a thorough discussion more than they enable them. (Demirbag and Yildirim 2023) have tried to pin down what is novel in skillsets of engineers. They identify “intrinsic motivation skills” apart from technology skills and data and information skills. These intrinsic motivation skills are topped by “self-confidence[2]”, followed by truly social skills like negotiation/persuasiveness, people management and leadership, later also by creativity, teamwork abilities and communication skills. Other skills seem to be inherent to the engineering profession, like judgement and decision making, curiosity, complex problem solving, critical thinking, cognitive flexibility, or a mindset for continuous improvement. (Demirbag and Yildirim 2023) can specify what an increase of social characteristics of engineers’ work means: increase in interaction outside one’s own organisation, workplace mobility, acting on feedback from others and social support. They also find that different technologies vary in their impact on the sociality of engineers’ work in that e.g., adaptive robotics and additive manufacturing technologies have a positive impact on the social characteristics of engineers’ work, instead data analytics and artificial intelligence, RFID/RTLS technologies and simulation have negative impact on the social characteristics of engineers’ work.

(Gilch and Sieweke 2021) observe that while digitalisation processes in firms increase the demand for digital talent, old recruiting practices tend to fail because digital talent has different characteristics from the traditional workforce. People with extensive digital skills are more diverse in terms of educational background, not necessarily having any certification or degree because they learned in online communities or in an autodidactic way. If they hold degrees, there does not seem to be a uniform discipline, instead there is a wide range of disciplines including geoinformatics or philosophy. Additionally, digitally skilled individuals are not necessarily long-term employees – they prefer exciting jobs, are more demanding because they are aware of their market power and they screen employers more intensely before application.

If digital talent is too difficult to hire and organisations hence face critical bottleneck, they tend to revert to support from external IT consultants. (Oesterle et al. 2022)These are then framed as co-creation processes between firms and IT consultants and require increased competences from IT consultants as well – in terms of being innovative, having technological and social expertise, to lesser extents also functional expertise. Clients need to have technological expertise as social and functional expertise in order to increase their absorptive capacity.

Employee wellbeing

(Kwiotkowska and Gebczynska 2022) argue that job satisfaction is critical for the efficiency and productivity of employees and has therefore to be considered when implementing digital technologies. Job satisfaction in turn, is highly related to knowledge characteristics of jobs in their study in Polish SMEs. Knowledge characteristics are present in all configurations of factors leading to high job satisfaction. Knowledge characteristics are knowledge, skills and ability requirements required to carry out assigned work. They consist of first, of job complexity meaning

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[2] How is self-confidence a skill? Either it is self-confident appearance in the face of uncertainties, however this can have downsides if it does not go along with very high competence, or indeed pure luck. Or it is simply wishful thinking on part of the uninformed, that someone knows it all, has all the solutions, no uncertainties involved.

that complex tasks require the use of multiple skills, second, of information processing which is highly associated with Industry 4.0 technology implementation in an SME setting, third, of problem solving which is close to creativity as it involves the handling of non-routine problems by generating innovative ideas, fourth, of skills variety referring to individuals' broad skillset as necessary for job completion, and fifth, of specialisation, seen as the depth of knowledge and skills necessary for job completion in a given field.

(Lyngstadaas and Berg 2022) support the notion that digitalisation may be a source of well-being also for operators but there are within-differences between individuals. They show that employee wellbeing is not determined by the same combinations of causal conditions but vary among employees. Whereas there are employee configurations with a preference for autonomy, e.g., with a need for demonstrating competence. Others, however, feel a decrease of wellbeing at work, if they feel socially excluded and unable to make job-related decisions. "While digitalization provides new means of creating or maintaining autonomy, people also have a fundamental need to experience a sense of belonging and attachment to other people. This suggests that the social dimension is important to not lose sight of when implementing various digital initiatives." (p26) Similarly, as (Kaasinen et al. 2020) point out, on the level of employees and workers a shaping of technological change approach leaves room for the individuality of workers. Not all share the same preferences, not all workers prefer challenges, self-organisation and participation.

The increasing use of technologies like artificial intelligence has not only impacts on skills as prerequisites and consequences of such technological change, but it changes the nature of jobs and work as whole which in turn impacts employees and workers and via this route also needs new skills for coping or exploring opportunities. (Malik et al. 2022) shed light on how work changes through applications of artificial intelligence are perceived by employees with a university degree (bachelors, masters, graduates in general). They emphasise positive as well as negative effects. Positive effects are a perceived increase in work-related flexibility, autonomy, creativity and innovation, overall perceived enhancement in job performance. However, they also noted that technostress increases due to more pervasive use of AI resulting from work overload, job insecurity and complexity. Furthermore, the potential risks of data leaks and security breaches creates uncertainties that potentially frustrate and demotivate.

Conclusions

This paper presents only part of our research, which is the focus on academic literature - and in this current version the 23 firm-level papers on the topic of industrial transformation and the future of work and skills. In a separate and parallel stream we also search for trends in industrial transformation in the grey literature and in industrial reports.

As a general observation we find that academic papers around industrial transformation seem to be more diverse and less optimistic than the grey literature and reports on the developments and trends in industrial transformation.

Most notably, in these firm level papers on industrial transformation, the topic of environment and climate change (and related skills) is not present at all. As this aspect was prominent in our search criteria and also resulted in a number of papers, we expect that this will be more prominent on the level of sectors or occupations.

This is ongoing work which will be further elaborated.

Acknowledgement

This research was funded by the European Union under grant agreement No 101069651. The contents of this publication are however the sole responsibility of the BRIDGES 5.0 project consortium only and do not necessarily reflect those of the European Union or HADEA. Neither the European Union nor HADEA can be held responsible for them.

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Annex

Annex Table 1: Papers included in the present study

Paper	(Expected) development/trend	Relation to job and skills
(Gualtieri et al. 2020)	Purely manual workstations are increasingly transformed into assemblies involving collaborative robotics	Workplace changes, targeting physical ergonomics and economic productivity
(Cirillo et al. 2021)	I4.0 wave is fostering leanness of the production system	Distinction between the notions of autonomy and discretion for identifying the spheres of workers' intervention authority
(Konstantinidis et al. 2020)	With cyber-physical production systems, human intervention is anticipated to drop off, reduced to maintenance of the assets	Supportive systems can be used by unskilled operators
(Kaasinen et al. 2020)	A central element of Industry 4.0 is human-centricity, a development towards Operator 4.0. Smart factories of the future are suited for workers with different skills, capabilities and preferences.	In highly automated environments, the operators' work consists mainly of monitoring the machines and problem-solving. Workers' concerns related to work practices at the workplace.
(Pérez et al. 2020)	Introduction of collaborative robots in the industry substituting a skilled workforce	Implementation of multi-robot systems from different manufacturers requires other expertise. KPIs technical
(Ghobakhloo and Fathi 2020)	SMEs can often only digitise certain areas of their operations, significantly limited regarding their financial and human resources, limited access to market information	Myriad of technical challenges, significant investments for new hires and technological partnerships
(Gilch and Sieweke 2021)	There is a significant increase in demand for digital talent	Old recruiting practices tend to fail because digital talent has different characteristics from traditional workforce
(Simsek et al. 2022)	Product-oriented business models turn into platform-oriented business models, platform as a service (PaaS).	Operating cloud-based ecosystems requires different skills in terms of R&D and sales processes.
(Porfírio et al. 2024)	Digital transformation often results in a change of the core business	Of importance are level of employees' education, and level of communication and understanding of the processes
(Kirklikçi 2024)	Implementation of I4.0 technologies lead to introduction of new business models	Lack of skilled workers and lack of knowledge of technologies

(Ostmeier and Strobel 2022)	As digital maturity rises, proactive skill developments rises as well.	Perception as opportunity, threat or as controllable.
(Demirbag and Yildirim 2023)	With industrial transformation, the dimensions of engineering work change and the skills need from engineers have to change.	New skills expected from engineers
(Malik et al. 2022)	The increasing use of AI in industries generates intended (positive) as well as unintended (negative) consequences.	Qualitative hierarchy of prominent factors constituting unintended consequences, technostress as well as positive impact
(Cirillo et al. 2023)	Firms with skilled employees are more likely to invest in new digital technologies	It is difficult to disentangle the skills that drive innovation from those which are demanded as a result of change
(Herceg et al. 2020)	Implementation of I4.0 hampered because of lack of competences	Lack of competences in workers as well as managers
(Kwiotkowska and Gebczynska 2022)	Employee productivity is related to job satisfaction. Job satisfaction is influenced by digital transformation.	Knowledge characteristic of jobs, job complexity, information processing, problem solving, skill variety, specialization.
(Heim and Sardar-Drenda 2020)	Digitalization-induced organizational transformations are mostly topdown	Based on their prior experience employees would like to be involved
(Oesterle et al. 2022)	Organizations with specific IT skills and often face bottlenecks and revert to support from IT consultants.	For value co-creation, IT consultants as well as clients need skills.
(Stadnicka et al. 2022)	Industries are still in an early stage of their digitization , especially around AI, edge computing and IoT	Lack of competences around connectivity and interoperability between industrial systems and devices a significant issue
(Lyngstadaas and Berg 2022)	Wellbeing in operations workforce is increasingly affected by digitalisation.	Within-differences between employees in the operations workforce.
(Reljic et al. 2023)	Increased robot implementation has asymmetrically distributed effects on employment	Robot adoption is associated with higher demand for managers, statistically significant negative association with manual workers.