RESEARCH REPORT

Eurofound

Anticipating and managing the impact of change

Digitisation in the workplace

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Eurofound

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Abbreviations

AI	artificial intelligence
BIM	building information modelling
DEI	Digitising European Industry
E&M	Engineering & Maintenance
ERP	enterprise resource planning
ETUC	European Trade Union Confederation
EU-OSHA	European Agency for Safety and Health at Work
GDPR	General Data Protection Regulation
GPS	global positioning system
ICT	information and communications technologies
IDC	International Data Corporation
ILO	International Labour Organization
IoT	internet of things
IT	information technology
JRC	Joint Research Centre
LGS	light guidance system
MES	manufacturing execution system
PLC	programmable logic controller
R&D	research and development
RFID	radio-frequency identification
SCADA	supervisory control and data acquisition system
SMEs	small and medium-sized enterprises
TOS	terminal operating system
TRL	technology readiness level
TTI	Total Terminal International
VR/AR	virtual and augmented reality
WEF	World Economic Forum

See also Annex: Key definitions, concepts and terms used in the report

Executive summary

Introduction

Much of the research on the impact of digitalisation on work and employment has focused on quantifying the potential job losses resulting from increased automation and digitisation. This has influenced the policy debate on the implications of the digital revolution for the future of work. Taking a qualitative approach, this research explored different use cases revolving around three key technologies that are crucial to the digitisation of business and work processes, clearly impacting on aspects of work organisation and job quality: the internet of things (IoT), 3D printing, and virtual and augmented reality (VR/AR). In the case studies, the emphasis is not only on the impact of these technologies on work, but also on the motivations behind technology adoption, how digitisation evolves in the workplace and the extent of employee involvement.

Policy context

The national and European policy debate around digitalisation is often two-sided: digital technologies are viewed as key drivers of innovation, competitiveness and environmental sustainability but also as a potential source of disruption for businesses and workers.

The European Commission has launched several initiatives aimed at fostering digitalisation and the uptake of novel digital technologies. Since the adoption of the Digital Single Market Strategy in 2015, the European Commission has highlighted the role of digital technologies in economic and sustainable growth. The digital transformation of the EU economy and society features prominently in European Commission communications on shaping Europe's digital future and Europe's digital compass, which sets specific targets in areas such as skills and business use of digital technologies. The Commission has pinned its ambitions for the post-COVID-19 recovery on digital and green technologies, and the NextGenerationEU fund – part of the post-COVID-19 EU recovery package – will play an important role in boosting the quality of the digital infrastructure and supporting skills policies and the roll-out of new technologies, particularly in small and medium-sized enterprises (SMEs).

While the European Commission's action plan for the implementation of the European Pillar of Social Rights underlines the important role of digital technologies in Europe's economic and social recovery post pandemic, the declaration of the EU's Porto Social Summit in May 2021 reaffirmed the need for a digital, green and fair transition.

Key findings

- Although none of the three digitisation technologies can be considered mainstream, IoT is the most established, providing a range of applications, particularly in manufacturing. The research shows the complementarity and versatility of these technologies, which can be applied to different contexts and activities, depending on company specificities and needs.
- Elements underpinning the successful implementation of digitisation in the workplace include the adoption of an explicit digitisation strategy with a phased approach to implementation based on experimentation and piloting, early communication and employee involvement, the provision of upskilling, reskilling and training on an ongoing basis, and strategic partnerships and collaborations with other companies and relevant organisations. These elements were embedded to varying extents in the establishments investigated. The approaches used tended to be top-down, with limited opportunities for employees to voice concerns and provide feedback based on their experiences.
- From a work organisation perspective, the technologies intensified communication and collaboration between different departments and teams and had a positive impact on workflows, quality control and standards. The technologies also impacted on task definition and content: IoT cut down on manual and routine tasks and put greater emphasis on managerial and analytical tasks; 3D printing reduced physically demanding tasks and shifted the emphasis to pre-processing/pre-production tasks; and VR/AR enriched or simplified existing tasks.
- All digitisation technologies have extensive logging, reporting and monitoring capabilities. While these can be leveraged for the benefit of workers (for example, to reduce physical effort and hazardous situations), they can also pose challenges, particularly in relation to data protection and privacy. IoT raises most concerns, especially when the data collected are used when making important decisions about wages, contract renewals and even dismissals.

- The overall impact of the three technologies on job quality was positive. With regard to the physical environment, IoT technologies decreased physical risks but potentially increased exposure to ergonomic risks associated with more sedentary work. The physical risks associated with 3D printing were offset by a range of preventive measures in the establishments investigated. Although the adoption of the technologies did not alter working time arrangements, performance slowed down and work intensity increased, particularly in the initial phase of deployment. IoT adoption drove the upgrading of skills, particularly for managerial and engineering positions and less so for lower skilled and blue-collar workers. The use of 3D printing resulted in a skills shift, with greater emphasis on 3D design and planning skills and production workers being more reliant on 3D designers and planners.

Policy pointers

- While digitisation technologies provide opportunities to increase business competitiveness, businesses tend to take a more conservative stance as the benefits of the technologies are relatively unknown. Governments at all levels have an important role to play in encouraging dissemination of good practices grounded in valid business cases and supporting investments in technology uptake.
- Public financial support and innovation policies are important enablers of digitisation, by supporting companies' upskilling, reskilling and training efforts and favouring the development of strategic partnerships and innovation ecosystems or clusters. Public policies should also incentivise value and supply chain diversity and the involvement of start-ups and SMEs (both commercially oriented and social enterprises).
- The role of social dialogue in digitisation – particularly at establishment level – should be further strengthened to ensure that employees reap the benefits of technological change and job quality is not compromised. Employee involvement – whether through formal employee representation bodies or direct participation – results in greater acceptance of technological change and employee buy-in, leading ultimately to a more effective approach to digitisation.
- Support for workers through upskilling, reskilling and training on an ongoing basis is a necessity as technologies evolve quickly. An investment in lifelong learning will support the transition of workers to new technologies, especially low qualified workers, older workers and temporary workers, who are most at risk of being left behind. Close collaboration between training and education bodies and companies can boost the supply of interdisciplinary business and technical skills to drive the adoption of technology in a way that benefits both employees and employers.
- Digitisation poses new regulatory challenges that need to be addressed by policymakers in order to build greater trust in the technologies. The data collection and processing capabilities of digitisation technologies call for strong safeguards to preserve employees' data protection and privacy rights, provide adequate mechanisms to contest decisions and redress options, and enable greater enforcement of existing provisions. Regulatory and policy solutions are also required to improve harmonised and interoperability standards and encourage greater coordination of technical committee standardisation bodies.

Introduction

Background and objectives

Digital technologies are important drivers of economic growth, social progress and sustainable development – by triggering, for example, innovation in products, services and business models. This can result in greater efficiencies, effectiveness and productivity, potentially leading to positive effects on net aggregate employment (European Commission, 2019a). Technological advances can also drive environmentally friendly practices and solutions, as seen in the shift towards electric vehicles or in the many smart city initiatives led or sponsored by regional and local governments across different domains to enable more efficient and sustainable public service delivery.[1] From a workplace perspective, digital technologies can contribute to a safer work environment, the creation of more meaningful job profiles through the elimination of menial tasks and the freeing up of working time for creative or cognitive work. They can also open up learning opportunities in the workplace, augment human capacities and drive the reskilling and upskilling of workers.

The COVID-19 pandemic has spurred an unprecedented demand for digital solutions and accelerated the digital transformation of many organisations globally (McKinsey & Company, 2020). In the midst of the health crisis, the European Commission renewed its commitment to the European digital strategy in its communication *Shaping Europe's digital future* – and adopted a new communication – *2030 digital compass: The European way for the digital decade* – which presents a vision for the digital transformation of Europe by 2030 (European Commission, 2020a and 2021a). This document sets out specific priorities and targets, such as boosting the level of uptake of digital technologies in companies and small and medium-sized enterprises (SMEs), in particular. Another initiative to ensure that EU companies can benefit from digital innovation is Digitising European Industry (DEI),[2] launched by the Commission in 2016 as part of its then Digital Single Market Strategy. Support for the development of public–private partnerships and investments in innovation hubs are among the main pillars of this initiative.

In parallel, the European Commission (2021b) has launched an action plan for the implementation of the European Pillar of Social Rights. This addresses some dimensions of job quality and reiterates the important role of digital technologies in Europe's economic and social recovery post pandemic.

While the European Commission continues to emphasise the importance of digital technologies for Europe's economic and sustainable growth, including for achieving the ambitions of the European Green Deal (the 'twin' green and digital transition), there is also a recognition among policymakers that the use of advanced technologies in the workplace can pose new and, in many cases, still unknown challenges and risks for employers and workers alike. The Porto Social Summit in May 2021, hosted by the Portuguese Presidency of the Council of the European Union, reaffirmed the 20 principles of the European Pillar of Social Rights, with European Commission President Ursula von der Leyen stating that 'Europe's social targets must go hand in hand with its green and digital targets' (European Commission, 2021c).

The European Commission has also been at the forefront of technological regulation addressing concerns of a legal nature arising from the use of technologies, primarily in the realm of data protection and privacy, with the adoption of the European General Data Protection Regulation (Regulation (EU) 2016/679), known as the GDPR. This legislation is recognised worldwide as the global reference legislation on data protection. With artificial intelligence (AI) becoming a strategic priority for the EU, the Commission has built on its 2020 *White paper on artificial intelligence – A European approach to excellence and trust* and proposed stricter rules for the responsible and safe use of AI applications in line with European values (European Commission, 2020b). At the time of writing, these are being debated at EU level. A regulatory framework on AI is expected to create legal certainty for businesses favouring investments in this fast-developing technology.

Not unlike previous technological revolutions, the digital revolution will require many organisations to change their business models and shift their operating paradigms, moving away from labour-intensive to more technology-intensive types of work organisation. Eurofound's conceptual framework on the digital age postulates that the digital revolution will bring about profound changes to work and employment along three vectors of change – automation, digitisation and

1 For more on smart cities, see the European Commission's dedicated web page: https://ec.europa.eu/info/eu-regional-and-urban-development/topics/cities-and-urban-development/city-initiatives/smart-cities_en

2 For more information about the DEI initiative, see https://ec.europa.eu/digital-single-market/en/digitising-european-industry

coordination by platforms – each associated with a set of technologies (Eurofound, 2018a).

Digitalisation is a challenging area for policymakers as it is driven by technologies and applications – such as the internet of things (IoT), virtual and augmented reality (VR/AR) devices, 3D printing, AI, robotics and autonomous vehicles (including drones) – that are rapidly developing and span many industries and use cases. There is also a tension in European and national policymaking and policy discourse between, on the one hand, the requirement to be at the forefront of the digital transformation and facilitate innovation and, on the other hand, the need to identify and address the new challenges arising from an increasingly connected and technologically embedded work environment.

In recent years, European employer and trade union organisations have issued several statements on what they see as the key policy priorities with regard to digitalisation. In *Recommendations for a successful digital transformation in Europe*, European employer organisation BusinessEurope called for continued investment in employee training, reskilling and upskilling to keep pace with technological change and enhance workers' employability (BusinessEurope, 2015). On the trade union side, the European Trade Union Confederation (ETUC), in particular, has raised concerns about the potential negative impact of digitalisation on job quality and workers' rights (ETUC, 2016) and has been advocating for a regulatory approach to the use of privacy-invasive digital technologies in the workplace, including AI-based systems, wearables and other data-gathering technologies (ETUC, 2019; ETUI, 2020). In response to the declaration of the Porto Social Summit, ETUC commented that 'digital change needs far more than increased skills training' (ETUC, 2021); the creation of high-quality jobs and guarantees on decent and fair working conditions are among the priorities of a stronger social Europe.

The European social partners – ETUC and the three major EU-level employer organisations, BusinessEurope, SGI Europe[3] and SMEunited – have, however, taken a common stance on digitalisation, with the adoption in June 2020 of a European framework agreement on digitalisation. They agreed on a five-stage process starting with an exploration of the opportunities, challenges and risks of digitalisation, their impact in the workplace, and viable actions and solutions. The common objective is 'to ensure the best possible outcome for both employers and workers' (ETUC, BusinessEurope, CEEP and SMEUnited, 2020).

Much of the research on the transformative potential of the digital revolution has taken a quantitative approach in an attempt to estimate changes in employment levels due to digitalisation, particularly automation (for a review see Eurofound, 2017a; Arntz et al, 2019; Valenduc and Vendramin, 2019). The reliability of the available estimates on the probability of job replacement by machines is a matter of academic debate. Such estimates vary across studies, ranging from 47% of US workers according to the pioneering study by Frey and Osborne (2013) to only 9% of jobs in the study conducted by Arntz et al for the Organisation for Economic Co-operation and Development (OECD, 2016). The lower estimates presuppose that the task contents of occupations change continuously as new production technologies are introduced. Jobs can be considered bundles of tasks and the automation of individual tasks does not necessarily equate to the substitution by machines of an entire job or occupation. Even in situations where occupations are fully automated, workers perform new tasks, for example those required to operate the new technologies.

To date, there is scant evidence grounded in actual use cases that illustrates how technological change unfolds in the workplace and what it means for the nature of work. The overemphasis on the potential for job losses as a result of technological change has partly contributed to the policy and media debate focusing on fears about the disruptive impact of advanced digital technologies on work, neglecting the benefits and opportunities that these technologies can bring if properly and effectively implemented. A more qualitative approach with a focus on actual use cases is therefore needed to move away from technological determinism, which contributes to polarising the policy debate. The negative impact of the use of advanced digital technologies in the workplace is not deterministic; it emanates, at least partly, from deliberate choices by management in the process of change. The organisational culture, extent of social dialogue and skills capabilities also play an important role in the successful deployment of technologies, reducing and possibly neutralising any negative effects.

With a view to filling this 'qualitative' gap in policy research, the main objective of this report is to explore selected use cases regarding digitisation technologies (IoT, 3D printing and VR/AR), the approach taken in each establishment to accompany the technological change and the impacts on work organisation and job quality. This is complemented by expert views (collected using the Delphi method) that provide some context to the use cases, and reflections on workplace strategies and

3 SGI (Services of General Interest) Europe, formerly known as CEEP (European Centre of Employers and Enterprises providing Public Services and Services of General Interest), changed its name in December 2020.

areas of work organisation and job quality that warrant greater attention in the roll-out of the technologies. This research can feed into European policymaking on digitalisation and digitisation; in particular, it calls for greater support for businesses' innovation efforts, including for the upskilling, reskilling and training of workers to adapt to technological change, and points to the important role of social dialogue in the digitisation process in the workplace.

Although the widespread adoption of new digital technologies will not happen overnight, the digital transformation of the workplace has accelerated during the COVID-19 pandemic – particularly in the context of telework – and is already changing the working lives of many people. It is therefore more pressing to prepare for a sustainable digital transition and design robust and future-proof policies that promote innovation without compromising job quality.

Key definitions

This report builds on Eurofound's conceptual framework on the digital age (Eurofound, 2018a), in which the term 'digitalisation' is used in a broad way to refer to the transformation brought about by the widespread adoption of digital technologies. Within digitalisation, 'digitisation' is defined as:

> *the use of sensors and rendering devices to translate (parts of) the physical production process into digital information (and vice versa), and thus take advantage of the greatly enhanced possibilities of processing, storage and communication of digital information.*
>
> (Eurofound, 2018a, p. 15)

Digitisation is associated with a set of advanced digital technologies, including IoT, 3D printing and VR/AR (Table 1). These digital technologies are the focus of this report.

As the report explores the impact of digitisation technologies on the workplace, job quality and work organisation are important dimensions in the analysis. Job quality is a multidimensional concept, however, on which there is a lack of definitional consensus (Muñoz de Bustillo Llorente et al, 2011). Drawing on Eurofound's job quality framework (Eurofound, 2017b) – which is based on European Working Conditions Survey (EWCS) data – the report refers to job quality as a set of essential characteristics of jobs that meet workers' needs for good work, incorporating many elements that cover both extrinsic and intrinsic job features. These are grouped under seven indices: physical environment, work intensity, working time quality, social environment, skills and discretion, prospects and earnings. Work organisation is an equally broad concept and, to some extent, it overlaps with elements of job quality; it refers to:

> *… how work is planned, organised and managed – via production processes, job design, task allocation, rules, procedures, communication, responsibilities, management and supervisory styles, work scheduling, work pace, career development, decision-making processes, interpersonal and interdepartmental relationships.*
>
> (Eurofound, 2017c)

Methodology

This report presents the findings from two main research strands, which used qualitative research methods: illustrative case studies of establishments and expert views collected using an online Delphi survey. The expert views helped to contextualise and enrich the accounts obtained from the case studies, and guided the analysis of the establishment practices, highlighting factors that may have facilitated or hindered the digitisation process at workplace level.

Case studies

The main research strand consisted of 12 case studies of establishments located in the EU. According to Choudrie and Dwivedi (2005), a case study is a widely used and accepted method for examining issues arising from technology adoption. This qualitative research method

Table 1: Definitions of digitisation technologies

Internet of things (IoT)	Networked sensors attached to outputs, inputs, components, materials or tools used in production. This also encompasses electronic monitoring systems and wearable computing devices used for different purposes including monitoring work processes and employee performance and ultimately guiding management decision-making.
3D printing	Using machines that can create physical objects from three-dimensional digital models, generally by laying down successive layers of material.
Virtual and augmented reality (VR/AR)	VR is a computer-generated scenario that simulates a real-world experience, while AR combines real-world experiences with computer-generated content.

Source: *Eurofound (2018a, 2020a)*

was used in this research in order to examine the impacts of technology adoption and implementation in real-life settings, with the important caveat that the impacts partly depend on the specific use cases and a variety of contextual factors.

As the workplace was the focus of this research, the unit of analysis was the establishment, defined as the local site at which employees work. One of the criteria used in selecting the cases was a significant level of technology uptake in each establishment, in order to analyse the effects of the technology adoption and its use in the workplace. This excluded cases where the technology was in a research and development (R&D) or piloting phase at the time of the research and not fully applied in the production process and/or service delivery. For each case study, primary data were collected between May 2020 and February 2021 through intensive one-to-one semi-structured interviews with key stakeholders in the selected establishments. These included a human resources manager, an innovation manager, two employees in occupations most affected by the technologies, and a representative of a trade union or works council (in establishments with formal employee representation). This multistakeholder approach was used to provide a balanced understanding of the implementation of the technology and its impact in the workplace. Findings were shared with all respondents to check for validation and obtain approval. One of the selected establishments was used as a pilot, with a view to refining the interview guide and approach to the analysis of the case studies. Secondary data sources included relevant company documents and websites.

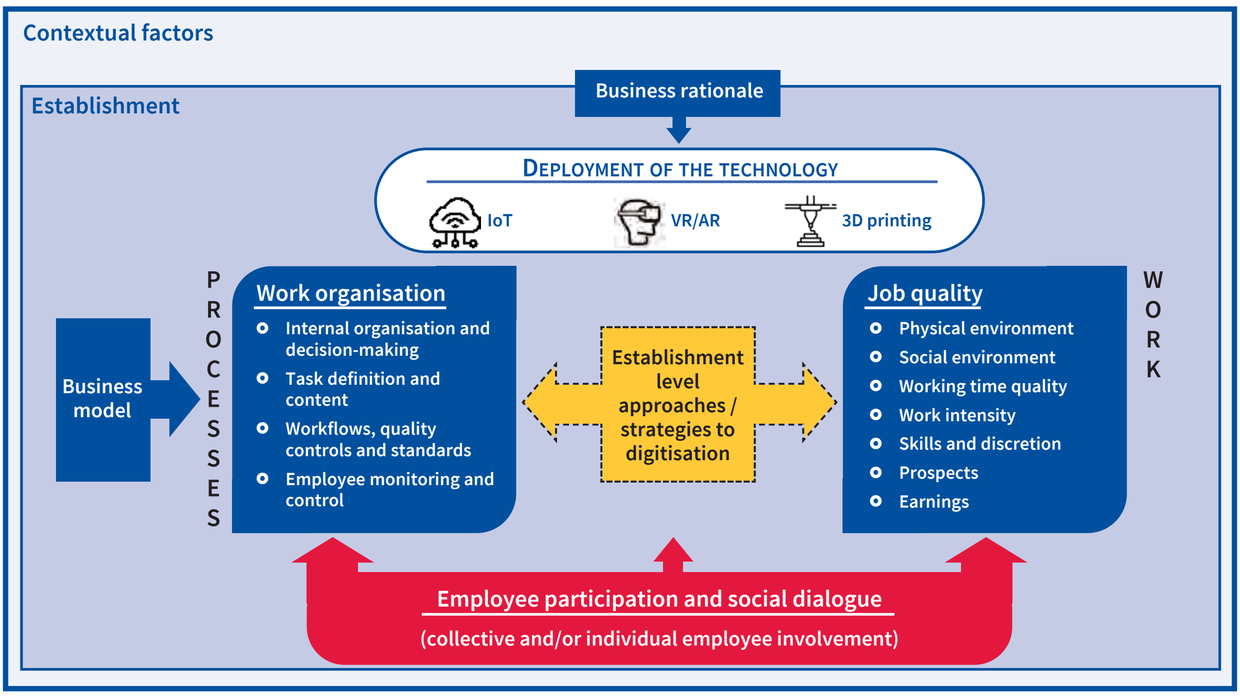
At an early stage of the research, an analytical model was developed to assist in conducting the interviews and reporting the findings (Figure 1). This model depicts the two core dimensions impacted by the introduction and implementation of the technologies in the workplace: work organisation and job quality. The two areas are not totally separate dimensions but intertwined; these links and overlaps were considered in the investigation of the cases.

Employee participation and social dialogue is a cross-cutting dimension as it can both influence and be influenced by the way a technology is deployed in the workplace. The model assumes that the technology – depending on its level of embeddedness in work processes – changes the business model, which in turn affects the work organisation and elements of job quality. Both contextual factors and establishment or company specificities may drive the digitisation efforts.

Two of the 12 case studies listed in Table 2 – Total Terminal International (TTI) Algeciras and Airbus – were provided by the European Commission's Joint Research Centre (JRC) and conducted using the same methodological approach developed by Eurofound and followed for the other cases investigated in this research.

Because of the explorative nature of this research, the 12 case studies comprise a mix of establishments of different sizes and operating in different sectors (although an affiliation to manufacturing prevails) and employing different applications of the technologies in focus. The level of technology maturity and applicability

Figure 1: Analytical model for digital technologies



Source: *Prepared by Eurofound and Technopolis for this project*

Table 2: Overview of the digitisation case studies

Establishment (country)	Sector (NACE)	Establishment size (no. of employees)	Property, ownership structure	Formal employee representation	Technology in focus (and TRL)
Airbus (Getafe, Spain)	Manufacture of air and spacecraft and related machinery (C30.30)	Large (6,030)	Wholly owned subsidiary of traded stock company (Airbus Group)	Works council and trade union	3D printing (TRL 6–7)
Bächer Bergmann (Cologne, Germany)	Manufacture of other products of wood (C16.29)	Small (20)	Limited company	None	3D printing and AR (TRL 8)
BAM Infra (Driebergen-Zeist, Netherlands)	Construction of buildings (F41) and Civil engineering (F42)	Large (3,500 total; establishment size depends on location); Driebergen-Zeist site employed 120–150 people	Wholly owned subsidiary of traded stock company	Works council and trade union	3D printing (TRL 9)
Consorcio de Aguas Bilbao Bizkaia (CABB) (Bilbao, Spain)	Water collection, treatment and supply (E36.00)	160 (at the headquarters; 220 in the rest of the metropolitan area)	Publicly owned company	Works council and trade union	IoT (TRL 9), VR and AR (TRL 6–7)
Bosch Rexroth (Lohr am Main, Germany)	Manufacture of machinery and equipment (C28)	Large (5,700, of whom 260 were apprentices)	Traded stock company	Works council and trade union	IoT (TRL 8), 3D printing and VR (TRL 7)
Centro Seia (Ragusa, Italy)	Growing of non-perennial crops (A1.10)	Large (900, of whom 750 were seasonal workers)	Limited company	Trade union	IoT (TRL 9)
Est-Agar (Saaremaa, Estonia)	Marine aquaculture (A3.21)	Small (25)	Limited company	None	IoT (TRL 9)
KLM Engineering & Maintenance (E&M) (Schiphol, Netherlands)	Repair and maintenance of aircraft and spacecraft (C33.16)	Large (approx. 5,000)	Traded stock company	Works councils and trade unions	3D printing (TRL 7–9, depending on the department)
Lohja/Helsinki University Hospital (Lohja, Finland)	Hospital activities (Q86.1)	Large (730 at Lohja Hospital, 26 on the neurological rehabilitation ward)	Public hospital	Trade union	VR (TRL 9)
Mariasteen (Gits, Belgium)	Manufacture of other fabricated metal products (C25.9)	Large (856)	Limited company	Works council and trade union	AR (TRL 9)
Sanmina (Örnsköldsvik, Sweden)	Manufacture of computer, electronic and optical products (C26), Manufacture of electrical equipment (C27), Manufacture of medical and dental instruments and supplies (C32.5)	Large (275)	Traded stock company	Works council	IoT (TRL 8)
TTI Algeciras (Cadiz, Spain)	Other transportation support activities (H52.29)	Medium (116)	Wholly owned subsidiary of traded stock company (HMM shipping company)	Works council and trade union	IoT (8–9)

Notes: *Technology readiness level (TRL) is described using a scale that assesses the level of maturity and applicability of a technology. The scale ranges from level 1, where a technology is in its preliminary phase and only its basic principles have been observed and reported, to level 9, where the technology is fully implemented and proven in a production environment. NACE: Nomenclature of Economic Activities.*
Source: *Eurofound, 2020–2021; European Commission JRC, 2021*

(technology readiness level, TRL) and embeddedness in work processes also vary across the case studies. The case studies investigated serve as illustrations of both the approaches taken to technology adoption and implementation and of the impacts in the workplace, but they are by no means representative of all establishments, including those of the same size or operating in the same sector.

Delphi expert survey

To supplement the case studies, this report also draws on expert views on the uptake of digitisation technologies across sectors, common and emerging use cases and the potential impacts of these technologies on work organisation and job quality, as well as suitable approaches to their implementation in the workplace.

These views were collected using a Delphi survey design, involving two survey rounds.[4] The Delphi method is based on an iteration process whereby opinions provided by survey participants in a previous round are fed back to them for evaluation in the next survey round, with a view to reaching consensus. The Delphi survey was conducted online using the EUSurvey platform.

A panel of 18 technology experts and policy stakeholders – who were selected on the basis of their area of expertise – participated in the two survey rounds. The first survey round took place between November and December 2020 and the second round was launched in February 2021 and ended in early March 2021. While the first Delphi questionnaire was largely open-ended, the second questionnaire mainly had a closed format, asking participants to rate (using a Likert-type scale) their agreement with a set of statements. As a result of the second survey round, areas of disagreement and agreement were identified, and survey participants were asked to state their rationale concerning their ratings and provide additional commentaries.

Report structure

The remainder of this report consists of three main chapters.

Chapter 1 outlines the expert views on the most relevant sectors in terms of the current uptake of each digitisation technology, including the most common and emerging use cases. These are also illustrated by means of the case studies investigated in this research and the examples identified and reported by experts in the Delphi survey. Expert views and illustrations from the case studies are supplemented by a review of secondary sources.

Chapter 2 begins with a discussion of the motivations and factors influencing technology adoption. It then discusses the expert views on the most appropriate strategies and approaches for the adoption and implementation of digitisation technologies in the workplace, including actual practices illustrated by the case studies. This chapter also explores the contribution of social dialogue to digital transformation in the workplace and the extent of employee involvement in the process of technological change in each of the investigated case studies.

Chapter 3 reports on aspects of work organisation and job quality that, according to expert views, are most likely to be impacted by the use of digitisation technologies in the workplace. This is supplemented by on-the-ground illustrations of impacts from the case studies.

The final chapter presents conclusions and policy pointers. The policy pointers specifically related to support for greater uptake of the technologies were largely derived from the feedback provided by the experts in the Delphi survey.

4 The Delphi survey questionnaires are available on request via the email address information@eurofound.europa.eu

1 Uptake of digitisation technologies in the EU

Prevalence of digitisation technologies across sectors

The digital transformation of the manufacturing sector has received a great deal of attention in the policy debate at national and European levels. As part of an EU-funded pilot project on the future of manufacturing,[5] Eurofound (2018b) examined the application of selected game-changing technologies – including IoT and 3D printing – in manufacturing industries. According to this research, IoT has reached operational maturity in sectors that are highly capitalised and already technology rich, such as the oil and gas and automotive sectors, enabling granular monitoring of production processes and predictive maintenance. For Espinoza et al (2020), however, IoT is still at an early stage of development, with many challenges to be addressed in order to unlock its full potential: for example, issues around privacy and data security, the need for greater investments in the infrastructure required to develop the technology further, the need for cooperation among different stakeholders to promote relevant policies and regulations, and issues around the development of IoT skills.

The level of maturity or TRL of 3D printing depends on the materials used, with 3D printing using plastic being applied at more advanced levels (TRL 7–9), particularly for prototyping and visual design, as in the automotive and aerospace industries. 3D printing using metals and ceramics is at low to intermediate levels of maturity (TRL 3–7) because more fine-tuning is necessary to meet quality standards for these materials. Although metal 3D printing is used in the manufacturing of aircraft parts and orthopaedic and prosthetic devices, it is only just entering the mainstream (MIT News, 2019).

The evolution and uptake of 3D printing depends partly on innovations in materials engineering, which open up new avenues for the use of novel materials in 3D printing. In addition, metal powders used for metal 3D printing are still expensive; as noted by one of the experts consulted in this study, as long as the metal powder market remains an oligopoly, the technology will continue to be unaffordable for many businesses.

There is also scope for experimenting with 3D printing powders derived from inert materials (for example, inert stainless steel), which could provide a solution to certain environmental problems, including waste management.

European data suggest that the level of digitisation is strongly associated with the sector of activity (Figure 2). According to Eurostat data from the ICT usage in enterprises survey (2020), IoT is used to a greater extent (18%) than 3D printing (5%) by enterprises in the EU27 employing at least 10 people. While the use of 3D printing by such enterprises is more prevalent in manufacturing (12%), the incidence of IoT use is higher in the utilities (38%) and transport and storage (27%) sectors. Particularly in these sectors, IoT provides a range of use cases that can enhance the efficiency and performance of public service delivery, for example in the context of smart city initiatives.

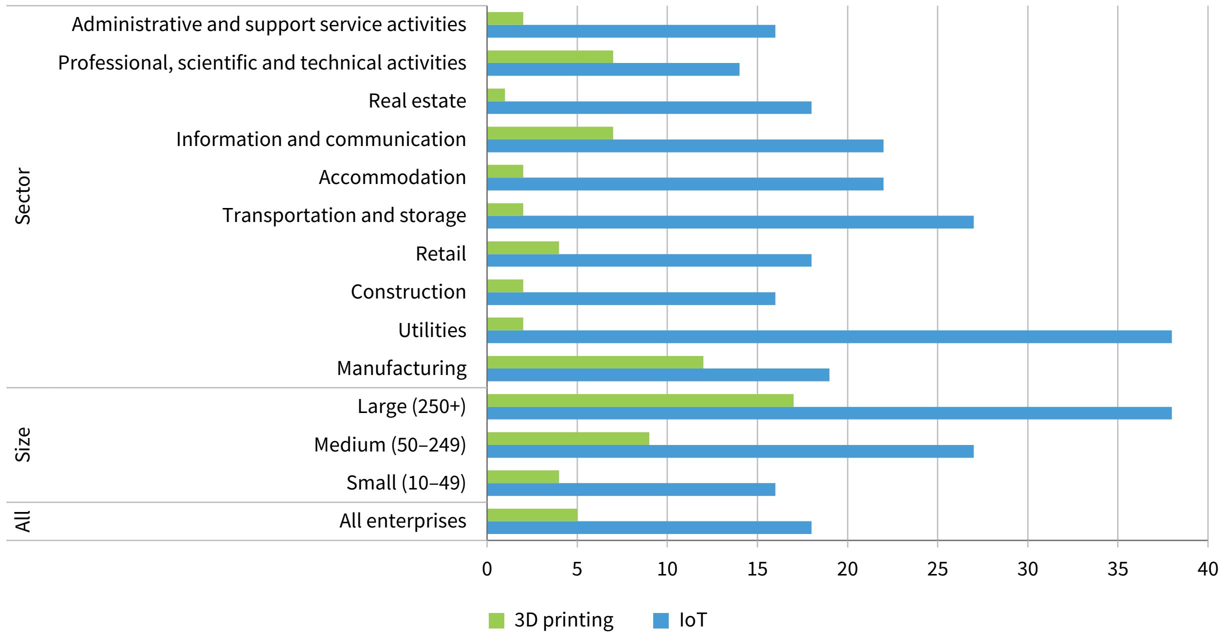
In terms of enterprise size, both technologies are more likely to be adopted by large enterprises employing 250 or more people than by smaller enterprises (Figure 2). SMEs struggle to source the investment needed to acquire new digital technologies, which require significant upfront investment. According to the experts in the Delphi survey, the low level of adoption of IoT technologies in SMEs (supplying larger companies) is a significant barrier to the more widespread use of the technology, ultimately impeding horizontal integration in value chains.

The EU average data also conceal large variations in the uptake of the two technologies (IoT and 3D printing) between EU Member States, with percentages ranging from 44% (Czechia) to 7% (Romania) of enterprises with 10 employees or more using IoT and from 9% (Denmark) to 2% (Romania) of such enterprises using 3D printing.

Insights into the uptake of digitisation technologies can also be gleaned from national surveys. One of these data sources is the IW Personnel Panel (IW-Personalpanel) conducted by the German Economic Institute among human resource and general managers in companies of all sizes (N = 1,105). According to the most recent data, IoT was used by 10% of the companies surveyed in 2020, and the use of 3D printing and VR/AR technologies was reported by 9% and 8% of companies, respectively.

5 The future of manufacturing in Europe (FOME) pilot project was proposed by the European Parliament and delegated to Eurofound by the European Commission (Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs). The project ran from 2015 to 2019 and all its publications are available at https://www.eurofound.europa.eu/observatories/emcc/fome/projects

Figure 2: Adoption by enterprises of IoT and 3D printing by size and sector, EU27, 2020 (%)



Source: *ICT usage in enterprises survey (isoc_e), Eurostat, 2020*

More limited data are available on the adoption of VR/AR across sectors. Drawing on a 2018 global survey of large multinational companies and other companies of significance because of their employee numbers or revenue size, the World Economic Forum (WEF) reported that 58% of the companies surveyed were likely to adopt VR/AR technologies between 2018 and 2022 (WEF, 2018). The sectors reporting a higher likelihood of adoption of these technologies were the ICT (72%), automotive, aerospace, supply chain and transport (71%) and aviation, travel and tourism (68%) sectors.[6]

Eurofound research on game-changing technologies in the services sector found that VR/AR technologies show cross-sector adoption, with VR simulation being used for training purposes particularly in the police and military services (Eurofound, 2020a). The advisory consulting firm International Data Corporation (IDC) has predicted that VR use for training will accelerate and become the largest use case in terms of VR business-to-business spending by 2023 (Business Wire, 2019). From a German perspective, Lester and Hofmann (2020) argue that, in spite of the increasing uptake of both VR and AR in vocational education and training over the last decade, the technologies are not yet part of mainstream vocational pedagogy. A German study mapping the current use of VR or AR for training across 42 providers and companies (against five technology maturity levels) found that in none of these organisations were the technologies fully integrated into the organisations' systems and processes (Osmers et al, 2019). Despite current misgivings regarding the maturity of the technologies, VR/AR software developers believe that the technology is mature enough to be applied to new areas beyond training and on-the-job learning (Eurofound, 2020b), for example guiding work through line-of-sight instructions or in project design, engineering and prototyping.

Based on the top technology trends released by research and advisory firm Gartner, both VR and AR have passed the experimental stage. They were reassigned in 2019 to a broader category under the label of 'augmented intelligence' in Gartner's hype cycle (Forbes, 2019; AR Post, 2020), a graphic representation used to signal the hypes around emerging technologies and track them up to the point where they reach maturity and can be considered commercially viable.[7]

Drawing on expert views from the Delphi survey, none of the three digitisation technologies can be considered mainstream. Based on these views, Eurofound identified common and emerging use cases for each of the three digitisation technologies (see Table 3 on p. 22).

6 The WEF survey used the Occupational Information Network (O*NET) classification of sectors.

7 More information about the hype cycles methodology is available at https://www.gartner.com/en/research/methodologies/gartner-hype-cycle

The three technologies can be applied in different ways in many sectors owing to their versatility.

Their uptake, however, varies both between and within sectors, and also from business-to-business to business-to-consumer contexts. Some of the use cases identified by the experts consulted are exemplified by the case studies investigated in this research (see boxes below).

Although the use cases are discussed in this report by type of technology (IoT, 3D printing and VR/AR), in practice strong synergies exist between these technologies as they share some key underlying principles, which makes them easy to combine. Previous Eurofound research on the future of manufacturing (Eurofound, 2018b) draws attention to the synergetic nature of these technologies. Both IoT and 3D printing are essential elements of the digitisation of production processes and are at the core of the cyber-physical model of manufacturing. IoT is used to collect, encode and process digital information on the physical process, while 3D printing is used to transform digital models into physical products.

Common and emerging use cases

Internet of things

IoT enables digital devices equipped with sensors to be connected to each other through the internet and record, transmit and process a vast number of data in real time. Based on expert views collected through the Delphi survey, of the three digitisation technologies, IoT is the most established across a range of sectors, with the number of business applications expected to increase over the next 5–10 years. As evidenced by the available IoT surveys, there is a large spectrum of current and potential IoT applications (Gil et al, 2016).

IoT-enabled applications are increasingly common in industrial manufacturing, ranging from the monitoring of production processes and conditions of machines (including predictive maintenance) to shop floor and supply chain management, and inventory management and control. IoT also allows for interlinked and automated process optimisation in factories, reducing the need for human decision-making and creating ‘smart factories’ characterised by a highly digitalised and connected manufacturing environment. IoT sensors can connect all parts of the production process, enabling integration across the entire manufacturing supply chain.

Sanmina (Sweden): Use of IoT for global supply chain visibility and real-time production control and monitoring

The Sanmina plant in Örnsköldsvik, which belongs to American electronics manufacturing services provider Sanmina Corporation, offers product design, test development, manufacturing, product delivery and repair services – with a focus on medical devices. The company has a long tradition in the digitisation of production and business processes. In the early 2000s, all Sanmina’s plants adopted a digital shop floor data collection technology to better monitor production processes. At this time, it was the first large IoT system to connect several machines in production. Since then, the digital data collection and management platform has been further optimised and, in 2015, a more unified and integrated IoT system, called 42Q, was developed in-house and deployed across all of Sanmina’s factories. 42Q is a cloud manufacturing execution system that connects 26,000 pieces of manufacturing equipment, equivalent to 90% of the production-related technologies at Sanmina. 42Q has the same system set-up across all of Sanmina’s plants, including technology settings, logistical indexes and a protocol that allows each machine to be controlled through the platform. The technology enables real-time manufacturing and supply chain visibility in all of Sanmina’s factories throughout the world. It facilitates data collection throughout the entire supply chain in an organised manner by connecting resource and product management systems, data storage, testing of products, reporting, execution, and monitoring of processes and employees’ activities. In addition, Sanmina has developed complementary technologies enabling the statistical analysis of the data generated. Such analyses serve to gain insights into production and business processes in the Örnsköldsvik plant and at Sanmina globally.

Source: *Eurofound, 2020–2021*

According to the experts consulted, the use of IoT in industrial manufacturing will intensify over the next 5–10 years, going beyond machine and plant management towards factory network management (business ecosystem level).

Bosch Rexroth (Germany): Use of IoT to monitor production processes and enable predictive maintenance

At its establishment in Lohr am Main, Bosch Rexroth develops, produces and sells components and systems for electric drive and control systems for machines. The company has been using a range of IoT technologies since 2010 to monitor production processes and the conditions of the machinery. This enables operators to be alerted about machine failures, such as leaks or decreases in production speed. IoT technologies are deployed throughout the establishment and take many forms. Examples of the technology embeddedness include radio-frequency identification (RFID) tags, IoT gateways and a manufacturing execution system (MES) that monitors machine parameters for predictive maintenance and production efficiency by connecting data from different machines in the production line. Every machine is connected to the data gathering system; employees are able to unlock only those machines they have been trained on. The list of machinery to which employees have access to is stored on an RFID tag that they wear (serving as an access key).

Source: *Eurofound, 2020–2021*

The utilities sector is one of the sectors at the forefront of IoT use, with the most common use case being smart metering for monitoring energy, gas and water production and consumption. According to the IDC (2019), the utilities sector is ranked in the top IoT segments in terms of revenue and spending. Global Market Insights (2017) also anticipates that the IoT utilities market will generate USD 15 billion (€12.5 billion) in revenue by 2024.

CABB (Spain): Smart grid technologies for water management and optimisation of the water supply and treatment network

CABB is a publicly owned company operating the water supply and treatment network covering almost the entire province of Bizkaia (85 municipalities), one of the three provinces of the Basque Country. In 2015, CABB introduced and fully deployed IoT-based smart grid technologies for real-time monitoring of the water supply and treatment network. To this effect, a range of sensors – online monitor sensors, smart flow and pressure meters, water quality sensors, smart water consumption meters and leakage monitoring sensors and intelligent predictive alarms – were installed throughout the water utility infrastructure; these transmit data to a central supervisory control and data acquisition system (SCADA)[8] with data analytics capabilities. This system is used for remote and real-time monitoring of water quality, water flow and pressure, the performance of the machines and equipment, and advanced industrial discharge control. All data are displayed on computer monitors and on dashboards that are accessible from a central monitoring station. The IoT-based monitoring system enables the optimal functioning of the water supply and treatment network and predictive maintenance. IoT technologies are also leveraged to improve environmental protection. For example, IoT digital sensors and digital preventive alarms used for real-time control and monitoring of critical pollution parameters in companies and industries ensure the optimal operation of wastewater treatment plants.

Source: *Eurofound, 2020–2021*

Agriculture is another sector in which IoT applications are gaining traction. They are used for monitoring crop quality yields, ensuring product traceability and quality control, and planning distribution. The experts consulted also anticipate the expansion of the use of IoT in this sector over the next 5–10 years, with IoT applications enabling ‘smart farming’ and ‘precision farming’.

8 SCADA is a system of software and hardware enabling the remote control and monitoring of industrial processes. It collects and processes real-time data, provides feedback to field devices, and controls processes by interacting with smart devices locally or at remote locations and recording events into a log file.

Est-Agar (Estonia): Use of IoT for real-time monitoring of production processes and employees

Located in Kärla (Saaremaa island), Est-Agar is an Estonian producer of a gelling agent (an ingredient providing texture to foods and beverages). In 2018, Est-Agar introduced two IoT-based systems for production monitoring and employee monitoring. Global Reader is a production monitoring system that collects real-time data from IoT sensors installed on production machines and stores them in a central location on the cloud. This system is used for monitoring the water temperature, moisture levels and pressure in production machines and their performance. Global Reader also detects technical errors and monitors the quality of the production processes. Begin is a separate IoT-based employee monitoring system. It monitors employees' working time when they log in and out of the system, thereby assisting accountants in calculating salaries based on hours worked. The system is connected to a biometric time registration terminal, which uses employees' fingerprints to register when they enter and leave work. Data collected from both systems are displayed on computer monitors during production and on dashboards accessible to management. The data collected are analysed and used by management to make more informed and strategic decisions for optimising production processes and reducing costs.

Source: *Eurofound, 2020–2021*

Centro Seia (Italy): Use of IoT for traceability of plant quality and updating production planning

With the introduction of a new certified grafting technique (called Elite) involving a single-use blade system to guarantee a sterile cut on plants, Centro Seia has deployed an IoT-based digital tracking system at its Ragusa plant nursery in order to certify plant quality (that is, sterility). All assembly lines are linked to sensors and computers, which are connected to the central IoT-based monitoring system. Once an operative has grafted all the plants in a batch, the tray is moved on the assembly line to the next station. Each step is scanned by sensors. The system records data on the quality of each batch, the time spent on it and the speed of handling of each batch by the operatives, as well as the amount of wastage, ensuring traceability of each grafted plant. If infections occur, they can be traced back to specific batches. As this is linked to the work of every single operative involved, their work is tracked indirectly during every step of the grafting process. The real-time data generated from the IoT monitoring system are visible on supervisors' dashboards and are also displayed on dashboards on individual workstations for operatives to see their own progress compared with that of their peers. The data collected are also used to automatically update production planning on a daily basis.

Source: *Eurofound, 2020–2021*

IoT also provides a range of use cases in transport and storage. In this sector, IoT is more commonly used for fleet or asset monitoring and optimisation, and predictive maintenance. In the area of urban transport, IoT technologies are being piloted for public transport optimisation as part of smart city initiatives. An example of such an initiative is the IoT-based urban transport system implemented by the city of Linz in Austria (in partnership with Cisco), connecting all light rail trams, buses, ticketing machines and stations (Forbes, 2017). The IoT system captures a large number of real-time data from all connected trams and buses. These are used to monitor the different health parameters of the vehicles and infrastructure, detect potential malfunctions and initiate predictive maintenance procedures. Real-time data on the braking and acceleration behaviour of each driver are also collected and analytics used to see how they might optimise their driving. These data are then used to tailor training for drivers to teach them how to brake and accelerate more efficiently.

With regard to service activities in water transport, a high-profile use case is exemplified by the Port of Rotterdam, which has deployed an extensive network of sensors to provide real-time water and weather data for the planning and management of shipping (Port of Rotterdam, 2019a). The port is committed to digitisation and becoming the first and smartest digital port by 2030 (Port of Rotterdam, 2019b). Among the most recent innovations being piloted at the port is Container 42, which is equipped with sensors and communication technology.[9] It will travel around the

9 For more information see https://weare42.io/about/

world for two years to collect geophysical data and add to the pool of data, enabling more accurate weather predictions and making shipping operations more efficient and effective.

In 2018, the Port of Antwerp also started piloting smart technologies, including IoT sensors for the predictive maintenance and optimisation of shipping operations (Port of Antwerp, 2018). On a smaller scale, Tallin yacht harbour (Haven Kakumäe marina) also uses sensors to optimise the port's operations (e-estonia, 2018).

According to the experts consulted, the transport sector is a sector where IoT holds promise for the future, enabling connected multimodal transport management and the assessment of infrastructure capacity for more efficient management of flows of goods within large-scale networked systems.

IoT is not only used to monitor assets, production or machineries. Wearables endowed with IoT sensors used in manufacturing or healthcare can be used to detect hazardous conditions and trigger automated alert responses. Healthcare applications are typically centred on patient monitoring and e-health. One example of a use case in the healthcare sector is the IoT-based home care system deployed in 2016 by the Swedish municipality of Växjö for older people who are eligible for municipal home care services (Perez et al, 2016). This initiative is part of the Swedish national e-health strategy aimed at reducing the cost of care for older people while at the same time increasing the efficiency of home care services.

In work settings, the use of IoT can also be extended to monitoring employees' activities and behaviours as a way to increase productivity, potentially opening the door to intrusive employee performance monitoring and surveillance practices, including tracking the length of rest breaks and out-of-work movements (Eurofound, 2020c).

3D printing

3D printing can be applied for different purposes depending on the industry concerned. According to the experts consulted in the Delphi survey, however, the technology has not yet reached full operational maturity. Within manufacturing, 3D printing is a complement to conventional production methods rather than a substitute. Among the most common use cases is rapid prototyping in the automotive and aerospace industry, enabling rapid iteration and testing during the product development process. 3D printing is also used for prototyping in sectors such as the design and architecture sector, enabling professionals to quickly test concepts and iterations. According to the 2020 Sculpteo global survey of 3D printing professionals (N = 1,600), design, testing, and building prototypes remain the key areas for 3D printing users. The prototyping and small series stages are where the benefits of 3D printing are most apparent (Sculpteo, 2020).

Furthermore, 3D printing enables complex and high-performance products to be produced (for example, parts with high strength-to-weight ratios). These are pieces that are difficult to manufacture normally and are in demand in the automotive, aerospace and medical industries. However, widespread application of the technology even in these

TTI Algeciras (Spain): Use of IoT for container traceability and remote control of all yard operations

Total Terminal International (TTI) Algeciras operates in the Port of Algeciras Bay in the Strait of Gibraltar – a geostrategic node for international trade and logistics. TTI Algeciras is the first semi-automatic terminal in southern Europe and the Mediterranean. All operations at the terminal are centrally controlled via screens by a tailor-made terminal operating system (TOS) – an advanced computer system managed remotely by the operations and systems department at the terminal's headquarters. The TOS controls the terminal's logistics (vessel planning, container inventory maintenance and gate operations) and managerial functions (billing, reporting, and communication among the terminal carriers and transport companies, etc.). The TOS generates automated orders by processing the information received through IoT sensors and connects with the machines through a virtual private network system. The tracking and management of containers and equipment is achieved through the full integration and communication of different systems: intelligent active RFID tags and other sensors placed on cranes and shuttle carriers, combined with an advanced real-time locating system, differential ground positioning system, optical character recognition and a licence plate recognition system, determining the exact location of shuttle vehicles under the cranes. Only the assigned carrier is allowed to pick up a particular container. This solution ensures total container traceability, increases crane productivity and creates a safer work environment. In addition, the TOS can process and analyse data at high speed and facilitate predictive maintenance, by warning engineers about any deficiencies that may result in breakdowns or malfunctions or require the replacement of parts.

Source: *TTI Algeciras case study provided by the European Commission JRC, 2021*

Airbus (Spain): 3D printing for manufacturing of aircraft components and tooling for aircraft and ground installations

French aerospace company Airbus has been operating in Spain since 2000, following a merger with the Spanish company Construcciones Aeronáuticas SA. Airbus Getafe is one of the seven manufacturing sites located in Spain and is responsible for designing, engineering and manufacturing components for all Airbus aircraft. At the Getafe site, the company produces horizontal stabilisers for the entire range of Airbus commercial aircraft, rear fuselages for Airbus helicopters, and military transport aircraft. The establishment started to use 3D printing within the production process in 2018; the technology is mainly applied for the manufacture of real components and tooling for aircraft and ground installations (using both plastic and metallic material).[10] The use of the technology in Airbus is, however, limited and subject to a highly regulated environment (to ensure safety of design, manufacture, use and maintenance). The technology was primarily introduced to replace traditional supply chain logistics, with 3D printing manufacturing used for low-volume and highly complex and high performance parts. The benefit is the fast-tracking of the production of relatively simple parts that previously would take a long time to arrive or require a minimum order quantity, therefore slowing down the whole operation.

Source: *Airbus case study provided by the European Commission JRC, 2021*

sectors has been limited to date owing to the complex operational and performance requirements, high costs per part and stringent regulatory compliance requirements.

Greater uptake of 3D printing in the next 5–10 years is expected in the manufacturing of machinery and equipment and for maintenance and repair, as parts can be individually printed in a faster and more accessible way.

KLM E&M (the Netherlands): 3D printing for the production of maintenance tooling

The E&M division of the Dutch airline KLM at Schiphol (Amsterdam) introduced 3D printing in 2018 to develop new tooling for aeroplane maintenance.[11] When an employee has a new idea to improve the tools used, a prototype is made and tested in maintenance operations. If the prototype proves to be of added value for maintenance activities, it becomes part of the official maintenance tools.

In addition, 3D printing is part of a recycling loop, whereby KLM E&M recycles waste to create tools for engineering and maintenance. The filament produced from empty water bottles collected from aeroplanes is used as a base material for 3D printing. A large share (albeit not all) of the 3D printed tools can be made from the recycled material. This fits with the company’s goal of reducing the volume of its waste by 50% by 2030 (in comparison to levels in 2011).

During the COVID-19 pandemic, 3D printing was used to print tools, ranging from special levers for taps to new doorknobs, to help limit the spread of COVID-19 in the workplace.

Source: *Eurofound, 2020–2021*

10 The manufacturing technology used for metallic materials is powder bed fusion, which is based on the fusion of metallic powder using a laser or an electron beam as a source of energy. Plastic materials are developed using two different techniques: filament layer manufacturing and selective laser sintering, using polyetherimide and polyamide, respectively.

11 KLM E&M is not entitled to fabricate aeroplane parts because of legal requirements and commercial/intellectual property restrictions.

Bosch Rexroth (Germany): Polymer, sand and metal 3D printing for the production of complex shapes and high-quality components

The Bosch Rexroth production facility in Lohr am Main has been using polymer 3D printing since 2015, while sand and metal 3D printing were introduced in 2017. Metal and polymer 3D printing are used in the production line, and sand 3D printing is used for the production of sand cores employed in metal casting in the foundry.

A complex form cast out of metal traditionally required a combination of sand moulds, resulting in holes that needed to be filled in a separate step. The 3D-printed sand cores allow complex shapes to be produced. Instead of having to produce multiple moulds, a single structure can be produced with sand printing, increasing end-product integrity. Metal printing has proved to be an adequate response to weaknesses in the traditional production of certain metal forms. Before the introduction of metal 3D printing, production of metal forms required welding, resulting in a potentially unstable product because of welding spots. Metal 3D printing has addressed this challenge, eliminating the weakness of welding spots and creating a consistent component that avoids problems further down the production line.

3D printing has not displaced other production processes in Lohr am Main, but it allows the company to produce highly complex shapes in low quantities. This addresses the unique demands of customers and does not require economies of scale to keep the price low.

Source: *Eurofound, 2020–2021*

Another sector of relevance for 3D printing is the healthcare sector, in which the technology is used for the production of unique and highly customised medical products and devices that take human requirements into consideration. These include anatomical bio models based on radiological images for use in surgical planning; surgical instruments and guides based on the specific anatomy of patients; and custom-made implants and orthopaedic and prosthetic devices (for example, artificial limbs and prostheses). According to research and advisory firm Gartner, by 2023, 25% of medical devices for pre-surgical planning and performing joint replacements, surgical implants and prosthetics in developed markets will make use of 3D printing (3D natives, 2019). Some hospitals are already using 3D printing to create physical models of patients' organs to better prepare their staff for difficult operations. A case in point is the Hospital General Universitario Gregorio Marañón in Madrid, where a team of surgeons and engineers established a 3D printing laboratory (FabLab) in 2015 that has accelerated the development and use of 3D printing technology within the hospital (3Dprint.com, 2016). This started as a manufacturing laboratory but has since developed into a hospital unit, being the first in Spain to have a manufacturer's licence to produce custom medical devices and to have ISO 13485 accreditation, the international standard for quality management systems for medical devices. The FabLab 3D prints surgical guides, tools and other clinical aids. For example, in the hospital, physicians use 3D-printed patient-specific heart models to familiarise themselves with their patients' anatomical structures and work out strategies for hemodynamic procedures before performing surgery.

3D printing has also played an important role in the response to the COVID-19 crisis, enabling the rapid and local production of products and devices, with companies fast-tracking the production of 3D-printed replacement respiratory valves, visors and swabs, to name a few examples.

Looking forward to the next 5–10 years, the use of 3D printing in the medical sector may become more common for the manufacture of drugs tailored to each patient and of custom-made implants that combine metal with other materials (for example, polymers or pharmacological coatings) that have bioactive therapeutic effects. In the area of bioprinting, with the current state of the art in the field of tissue engineering and new biocompatible materials such as scaffolding, it may even be possible to produce custom-made organs and tissues.

Another sector in which the use of 3D printing is not yet established – but is potentially highly disruptive – is construction. In recent decades, the industry has come to the realisation that much can be gained by better planning before the start of a project. Several large construction companies – including Royal BAM Group, Bechtel and Italcementi, the Italian subsidiary of German construction group HeidelbergCement – have started using building information modelling (BIM),[12]

12 BIM is a 3D model-based process that is supported by various tools and technologies for the generation and management of digital representations of building projects. It is used for design simulation, construction planning and facilities management.

BAM Infra (the Netherlands): 3D printing of construction elements

Part of the construction company Royal BAM Group, BAM Infra operates at different sites for the duration of the engineering works. 3D printing of construction elements was introduced at BAM in 2017, with the building of a 3D-printed concrete bridge – consisting of six joined printed elements and totalling a length of 8 metres and a width of 3.5 metres – in the province of North Brabant. Since then, 3D printed elements have been integrated more systematically in construction sites.

Between 2017 and 2020, BAM Infra undertook the reconstruction of the Driebergen-Zeist railway station and surrounding roads for the Dutch railway infrastructure company ProRail (acting on behalf of the Dutch Ministry of Infrastructure and Water Management, the province of Utrecht and the municipalities of Driebergen and Zeist). The project included the construction of an underpass for cars, cyclists and pedestrians, reconstruction of the railway station building and its external surroundings, and the construction of an extra railway track. Driebergen-Zeist railway station is considered to be a prime example of the professional use of digital construction (Royal BAM Group, 2017).

For this construction project, BAM Infra used 3D-printed elements of a decorative nature. The 3D concrete elements were printed in a 3D printing factory in Eindhoven (in a joint venture with a cement production firm) where the printer robot operated. The factory provided a good indoor temperature for the cement to dry and allowed for the storage of printed elements. From this location, the 3D-printed elements were transported to the construction site as needed.

3D printing is an alternative to using cast-in-place (reinforced) concrete elements, which involves construction of the formwork (temporary or permanent moulds into which concrete or similar materials are poured), positioning and securing of steel reinforcing bars, and pouring of the concrete. The curing of the concrete can take some time (up to several weeks for large constructions) before the next step in the building process can be initiated. With 3D printing, the different steps are carried out off site at the 3D printing factory.

The ambition of the company to become a leader in digital construction has also entailed changes in the planning of construction work, with a shift from the use of 'blueprint' 2D drawings to 3D digitised models using BIM methodology.

Source: *Eurofound, 2020–2021*

not only for the design of 3D construction models but also for construction site planning, including step-by-step simulation of construction elements. Combined with BIM-related technologies, 3D printing could lead to a revolution in the construction sector. Innovation in building materials is also driving the uptake of 3D printing in the sector. Italcementi has been researching 3D printing applications in building construction since 2015 and has developed a high-tech material, i.tech 3D, which was used in 2020 to 3D print Germany's first residential building (HeildelbergCement Group, 2020).

3D printing is also being explored in a number of other domains ranging from the printing of food items to the design and manufacture of a range of consumer products, including clothes, fashion and lifestyle products (for example, furniture, jewellery and accessories), and home gadgets and decorations. Such applications are being piloted mainly by start-ups but may become more widespread in the near future.

Because 3D printing produces objects based on 3D model data, designs can be easily adapted and customised to specific needs, whereas traditional manufacturing methods are limited in their ability to create customised products. Mass customisation is already a reality for a number of products, particularly medical and dental appliances and implants (for example, hearing aids and orthodontic plastic aligners). Although there was consensus among the experts consulted that 3D printing will be applied in more and more manufacturing industries in the future, the technology is not competitive enough for mass production and is more suited for the production of high-value-added products.

Bächer Bergmann (Germany): 3D printing for the rapid prototyping and creation of customised parts in woodworking

Bächer Bergmann is a small woodworking company based in Cologne that specialises in the digitally aided small-scale production of design elements for museums, churches and public fairs. It works on unique designs for individual stakeholders on a project basis. As part of the company's core business, Bächer Bergmann uses digital technologies to develop its niche in the woodworking sector.

With the possibility of creating complex forms that would not be possible using subtractive methods such as computer numerical control milling, 3D printing is now embedded in the work process as a tool for both designers and shop floor employees and used alongside other more traditional production methods. According to both the director and employees, the technology is an asset in the 'tool belt' of the company.

3D printing allows designers to produce mock-up models and consider parts that are unavailable or very expensive in the market, while shop floor employees can now print components and parts to fit unique project requirements. In addition, 3D printing allows overnight production, optimising the uptime of machinery and utilisation of employee time.

Source: *Eurofound, 2020–2021*

Virtual and augmented reality

AR provides additional, often complementary information by overlaying computer-generated content onto the real world using a device such as AR glasses, while VR simulates an environment in which the user can interact with objects and is fully immersed (Eurofound, 2019a). Both variants have a high number of potential applications (UploadVR, 2016). Their development and adoption tend, however, to be targeted at the consumer rather than at enterprise activities (Ecorys, 2017; Eurofound, 2019a). According to the experts consulted in the Delphi survey, VR/AR technologies are more commonly used to create and refine virtual prototypes that are otherwise expensive to build (for example, vehicles, heavy machinery and equipment) and assist in design and customisation, for example in the architecture and manufacturing sectors.

Bächer Bergmann (Germany): AR for assisting with design visualisation and project oversight

Alongside 3D printing, German woodworking company Bächer Bergmann has been using AR since 2016 to assist in the translation from concept to product and enhance the visualisation of product design. It also helps shop floor employees to have a better overview of the whole project to which their work is contributing and facilitates communication between employees involved in the different steps of the production process. The company does not work with AR glasses but with tablets. A sheet with a QR code is placed on the floor of the workshop. Employees can then walk around it with a phone/tablet that acts as a lens, showing the object based on the position of the QR code. The system relies on the same output data produced by the company's virtual computer-aided design (CAD) tool. The software has an AR output plug-in available, allowing the company to visualise designs using AR. VR goggles were also subsequently introduced but testing of these was less successful because of technical problems and their implementation was put on hold.

Source: *Eurofound, 2020–2021*

AR, in particular, has been applied successfully in business logistics, where the technology is used to give workers access to real-time information for route optimisation and for assisting with picking processes in warehousing operations. Shipping company DHL and online retailer Amazon use AR goggles in some of their warehouses, providing workers with instructions on how to complete their assigned tasks.

Other use cases identified in this research were regarded by the experts consulted as emerging rather than commonplace cases. For example, AR can be used to instruct or guide workers using step-by-step processes because of its capabilities to visualise information. Manual instructions for production, maintenance and repair can be overlaid directly on the target using AR, simplifying the repair or production

Mariasteen (Belgium): AR-based guidance system for assembly work

Mariasteen is a social enterprise based in Gits (West Flanders, Belgium) that specialises primarily in metal assembly work. Of the 860 employees, the majority (about 80%) have some form of occupational disability. With a view to delivering a higher volume of orders and more complex assembly work, in 2016 the company deployed an AR-based system (light guidance system, LGS) to guide employees through the assembly process step by step, taking into consideration their individual capabilities. The AR system combines computing, projection and sensor technologies. The LGS is mounted on a workstation and programmed to guide employees through any assembly process, in line with client requirements. Sensors are attached to the LGS and workstations to monitor the quality of the assembly work by measuring the shape and weight of products. The LGS also keeps track of the time taken to complete each step, the number of errors made and the adjustments required before proceeding to the next step. This information is used to assess the complexity of the tasks that each employee can handle and to adjust the workload to best fit employees' own capabilities.

Source: *Eurofound, 2020–2021*

process. Car manufacturer Volkswagen provides 3D smart glasses to assembly line workers at its German manufacturing plant in Wolfsburg to help them perform their tasks more easily and with greater accuracy. AR has also been used for some time at the BMW manufacturing plant in Munich for quality control inspections, for example to ensure that parts are installed and mounted correctly (BMW Group, 2019).

AR visualisation capabilities can also be used for maintenance operations in the utility sector. AR systems incorporated with mobile devices (for example, drones) are being piloted by public utility companies in the EU, for example in France, Germany, Italy and Spain (Water World, 2017; Reuters, 2018; Digital Water.City, undated).

CABB (Spain): AR drones for asset management and predictive maintenance

Introduced in 2019, AR drones are used at CABB to visualise in AR the entire water supply and treatment network and thereby facilitate inspections of critical assets and maintenance and repair activities relating to the water utility infrastructure in the province of Bizkaia. The AR drones are instrumental in carrying out virtual 3D mapping of the water supply network and detecting breakdowns and requirements for maintenance operations (which are subsequently performed on site). The technology is used in situations in which it is complicated, costly and risky for operators to access the areas to be inspected for repair or maintenance work. In this respect, the technology saves time and costs, reduces occupational risks and optimises maintenance operations, allowing the challenges posed by infrastructure obsolescence to be dealt with more efficiently. The technology is still at an early stage of adoption and has not been extended to all maintenance activities. AR is also used to train operators to perform high-risk tasks (including high voltage work and the handling of chemicals, for example chlorine for use in water treatment) and therefore enhance workplace security.

Source: *Eurofound, 2020–2021*

BAM Infra (the Netherlands): AR glasses for the identification of maintenance requirements

VR is being piloted at the construction company BAM Infra to enhance the designs of construction projects and help designers to visualise their designs from all angles, as well as involve clients in the final stage of their project. The company is also experimenting with AR glasses to assist in the identification of requirements for and steps involved in maintenance work once construction is complete. AR glasses are not, however, used during the construction work. Although construction workers at BAM Infra tried several AR prototypes to visualise the whole construction project while still building, the equipment was deemed too expensive and not robust enough to be handled on a construction site.

Source: *Eurofound, 2020–2021*

CABB (Spain): Integration of VR in BIM (building information modelling) software

VR glasses have been deployed at CABB since the beginning of 2020 to support and enhance the use of BIM (VR/AR) methodology for the design, construction, renovation and maintenance of physical infrastructure projects. The BIM methodology is applied using software with integrated VR capabilities. Virtual models of building structures and the system infrastructure can be designed and viewed in VR, instead of using 2D plans or expensive computational images based on 3D reconstruction techniques. VR is used in BIM mainly for water network infrastructure design projects to facilitate the design evaluation process and enable a more detailed representation of the infrastructure and a better perspective of the actual scale of a building or installation project to be obtained.

Source: *Eurofound, 2020–2021*

VR also presents opportunities for site and logistics planning in the construction sector and AR can be used for hazard identification in construction sites. The use of BIM in construction can be further enhanced by the integration of VR, which adds interactive capabilities.

Both VR and AR have the potential to enhance learning and change the way that training is organised and delivered in different areas (for example, in fire and other emergency and rescue services, military tactics, aviation, chemistry and surgical procedures) (Eurofound, 2019a). Previous experimental research into AR use in a vocational learning environment found improvements in learning performance and mental modelling (Lester and Hofmann, 2020). There is, however, mixed evidence with regard to VR/AR training yielding better performance outcomes in comparison to traditional training methods (Eurofound, 2019a).

Both VR and AR technologies are already used in the public and private sectors to deliver training in specific circumstances that cannot be easily replicated in the real world (Ecorys, 2017; Eurofound, 2019a). German railway company Deutsche Bahn has, for example, been using VR since 2018 as an integral part of the vocational training and professional development of its employees (Deutsche Bahn, 2021). VR has expanded training opportunities in the company, making it possible to train numerous employees on complex work processes in a safer and more cost-effective way. Large oil and gas companies such as Eni, Shell, Chevron and ExxonMobil have leveraged VR technologies to train more of their employees to complete risky operations by simulating scenarios based on real hazardous work environments. VR training applications are also becoming more common in logistics. For example, cargo handling company IAG Cargo's freight hub at Heathrow Airport

Bosch Rexroth (Germany): AR technology for the provision of training, expert guidance and remote product inspections

Bosch Rexroth introduced AR technology at its Lohr am Main plant in 2011 to enhance its training methods. As Bosch Rexroth's subsidiary RE'FLEKT offers software for AR solutions, the establishment has good access to the technology. In the establishment, AR supports training for manual assembly work (work for which the parts are too complex for machines to assemble). Previously, in order to train someone in these tasks, it was necessary for two employees to work together, with one receiving the training and the other working in a supervisory role. AR enhances efficiency in training as it allows employees to learn more on their own (without senior supervision) in both mandatory and elective training. It also allows apprentices to observe the work of a trainer in situations where the trainer and trainees would not have physical room to work together (such as for certain machinery repairs).

Because of the large number of different products offered by Bosch Rexroth, repair technicians in the field sometimes require expert guidance. Previously, this was carried out over the phone. While this system has been improved in recent years, the company is now piloting an AR solution for its technicians in which they receive expert feedback and instructions on a head-mounted display for real-time hands-free support. Since 2019, the training department at Lohr am Main has also run a pilot virtual hydraulics facility to fully immerse apprentices in VR training, rather than them simply receiving additional information overlaid on the real world, as in AR.

Lastly, in response to the travel restrictions imposed during the COVID-19 pandemic, the establishment began a VR pilot allowing virtual tours of the local facility, which in the future could be extended to enable overseas customers to inspect products or prototypes without physically travelling to the plant.

Source: *Eurofound, 2020–2021*

has started using VR simulation to familiarise cargo operators with freight handling and train them to perform tasks in a safe environment, for example to drive forklift trucks or prepare cargo for aircraft (Vrai, 2021). Reportedly, the VR training at IAG Cargo has increased employees' understanding of operations, from an average score of 5/10 to an average score of 8/10, and the average induction session length has been reduced from 90 minutes to 15 minutes (*The Irish Times*, 2021).

According to the experts consulted, VR technology may play a bigger role in healthcare in the future, such as providing a virtual interface for performing rehabilitation-related tasks and treating various medical conditions (for example, post-traumatic stress disorder and anxiety). Researchers have also made the case for the use of VR technology in tailor-made rehabilitation for post-COVID-19 patients (Smits et al, 2020).

Lohja Hospital (Finland): VR for neurological rehabilitation

In 2018, VR headgear was introduced at the new neurological rehabilitation ward at Lohja Hospital, which is part of the Helsinki University Hospital (HUS) network. The ward provides outpatient rehabilitation mainly to patients with cerebrovascular disorders or brain injuries.

The VR headgear, developed by an external provider, makes it possible for therapists to modify the VR environment towards specific and tailored rehabilitation exercises for the patients. The approach taken to rehabilitation is tailored to each patient's individual needs. Therefore, the VR headset is deployed only when a therapist has a clear understanding of whether or not it will be beneficial to a patient within their rehabilitation plan. The VR headgear is one tool of many – most being more conventional rehabilitation tools – available for therapists to use as they see fit.

By integrating the VR headset into the neurological rehabilitation tools available at the hospital, therapists are able to provide a larger selection of exercises to patients. When using the VR headset, patients are guided through the rehabilitation activities planned beforehand by their therapist. Nurses oversee the process and support the patients as required during the sessions.

The VR application presents opportunities for work efficiency by facilitating the treatment of multiple patients at the same time and allowing more informed decisions to be made about specific patient rehabilitation procedures. The long-term goal would be to create a rehabilitation service that allows patients to take a VR headset home and work on rehabilitation exercises outside the hospital setting, which would significantly decrease the time that staff spend interacting with patients.

Source: *Eurofound, 2020–2021*

Other emerging use cases for VR include for synchronous collaboration and learning between on-site and remote workers (or dispersed teams). Multinational companies such as Mattel and Ford already use VR across their global workforce for collaborative work. Design teams around the world can come together in a photorealistic virtual space to work on new concepts with true-to-life accuracy – discussing and iterating in real time. Similarly, VR solutions can be used to support and enhance remote communication with customers and collaboration with supply chain partners, thus reducing response times.

Table 3 shows the most relevant sectors for uptake of the three technologies and different use cases.

Table 3: Most relevant sectors for technology uptake and use cases

Technologies	Use cases	Agriculture	Manufacturing	Utilities	Construction	Transport and logistics	Information and communication	Professional scientific and technical activities	Education	Human health activities	Arts, entertainment and recreation	Other service activities
IoT	**Sectors (NACE)**	A01	C10, C11, C21, C26–29	D35		H52, H53						
	Monitoring livestock and crop quality yields	X										
	Product traceability and quality control	X	X									
	Inventory management and control		X			X						
	Planning and monitoring of delivery activities/distribution	X	X	X		X						
	Predictive maintenance and repair		X	X								
	Monitoring assets and machines		X	X								
	Fleet monitoring and optimisation					X						
3D printing	**Sectors (NACE)**		C22, C25, C28–30, C32, C33					M72	P85	Q86 (and C32.5)		S95
	Prototyping		X					X	X			
	Production of specialised machine tooling		X									
	Production of highly complex products		X									
	Maintenance and repair		X									X
	Mass customisation									X		
VR/AR	**Sectors (NACE)**		C20, C26–30	D35, E36–38	F41, F43	H52	J58	M71, M73	P85	Q86	R90	
	Training		X	X					X	X		
	Prototyping, design and customisation		X		X			X				
	Assisted workflow, repair and maintenance		X	X		X						
	Enhanced visualisation and marketing						X				X	

Source: *Based on expert views from the Eurofound Delphi survey, 2020–2021*

Synergies between technologies

Combining the three digitisation technologies provides even more value than using the technologies individually, for example using AR to visualise data collected through IoT devices or sensors that automatically signal to a 3D printer to produce spare parts in cases of machine malfunctions (Richardot, 2018).

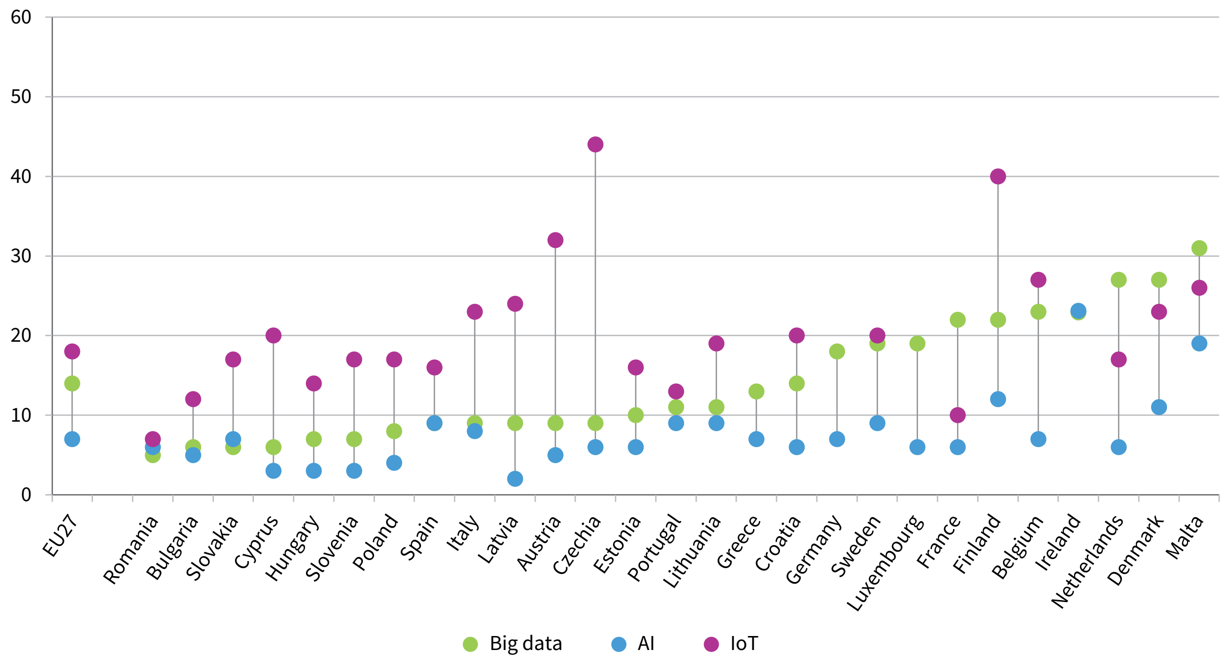
An example of synergies between these technologies is the software application Vuforia, a platform that allows developers to connect IoT devices with AR applications to augment real objects using a virtual display (Electronicsforu.com, 2019). Companies in the automotive sector such as BMW, Mitsubishi and Porsche have been experimenting with a combination of AR and IoT-based software solutions to improve maintenance and quality assurance processes (Electronicsforu, 2019; Eurofound, 2019a). An example of combined technologies in the utility sector is the use by CABB of AR drones equipped with IoT sensors to access and visualise the entire water supply network and assist in detecting faults and malfunctions. In this application, AR further enhances predictive maintenance, which is typically a prerogative of IoT.

The capabilities of digitisation technologies can be further boosted by the use of artificial intelligence (AI), with many potential applications. In 2020, online retailer Amazon introduced in some of its warehouses an AI-powered system called 'distance assistant' that uses AR to track employees' movements in real time and remind workers of social distancing guidelines (Amazon, 2020). Although Amazon claims that no data about employees' movements are stored, the application has raised suspicions and sparked privacy concerns (The Verge, 2020).

Less controversial are applications combining IoT and AI in smart city projects, for example for traffic management. One illustration of such an application is the use of drones endowed with IoT sensors to collect traffic data in real time and feed into AI systems to assist in making decisions about ways to alleviate traffic congestion (Forbes, 2020).

Applications leveraging the combined capabilities of IoT, big data and AI are, however, still at an experimental stage. Eurostat data from the ICT usage in enterprises survey show that only 7% of enterprises (with at least 10 employees) in the EU used AI applications in 2020, whereas higher shares of such enterprises used IoT (18%) and big data analytics (14%) (Figure 3).

Figure 3: Advanced technology use by enterprises (with at least 10 employees) by country, EU27, 2020 (%)



Notes: *No data on IoT use for Greece, Ireland and Luxembourg; no data on any technology for Germany. Big data and AI figures are the same for Ireland and Spain. Countries are ordered by use of big data.*
Source: *ICT usage in enterprises survey (isoc_e), Eurostat, 2020*

These technologies are inherently linked, for example IoT data are often referred to as big data having volume, variety and velocity (Kaisler et al, 2013), and AI systems need big data to get the most out of their capabilities. IoT is an enabling technology for AI systems; objects endowed with interconnected IoT sensors within the production process are transformed into digital devices that can interact and be algorithmically controlled.

Among the countries with above EU average use of the three technologies are Denmark, Finland and Malta. In addition, Ireland is one of the countries with a high share of enterprises with at least 10 employees reporting using AI and big data (23% for both technologies). At the other end of the spectrum many eastern European countries have a below EU average share of such enterprises reporting the adoption of the three technologies, namely Bulgaria, Hungary, Poland, Romania, Slovakia and Slovenia. Although Czechia reports the highest use of IoT (44%) across all EU countries, its adoption of AI and big data is below average, at 6% and 9%, respectively.

Chapter 1 – Summary

- All three digitisation technologies are very versatile and, as illustrated in this chapter, they can be applied to different contexts and activities and to different purposes, depending on company specificities and needs.
- Among the three digitisation technologies, IoT is the most established across a range of sectors, with the number of applications expected to increase over the next 5–10 years. The use of 3D printing tends to be more concentrated in manufacturing. The level of maturity and uptake of 3D printing depends, however, on the materials used, with 3D printing using plastic being applied at more advanced levels. VR/AR technologies show cross-sector adoption but are not yet considered mainstream in any given sector.
- IoT is a key technology for smart factory, smart city, smart health and smart farming systems, interacting with many other digital technologies (cloud computing, big data and analytics, etc.). IoT is also an important enabler of vertical and horizontal integration, contributing, for example, to servitisation in manufacturing.[13]
- Many materials can be used in 3D printing – for example plastics, metals and ceramics – allowing many applications and the manufacture of many different products. The most common applications are currently confined to prototyping and visual design, particularly in the automotive and aerospace industries. Although 3D printing is still a complement to conventional production methods, it has a large potential to change the way in which products are designed, developed and manufactured, thus transforming industrial production altogether.
- VR/AR applications are used by large companies to train employees for risky operations in hazardous work environments. The technology is, however, mature enough to be extended to other areas beyond training (for example, assisting in design processes and guiding assembly and maintenance or repair work), with innovative companies proving the business case.
- Combining the three digitisation technologies provides more value than using the technologies individually. Use cases of the combined technologies are still at an experimental stage. IoT is also a powerful enabler of other digital technologies, as it can provide large quantities of data for analytics and algorithm management control.

13 Servitisation refers to the strategy of manufacturing companies of adding value by attaching services to products.

2 Technology adoption and implementation in establishments

Drivers, barriers and factors influencing technology adoption

Based on evidence from the case studies and expert views, the drivers of the adoption of digitisation technologies are largely of an economic and financial nature. The overall rationale behind technology adoption is to improve the quality of products or services, increase productivity (and profitability) and reduce costs. The management representatives interviewed in the selected establishments also reported that technology adoption is motivated by the need to remain 'in the game' and create a competitive edge for the business. The experts enriched the accounts from the case studies according to the specificities of each establishment investigated and pointed to technology-specific drivers of and barriers to technology adoption, as well as more generic factors influencing technology uptake. Table 4 summarises the key drivers of and barriers to technology adoption identified in this research.

Internet of things

In all establishments investigated that use IoT, adoption of the technology was mainly motivated by the need to optimise resources and increase operational efficiencies through real-time data collection, monitoring and quality control.

At Bosch Rexroth, the adoption of IoT technologies (developed in-house) was driven by a desire to leverage the many benefits of connecting machines together in an overarching IoT ecosystem within the establishment, including improved planning capacity, greater oversight of machine performance, and process optimisation (through predictive maintenance).

In the case of Est-Agar, IoT technologies were adopted not only for monitoring the state of machines and ensuring timely maintenance and repair but also to provide greater oversight of employees' activities and their performance. The overall rationale behind the adoption of IoT technologies was to provide reliable and high-quality data to support decision-making in relation to the production of existing products and the management of factory equipment and human resources.

The exchange of information and the connectivity of machines, components and products can increase efficiencies not only across business functions (vertical integration) but also throughout supply chains (horizontal integration). In the case of Sanmina, the IoT system developed in-house was primarily introduced to provide better analysis and control of product development across the whole value chain. Considering the interdependencies between different Sanmina factories and the relatively high cost of production errors, the availability of and remote access to data in real time are critical for ensuring that the complex production processes are able to run smoothly.

Table 4: Drivers of and barriers to the adoption of digitisation technologies

Drivers and barriers	Digitisation technologies		
	IoT	3D printing	VR/AR
Efficiency and competitiveness gains	green	green	green
Level of digitisation in establishment	green		
Standardisation and interoperability	red	red	
Technology capabilities (and technological advances)	green	green	green
Public support and innovation policies	green	green	green
External framework conditions and regulations	yellow	yellow	
Costs/investments in infrastructure	red	red	red
Knowledge gap and in-house expertise	red	red	

Note: *Colour coding applied in the table highlights whether each item is a driver (green), a barrier (red) or a factor constituting either a driver or a barrier depending on a range of circumstances (yellow). Item not applicable if cell left blank.*
Source: *Based on expert views and the case studies, 2020–2021*

An additional driver of IoT adoption at Sanmina, Bosch Rexroth and CABB was the relatively high level of digitisation in these establishments. The approach taken to digitisation in these establishments was incremental, building on previous digitisation efforts and the reuse of existing systems or front-end technologies – such as PLC (Programmable Logic Controller), ERP (enterprise resource planning), MES (manufacturing execution system) and SCADA (supervisory control and data acquisition system) – with IoT (and cloud computing) providing connectivity and intelligence for such systems.

In the case of TTI Algeciras, the terminal was already highly digitised when established and, over the years, it has continued to digitise and automate more processes. The rationale behind technology adoption at TTI Algeciras was the need to constantly track and monitor shipments (containers) and equipment, given that container traceability is considered one of the main issues in the sector. In addition, the full digitisation and automation of yard operations, supported by IoT, facilitated cost reductions and increased competitiveness in a sector that is largely characterised by downwards pressure on labour costs.

As IoT relies heavily on data exchange, standardisation is another important factor influencing the adoption of IoT applications, both within companies and across value chains. This requires interoperability across different devices, systems and applications, whether manufactured in-house or purchased from different companies. Greater standardisation also broadens the scope of applications and ensures data quality and reliability. According to the experts in the Delphi survey, however, lack of standardisation and limited interoperability continue to be major barriers to IoT adoption. Different and inconsistent communication protocols hamper the emergence of IoT ecosystems. Establishments using IoT technologies that rely on different communication protocols are less likely to capitalise on their investments. A briefing of the European Parliament (2019) pointed to the proliferation of standards, which can increase complexity and hinder innovation. There are currently 600 closely related standards in the area of IoT.[14] In the briefing, the European Parliament calls for ‘a clear mapping of relevant standards in different fields’ and ‘more agile standardisation systems’, particularly in the area of IoT.

As noted by the experts consulted, however, this is not only a technical issue. Weak governance also hampers further progress in standardisation, leaving the field to global players (for example, Google, Apple, Facebook and Amazon). Standardisation is, in fact, a private sector-driven process and the setting of standards is carried out by technical committees of experts appointed by business and industry stakeholders, consumer organisations and interest groups.[15] Enhanced adoption of IoT would be facilitated by public institutions playing a bigger role in the process of standardisation.

Other drivers behind technology adoption identified by the experts are linked to technological advances in (lower cost) sensor technologies and other convergent IoT-enabling technologies, and the expansion of new IoT-based business models with innovative product and service applications within high-growth sectors (for example, biotechnology, transport, utilities and logistics). However, the sharing and exchange of data enabled by IoT introduces new data security, protection and privacy-related concerns that may limit its uptake.

A more generic, albeit important, driver of IoT adoption is the presence of national and regional innovation strategies and policies creating awareness, supporting investments in advanced technologies and ecosystems, and facilitating technology adoption and transfer (for example, through the establishment of innovation clusters). A mapping of IoT innovation clusters in Europe showed large disparities across EU Member States, with the highest number of IoT clusters found in Spain, Germany, Italy and France (European Commission, 2019b) (Figure 4).

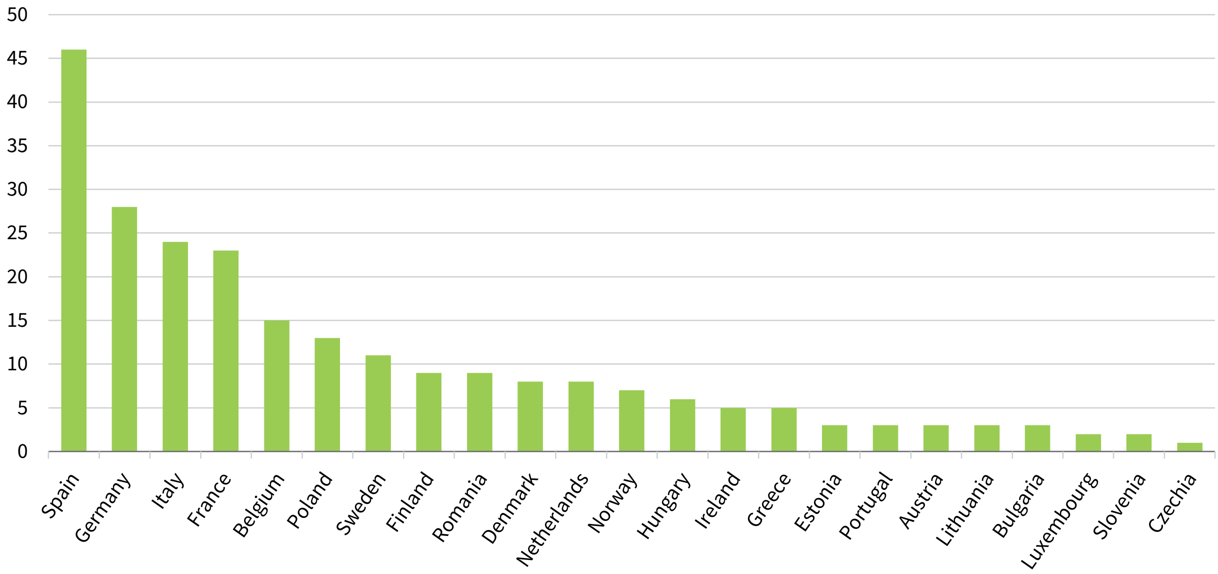
Although Spain has the highest number of IoT clusters, Spanish regions are heterogeneous in their level of digitisation, with the Basque Country being one of the leading regions in the implementation of advanced digital technologies (Grande, 2018). Since the beginning of the 21st century, the region has made an important commitment to Industry 4.0.[16] The role of clusters – in the form of multi-level governance and public–private partnerships – has been a factor determining the greater uptake of digital technologies in the Basque Country than in other Spanish regions (Aranguren et al, 2010, 2016; Holl and Rama, 2016). The CABB case study exemplifies the important role of innovation clusters in driving the digitisation process in the establishment

14 For more information see https://ec.europa.eu/commission/presscorner/detail/el/MEMO_16_1409

15 In *Standards and the digitalisation of EU industry,* the European Parliament (2019) defines standards as ‘voluntary rules or guidelines that codify information. They provide specifications and technical information (intended for common use) on products, materials, services and processes’ (p. 2).

16 The Fourth Industrial Revolution (4IR or Industry 4.0) is the ongoing automation and digitisation of traditional manufacturing and industrial practices, using modern smart technology.

Figure 4: Distribution of IoT clusters in Europe, 2019



Source: *European Commission (2019a)*

itself. The participation of CABB in a number of innovation clusters involving other public institutions, companies and research organisations provided several opportunities to experiment with the technologies and paved the way to technology adoption and implementation in the establishment itself. Although TTI Algeciras is not part of an innovation cluster, it is another successful example of international public–private partnership, combining foreign direct investment from Hanjin Shipping (Korea) with funding from the regional government of Andalusia and the Spanish Ministry of Industry, Tourism and Trade under the aid programme for reindustrialisation.[17]

External framework conditions and regulatory frameworks can also play a decisive role in technology adoption. In the case of plant nursery Centro Seia, the EU ban on the use of methyl bromide as a pesticide prompted the company to experiment with and develop new solutions to guarantee plant quality (Council of the European Union, 2005). The new grafting technique guaranteeing a sterile cut on plants (called Elite), which was patented by the company and complemented by an IoT-based digital tracking system, provided a viable alternative to the use of pesticides, preventing the spread of infections in plants, enabling full traceability of plant batches and ultimately certifying plant quality.

3D printing

In the specific case of 3D printing, the key driving forces for technology adoption are linked to both product innovation and process innovation, enabling businesses to maintain or increase their competitiveness. Product innovation relates to freedom of design enabled by 3D printing, making it possible to produce complex shapes, high performance parts and highly customised products while at the same time reducing the part count.[18] Process innovation refers to the greater flexibility afforded by 3D printing, for example entailing reductions in costs and lead times in development (through quick prototyping) and logistics (enabled by print on demand and decentralisation of production), with the possibility of producing core components in-house. These drivers are important as they directly impact on the quality and price of the manufactured products.

At Bosch Rexroth, the underlying motivation for introducing 3D printing was precisely to gain in efficiency, by enabling the production of more complex forms in smaller quantities and of better quality, while at the same time reducing manufacturing waste in comparison to subtractive production methods. Similarly, Airbus Getafe adopted 3D printing to produce complex parts and tools that were previously built by external suppliers, as a way to attain efficiency, cut costs and reduce lead times.

17 For more information see the website of the Andalusian regional government at https://www.juntadeandalucia.es/presidencia/portavoz/046608/tti/algeciras

18 In conventional manufacturing, very complex shapes are made up of many parts.

For construction company BAM Infra, the use of 3D printing was also linked to the opportunity to design more complex shapes with less waste and achieve efficiency gains. These included, for example, no longer needing to store materials on construction sites (as 3D-printed elements are remotely produced and delivered as needed), less labour-intensive work, low amounts of waste and cleaner working sites.

Several motivations lay behind the use of 3D printing at KLM E&M, including the need to optimise operational processes (for example, to achieve time and cost savings with regard to the procurement of parts) and reduce waste. At KLM E&M, 3D printing is part of a recycling loop: the establishment recycles waste and uses it to create tools for engineering and maintenance.

In the case of woodworking company Bächer Bergmann, although 3D printing was initially introduced out of curiosity and with no economic interest in mind, it quickly opened up new opportunities by enabling the production of mock-up models and quick and cheap access to parts that are unavailable or are expensive on the market.

Although the experts consulted indicated that interest and impetus from policymakers in exploiting the benefits of 3D printing across multiple sectors are also essential to encourage greater uptake of the technology, none of the establishments investigated that use 3D printing reported either being aware of or having availed of any public support schemes or incentives as part of national or regional innovation strategies. Greater awareness of national and EU funding initiatives should be fostered to boost European capabilities, know-how and the starting up of commercial activities in the 3D printing domain.

In terms of barriers to adoption, previous Eurofound research identified a range of barriers mainly linked to technological maturity (depending on the material used), standardisation and interoperability issues, and a lack of certification (Eurofound, 2018c). In this regard, the Airbus Getafe case study drew attention to the strict legal requirements relating to 3D printing use, which may inhibit greater uptake of the technology. All 3D-printed parts must satisfy extensive certification requirements to prove that they are safe, resistant and sustainable. In addition, according to the European Agency for Safety and Health at Work (EU-OSHA), some new 3D printing techniques require thorough testing and regulation because of the health and safety risks that they may pose (EU-OSHA, 2019).

A greater uptake of 3D printing also raises concerns with regard to liabilities because of unclear intellectual property rights; a rethinking of intellectual property policies is required as products can be easily replicated based on their digital representations. This may entail a shift to novel forms of intellectual property rights, for example creative commons licences, sharing licences or open source licences, as viable alternatives (Jiang et al, 2017).

The Sculpteo global survey of 1,600 3D printing professionals points to other important barriers to the greater use of 3D printing. According to the 2020 edition of the survey, budget remains the biggest barrier to expanding the use of 3D printing in companies. In addition, the knowledge gap and cost of entry are commonly viewed as limiting the potential for the adoption of 3D printing (Sculpteo, 2020). The experts consulted in the Delphi survey also flagged insufficient in-house expertise for establishing the new processes required for 3D printing as a major barrier to technology adoption. As noted by some experts, 3D printing is still not part of many educational or apprenticeship programmes; learning 3D printing-related skills on the job is the most common practice in companies. This was also the practice in most of the establishments investigated.

Virtual and augmented reality

As in the case of IoT and 3D printing, the adoption of VR/AR applications is driven by the need to reduce costs and achieve greater efficiencies. For example, in the neurological rehabilitation ward in Lohja Hospital, a VR application was introduced to enhance patient care and ensure a more efficient work allocation for occupational therapists, making it possible to work with several patients (using the VR headset) at the same time or concentrate on patients who cannot benefit from VR-enhanced care.

Applied to assembly work, AR can increase operational efficiency by enabling faster product development and launch cycles (speeding up the time to market). This was one of the motivations behind the use of AR in woodworking company Bächer Bergmann, along with the need to simplify the process of knowledge transfer from the design office to the shop floor.

In the case of social enterprise Mariasteen, the adoption of an AR solution was driven by the need to provide adequate support to employees for working on more complex assembly projects, which the company had to take on to remain competitive in the market. Prior to the digitisation process, the company had experienced a substantial decline in orders from industrial clients, which were increasingly outsourcing simple repetitive assembly work to low-cost countries. The introduction of the AR technology eventually resulted in turnover growth, from €15 million in 2011 to almost €20 million in 2019, which led to the creation of 30 new jobs.

According to experts in the Delphi survey, more generic drivers behind VR/AR technology adoption include the reduced costs and increased reliability of the software and hardware, the greater availability of digital content and data, and the versatility of VR/AR technologies, which have many application possibilities. The last driver is exemplified by practices in several of the establishments investigated. For example, at Bosch Rexroth, AR is used not only for training delivery but also to provide remote expert guidance to repair technicians in the field.

VR/AR applications will also benefit from the advent of 5G networks, which will contribute to reduced latency and hence smoother and more engaging user experiences. The deployment of 5G networks will also push processing and storage on to the cloud, reducing costs and enabling more user-friendly designs.

In most cases, the rationale behind technology adoption varied depending on the specific use case. At CABB, AR training was motivated by the need to enhance workplace safety and best prepare employees for risky maintenance operations, while the use of AR drones was primarily driven by the need to improve the accessibility of the water supply network and perform predictive maintenance.

In spite of the versatility of VR/AR technologies and the many benefits they offer, a number of factors limit their more widespread adoption. These are related to their still-limited computational and processing power and web connectivity. For example, this problem was encountered by occupational therapists and nurses at Lohja Hospital using the VR headset for patient rehabilitation, which created some initial resistance to the more regular use of the technology on the ward.

Other barriers to technology adoption concern the relatively high costs of initiating and maintaining a VR/AR system infrastructure, and usability issues. These include the limited comfort of most VR/AR headsets, the chunkiness of the hand controllers and the lack of feel and touch in VR applications. In the BAM Infra case study, the company had been experimenting with AR goggles on construction sites for on-site inspections but the handling of the equipment was deemed impractical and the goggles themselves not sufficiently robust to survive the harsh conditions of construction work.

Although a growing number of use cases have started to emerge, the experts consulted agreed that there is still insufficient evidence of the benefits (including the return on investment) of the technology to prove the business case, which discourages companies from committing to the technology.

Key elements for successful technology adoption and implementation

The experts in the Delphi survey identified key elements underpinning the successful implementation of digitisation in the workplace; these can generate more positive outcomes for both workers and organisations (Figure 5). Many of these elements are also identified in other Eurofound research on innovation in European companies, particularly the importance of open communication between management and employees, investment in training and skills development as the basis for innovation, and employee involvement in the innovation process (Eurofound and Cedefop, 2021).

Technology implementation starts with strategic orientation and a phased approach to technology adoption based on experimentation and piloting, with a view to establishing the feasibility of each use case and assessing the risks prior to the roll-out of the technology. Experimentation allows companies to understand the opportunities and challenges of the technologies, which helps them to devise the most appropriate digitisation strategies. A central element in this experimentation is the full involvement of employees at an early stage, allowing them to provide feedback and have input based on their experiences of using the technologies. In a similar vein, previous Eurofound research found that the outcomes of restructuring – and digitisation can be considered a form of restructuring – are better for workers when they are involved and have a voice in the change process (Eurofound, 2018d).

Figure 5: Key elements for successful technology implementation

Source: *Based on results from the Eurofound Delphi survey, 2020–2021*

Establishing an innovation or digitisation strategy does not necessarily imply a top-down approach; a strategy driven solely from top management can give rise to apprehension among employees and resistance to change, which ultimately undermines the digitisation process. By contrast, an innovation culture characterised by ongoing communication within the workplace fosters a greater acceptance of new technologies and employee buy-in. Resistance to change often comes from those workers who benefit the least from the technology or for whom the benefits of the newly introduced technology are not as apparent. Introduction of technology should also be underpinned by a problem-solving orientation, sensitive to the needs of the company, as opposed to a technology-driven approach that is influenced by digital hypes.

Other crucial elements for successful technology implementation include investing in new qualifications as well as upskilling, reskilling and training of employees on an ongoing basis, and establishing strategic partnerships with early adopter companies and other relevant organisations (innovation centres, start-ups, universities, research institutes, etc.) to learn from existing use cases and acquire familiarity with the technologies. Supportive policies stimulating cooperation, strategic partnerships and knowledge transfer; public incentives for worker upskilling, reskilling and training, targeting SMEs in particular; and the presence of regional and local ecosystems all play an important role in facilitating technology adoption and implementation.

Evidence from the case studies, however, suggests that technologies were often adopted and introduced without resorting to public funding or incentives. An exception was at CABB, which leveraged public regional and European funding for testing and experimenting with the technologies in various pilot schemes. For example, funding from the EU's LIFE programme was used for the industrial wastewater reduction pilot project, named LIFE Vertalim (2016–2019). As part of this pilot, IoT sensors and preventive alarms were installed and tested in an area with a high concentration of fish-processing industries to monitor pollution parameters and measure industrial discharges into the urban wastewater network.

Approaches to digitisation and employee involvement

Of the 12 case studies, establishments looking for a technology solution for a specific problem followed a more top-down approach to technology adoption. The approach – whether formalised in an explicit strategy or more informal – also varied depending on companies' specificities and the purpose for which the technology was introduced. The approach taken in each establishment also varied in the extent to which employees were involved in the digitisation process – regardless of the presence of a formal employee representation body – and participated in the testing and piloting of the technologies, and were given the opportunity to provide feedback that was then taken into account by management to refine the digitisation strategy.

At Sanmina, the introduction of an IoT-based system (42Q) for real-time manufacturing and supply chain visibility was decided at corporate level and managed centrally, as it concerned not only the Örnsköldsvik plant but all of Sanmina's factories. As this was a corporate decision, employee involvement in the Swedish establishment was limited to providing feedback on the use of 42Q prior to the roll-out. The corporate strategy on digitisation included an internal and external communication strategy and a detailed technical plan for technology deployment, with instructions on how each plant was to set up the technology, the list of settings, protocols and other specifications for uniform use of the system.

At TTI Algeciras, an IoT system was introduced at corporate level at the time of the establishment of the terminal's operations, with the intention of replicating the model of the South Korean port of Busan (the fifth busiest container port in the world). Subsequent improvements to the system, especially in terms of container traceability and reductions in accidents, were, however, based on worker feedback.

Although the strategy for the introduction of new digital technologies at Bosch Rexroth was also devised by the top management, the approach was more employee centred, as the rationale for introducing any new digital technologies in the workplace was to assist employees in performing their tasks more efficiently. At each stage of the digitisation process, employees were consulted and provided feedback, which was taken into account by management to improve the digitisation process. Employees are also routinely encouraged to trigger bottom-up technological change by identifying new digital solutions, putting forward ideas and providing feedback to management, which can lead to the introduction of new technologies (as was the case for AR applied to training). The high level of employee involvement in the introduction and implementation of new technologies has fostered a broad acceptance of new digital technologies among employees.

An employee-centred approach was also followed in the Belgian social enterprise Mariasteen, where adjusting production to changing market demands was paramount in keeping the business viable. The R&D team was prompted to scout for suitable solutions to enable employees to take on more complex assembly projects in spite of their disabilities. Seeking and introducing solutions tailored to employees' own capabilities is a core business practice at Mariasteen. The introduction and implementation of technology in the establishment was supported by a communication strategy, to engage employees in the technological change from the beginning and foster a sense of ownership over the entire process.

In the case of Est-Agar, the company is a single establishment and technology adoption was driven solely by the company chief executive officer (CEO), without setting out any explicit digitisation strategy or roadmap, although there are plans to adopt other digital technologies in the future. While management was consulted about the introduction of IoT technologies for monitoring production and employee performance, employees from the production unit did not have a say in the process of change nor were they involved in the piloting of the technologies. Similarly, at Italian plant nursery Centro Seia, the approach to technology adoption was top-down, with limited or no input from shop floor workers (at least regarding the introduction of the IoT digital tracking system). Furthermore, strategic orientation concerned the new plant grafting technique patented by the company rather than the deployment of the IoT digital tracking system itself.

In addition, on the neurological rehabilitation ward at Lohja Hospital, the deployment of the technology was decided exclusively by the management of the ward, with no scope for medical staff to influence the process of technology adoption and implementation. This was not framed by any explicit innovation strategy but underpinned by a vision for the ward to be at the cutting edge in the area of neurological rehabilitation. The approach taken was to make the new technology available to staff as part of their toolkit, thus respecting the role of the therapist in deciding the most suitable procedure for patient rehabilitation.

The case of CABB was different. An innovation unit was set up in 2018, three years after the deployment of smart grid technologies, for the monitoring and management of the water supply and treatment network. The innovation unit at CABB developed the innovation strategy and was tasked with its implementation. The strategy set out the objectives for introducing the technologies, and mechanisms to inform employees about changes to the work environment and to assess the impact of each new digital technology in the workplace. Although the innovation strategy at CABB follows a top-down approach, it is driven by middle management, who are responsible for putting forward digitisation projects, implementing them and communicating the changes to the employees who are directly involved.

At KLM E&M, the strategy and roadmap for the setting up of 3D printing offices was, in the first instance, based on employee input on the potential applications of the technology and a broad consultation involving representatives from the different departments (in both engineering and management positions) and external parties, such as providers of 3D printing materials and training institutes. This process was led by the Radical Innovation Team – part of the Transformation Office – which is responsible for orchestrating the KLM innovation ecosystem. In the establishment, 3D printing was rolled out gradually, with the department of component services being the first to apply the technology, proving its added value for the development of new tooling for aeroplane maintenance. Before the start of the COVID-19 pandemic, KLM opened Plant X, an innovation lab in which technicians could experiment with 3D printing, with the central engineering team responsible for certification and quality control. Having a physical space where engineers could work on new solutions greatly benefited interactions between the central engineering team and the different E&M departments, but the initiative was put on hold following the outbreak of the pandemic.

The approach to digitisation taken by each establishment investigated also varied in the degree of preparation and control. Overall, larger establishments – such as Airbus Getafe, CABB, Bosch Rexroth, Sanmina, KLM E&M and Mariasteen – followed a more planned approach, including a schedule for the roll-out of each technology, testing and piloting, and communication with workers. The strategy for adopting 3D printing at Airbus Getafe had been in the pipeline since 2012; it took three years to move on to the prototyping phase (which started in 2015) and three more years of testing and piloting (until 2018) to obtain the necessary certification in terms of safety, resistance and sustainability standards to enable the technology to be implemented.

At Airbus Getafe, CABB, Sanmina and KLM E&M, the piloting focused on technical aspects to ensure the effective operation of the technology, while a greater focus on job quality was prioritised at Bosch Rexroth and Mariasteen.

At Mariasteen, the R&D team devoted a lot of time to scouting for suitable solutions and experimentation, which culminated in the purchase in 2016 of the first eight LGSs. However, the new system required adaption to individual workstations. In addition, tailored visual instructions were developed in-house, programmed and tested by the R&D team following a human-centric approach, taking into account the needs and abilities of each employee. A new cycle of programming and testing starts each time the company takes on a new assembly project. The human-centric approach adopted at Mariasteen is in line with the company's primary function as a sheltered workshop and vision of being a provider of sustainable, safe and rewarding employment. This approach is consistent with findings from previous Eurofound research on social enterprises and cooperatives, which, because of the very nature of this type of organisations (prioritising social aims over profit making), strive to provide good working conditions for their workers (Eurofound, 2019b).

In the case of BAM Infra, although the company has an overall digital construction strategy setting out its ambitions for the future, its approach to the rolling out of new technologies is less defined. According to the interviews carried out in the establishment, this is partly because of the ‘learning by doing’ mentality that prevails in the construction sector.

On the neurological rehabilitation ward at Lohja Hospital, the roll-out of the VR solution for patient rehabilitation followed a successful pilot scheme carried out at another hospital in the HUS network. However, the limited planning and more ad hoc approach to technology adoption resulted in an initial unsatisfactory roll-out as technical issues (mainly related to poor connectivity) continued in the implementation phase.

Of all the establishments investigated, woodworking company Bächer Bergmann adopted the least structured and more informal approach to digitisation, mainly because of its small size. Its approach was based on trial and error, with no precise plans or scheduling of pilot schemes. At this establishment, technologies are not pursued if there is insufficient interest in using them or no engagement from employees and, in some cases, they are dismissed before a pilot is completed. However, this informal approach to digitisation makes it more difficult to untap the potential of each technology being explored.

Table 5 provides an overview of the approaches to digitisation in the establishments investigated.

Table 5: Overview of approaches to digitisation across the establishments investigated

Establishment	Type of approach to digitisation	Level of employee involvement (referred to as ‘direct employee participation’)
Airbus Getafe	Top-down approach, with testing, pilot schemes and certification required. Bottom-up approach emerged later with employees putting forward innovative ideas, which were taken on board by management.	Staff fully involved in pilot schemes. An internal network of 3D printing users emerged over time.
BAM Infra	Company board-level decision to adopt technology. No precise or well-defined approach to piloting.	Employees at construction sites informed about technology adoption (told they would have to handle 3D objects).
Bächer Bergmann	Informal approach to technology adoption. No pilot schemes as such. Employees encouraged to experiment with and scout for new digital solutions.	All staff actively involved in experimenting with and testing new technologies.
Bosch Rexroth	Top-down approach but scope for employees to influence decision-making on technology adoption.	High level of employee involvement through social dialogue structures. Employee involvement in pilot schemes and risk assessments.
CABB	Top-down approach with middle management taking the lead in implementation and employee communication. Piloting and testing are part of the strategy.	Employee involvement in piloting and testing (only employees directly affected by the technology).
Centro Seia	Top-down approach. Small team tested the technology prior to roll-out.	Shop floor employees informed, but no tailored communication to prepare employees for change. No employee consultation or scope to influence decisions around the technological change.
Est-Agar	Top-down approach. Limited piloting and testing, mainly carried out by the CEO.	Shop floor employees informed. No employee consultation or opportunities for employees to have a voice in the digitisation process.
KLM E&M	Process led by the Radical Innovation Team responsible for orchestrating the KLM innovation ecosystem. Clear roll-out plan with pilot schemes.	Local innovation picked up by the Radical Innovation Team. Employees encouraged to experiment but at the same time quality processes put in place and successful innovations approved.
Lohja Hospital	Head of department led. No piloting in the ward prior to roll-out.	Medical staff informed. No scope to influence decisions in relation to the technology adoption.
Mariasteen	Extensive piloting and gradual implementation allows for adaptation.	Piloting by R&D team, with involvement of employees from production unit for each project initiated.
Sanmina	Top-down approach (corporate level). Clear roll-out plan with pilot schemes.	Employees informed but limited scope to influence decisions on the digitisation strategy or process. Employees involved in pilot schemes.
TTI Algeciras	Top-down approach (corporate level). Pilot schemes carried out in the original Korean terminal, which was the template used at TTI Algeciras.	Employees informed as new technologies are introduced. Limited scope for employees to influence decisions on the digitisation process.

Source: *Based on findings from the case studies, 2020–2021, and from the European Commission JRC, 2021, for information on Airbus Getafe and TTI Algeciras*

Strategic partnerships and collaboration with other organisations

In a number of establishments, strategic partnerships facilitated technology adoption and implementation and, in some cases, paved the way for the upscaling of technologies. The most notable example was CABB, which is part of a number of local and regional innovation clusters, including the Spanish water collection, treatment and supply cluster (Asociación Española de Abastecimientos de Agua y Saneamiento, AEAS),[19] the regional environmental cluster of the Basque Country (Aclima)[20] and the regional innovation cluster of the Basque Country (Innobasque).[21] Over the years, CABB has also established collaborations with different scientific and technological providers as part of R&D projects, which have provided opportunities to experiment with the technologies and acquire expertise. Strategic partnerships with public institutions and private companies have also encouraged the development of innovative solutions that complement the technologies already in use in the establishment. For example, CABB makes its IoT data available to the University of the Basque Country's Centre for Applied Mathematics to develop time series and advanced data analysis models, which are expected to be used at a later stage at CABB to enhance the establishment's data analytics capabilities.

In the case of Mariasteen, in 2014 the company established a collaboration with the Catholic University of Leuven to test the suitability of the light guidance principle. This led eventually to the adoption of the LGS technology in 2016. After the successful roll-out of the technology in the establishment, a spin-off was created in 2019 as a public–private partnership with a network of job coaches and other sheltered workshops in the region. The aim was to capitalise on the experience of the use of the LGS technology in Mariasteen and promote technology transfer to other sheltered production environments.

In addition, the neurological rehabilitation ward at Lohja Hospital has been expanding its partnerships with other VR headgear and software developers, not only to avoid reliance on a single technology provider, but also to engage in co-creation whereby the ward is more actively involved in the development of more effective and tailored VR patient rehabilitation solutions.

At Bosch Rexroth, partnerships were established with external providers in the area of training, such as LinkedIn Learning, providing employees with opportunities to advance their skill sets, including both soft and more technical skills.

Of the establishments that introduced 3D printing, Bächer Bergmann entered into an active partnership with a 3D printing company for the use of 3D printers and scanners, while BAM entered into a partnership with a cement producer to jointly bear the risk of developing the 3D printing technology.

Investment in upskilling, reskilling and training

The experts in the Delphi survey pointed to the importance of investing in upskilling, reskilling and training before technology deployment and then on an ongoing basis. Upskilling and reskilling are considered essential, particularly for lower skilled workers, as manual tasks are threatened more by digitisation. This may, however, depend on the sector or specific use case. There is a body of research that postulates that the destruction of jobs is concentrated in the middle range of the employment structure, affecting routine jobs, whereas manual and intellectual jobs are less affected as they are characterised by less routine-intensive tasks (Goos and Manning, 2007; Goos et al, 2009). With regard to the deployment of IoT, experts also mentioned discretion and autonomy as necessary conditions for skills development.

Some insights into companies' future strategies to manage skills gaps arising from the adoption of the technologies come from the global future of jobs survey conducted between 2017 and 2018 by the World Economic Forum (WEF) among human resources managers and CEOs of large companies (WEF, 2018). According to the survey, reskilling and retraining of the workforce is a priority for employers when dealing with digital disruption, with more than half of the respondents indicating their intention to focus their upskilling and reskilling efforts on employees currently performing high-value roles, and only 33% stating that they would prioritise employees whose roles are at risk because of technological change. The WEF advocates for a 'workforce augmentation strategy', entailing the automation of routine and repetitive tasks while empowering employees through training to better use their 'human' skills as a complement to technology. The 2019 European Company Survey also shows a positive association between the level of digitalisation in European establishments and the approach to skills development. A high level of training provision, including formal training sessions and on-the-job training, was found to be most prevalent in 'highly digitalised' establishments and least prevalent in those characterised by 'limited digitalisation' (Eurofound and Cedefop, 2020).

19 For more details on the AEAS see http://www.aeas.es/servlet/mgc

20 For more details on the Aclima cluster see https://aclima.eus/en/

21 For more details on the Innobasque cluster see https://www.innobasque.eus/

The evidence from the case studies, however, suggests that the provision of formal training is far from standard practice and often occurs on a one-off basis at the time of the introduction of the technology and only for employees in occupations most impacted by the technology or who are willing to engage with the technology. For example, at KLM E&M, when 3D printing offices were set up in each department, training was provided only to a small group of employees who expressed an interest in working with 3D printing, who already had some 3D design skills and who could apply the technology in their current job.

Other establishments such as Airbus Getafe, Bosch Rexroth and Sanmina followed a more structured approach to training, identifying skills needs and developing training plans from the outset prior to the introduction of the technologies, as part of their digitisation strategies. At Airbus Getafe, engineers and design teams involved in the deployment of the technology in 2018 were sent to the Airbus training centre in Hamburg (Germany) to receive appropriate training. Over time, the knowledge of the internal network was strengthened and it now organises its own training locally (courses, seminars and workshops) with both internal and external trainers. In addition, Airbus periodically carries out a skills study by department to detect new training needs.

The development of training plans is also at the core of Sanmina's digitisation strategy. Because of the continuous upgrading of technologies and introduction of new products and services, upskilling and training are provided to all employees on an ongoing basis. Information about training that has been successfully completed by employees is recorded on an internal human resources system, which is linked to an electronic badge system for employees. Without the required training, employees are not permitted to work on particular machines.

Similarly, at Bosch Rexroth, digitisation goes hand in hand with the identification of training needs (based on a competency matrix) and the development of training plans. Job profiles evolve continuously as a result of technological change, resulting in skills gaps; these are assessed regularly and addressed through a variety of training, provided either internally (online or in person), mainly through the local competency centre, or by the providers of the technologies. While training is mandatory for employees working with specific machinery or technology, it is also made available on a voluntary basis to other employees who are interested in the technologies and who are willing to develop new skills. Because of the high penetration of the technologies in the establishment, most employees are routinely provided with training. There is a training culture at Bosch Rexroth whereby training is considered a necessity to keep up with technological change and a way to deal with labour shortages.

Although there is no integrated training plan at CABB to adapt to digitisation, a broad range of training has been provided to employees, ranging from training to develop technical skills for workers most impacted by the technologies to occupational safety and health training based on the peculiarities of each position and reinforced by new internal regulations. Blue-collar workers – for example plant operators – were targeted in these training efforts as many of their core tasks had been digitised. This required an upskilling of their job profiles, which involved learning about and familiarising themselves with a range of digital devices and software. However, many challenges were identified in this establishment in relation to upskilling and reskilling. These included the lack of an innovation culture, the age divide in terms of digital skills and openness to innovation and, more recently, the COVID-19 crisis which took resources away from training and change management initiatives aimed at fostering greater innovation in the workplace.

TTI Algeciras also pursued a strategy of upskilling to ensure that its predominantly local staff (who used to work for less technologically advanced port companies) were able to use the complex, advanced technological system developed by the South Korean engineers. TTI Algeciras arranged a series of training courses in-house, provided by supplier companies, especially during the first years after introduction of the new technology (from 2010 to 2015). In the last five years, however, there has been a slowdown in training provision in the establishment.

The approach followed at Mariasteen was to provide initial training during the piloting phase on how to use the new LGS technology; based on the progress observed and feedback received from employees, the R&D team was then able to calibrate the steps (shorten the instructions, increase autonomy) and make adjustments to ensure the best fit of the technology to employees' individual capabilities.

Peer mentoring and more informal and on-the-job training were regarded in many establishments as more viable options. At BAM Infra, workers assigned to a building site are expected to learn on the job how to handle 3D-printed elements; according to the staff interviewed, this fits with the on-the-job training mentality in the construction sector. Similarly, plant nursery Centro Seia did not deliver formal training programmes as part of the change process to support operatives and facilitate the acquisition of digital skills required to operate and use the new system. The approach was to allocate extra time in the initial phase of the roll-out of the technology for learning on the job, with support provided by more experienced users.

Similarly, on the neurological rehabilitation ward at Lohja Hospital, much of the learning about the VR technology was on the job and informal. One-off training was provided only to occupational therapists

(10 in total) at the time of the roll-out. While therapists are the primary users of the VR headset, nurses are equally expected to assist patients in rehabilitation exercises using VR, with this assistance being more than just helping them wear the headset. The limited training provision generated some initial reluctance on the ward to use the VR headset for patient rehabilitation. As nurses were not provided with any training, the informal exchange of knowledge between therapists and nurses was encouraged, which contributed to a tighter sense of community within the ward. The chief physician and other therapists also acted as 'champions' of the new technology, motivating other medical staff to engage with the VR headset.

Owing to the small size of the establishment, no training plans were developed at Bächer Bergmann either. Most training is typically carried out through in-house mentoring: employees are given training projects to work on and practise, and working time is allocated for mentoring and on-the-job learning. The company has, however, been participating in projects promoting the learning of new digital-based production methods – including 3D printing – as part of its apprenticeship training. An example is the Digitale Ausbildung im Tischler-/Schreinerhandwerk (digiTS) project,[22] in cooperation with various universities and the Craft Chamber, which is aimed at encouraging the teaching of digital technologies as part of existing inter-company carpentry training (BM Online, 2018).

The digitisation process in a number of establishments – such as CABB, Centro Seia and Bosch Rexroth – led to a reorientation of recruitment, with a greater focus on employing higher skilled workers (particularly engineering and information technology (IT) professionals) and creating higher value-added roles, with a view to developing further the capabilities of the technologies.

Role of social dialogue in digitalisation and digitisation

The International Labour Organization (ILO) resolution adopted by the International Labour Conference in June 2018 underlined the important role of social dialogue in shaping the future of work (ILO, 2018). In the past few years, EU-level social partners have issued several joint declarations and statements on the impact of digitalisation on work and the economy, both at sector and at cross-industry levels (Muñoz de Bustillo Llorente, 2020). In their joint statement on digitalisation of 16 March 2016, the European social partners called on the EU 'to create a favourable policy and regulatory environment to safeguard the interests of enterprises and working people at the same time'.[23] Digitalisation is also one of the key priorities underpinning the European Social Dialogue Work Programme 2019–2021, which paved the way for the adoption in 2020 of the European social partners' autonomous framework agreement on digitalisation (ETUC et al, 2020). This landmark initiative marks the beginning of a multi-stage process, which is to culminate in the adoption of a strategy on digitalisation and an agreement on its implementation, followed by regular monitoring and evaluation.

However, digitalisation is an area in which social dialogue struggles to extend its influence, with social partners' negotiations still focused on more traditional issues such as wages and employment (ILO, 2020). According to an online small-scale survey (N = 40) conducted by the ILO among representative employer and worker organisations in EU Member States, 40% of the respondents surveyed stated that social dialogue was not at all (or only to a very limited extent) influential with regard to digitalisation and a further 20% reported that this topic had never been addressed by national social dialogue institutions. Another survey carried out by ETUC (2018) among trade unionists and company-level worker representatives (N = 1,500) found that a significant minority of unions did not address many digitalisation-related topics (ranging from 21% to 43% depending on the specific topic); the introduction of new digital technologies and changes to work organisation and processes linked to the use of digital technologies were reported as being more frequently addressed through the provision of information to employees and consultation than by company- and sector-level collective agreements.

Expert views: influence of social dialogue from European to establishment levels

The experts in the Delphi survey were asked to provide their views on the most appropriate level at which social dialogue should play a role in the introduction and implementation of digital technologies. The views provided come with the caveat that social partner roles and social dialogue on digitalisation vary across EU Member States, depending on national economic structures, the degree of exposure to the technologies and the prevailing model of industrial relations.[24]

22 For more information see http://digits.education

23 For further information on the Tripartite Social Summit of 16 March 2016, see https://www.businesseurope.eu/sites/buseur/files/media/position_papers/social/2016-03-16_tss_-_statement_on_digitalisation.pdf

24 See the industrial relations index developed by Eurofound at https://www.eurofound.europa.eu/data/industrial-relations-index?period=2013-2017&breakdown=index&mode=all&country=all. This was used by Eurofound to measure the different types of industrial relations in Europe (Eurofound, 2018f).

According to the experts, social dialogue plays a role with regard to digitisation at many different levels. Both national- and EU-level social dialogue is regarded as instrumental in setting minimum requirements and standards, adjusting educational programmes, ensuring that resources and incentives are made available to support companies' upskilling, reskilling and training efforts, and guaranteeing a security net for workers at risk of losing their jobs as a result of technological change. This should be seen, however, in the context of a broader dialogue about technological change. At EU level, according to the experts, there should also be greater involvement of sectoral social dialogue committees. Social dialogue at regional or sectoral level is key not only for monitoring trends in the impact of the technologies and identifying good practices, but also for identifying common challenges for, needs of and opportunities for companies in specific regions or sectors, which can be addressed by supportive policies. Experts agreed that social dialogue is particularly important at establishment level, to generate confidence in new technologies and to ensure that employees are kept informed and have a voice in the process of change and that digitisation strategies are attentive to employees' needs and concerns (especially in relation to threats to existing job roles, potential job losses or redeployment, upskilling or reskilling needs, and impacts on wages). Social dialogue deficits at this level may amplify the negative impacts of technologies on working conditions.

Experts also indicated their agreement on the areas in which social dialogue at establishment level can be particularly beneficial in the context of technology implementation, by encouraging greater acceptance by employees of the technological change and promoting employee buy-in. Providing information to employees in advance and consulting with employees were indicated as obvious areas in which social dialogue can exert some influence. This also includes communication and consultation about the potential impacts of the technologies in the workplace. There was also broad agreement among the experts that training, upskilling and reskilling is a crucial area in which social dialogue can make a difference and influence the digitisation process positively. The monitoring and evaluation of the impacts of technology implementation, particularly in the case of IoT and VR/AR, is another area in which social dialogue should play a central role, for the benefit of both workers and organisations. With regard to 3D printing, the assessment of risks and the monitoring of impact mainly concern workers' health and safety. In the context of IoT use, social dialogue can contribute positively by ensuring that adequate safeguards are put in place to protect workers' fundamental rights (including privacy and data protection rights) and make sure the technology is not used for purposes other than those initially communicated to employees.

Role of social dialogue in the selected establishments

In establishments with works council representation – such as Airbus Getafe, BAM Infra, Bosch Rexroth, CABB, KLM E&M, Sanmina and TTI Algeciras – the involvement of works councils in the digitisation process varied. Overall, works councils were mostly concerned with occupational safety and job security rather than challenges or issues directly linked to digitisation (for example, privacy and data protection). This may be because of worker representatives' lack of training and vision about the medium- and long-term implications of digitisation for working conditions. An exception is Bosch Rexroth, where the works council is formally involved in the introduction and implementation of all new digital technologies. This practice is not uncommon in German establishments,[25] given that the Works Constitution Act (Betriebsverfassungsgesetz) provides works councils with a variety of co-determination rights, including in areas impacted by technological change.

At Bosch Rexroth in Lohr am Main, the works council exerts its oversight of technology adoption in terms of potential impacts in the workplace, for example in relation to working time, changes to occupations, ergonomics and physical workplace design, and data protection. Since 2014, a dedicated committee of the works council has been addressing Industry 4.0-related issues that may affect employees, by assessing, in advance, the changes and potential negative effects of the introduction of any given technology on working conditions through risk assessments, taking into account employees' concerns, their experiences of using the technologies and examples from other companies that have deployed the same technologies. Once a technology is approved and implemented, works council working groups at the department level keep monitoring the impacts on employees. Since 2016, the procedure has been formalised in a central company agreement between the works council and the management board. The experience at Bosch Rexroth suggests that formalising the procedure in a set of rules and processes, with a focus on monitoring the process and the effects of technologies, facilitates technology adoption in the workplace and fosters greater employee engagement and buy-in.

25 The Works Constitution Act establishes the right of employees in Germany to form a works council in establishments with at least five employees.

In the other establishments, the role of the works council in digitisation concerned the provision of information and carrying out consultations, with limited or no scope to influence decisions on technology adoption and implementation. In these establishments, as long as a plausible reason for adopting the technology was given (efficiency and quality gains), the decision was not challenged, or any concerns flagged by works council representatives.

In establishments with trade union representation (in some cases in addition to works councils) – that is, Airbus Getafe, CABB, Centro Seia, Lohja Hospital and TTI Algeciras – trade unions focused mainly on pay and working hours and less on the introduction of new digital technologies and potential risks arising from their use in the workplace.

At CABB, although the works council and trade union representatives had no influence on decisions related to technology adoption, they played an important role in some aspects of the digitisation process, for example by demanding and participating in risk impact assessments carried out during the pilot phases and the monitoring of potential risks – mainly health and safety risks – during the roll-out of the technology. The assessment of health and safety risks in the workplace is an important requirement according to the European Framework Directive on Safety and Health at Work (Directive 89/391/EEC). Furthermore, the most recent collective bargaining agreement signed in 2021 mentions aspects linked to digitisation, for example new skills and training requirements arising from the increasing use of digital technologies and compliance with data protection and privacy rights.

Similarly, at Mariasteen, technology adoption and its impact on the workforce has not been per se a topic of negotiation with formal employee representation, but trade union representatives have been very involved in the digitisation process since the beginning and have provided input at different stages. For example, they raised some initial concerns over the speed at which changes would have been introduced in the workplace, which were addressed by the management team by allocating extra time for testing and fine-tuning before the technology was rolled out.

Overall, in establishments with trade union representation and worker representative bodies, digitisation was generally viewed positively by employee representatives for creating opportunities for higher wages or better working conditions. This was particularly the case at Centro Seia, located in Sicily, where wages are lower than the national standard wage, and trade unions' main concerns are to increase wages, ensure equal pay for women and provide job security. From their perspective, innovation and technological change is not seen as a threat to employment but rather is welcomed insofar as it contributes to higher returns or greater market shares, paving the way to better employment opportunities and higher wages.

Chapter 2 – Summary

- The underlying reasons for introducing and implementing digitisation technologies in the establishments investigated was to optimise processes, improve the quality of products or services, increase efficiencies and ultimately reduce costs. Technologies were also seen in most establishments as a source of competitive advantage.
- Experts in the Delphi survey pointed to key elements of the successful implementation of technologies in the workplace. These include having an explicit strategy with a phased approach to implementation based on experimentation and piloting, early communication and employee involvement, the provision of upskilling, reskilling and training on an ongoing basis, and setting up strategic partnerships and collaborations with other companies and relevant organisations. These elements were found to different extents in the establishment practices illustrated in the case studies.
- In most establishments investigated, peer mentoring and informal and on-the-job training were more common than formal training. Apart from Bosch Rexroth and Sanmina, where training is an important part of the digitisation strategy, the establishments did not make a prior assessment of skills needs or establish training plans to prepare the workforce for the technological change.
- In most of the case studies, the approach to digitisation was top-down, with limited employee involvement in the decision-making process, even in establishments with formal employee representation. Technological change was more readily accepted at Bosch Rexroth than in the other establishments, as employees were fully involved in the process of technology adoption and their feedback was incorporated into the decision-making on digitisation.
- While social dialogue can play an important role in and influence positively technology adoption and implementation at the establishment level, the evidence from the case studies suggests that digitisation is not a major source of concern for trade unions and works councils in most of the establishments investigated. In these, the implications of technological change did not feature prominently on the agendas of works councils and trade unions representing employees. Negotiations and consultations continue to revolve around more traditional social dialogue topics.

3 Impact of digitisation technologies on work organisation and job quality

Business model and performance

A business model defines how an organisation is organised to deliver value to its customers (Teece, 2010). Digitisation is expected to lead to a reconfiguration of existing business models (Schiavi and Behr, 2018), for example by rendering them more data driven. The collected data can be used for different purposes, for example to systematically detect patterns and generate valuable insights, informing the ways in which products and processes could be better designed, manufactured, operated and serviced, and ultimately can be used to run complex production processes. Digitisation can also blur the distinction between technology companies and other types of companies, creating new business models. This is particularly the case for IoT, which allows companies to leverage collected data to offer new product–service bundles (McKinsey Digital, 2015).

In the establishments investigated that have adopted IoT technologies, data have become more central to their business models. The quality of management and decision-making has also improved as a result of more advanced analysis of the IoT-generated data. The greatest impact on the business model was found at the Swedish Sanmina manufacturing plant where, following the adoption of the integrated IoT platform, production became much more distributed and closer to customers. Sanmina customers can remotely access data on the status of different products and obtain new insights. The establishment is also moving towards a co-creation model, whereby customers can provide new input data or change their orders; the data are automatically updated on the system and taken into account in the production process. The Sanmina case exemplifies the extent to which technology can be leveraged to provide new value-added services for customers, with positive impacts on profitability.

Similarly, for Estonian gelling agent producer Est-Agar, access to real-time, granular and more reliable data improved relationships and communication with clients about products and production processes. IoT was also an enabler of other digital technologies, resulting in a more data-centred business model and creating new business opportunities.

In general, the technologies adopted broadened the range of products or services provided, allowing the establishments to keep up with the pace and demands of changing markets. This was particularly the case for the establishments adopting VR/AR solutions, where the technologies were mostly applied to increase the efficiencies of day-to-day operations.

In the case of 3D printing, the technology did not significantly influence the establishments' business models, as 3D printing was used as another production technology alongside other more traditional manufacturing methods. Rather, the technology was used to support and further enhance already established business models. 3D printing allowed some establishments – such as Bächer Bergmann and Bosch Rexroth – to increase their value proposition and market access by offering new and specialised services while at the same time reducing reliance on external suppliers. At KLM E&M, the technology was leveraged to increase efficiencies by enabling the production of custom-made tools for more efficient maintenance. 3D printing also provided a solution for plastic recycling, helping KLM E&M work towards its goal of reducing plastic waste by 50%.

The use case of 3D printing at Airbus Getafe is an example of a decentralised production process: aircraft parts are printed on site when needed, reducing delivery costs and inventories. There is an extensive exchange of 3D printing designs between the Getafe site and other Airbus sites in the rest of Europe and the United States.

No major change in its business model as a result of 3D printing use was apparent for construction company BAM Infra, where the extent to which the technology is used largely depends on clients' willingness to incorporate this novel technique in their constructions. A greater demand for 3D printing may substantially shape the company's business model in the future: rather than establishing large construction sites and organising most of the building activities on site, construction work may become a just-in-time logistical process, whereby building materials are made available at construction sites only when needed.

Work organisation

There was agreement among the experts that, of the three digitisation technologies, IoT is potentially the most disruptive, impacting all areas of work organisation investigated (Table 6). However, this impact varies, depending on technology implementation and the sector of activity. The impact of the other two digitisation technologies is considered more limited to workflows and quality control and standards, and potentially also involves the redefinition of tasks in the case of VR/AR technologies. These findings were confirmed and enriched by the case studies.

Table 6: Areas of work organisation most impacted by the use of digitisation technologies

	IoT	3D printing	VR/AR
Internal organisation and decision-making	Supports greater individual decision-making and increased communication between departments.	No major impact on internal organisation or decision-making.	Supports greater individual decision-making.
Task definition and content	Shift from manual and routine tasks to managerial and analytical tasks.	Greater emphasis on pre-processing/pre-production tasks and reductions in physically demanding tasks. Shift to more cognitive tasks for manual workers.	Tasks either enriched or simplified.
Workflows, quality control and standards	Enhanced quality control and optimisation of workflows and processes. Data-driven workflows and quality control, leading to better planning.	More predictable and streamlined workflows. More flexible processes favouring decentralisation of production.	Enhanced quality control and optimisation of workflows and processes.
Employee monitoring and control	Greater scope for close employee monitoring. Technological capability to expand employee data usage to other purposes.	No specific concerns over employee monitoring.	Data protection concerns arise when combined with other more potentially invasive technologies, such as IoT.

Note: *Only survey answers consistently rating the above areas as having an intermediate to high impact were considered. The colour coding is indicative of the extent to which the expected impacts of each technology were reported by experts as positive (green) or negative (red). Ratings for areas for which there was no overall agreement among experts on the impacts are not reported, that is, the colour scheme is not applied. Although no consensus was reached for some of the broad areas of work organisation in relation to 3D printing and VR/AR, the experts nonetheless agreed on specific statements, which are reported in the narrative below. The text in each cell refers only to findings from the case studies.*
Source: *Based on results from the Eurofound Delphi survey and the case studies, 2020–2021*

Different gradients of impacts on work organisation were found across the case studies. This partly depended on the embeddedness of the technologies in business and work processes. The most frequent impacts reported were in the areas of workflows, quality control and standards, and task definition and content. For IoT, impacts on decision-making and employee monitoring and control were also reported.

Internal organisation and decision-making

According to the experts in the Delphi survey, the introduction of the IoT leads to more data-driven decision-making, reducing paperwork and enabling more accurate planning. This was also apparent in the establishments investigated that adopted IoT technologies. In the case studies, access to real-time data also increased the interdependency between departments and roles and, as a result, teamwork became more central in day-to-day operations. However, technology adoption did not entail any major changes to organisational structure compared with before the digitisation process.

At Italian plant nursery Centro Seia, the better quality and richness of the data collected through the IoT tracking system enabled supervisors and production managers to plan shifts better and deploy resources as needed. Similarly, at the Bosch Rexroth manufacturing plant in Lohr am Main, the deployment of IoT technologies allowed supervisors to plan shifts more precisely and efficiently based on the data collected and processed automatically through the manufacturing execution system. Previously this was carried out by hand.

The introduction of the central monitoring system at utility company CABB, fed by data collected from a range of IoT sensors installed throughout the water supply network, facilitated individual decision-making at all levels, reduced the need for paper-based reports and improved information management: ‘you no longer have to go and write down the data, the data come to you’, according to one manager interviewed. Similarly, the use of AR drones equipped with IoT sensors made it possible to visualise the entire water network by mapping and generating high-quality images, hence facilitating maintenance operations, as faults and breakdowns could be located without the need for manual point-by-point checks. Once the source of a problem was detected, operators were dispatched to execute repairs on site. In this way, the AR application significantly simplified decision-making processes for technical staff in the asset and technical services department.

Interactions and communications between departments also increased in all establishments deploying IoT solutions. This was particularly prominent at the Sanmina manufacturing plant, where communication between the shop floor, engineering units and customer service teams intensified following the adoption of the IoT platform, with assemblers being more involved in decision-making on the shop floor, for example on the most suitable tests to conduct on products or the root causes of errors. The technology also reduced the need to produce paper reports as all reports are automatically generated by the system.

The use of IoT technologies at TTI Algeciras also led to the intensification of communication using digital means, reducing the necessity for the in-person execution of orders, and automating most of the decision-making processes. However, even though most activities are automated and digitised, workers are still required to intervene when specific problems arise.

With regard to 3D printing, the experts agreed that use of the technology may have impacts on work organisation and decision-making if it is fully embedded in work and business processes, necessitating better communication and coordination between departments (from pre-processing, production and post-processing to product management, marketing and sales). Overall, however, the use of the technology in the establishments investigated did not have a significant impact on either internal organisation or decision-making.

At Bosch Rexroth, the use of 3D printing required some adaptations to the production line to fit the new process better, allowing the incorporation of 3D printers. For example, a second production line for 3D-printed parts was incorporated that operates separately from the more traditional approach to produce more complex products. In the case of construction company BAM Infra, the use of 3D printing resulted in the greater dependence of workers at building sites on 3D designers and planners. Because of the intricacies of the construction design, not all problems could be solved on site; some had to be relayed to designers, often operating at a distance.

Similarly, with regard to VR/AR systems and applications, the experts agreed that adoption and implementation of these technologies is likely to result in improved communication between teams (or workers in different locations), more distributed decision-making and a move to new forms of collaboration (for example, telementoring), depending on the particular use case.

Evidence from the case studies, however, suggests that the use of VR/AR applications tended to enhance individual decision-making and, to a more limited extent, improved communication or collaboration between departments or teams. For example, at Bächer Bergmann, AR allowed workshop employees to be more autonomous in their work by relying exclusively on AR visualisations without having to consult with designers, thus potentially reducing opportunities for collaboration and mutual learning.

The extent to which VR/AR solutions impact on teamwork and collaboration depends on the particular use case. At Bosch Rexroth, where AR was used as a communication tool, the application enabled more efficient collaboration and real-time communication between service engineers and repair technicians in the field, with the latter providing guidance from a central location more precisely and effectively without having to be physically present or having to rely on images.

A mixed impact was found at CABB, where the integration of VR in BIM software both supported collaboration within work teams, with employees able to enter the VR model at any time and check and analyse distinct aspects of a water network installation project, and facilitated individual decision-making, cutting down on interactions with team members and requests for approval within the line of command.

Task definition and content

According to previous Eurofound research, physical, routine and machine use tasks are in decline, while intellectual tasks, social tasks and use of information and communication technologies (ICT) are becoming more prevalent (Eurofound, 2016a). Digitisation has been shown to bring transformations in existing jobs, by changing the way that tasks are carried out and their content and – as a consequence – the skills needed to perform these tasks (Eurofound, 2018e). According to the experts in the Delphi survey, IoT and VR/AR technologies are likely to have impacts on task definition and content, albeit to varying extents, depending on the particular use case.

With regard to IoT, the experts agreed that the technology entails a shift from operational tasks to supervisory, control, coordination and planning tasks, and from manual to data-driven tasks. For some job profiles, tasks may also become more complex, requiring the interpretation of different sources of information. These findings were corroborated in the case studies.

In most establishments, the IoT systems simplified the work of production workers while adding more complexity to the work of supervisors and production managers and engendering a shift from more routine tasks towards planning and data-driven analytical tasks. Prior to the deployment of the automated IoT systems, supervisors and managers at the establishments had to rely on handwritten data compiled by workers on process specifics such as shift start and end times, breaks, number of products handled and number of faults. The greater reliance on data by supervisors and production managers necessitated more frequent collaborations with innovation and IT units when performing more analytical tasks.

Furthermore, at Sanmina and Est-Agar, the IoT systems eliminated some manual and repetitive tasks of production and assembly workers while adding variety to their work; for example, they were required to conduct more tests or perform more frequent repair work and maintenance, thus increasing their level of responsibility overall. Despite such changes, a large part of the work of production workers and assemblers in these establishments is still manual.

While the adoption of IoT contributed to the replacement of some routine tasks with higher value tasks in most establishments, at Sanmina the digitisation process – which began in the early 2000s – led to the gradual replacement of about 45% of all job positions at the plant. The jobs that were eliminated were predominantly manual jobs, while roughly the same number of engineering and managerial positions were created for conducting in-depth data analysis.

At TTI Algeciras, the digitisation process abolished some of the most dangerous manual tasks, for example the manual twistlock operations during the load and discharge process, which would otherwise have been carried out by stevedores. By contrast, cognitive tasks such as data analysis and taking responsibility for operational control and supervision have increased in recent years. Similarly, at CABB, the extensive use of IoT in the establishment led to the elimination of manual tasks performed by plant operators, for example manual meter reading and on-site inspections; their job profile was subsequently upgraded to reflect the take-up of more supervisory roles.

Depending on the specific application, VR/AR technologies can also lead to either the enrichment of tasks and content or the simplification of tasks to a sequence of steps. The Mariasteen case, for example, shows that digitisation technologies can be used to empower employees and help them to perform more challenging or demanding tasks. Similarly, at Lohja Hospital, the VR application enabled nurses to take on greater responsibilities and work with patients on rehabilitation, replacing therapists, whose time was freed up to provide tailored therapeutic support to patients with more complex needs who could not benefit from VR-assisted therapy. Albeit applied to a different domain, VR use in utility company CABB also contributed to enriching task content, particularly for engineers and technicians. In this case, the integration of VR into BIM software made it possible for them to step into 3D models and designs, inspect the work in progress and, in doing so, detect possible errors or assess labour risks in water network installation or renovation projects.

Although 3D printing was not consistently rated by the experts as impacting on task definition and content to a large extent, there was agreement that the technology entails a shift away from more conventional production and assembly methods and the creation of new processes, potentially triggering a redefinition of jobs and tasks. This was apparent in the case of Bächer Bergmann, where the use of 3D printing shifted task content from more repetitive tasks towards the preparation of material, organisation of the process and finishing touches. At both Airbus Getafe and Bosch Rexroth, the use of 3D printing somewhat increased task variation, resulting in greater employee motivation and engagement. The innovation manager interviewed at Airbus Getafe highlighted that the technology enables manual workers to come up with innovative and practical ideas, increasing the added value of their work.

In the case of BAM Infra, at the Driebergen-Zeist site, 3D printing entailed a subtle shift in certain tasks carried out off site at the 3D printing factory, for example formwork, steel fixing and curing of the cement. Since the construction sector is moving towards more up-front planning, problem-solving is also concentrated more at the design stage than at the construction site. The assembly of the 3D-printed elements was viewed as a similar task in the spectrum of assignments, which only required more precision in handling once on site.

According to the experts consulted, changes to task content may also affect recruitment policies, with relatively new job profiles (for example, innovation managers, digital strategists and data scientists) and those with added value functions being prioritised. This was also found in some case studies. For example, Centro Seia hired additional ICT staff to handle the programming and maintenance of dashboards to enable supervisors to analyse data generated by the IoT system. The 3D printing factory at BAM created a new step in the construction supply chain requiring five specialists (tertiary-educated process engineers) with knowledge of the new technology. The set-up at the factory is scalable: if the demand for 3D printing increases, the set-up at the factory can be copied and pasted at another site to allow more jobs to come on stream.

Workflows, quality control and standards

All three digitisation technologies were found to have positive impacts on workflows, quality control and standards. According to the experts, the use of IoT, in particular, leads to more formalised procedures and processes, faster and leaner workflows with greater emphasis on quality control and standards, and increased data sharing within businesses and throughout the value chain (in the case of horizontal integration). Some work processes may also become centralised as data can be collected across different departments.

Evidence from the case studies – CABB, Bosch Rexroth, Centro Seia, Est-Agar and Sanmina – shows that the introduction of IoT has contributed to reductions in bureaucratic processes and the handling of paper-based reports, and to the streamlining of workflows, with a general reduction in execution times and errors, improved efficiency of operations and a greater focus on product quality control.

At plant nursery Centro Seia, the implementation of quality standards and controls through real-time monitoring became much more refined, delivering rich and granular data about the production process, and enabling the traceability of plant batches, required to certify production quality. Similarly, at the Swedish Sanmina manufacturing plant, the adoption of a unified IoT platform has made the production process more systematic, with a strict order of tasks and procedures across the value chain, ensuring quality control and uniform high standards across delivered products and services. For example, the IoT system automatically checks whether each process has been performed correctly. If a wrong procedure is launched, or a value is beyond the set limits, the system shows an error, which must be corrected before other activities can be performed.

At CABB and Bosch Rexroth, IoT enabled a shift from ad hoc supervision in cases of malfunctions to continuous monitoring and predictive maintenance. Prior to the deployment of the IoT system at CABB, leak detection and water flow measurements were carried out manually, with lower levels of accuracy, and could not be performed on a regular basis, resulting in downtime and inefficiencies.

The extensive IoT network at TTI Algeciras improved the efficiency of work processes, with general reductions in operation times and process errors; facilitated maintenance tasks thanks to the remote control systems; and, as a result of predictive maintenance, led to general improvements in the safety and control of occupational risks.

With regard to 3D printing, the experts agreed that the technology can simplify production processes and make them leaner, as the value-added activities are concentrated in the pre-production phase (for example, design and prototyping). 3D printing is also expected to significantly reduce lead times and costs, allowing designers to iterate multiple prototypes compared with conventional manufacturing, which will also open the door to co-creation, whereby customers are involved in the production process. As 3D printing also requires post-processing activities, these may give rise to new processes, and new workflows may be needed to manage overlapping orders and work carried out in different locations in the case of decentralised manufacturing.

Among the establishments investigated that use 3D printing, the greatest impact of the technology on workflows and quality control was seen at Bächer Bergmann. In contrast to traditional woodworking, almost all design work is carried out in advance, with 3D printing (on the computer) and most production work carried out unsupervised. In addition, as the technology makes exact reproduction easier, adapting a pilot design is simplified. As a result, trial-and-error approaches to design have become more viable. As the whole design is available digitally, pre-emptive design checks can be carried out more easily, without material being unnecessarily used. The use of 3D printing at Airbus Getafe favoured the decentralisation of production processes, as the design site, the printing order site (often remote) and the final printing of a given part can be separated. Some parts designed in Spain are meant for the US and German markets, whereas other parts printed in the establishment are designed in the rest of Europe. This decentralisation of production gives rise to co-production activities and has various advantages, for example reducing the distances that parts have to be transported and the stock on hand, thus changing transport and warehousing strategies.

In the case of construction company BAM Infra, the dependence on (off-site) designers and planners has gone hand in hand with a more planned and predictable workflow, which has shifted to a more just-in-time-based construction process. Furthermore, the use of 3D-printed elements in construction has added a layer of quality control away from the construction site: the elements are checked at the production factory for adherence to specifications. When the elements are assembled, regular quality checks of the whole construction are still required; 3D printing has not altered construction standards, even if more complex shapes and forms can be produced. These complex shapes and forms must still adhere to regular construction standards, which puts the burden of proof on engineers in terms of calculating construction strengths, to prove that 3D-printed elements have the same strength as solid concrete blocks.

Quality control was an issue for KLM E&M in the initial phase of technology adoption as employees could freely experiment and print their own prototypes and tools. This resulted in different departments within KLM E&M printing different tools, with little coordination and monitoring of quality. There was hence a need for greater involvement of the central engineering team responsible for certification and quality control, to ensure that all necessary steps were completed, including making an official drawing of a new tool, classifying the tool and registering it using a data management programme.

With regard to VR/AR, the experts consulted noted some positive impacts as the technologies contribute to greater quality control and compliance with protocols, and optimisation of workflows and processes, with workers accessing information when needed and executing pre-defined tasks step by step. This positive impact was found, for example, in the social enterprise Mariasteen, where the LGS – equipped with (weight, shape and position) sensors – monitors the fulfilment of quality parameters at each step of the production process. If a quality standard is not met (signalled by a red light), shop floor employees are guided step by step to complete the task correctly.

At CABB, the use of BIM software with integrated VR capabilities also resulted in greater quality control. The visualisation of VR models helped to reduce errors and enabled a more accurate assessment of labour risks in the development of water network installation projects.

Employee monitoring and control

To varying extents, most advanced digital technologies have logging and reporting functionalities to enable the collection of fine-grained information about their usage. According to the experts consulted in the Delphi survey, 3D printing is not regarded as significantly influencing workplace monitoring and control practices. The logging and reporting capabilities of 3D printing are, however, important in terms of guaranteeing the traceability of the process for the optimisation of production and delivery times, and in providing security for the process (for example, in the case of production of medical products and devices).

By contrast, IoT and, to some extent, VR/AR applications are potentially more intrusive as they can harvest and record a wide range of data, which can potentially be used for monitoring and surveillance purposes, raising ethical concerns, particularly about privacy and data protection. Such concerns are heightened when digitisation technologies are combined in more pervasive applications, for example when VR/AR devices used for training are endowed with IoT sensors, enabling the collection of biometric data to determine personal factors hindering learning with VR/AR devices. Equally intrusive is the use in warehousing and logistics operations of AI-powered AR glasses with extended functionalities that record employees' movements and interactions. Even in situations in which the collected data are anonymised, the underlying algorithms may have the capability to identify users by cross-referencing data with individuals' digital traces (Eurofound, 2019a).

In most establishments investigated, however, digitisation technologies were primarily introduced to optimise business processes and increase efficiency rather than for employee monitoring and control purposes per se. This is also consistent with findings from the 2019 European Company Survey, which showed that data analytics tended to be used with the objective of improving processes rather than for employee monitoring (Eurofound, 2020c). The analysis of the survey data also points to a correlation between the existence of data analytics for monitoring employee performance and workplaces where employees' pace of work is determined by machines or computers to a significant extent, suggesting that such monitoring may be a by-product of such technological processes of production.

The data collected and recorded by VR/AR devices at Bächer Bergmann, Bosch Rexroth, CABB and Mariasteen are primarily used for quality control purposes, while the VR application deployed at Lohja Hospital for patient rehabilitation does not use any data gathering software. In the specific case of Mariasteen, the data collected are used to assess the complexity of the tasks that each employee can handle and to adjust the workload in a way that fits better with their capabilities. The R&D team is considering adding stress sensors (biometric data) to the AR guidance system for gathering and analysing data to allow adjustments to be made to employees' workloads and task allocations, with a view to reducing their stress when performing the assigned tasks. In such cases, the data collected would be far more personal than those currently being collected, and adequate protections and safeguards must to be put in place to preserve data protection and employees' privacy.

Of the four establishments investigated that have used IoT, only Est-Agar leveraged the technology to closely monitor the quality and quantity of work carried out by employees. The increased monitoring and surveillance of the work of employees in production initially raised concerns among employees and created some anxiety. To address such concerns, the management team held individual meetings with employees and general staff meetings to explain the benefits for employees of the two adopted technologies (in terms of higher wages and a greater variety of tasks) and the positive impacts on working processes. According to the company CEO, the introduction of the technology created a productivity-driven culture in the establishment, in which employees are financially compensated for their greater performance and the monitoring is accepted as a necessity.

Although the IoT-based digital tracking system at the plant nursery Centro Seia was primarily introduced to ensure full traceability of the grafted plants, it also enables the collection of real-time information about the individual performances of operatives on the shop floor in terms of the quality and speed of their work. While shift supervisors use the monitoring data for shift planning purposes, the management team uses them for forecasting and strategic planning and for calculating financial rewards, as well as a basis for offering more suitable shifts, contract extensions and promotion opportunities to operatives (to supervisory roles).

At Est-Agar and Centro Seia, employee monitoring was not challenged by staff nor were major concerns raised. Contextual factors may have played a role in the acceptance of the monitoring technology in these establishments. At Est-Agar, the ready acceptance of employee monitoring may be ascribed to cultural norms, inherited from the Soviet period, and the general acceptance of monitoring in society. At Centro Seia, which is located in an area with limited employment opportunities, both operatives and supervisors welcomed the IoT monitoring for creating new opportunities for promotion and incentives, as the employee data are used to determine financial and non-financial rewards. According to the management team, the greater accuracy and reliability of the IoT data allows incentives to be better targeted to high-performing operatives and supervisors.

At the Samina manufacturing plant and TTI Algeciras, the management teams reported they did not use employee data to determine employees' wages and promotions; however, both establishments have the technological capability to do so and a wide range of employee data is nonetheless collected.

In the case of Bosch Rexroth, the central company agreement explicitly states that, while feasible, neither behavioural nor productivity control is a goal of technology introduction. In the case of AR used in training, data are evaluated only in the context of the training efforts (to provide immediate guidance) and are discarded afterwards. For data resulting from human-to-machine connection through IoT, a manual is in place that clarifies in detail who has access to the data, to what degree and for what purpose. Interestingly, different rules apply in company establishments in China, where global positioning system (GPS) trackers on the shop floor are commonly used to monitor the whereabouts of employees.

One general concern is that, once introduced in the workplace, pervasive technologies such as IoT can be scaled up quickly, enabling higher levels of employee monitoring and control and possibly allowing these technologies to be used for other, more intrusive purposes than were initially intended. Such practices can have negative collateral effects, such as increased levels of stress and frustration for the employees being monitored, loss of privacy and reduced trust in management (Eurofound, 2020c).

Job quality

In terms of job quality, expert opinion and evidence from the case studies point to a particularly significant impact of the three digitisation technologies in the area of skills and discretion. In the case studies, technology use was also found to increase work intensity, notably at the time of initial deployment. While IoT adoption was found to reinforce the existing task-driven work organisation, characterised by more limited work autonomy for those working on assembly lines, it increased job discretion for higher skilled workers in managerial and engineering positions. Other impacts of IoT include a reduction in exposure to more traditional occupational risks, making the work environment safer. Experts also rated the impact of VR/AR on the social environment as intermediate to high, opening up opportunities for new forms of collaboration. This was also found in some case studies, but the technologies can either diminish or increase social interactions, depending on the specific applications and workplace practices involved.

Table 7 provides an overview of the elements of job quality impacted by the three digitisation technologies.

Table 7: Elements of job quality impacted by the use of digitisation technologies

	IoT	3D printing	VR/AR
Physical environment	Reduced exposure to physical risks but potential increased exposure to ergonomic risks.	Reduction in physically demanding tasks, resulting in less physical strain. Potentially negative physical risks offset by health and safety measures.	Overall positive impact on physical environment. Potential physical risks flagged only in cases of prolonged use of VR headsets (which, however, did not occur in the case studies).
Social environment	Technology can either increase or decrease social interactions depending on the particular application and method of implementation.	Increase in social interactions between departments and roles.	Technology can either increase or decrease social interactions depending on the particular application and method of implementation.
Working time quality	No change to working time arrangements; rather, more efficient use of working time. 24/7 production shifts continue to apply.	No change to working time arrangements; rather, more efficient use of working time.	No change to working time arrangements; rather, more efficient use of working time.
Work intensity	Higher work intensity in the initial phase of technology implementation because of the need to adjust to new tasks and responsibilities, especially if no formal training is provided. Over time, decrease in work intensity for shop floor or operational staff and some increase in work pressure for employees in managerial positions tasked with analysis of constant and larger data flows. In highly digitised workplaces where technology sets the pace of work and order of tasks, there are greater risks of work intensification.	Direction of effects (positive or negative) depends on different factors, for example the materials used and scale of use of the technology.	Only one application resulted in ‘digital stress’; this occurred because of limited training provision.
Skills and discretion	Technology results in greater job discretion for employees in managerial and engineering positions and drives acquisition of new advanced digital and analytical skills, providing better career prospects within and outside the establishment. Technology reduces work autonomy for production and assembly workers and reinforces the task-driven work organisation characterised by limited work autonomy for those working on assembly lines. Technology drives the acquisition of basic digital skills for blue-collar workers and technology-specific skills, which are not necessarily transferable to other companies (limiting occupational mobility). Digitisation of most tasks of blue-collar workers drives the upgrading of job profiles if upskilling and training are provided.	Adjustment in skills, depending on the context and sector. Greater emphasis on 3D design and planning skills. Production workers become more reliant on designers. Skills generally acquired on the job, rather than through formal education.	Applications enhance workers’ capabilities and skills. More limited impact found on work autonomy.
Prospects and earnings	Impact on wages when technology used to monitor employee performance. Greater career opportunities based on training or experience, particularly for employees in engineering and managerial positions.	No direct impact on wages, but possibility of receiving financial rewards for added value activities. Greater career opportunities through acquisition of skills on the job.	No direct impact on wages or career opportunities.

Note: *Only survey answers rating the above elements as having an intermediate to high impact were considered. The colour coding is indicative of the extent to which the expected impacts of each technology were reported by experts as positive (green), negative (red) or neutral (orange). Ratings for areas for which there was no overall agreement among experts on the impacts are not reported, that is, the colour scheme is not applied. Although no consensus was reached for some indices of job quality in relation to individual technologies, the experts nonetheless agreed on specific statements, which are reported in the narrative below. The text in each cell refers only to findings from the case studies.*
Source: *Based on results from the Eurofound Delphi survey and the case studies, 2020–2021*

Physical environment

The experts in the Delphi survey agreed that IoT has an overall positive impact on the physical environment in the workplace thanks to the sensors that control various parameters, reducing exposure to physical risks and accidents, for example with regard to maintenance and repair. In relation to the use of VR/AR devices, the experts highlighted potential ergonomic risks specifically involving hand gestures and tracking (activation of the upper body), but these can be minimised or neutralised if the technology is integrated in a way that ensures compliance with existing rules that prevent such risks. A 2018 EU-OSHA foresight study identified a number of occupational risks associated with the use of VR/AR devices, including a decrease in 'situational awareness' because of motion sickness and temporary loss of awareness of the user's immediate surroundings (EU-OSHA, 2018). There is, however, a general lack of empirical evidence about the physical risks arising from the use of VR/AR technologies in the workplace. In relation to IoT and sensor technologies, the EU-OSHA foresight study also drew attention to the occupational safety and health risks posed by cyberattacks. Hackers may take control of work devices, making them behave in unexpected or hazardous ways, or may obtain occupational safety and health-sensitive data or personal data.

In the case studies, both IoT and VR/AR technologies were found to improve workers' physical safety by monitoring the work environment, detecting potential hazards at an early stage, reducing risks of errors and automating more hazardous tasks. No specific physical risks were found in relation to VR/AR use in any of the case studies, possibly because none of the use cases involved prolonged use of VR or AR headsets. In addition, the use of such headsets was discretionary for employees, as at Lohja Hospital for patient rehabilitation or at Bosch Rexroth for training purposes.

The positive contribution of IoT and VR/AR to the physical environment was particularly noticeable at CABB, where the technologies reduced the need for on-site inspections and decreased exposure to risky environments in relation to monitoring, data collection and maintenance operations in the water network (including in difficult-to-access areas). This is a very relevant aspect for the establishment, given that the traditional activities of water network operators involve exposure to very diverse ambient and chemical risks (for example, handling of chemicals and exposure to excessive noise, very high or low temperatures, high humidity and bad odours).

Similarly, IoT-based automation at TTI Algeciras resulted in a significant reduction in the number of work accidents, which is remarkable in a sector in which the rate of work accidents is high. The yard, where automatic stacking cranes and semi-automatic shuttle carriers and port cranes operate, is fully fenced, preventing workers entering unless they are authorised to carry out repairs or preventive maintenance. This creates a system in which there are fewer interactions between humans and machines and there is therefore less danger.

One concern related to IoT use highlighted in the interviews at both Est-Agar and CABB was the increase in sedentary work. Employees are able to access data from their workstations or computers, thus potentially increasing their exposure to ergonomic risks and affecting their eyesight and levels of physical activity. This concern has become more prominent in these establishments during the COVID-19 pandemic with more staff teleworking, given the poorer ergonomic conditions at home compared to the workplace.

In the establishments investigated that used 3D printing, the technology was said to diminish physical strain by reducing physically demanding tasks. In the case of BAM Infra, 3D printing also allowed for 'cleaner' construction sites, with 3D-printed elements made available on site as required. This was considered to contribute to site safety as more materials on construction sites means more hauling, more strenuous movements and more waste, thus increasing the risk of accidents occurring.

At Bosch Rexroth, a change in risks in the working environment was reported in relation to 3D printing use. While there was a reduction in risks from flying metal and sparks, which are encountered when using cutting machines, there was an increase in risks from the metal powder used in printing, which can potentially be harmful to employees' respiratory systems. However, these risks were assessed in the establishment to be equal to if not lower than the risks from cutting machines when wearing the right equipment and taking adequate precautions. This was also the opinion of the experts consulted, who acknowledged that the raw materials used in 3D printing – often in a hard to contain liquid or powder form, as well as ultrafine powders – can pose health risks for workers but that these risks can be offset by putting in place effective strategies and protective measures to minimise exposure.

Health and safety measures were taken in all establishments using 3D printing. These included the provision of safety training to workers using 3D printers and the requirement to wear protective equipment and clothing, enclosing 3D printing systems in a highly controlled environment with proper ventilation and, in larger establishments, performing health and safety and risk assessments and implementing specific protocols for risk prevention.

On a more general level, technology innovation was described in the interviews conducted at Bosch Rexroth as an issue that could cause new psychological risks and discomfort for some employees. In situations in which employees have no choice other than to use a new technology, this may lead to resistance, rejection or lower levels of performance, which in turn can negatively affect both employees and organisations. From this perspective, information provision, adequate training and awareness raising were found to be of particular importance in the change process and areas in which to focus investments.

Social environment

Although the experts did not consistently rate the impact of IoT and 3D printing on the social environment as high, they nonetheless agreed that the adoption of these technologies is likely to increase interdependencies between departments and roles, thus putting a greater emphasis on teamwork and communication. This collaboration extends to customers, particularly in the case of 3D printing, as businesses using this technology tend to adopt a strong customer orientation.

The evidence from the case studies pointed to different outcomes depending on the particular technologies involved and the specific use cases. For example, at Sanmina, IoT adoption resulted in better communication and more interactions within the production unit (between assemblers) and between engineering and management units, as more decisions are taken in collaboration with engineers. At Est-Agar, although production workers continued working in teams, the IoT-based monitoring system reduced the presence of (and interactions with) managers on the shop floor. The close monitoring of employees' activities enabled by the IoT system – including the number and duration of rest breaks – also influenced employees' behaviours to some extent and reduced informal exchanges and interactions between employees during working time. Fewer interactions between production workers and supervisors were also reported at plant nursery Centro Seia, as work activities and processes are mainly monitored on screen. Although operatives are able to monitor their own progress on a dashboard at their workstation and compare this with that of their peers, this was not reported to have led to a more competitive culture. A reduction in face-to-face communication and interactions was also reported at utility company CABB, where the IoT monitoring system facilitated the running of operations remotely, which was a major advantage during the COVID-19 pandemic. However, according to the interviews conducted at CABB, this contributed to weakening the social climate in the establishment. This negative impact on the social environment as a result of the greater ability to carry out work remotely, enabled by IoT, was also noted by the experts in the Delphi survey. These negative consequences can, however, be mitigated through the use of tools for remote communication and information sharing. For example, this was the strategy followed at CABB, where both employees and their representatives underlined the importance of 'the human factor' and face-to-face contact to facilitate teamwork and the need to strike a balance between remote and office work. At TTI Algeciras, to counteract the negative impacts on the social environment, the management team encouraged in-person interactions and meetings as part of day-to-day work alongside use of the highly advanced IoT-based communication system.

In all establishments using 3D printing, the technology did not diminish social interactions in the workplace. If anything, the technology had a positive impact on the social environment. This was particularly noticeable at KLM E&M, where employees from different departments started experimenting with the technology, which led to the creation of a 3D printing community. Trainees from different universities – Delft University of Technology, Amsterdam University of Applied Sciences and Eindhoven University of Technology – who join KLM E&M for about six months, are a major asset to this community, helping employees with limited knowledge of the technology to translate the technical specifications into 3D designs or assisting with the 3D printing of new prototypes. Similarly, an internal informal network for experimenting with 3D printing emerged over time at Airbus Getafe, increasing communication and exchanges between team members and departments and with external service providers. There is also a widespread exchange of digital files between the Spanish Airbus sites and other Airbus sites around the world. Communication and collaboration are important features of working with 3D printing in the context of the decentralisation of production processes.

With regard to VR/AR technologies, both expert opinion and evidence from the case studies pointed to some positive outcomes in the area of the social environment, depending on the particular applications involved. At Mariasteen, the AR application was designed to provide additional support to employees with disabilities engaging in more complex assembly work, without, however, diminishing social interactions between employees. The provision of employee support is an important feature at Mariasteen and is in line with the company's mission and values. Albeit a different application, VR for patient rehabilitation at Lohja Hospital was also assessed positively by staff, stimulating greater collaboration on the ward and resulting in tighter bonds between medical staff, with nurses learning from therapists how to assist patients using the VR headset and taking on more responsibilities. By contrast, AR applied to training – as at Bosch Rexroth – was found to reduce the social component of learning compared with in-person training. VR remote inspections at the same establishment also led to fewer person-to-person contacts, which, during the COVID-19 pandemic, was important in limiting the spread of the virus, while, at the same time, improving real-time communication for service engineers.

The use of VR at CABB for the modelling and visualisation of water network installation projects changed the nature and mode of social interactions rather than diminishing the level of interactions, as the work is carried out by team members virtually but still in a collaborative way. The impact on the social environment was reported to be positive overall, with the technology contributing to greater information sharing and collaboration between different departments and team members.

Working time quality

None of the three digitisation technologies was consistently rated by experts as impacting significantly on working time arrangements. The experts agreed, however, that all three digitisation technologies provide more scope for remote working, including teleworking. This can impact on employees' engagement and work–life balance positively or negatively, depending on management and work practices. Previous Eurofound research found that teleworkers experience longer and more irregular working hours, which can challenge work–life balance (Eurofound, 2020d). The research also showed that different aspects of work organisation (for example, communication and coordination), and management style and corporate culture, play an important role in the impact of this form of work on employees' working time and work–life balance.

Overall, evidence from the case studies shows that the implementation of the technologies did not alter working time for employees; however, there are instances in which technology adoption resulted in more favourable working time arrangements. For example, at CABB, IoT and VR/AR technologies improved working time quality, particularly for water plant operators, even though the establishment continued to operate 24/7. The continuous monitoring of the water network enabled by the IoT system made it possible to reduce night and weekend shifts. The use of both IoT and VR/AR also opened up opportunities to work remotely, which, although appreciated by staff, brought new challenges, particularly for white-collar employees, creating expectations of continuous availability and making it more difficult for them to disconnect.

The effects of digitisation at TTI Algeciras were bi-directional: on the one hand, digitisation led to more flexible working time arrangements and facilitated the move to teleworking during the pandemic; however, on the other hand, it increased work pressure and compromised work–life balance because of the constant flow of information.

The contribution of 3D printing to working time quality was found to be positive in the case studies. Given that 3D printers can also work overnight, employees at Bächer Bergmann were able to schedule their time more efficiently, making more use of their daytime hours. At Bosch Rexroth, employees' work is split between time working at the printer and time spent on other tasks while the printer is running, and this is accomplished within the limits of regular shifts.

Only at KLM E&M did the use of 3D printing result in less favourable working time arrangements. This is because 3D printing is not part of the formal task description of employees in this establishment; 3D design, prototyping and printing are extra tasks that are carried out during downtime or outside working hours, often resulting in unpaid overtime. As reported in the interviews, prototyping new tooling is a process of trial and error and can be time-consuming. The practice at KLM E&M is to allocate additional resources to any new task only when it becomes clear that extra staff members are needed more regularly or on a permanent basis.

Work intensity

According to the experts in the Delphi survey, work intensity is expected to increase if IoT and VR/AR technologies are used for employee monitoring purposes. Use of IoT can also result in increased pressure to fulfil productivity metrics. Although work intensity was not noted by the experts consulted as an area of concern in the case of 3D printing, the deployment of the technology is nonetheless expected, at least initially, to increase demands on the workforce and management in terms of them having to integrate new working practices, methods and skills. This impact will be more apparent in work environments where the technology is used regularly and is fully embedded in work and business processes.

The evidence from the case studies suggests that use of the technologies can lead to greater work intensification, particularly in the initial phase of deployment and particularly if no or limited training or support is provided to workers. For example, the use of the VR headset for patient rehabilitation at Lohja Hospital led to a degree of 'digital stress' for occupational therapists, and especially for nurses, who learnt to use the new equipment on the job. This 'digital stress' reportedly diminished over time as familiarity and IT skills improved, either through usage of the technology or through informal knowledge transfer between medical staff. In addition, at CABB and Est-Agar, the use of IoT resulted in higher levels of stress among staff during the transition phase, mainly relating to the process of learning and adjusting to new tasks and responsibilities. However, once workers familiarised themselves with the newly introduced technology, the workload eased off, notably for shop floor or operational personnel, although employees in managerial positions had to cope with new tasks requiring additional analytical skills, thus adding more pressure to their day-to-day work. The approach followed in Centro Seia was to hire additional operatives and supervisors to stabilise the pace of work and reduce the pressure on existing operatives while learning to use the new system. A high level of digitisation has been a feature at TTI Algeciras since it was established. In this highly digitised port terminal, the technology determines, to a large extent, the speed of work and order of tasks; this demands working at high speed, adding pressure for workers.

Although at Mariasteen the AR technology was designed to help employees cope better with more complex assembly tasks, some employees experienced an increase in work intensity in the initial phase of deployment. Production targets were lowered and extra support and supervision were provided to those employees struggling more in the transition phase. In addition, the intensity of work increased for the R&D team as the programming of instructions in the AR system is demanding and requires a more structured and analytical approach. The introduction of AR applications in other establishments – such as Bächer Bergmann, Bosch Rexroth and CABB – did not result in greater work intensity, but in fact alleviated the workload of employees.

Particularly at Sanmina and Bosch Rexroth – where more extensive training was provided to staff – the use of the technologies did not result in greater work intensification. If anything, the technologies facilitated many processes and simplified work tasks, contributing to lowering the workload; any short-term increase in work intensification was offset by further training provision. At Sanmina, the greater ability to trace and control processes, as well as the corrective mechanisms enabled by IoT, reduced the potential for mistakes and, to some extent, decreased the stress levels of employees.

Various factors were found to determine the (positive or negative) direction of effects of 3D printing in relation to work intensity. In the case of Bosch Rexroth, this depended on the materials used. While polymer 3D printing is viewed as a tool for decreasing work intensity, given its capacity to reduce the number of steps compared with manual labour (such as the need to assemble parts), there is no doubt that metal 3D printing entails greater responsibilities and more fine-tuning to meet quality standards, as the technology is not as well developed as other more conventional production techniques. Because of the novelty of the technology, fewer fail-safes or automated warnings are implemented than is the case when using production machinery. This requires employees to work precisely with higher levels of concentration during all phases of production to avoid mistakes, which may lead to major failures at more advanced stages of production.

At Bächer Bergmann, 3D printing led to a decrease in work intensity as heavy manual tasks were outsourced to machines, easing the workload of shop floor employees. However, especially for large-scale projects, the use of 3D printing somehow increased the pace of work on the shop floor. A decrease in work intensity was also reported at Airbus Getafe, especially for the prototyping of parts using polymer 3D printing.

The case of BAM Infra was different. Here, the use of 3D-printed elements did not lower work intensity on construction sites. Instead, the just-in-time logistics (no storage on site) put pressure on workers to handle the elements as they arrived, as delays can lead to unwanted storage of materials on site, with ripple effects along the supply chain.

Skills and discretion

Based on expert opinion, skills and discretion is the area most impacted by all three digitisation technologies. Table 8 lists the impacts in this area for which there was consensus among the experts consulted.

Table 8: Specific impacts of digitisation technologies on skills and discretion

IoT	3D printing	VR/AR
Shift from traditional production line work towards higher skilled job profiles, for example industrial data scientists, process automation specialists, network security analysts, encryption experts and IoT application developers.	Increase in demand for highly skilled workers with knowledge in different computer science domains (for example, computational geometry, AI and physical simulation) who can use computational tools such as generative design and simulation.	Increase in workers' skills levels when VR/AR is used for training purposes or on-the-job learning.
Growing demand for multidisciplinary or hybrid skill sets combining IT skills (mainly data management) with specialist knowledge.	Increase in demand for medium-skilled blue-collar workers who can support the production process, operate the 3D printers and perform some post-processing activities.	
Greater need to develop new skills and to invest in continuous learning (with discretion and autonomy as necessary conditions for skills development).	Greater emphasis on hiring of employees with new design and ICT capabilities, creating a bridge between traditional design activities, manufacturing and customer relationship management.	

Note: *The table provides the statements for each technology on which consensus was reached among the experts consulted.*
Source: *Based on results from the Eurofound Delphi survey, 2020–2021*

Two case studies – Estonian gelling agent producer Est-Agar and the Swedish Sanmina manufacturing plant – drew attention to the reduced autonomy of shop floor and assembly line workers in the more controlled environment created through IoT. In this sense, the technology can be regarded as having a dual effect, increasing the efficiency of employees, while undermining the autonomy of lower skilled blue-collar workers. The IoT technology at Italian plant nursery Centro Seia did not diminish job discretion per se; however, it reinforced the existing task-driven work organisation characterised by limited work autonomy for those working on the assembly line. In these establishments the use of IoT-based systems did not require the acquisition of advanced digital skills by shop floor and assembly workers, but rather created opportunities to develop more basic digital skills. In the case of Sanmina, these skills were said to be very specific and unlikely to be transferable to other companies, hence they did not necessarily contribute to greater employability for this group of workers. The outlook for employees in managerial, technical and engineering positions was more advantageous as they had greater opportunities to develop more advanced analytical skills, resulting in better career prospects both within and outside the establishments.

The case of utility company CABB is somewhat different with respect to the impact on skills. In fact, in this establishment, data recording and control tasks of medium-skilled blue-collar workers (for example, plant operators) were fully digitised through the deployment of IoT sensors throughout the water supply network. Adoption of this technology resulted in blue-collar workers taking on more supervisory, analytical and interpretative roles, which required new analytical skills. However, this change to or upgrading of the job profile of plant operators – facilitated through training – did not result in greater work autonomy. On the contrary, job discretion was curtailed as the technology determines the order of tasks and the speed and pace of work. For example, plant operators execute tasks only when they are flagged in the IoT-based system. The introduction of IoT technologies also fostered the development of a range of new skills (data analysis, programming and problem-solving) by white-collar workers in engineering, technical and managerial positions, and resulted in increased work autonomy for them. Access to better quality data, generated and shared through the BIM and the IoT system, allowed employees to have better oversight of processes for which they are responsible, reducing reliance on higher levels of management in their day-to-day work.

Similarly, the move towards digitisation and automation at TTI Algeciras had a major influence on job profiles. Technical professions were in greater demand (for example, engineers, programmers and data scientists) and there was a strong emphasis on digital skills. Beyond the more advanced technical skill sets and competencies required, the staff interviewed highlighted the importance of the soft skills that are required in complex digital environments, for example creativity, an open attitude to innovation and continuous learning.

The use of VR/AR technologies also resulted in the development of new skills. At Mariasteen, the whole rationale behind the adoption of the LGS was to support and empower employees to learn the skills required to produce more complex products, while, at Bosch Rexroth, AR training was in itself a learning tool, enabling greater autonomy in the training context. In addition, at Lohja Hospital, the use of the VR headset for patient rehabilitation was conducive to learning new (IT-related) skills for both occupational therapists and nurses, while also adding task variety to their work.

At KLM E&M, Bächer Bergmann and Bosch Rexroth, where 3D printing supplemented more conventional production methods, the technology was most often used by young and innovation-minded staff, who appreciated the additional cognitive challenge and opportunity to learn new skills. In most cases, professional knowledge about 3D printing was acquired on the job rather than through formal educational channels.

The director of woodworking company Bächer Bergmann highlighted nonetheless the significant adjustments in skills and mindset that are required with the more systematic use of 3D printing. Not only do designers need to plan whole designs in advance, rather than considering designs throughout the development of a project, but also shop floor workers need to develop new skills and change their approach to woodworking projects. In addition, while traditional skills – such as careful planning and understanding and handling of materials – remain viable, new skills, such as the ability to programme small tasks for machines to carry out, are also required.

From a different angle, the BAM Infra case study suggests that a more systematic use of 3D printing in construction may decrease the demand for carpenters and steel fixers, with greater emphasis expected on the design stage, requiring more engineering and 3D modelling skills. Once the 3D models are finalised, they are turned into working instructions by schedulers, who are typically engineers. As 3D planning becomes more prominent in construction, one way for construction workers and supervisors to progress in their careers will be to learn to read 3D plans, so that they can become schedulers. In terms of job discretion, while construction workers typically enjoy relative autonomy, this may be reduced, at least to some extent, with the advent of BIM and 3D-printed elements, as workers will be required to adhere to predetermined plans and more factory-type work. In this scenario, errors in the prefabricated construction elements will no longer be able to be solved on site but will travel up the chain of design to 3D modellers, who are often not present on site.

Prospects and earnings

According to the experts consulted, the implementation of digitisation technologies may lead to wage increases and enhance career progression for more qualified and experienced workers, either within or outside their current workplace, as a result of the positive returns on firm performance and profitability or the acquisition of new skills. For 3D printing, expectations of higher earnings may relate especially to white-collar jobs, particularly those involved in design- and pre-production-related activities. In the case of VR/AR technologies, there may be different outcomes depending on the specific application. For example, if VR/AR is used for training purposes to increase employees' skills levels and augment their capabilities, this may lead to wage increases. By contrast, a decrease in wages may be expected in situations in which the technology is used to guide unskilled employees to perform certain tasks (for example, maintenance or repair tasks), using a guidance system or remote guidance by more experienced workers.

In most establishments investigated, earnings were not tied to the extent of use of digital technologies or determined by the technologies. A notable exception was the plant nursery Centro Seia, where employee performance data generated by the IoT system were used to calculate financial rewards and as a basis for providing more advantageous shifts or promotions to supervisory roles. These rewards were considered valuable to both permanent employees and seasonal workers, as the establishment is located in the south of Italy, in an area with limited employment prospects. At the Estonian company Est-Agar, the deployment of the IoT system eliminated some manual tasks and eventually led to the dismissal of eight staff members in the production unit. While this resulted in a wage increase for the remaining production workers, it also heightened feelings of job insecurity.

When considering 3D printing, use of this technology in the establishments investigated did not have an impact on wages. However, at Bosch Rexroth, the added responsibilities of machine operators were financially rewarded. In the interviews, the management team reported considering a new position within the establishment to cover this expertise, with attractive salary prospects for qualified employees.

In establishments with formal employee representation, wages were said to be regulated through collective bargaining. However, there is scope in the future to negotiate wage increases in the context of technological change and as part of collective agreements. At CABB, the 2016 collective bargaining agreement introduced a new employee performance appraisal system, which allows employees to highlight their training needs and propose specialised training courses. According to management, this system may be used in the future to assess employees' attitudes to innovation and as a tool to encourage a commitment to technological change and to compensate for such change.

The use of digitisation technologies provided opportunities for career progression through the acquisition of new skills based on experience and training. This was found to be the case especially for engineers and staff in managerial positions, for whom the use of technologies and the development of analytical, quantitative and IT skills may enhance their professional development within the establishment or in other companies.

An example of this is TTI Algeciras, where training opened up opportunities for career advancement within the establishment or resulted in better employment prospects in other international companies. In fact, although wages at TTI Algeciras are reportedly higher than the average in the region, career prospects in the establishment are limited, in that the terminal is relatively small and not many high-level (managerial) positions are available. More generally, the Airbus Getafe case study also pointed to the positive effects of technologies on career prospects; employees who more readily accept new technologies are more mobile and eventually improve their positions within the company.

A different effect was seen on the career prospects of lower skilled employees at the Sanmina plant; apart from the acquisition of basic computer skills, other technical skills developed by assemblers are directly related to the execution of tasks using the IoT platform and are not readily transferable to other companies.

Chapter 3 – Summary

- IoT technologies had the biggest impacts on business models, making them more data driven, enhancing establishments' value proposition and expanding their customer offerings (by combining physical products with digital services). The impact of 3D printing on business models was more limited, as the technology is used as an additional tool rather than in place of more conventional production methods. Similarly, VR/AR technologies were used in the establishments to support workers, without significantly impacting their business models. The overall tendency was to integrate the new technologies into existing processes, tailoring them to the specific needs of each establishment.
- Drawing on expert opinion from the Delphi survey and evidence from the case studies, IoT was found to have the most impact of the three digitisation technologies on work organisation and job quality, in both a positive way and a negative way. The adoption of the technologies did not have an impact on internal organisation in any of the establishments investigated; rather, the technologies intensified communication and collaboration between different departments and work teams. The overall impact on workflows, quality control and standards was also found to be positive. In particular, IoT and VR/AR made processes smarter, better and easier to optimise. The technologies also had an impact on task definition and content, with IoT reducing manual and routine tasks and putting greater emphasis on managerial and analytical tasks; 3D printing reducing physically demanding tasks and shifting the focus on to pre-processing/pre-production tasks; and VR/AR either enriching or simplifying existing tasks.
- Although all of the digitisation technologies have logging and reporting functionalities and enable the collection of fine-grained information about their usage, IoT was found to be the most pervasive, raising the greatest concerns when used for employee performance monitoring. However, in most cases the technology was introduced primarily to optimise production processes. Only in one case study was IoT specifically designed to monitor employees' activities and performance. In another case, employee monitoring was a by-product of the IoT-enabled monitoring of the production process and the data were used to determine financial and non-financial rewards for shop floor workers.
- In terms of job quality, the overall impact of the three technologies was positive. With regard to the physical environment, IoT technologies were found to decrease physical risks but potentially increase exposure to ergonomic risks associated with the more sedentary work and reduced levels of physical activity. Exposure to the physical risks commonly associated with the use of 3D printing – for example exposure to ultrafine powders – was reduced by a range of preventive measures in the establishments investigated, which lowered the potential negative impacts. The direction of the effects of the technologies on the social environment was found to depend largely on the specific use case. While the adoption of the technologies did not alter working time arrangements, it slowed down performance and increased work intensity, particularly in the initial phase of deployment, because of the steep learning curve. The area most impacted by the technologies – particularly IoT and 3D printing – related to skills and discretion. IoT adoption was found to lead to the upgrading of skills, particularly for managerial and engineering positions, but less so for lower skilled and blue-collar workers. The technology was also found to increase job discretion for high-skilled white-collar workers and reduce or reinforce the task-driven work organisation, characterised by a low level of autonomy of assembly line workers. In addition, the use of 3D printing resulted in a shift in skills, with greater emphasis on 3D design and planning skills and a greater reliance of production workers on 3D designers and planners.

4 Conclusions and policy pointers

Greater support needed to boost technology uptake

Innovation clusters and local ecosystems

The presence of innovation clusters or local ecosystems supporting innovation and Industry 4.0 is an important enabling factor for the implementation of digitisation in the workplace. These clusters or ecosystems can provide support to businesses, particularly SMEs, for accessing public financing and training, create awareness of the potential benefits of the technologies, and facilitate networking and knowledge transfer between firms and with technology suppliers. The managers interviewed at the smaller establishments mentioned that, especially for fast-moving technologies such as 3D printing, the costs of keeping up with technology developments are high, even when acquisition is supported by government subsidies.

The growing network of innovation hubs in the EU has been instrumental in stimulating further experimentation, cooperation and strategic partnerships and has helped SMEs keep pace with the digital transition. Efforts directed at the creation of ecosystems should be further encouraged and intensified. Horizon Europe, the new EU research funding programme for 2021–2027, the Digital Europe Programme, Europe's Green Deal, national Industry 4.0 strategies and the Recovery and Resilience Facility, implemented through national plans, are all potential sources of funding and support for businesses and national and transnational ecosystems. National governments have an important role to play in creating an environment in which 3D printing and IoT ecosystems can thrive and grow. However, it is not only a matter of providing public incentives to support innovation but also about creating awareness about the available financial instruments and facilitating access to them, minimising the administrative burden on businesses. In this regard, an important consideration is the level of digitisation of public administrations, which can contribute to more effective communication and faster processing of grant applications.

Making a business case

Perceived business opportunities (cost efficiencies and revenue growth) are a critical requirement for the greater uptake of technologies in the workplace. The uptake and implementation of digitisation technologies must result in value creation in terms of products, services or processes. A valid business case emerges when the advantages of digitisation technology are fully leveraged. Such business cases, however, tend to require financial and human resource investment in terms of design, development and experimentation and are difficult to justify, as there is a lot of uncertainty about the risks involved. Despite all the hype surrounding digitisation technologies, particularly 3D printing and VR/AR, their benefits are still relatively unknown for many businesses. Many companies tend to take a conservative stance and wait for others to prove the business case before committing to a technology. Greater efforts should be made to disseminate good practices grounded in valid business cases, raise awareness about the opportunities that digitisation technologies can provide and demonstrate the business case for investment.

Experimenting with technologies

Innovation could be supported through 'sandpit' grants, which enable organisations to experiment (and take calculated risks) with technologies. Several EU initiatives (for example, Horizon Europe and Smart Specialisation) play an important role in establishing experimentation environments. Innovation policies should incentivise value and supply chain diversity, the involvement and inclusion of start-ups and SMEs (both commercially oriented companies and social enterprises) and exchange and cooperation between research institutes, technology developers and businesses, including, for example, through co-creation and internships.

Creating a 3D community

As the 3D printing industry is relatively small, a mapping of suppliers, developers, users and clusters may be particularly beneficial to enable actors in the industry to liaise with each other and leverage what is already in place. This would also provide a snapshot of regions that are successfully promoting and adopting 3D printing, and provide impetus and a 'sense of urgency' for regions that are falling behind. One potential approach to collecting these data could be through national 3D printing organisations.

Regulation and standardisation

Regulatory solutions are required to improve IoT interoperability standards and enhance the scaling up of IoT applications within firms and across supply chains. Many IoT devices have been deployed with proprietary protocols, which makes communication between devices and applications from different vendors difficult and impedes vertical and horizontal integration. Interoperability and standardisation are, however, not exclusively technical issues; the weak governance in the institutional standardisation process is a major barrier to the greater uptake of IoT, leaving the field to major global business players. As for standardisation issues related to 3D printing, an important aspect is to ensure greater coordination among specialised technical committees of standardisation bodies and avoid the duplication of activities. Digitisation also brings about challenges related to intellectual property rights, which need to be adequately addressed in policymaking and by updating current regulations (including those about the introduction to the market of finished products made by 3D printing using innovative materials).

Investment in training, upskilling and reskilling

The most significant disruption caused by the introduction of digitisation technologies is expected in the area of skills use and skills development, hence the importance of investing in training, upskilling and reskilling. Close collaboration between higher and further education bodies and businesses can boost the supply of interdisciplinary business and the technical skills needed to enable the digital transition. National training curricula need to be modernised to provide the skills demanded by digitisation. In particular, IoT requires educational and vocational education and training systems to be able to produce highly qualified employees with up-to-date skills, specialised blue-collar workers and multidisciplinary white-collar workers. Investments in lifelong learning are also sought to support the digital transition of more vulnerable workers, especially workers with low levels of qualifications, older workers and contract workers, who are most at risk of being left behind. The new European Skills Agenda – linking to several other EU initiatives such as the European Digital Strategy, the industrial and SME strategies and the recovery plan for Europe – is aimed at implementing actions to equip people with the right skills for jobs and at supporting lifelong learning. The investments in training, upskilling and reskilling will, however, take time to obtain a return on investment and this may be a disincentive for businesses, especially SMEs lacking sufficient resources. The case studies show that investing in training was by no means the norm – with training often targeting only specific groups of employees – and learning on the job and peer mentoring were regarded as more viable and less costly options. Public support in the form of funding, incentives and advice, as part of European, national and regional innovation strategies or schemes, can be leveraged to help companies identify skills gaps and needs and assist them in the preparation of training plans and measures to meet the skills requirements arising from the adoption and use of digitisation technologies.

Scope for systematic approach and a greater role for social dialogue

Developing a digitisation strategy and involving employees

The research draws attention to the importance of developing an explicit digitisation strategy (with a phased approach to best leverage the technologies) and putting in place mechanisms for the active involvement of employees in the adoption and deployment of the technologies in the workplace. It is important that IoT, 3D printing and VR/AR solutions are developed and introduced in a participative way that involves workers as much as possible. However, most of the case studies showed no systematic approach to the introduction of the technologies in the workplace, and employee involvement in the digitisation process was limited to testing the technologies.

Role for social partners and employee representatives

Aspects related to the quality of work and work organisation are not sufficiently addressed in national innovation strategies and Industry 4.0 programmes. Research points to the insufficient involvement of social partners in European and national technology-related and innovation strategies. Evidence from the case studies also shows that, at establishment level, the role of social dialogue in the introduction and implementation of the technologies is, in many cases, weak, not going much beyond the legal requirement of providing information and carrying out consultations in the initial stage of technology introduction. Social dialogue deficits at establishment level can amplify the negative impacts on working conditions stemming not from the technology per se, but from a digitisation approach that neglects employee participation and engagement. In particular, IoT technologies require a greater involvement of employee representatives, considering their pervasiveness and extensive monitoring capabilities. At the level of the establishment, social dialogue has an important role to play in ensuring compliance with data protection regulations and policies and in negotiating procedures for contesting decisions based on sensor-collected data. At European level, one avenue for addressing the issue of employee monitoring may be the negotiation among European social partners of a specific framework agreement on the collection and use of personal data in the employment context.

Impacts of digitisation in the workplace: risks and opportunities and the way forward

Process optimisation and efficiency as main drivers of workplace digitisation

The research indicates that digitisation technologies are primarily introduced to optimise business processes and increase efficiency. The monitoring capabilities of IoT-enabled businesses are increased, enabling them to anticipate or receive warnings about machine failures and ensuring the traceability of processes and the quality of products, not only within the businesses but also throughout the supply chain. In the establishments using 3D printing, the technology increased the efficiency of production (by rationalising the use of raw materials and the time of skilled employees) and expanded the range of offerings (for example, bespoke orders), while reducing reliance on external suppliers. The VR/AR applications deployed at the Belgian social enterprise Mariasteen and at Lohja Hospital (Helsinki), respectively, made work processes simpler and more accessible for employees.

Data collection capabilities of digitisation technologies raise data protection and privacy concerns

Although all three digitisation technologies provide logging and reporting functionalities and enable the collection of fine-grained information about their usage, IoT and, to some extent, VR/AR have greater data collection capabilities and therefore raise greater concerns about employees' privacy and data protection. The management teams at establishments where IoT systems were deployed indicated compliance with data protection regulations and reported that employees were informed about data collection and processing and asked for their consent. However, the notion of employee consent specified in some national legislation is not a valid ground for processing personal data owing to the imbalance of power in the employment relationship. Employees may agree to monitoring out of fear of retaliation on the part of their employer and losing their job. Feelings of job insecurity and uneasiness among employees about the monitoring – at least in the initial stage of technology deployment – were reported in some instances. A lack of social dialogue structures can further reinforce this power imbalance, affecting employees' ability to voice their concerns and having negative impacts on trust in management. At the workplace level, it is important to develop clear governance procedures around employee monitoring and apply principles of privacy and data protection, including purpose limitation and data minimisation (collecting data that are strictly necessary and not pursuing surveillance or using technologies for purposes other than those that were initially specified). The enforcement of and compliance with GDPR rules should also be further strengthened. At EU level, building on Article 35 of the GDPR, consideration could be given to the development of a European data protection impact assessment framework for the IoT. Privacy-invasive devices such as those equipped with IoT sensors should be designed with privacy and data protection principles in mind and their use governed by stringent privacy law. Actions at EU level will contribute to building trust in IoT systems and applications in the workplace, especially when IoT is combined with AI technologies.

Digitisation contributing to a safer work environment

From a job quality perspective, in the area of the physical environment, IoT was found to contribute to a reduced exposure to physical risks, making the work environment safer for employees. There are, however, some concerns that ergonomic risks may become more prominent over time because of the more sedentary nature of the work and the lower levels of physical activity in more data-driven work environments. The use of 3D printing also reduced the more physically demanding tasks, lessening the dangers from moving parts of machinery and equipment. Risks typically associated with 3D printing – for example exposure to ultrafine powders and high temperature printer nozzles – were largely offset in the establishments investigated by putting in place a range of preventive measures. Sharing information and raising awareness of such preventive measures along with assessments of their effectiveness in specific contexts can encourage businesses to more readily adopt the technologies. Risk assessments and monitoring of risks should be an important part of technology introduction and implementation in the workplace; however, the evidence from the case studies suggests that this is not standard practice. This also requires mechanisms to be put in place to monitor regulatory compliance at workplace level without creating extra bureaucracy, which can slow down the digitisation process.

Digitisation facilitating remote working and potentially blurring boundaries between work and private life

Based on the evidence from the case studies, the introduction of digitisation technologies in the workplace did not have a significant impact on working time arrangements. It did, however, in the case of IoT, for example, create opportunities for remote working, which were important in the context of the COVID-19 pandemic. It is too early to say if this will be a long-lasting trend that will continue after the crisis. Some concerns were raised in the interviews carried out in the establishments that remote working facilitated by digitisation technologies created expectations of continuous availability and difficulties in terms of disconnecting, which may compromise work–life balance and lead to increased levels of stress in the longer term. This suggests that impacts on working time quality do not depend directly on one or other technology but are strongly affected by organisational culture, internal company policies on working time, and organisational changes following the adoption of a broader spectrum of technologies. It is important to monitor the extent to which digitisation has an impact on the organisation of working time, and, at the workplace level, create awareness about the potential risks of remote working for employees' well-being and the need to manage effectively the greater flexibility that the technologies provide.

Increased work intensification in the initial phase of technology adoption

The adoption of the digitisation technologies in the establishments investigated did not result in increased workloads or a greater intensification of work. For example, the introduction of IoT resulted ultimately in a steady and more controlled pace of work. However, in some establishments, employees experienced a higher work intensity in the early phase of technology adoption, as they needed time to acquaint themselves with the new technology and ways of working. This was often the case in establishments that did not provide enough training to employees to prepare them for the changes to working methods and practices and that did not sufficiently involve employees in the piloting of the technologies. Both training provision and employee involvement (as in 'direct employee participation') serve as buffers that can diminish the perceived increase in work intensification, making employees feel in greater control of the change process.

Intensification of collaboration and greater information sharing within the workplace

Overall, all of the digitisation technologies – albeit to different extents – contributed to greater levels of collaboration and communication between departments and work teams and, in some cases, also with clients. Any decrease in social interactions was attributable to the specific use of the technology, for example use of IoT for monitoring employee performance. The intensification of communication and collaboration points to the greater importance of interdisciplinarity and the capacity to work in teams in more complex work environments.

Digitisation technologies impacting on employees' skills and discretion

- The area of job quality most impacted by use of the digitisation technologies was skills and discretion. The direction of the effects (positive or negative) depended largely on the technology design, managerial choices and the extent to which employees were supported and provided with training and learning opportunities. IoT is the most potentially disruptive technology in this area. In the case studies, this technology was found to drive the acquisition of more analytical and technical skills by higher skilled white-collar employees, enhancing their career prospects. The situation for manual and blue-collar workers was different; they developed more basic digital skills or technology-specific skills and had more limited career prospects, unless upskilling was provided to meet the demand for higher skills levels.
- A necessary condition for skills development is discretion and autonomy. The evidence from the case studies, however, suggests that, although production workers developed some basic digital skills, the technology, particularly IoT, reduced job discretion by creating a more controlled environment. In the best-case scenario, the technology reinforced the task-driven work organisation, characterised by the low autonomy of assembly line and production workers. The opposite was true for high-skilled white-collar employees in managerial, technical and engineering positions, for whom the technology instead enhanced individual decision-making (based on IoT data) and work autonomy.
- In most case studies, the digitisation process did not lead to immediate redundancies: instead, job profiles tended to evolve over time. Blue-collar positions are more at risk from digitisation as manual tasks become increasingly digitised. This requires a greater upskilling effort to meet the growing demands for skilled labour arising from digitisation. Another important pillar is reskilling, with a view to overcoming resistance to technological change. Solutions should also be provided by public stakeholders (from education and training sectors to employment and social services sectors) for those who cannot make the transition in the workplace, giving them access to alternative learning pathways.

Synergistic use of technologies amplifying impacts in the workplace

Digitisation technologies are diverse and can be implemented in different ways, resulting in different impacts on business models, work organisation and job quality. It is not just the impacts of individual technologies that are important: the synergistic use of these technologies and the resulting organisational changes amplify the impacts in the workplace. Having both an innovation culture and developing the skills and capabilities of the workforce can, moreover, lead to a better appreciation of the business value of deploying the technologies while remaining alert to the potential challenges for job quality and business performance.

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Annex: Key terms used in the report

Term	Definition
3D printing	Technique using the superimposition of successive layers to create a product. It is additive in the sense that products and product components are built up rather than cut out of existing materials (subtractive manufacturing). The key prerequisite of this process is that products can be digitally modelled before being physically generated (Eurofound, 2020a).
Advanced technologies	'Advanced technologies are a fusion of digital and key enabling technologies (KETs), and the integration of physical and digital systems. They give rise to innovative business models and new processes, and the creation of smart products and services' (European Commission, undated-a).
Artificial intelligence	AI is a general-purpose technology that enables and supports the application of many other technologies (Brynjolfsson et al, 2017). The definition adopted by the European Commission refers to narrow AI, which uses machine learning and deep learning tools to extract information from an enormous number of data and to generate new value based on models built with those data (Eurofound, 2020a). In Eurostat's ICT usage by enterprises survey, AI is defined as 'systems that show intelligent behaviour: by analysing their environment they can perform various tasks with some degree of autonomy to achieve specific goals.' In the survey, the use of AI applications considers only four systems: 'chat service where a chatbot or a virtual agent replies to customers, use of machine learning (for example deep learning) for analysing big data internally, use of natural language processing, natural language generation or speech recognition for analysing big data internally, use of service robots (for example for surveillance, cleaning, transportation, etc.).'
Automation of work	The replacement of (human) labour input by machine input for some types of tasks within production and distribution processes (Eurofound, 2018a).
Big data	According to the definition provided by the European Commission, 'big data refers to large amounts of data produced very quickly by a high number of diverse sources. Data can either be created by people or generated by machines, such as sensors gathering climate information, satellite imagery, digital pictures and videos, purchase transaction records, GPS signals, and more' (European Commission, 2020c).
Building information modelling	A 3D model-based process supported by various tools and technologies for the generation and management of digital representations of a building project, and used for design simulation, construction planning and facilities management.
Business model	The way that an enterprise is organised to deliver value to its customers (Teece, 2010).
Computer numerical control milling	Milling machines use rotary cutters to remove material by advancing a cutter into a work piece. Computer numerical control allows milling machines to automatically create a form by automatically changing tools and angles based on a computer design.
Coordination by platforms	The use of digital networks to coordinate economic transactions in an algorithmic way (Eurofound, 2018a).
Data analytics	The use of digital tools for analysing data collected at an establishment or from other sources (Eurofound and Cedefop, 2020).
Digitalisation	The broad transformation brought about by the widespread adoption of digital technologies (Eurofound, 2018a).
Digital revolution	A general acceleration in the pace of technological change in the economy, driven by a massive expansion of the capacity to store, process and communicate information using electronic devices (Eurofound, 2018a).
Digitisation	The use of sensors and rendering devices to translate (parts of) the physical production process into digital information (and vice versa) (Eurofound, 2018a).
Employee involvement	Employee involvement refers to the opportunities for employees to take part in decisions that affect their work, either in their immediate job or tasks or in relation to wider organisational issues (organisational participation) (Eurofound, 2016b).
Internet of things	Sensors applied within the manufacturing industry create cyber–physical systems in which the information collected from the sensors is fed, via the internet, to computers in order to gather data about production processes and analyse these data with unprecedented granularity. In advanced cyber–physical systems, a whole factory can be digitally mapped and enabled using such sensors (Eurofound, 2020a).
Internet of things gateway	An internet of things gateway is the central connection point between physical objects such as sensors or controllers (things) and the cloud (internet). It pre-processes the data generated by the things and routes them to the appropriate place in the cloud.

Term	Explanation
Job quality	Job quality is a multidimensional concept referring to the essential characteristics of jobs that meet workers' needs for good work. The Eurofound job quality framework encompasses seven indices, representing different dimensions of job quality: physical environment, work intensity, working time quality, social environment, skills and discretion, and prospects and earnings (Eurofound, 2017b).
Manufacturing execution system	A manufacturing execution system (MES) is an operational production management system supporting tasks such as production planning, tracking and control. An MES provides a digital image of production, including the conditions on the shop floor, and enables production processes to be monitored in real time.
Programmable logic controller	A programmable logic controller (PLC) is an industrial digital computer that receives information from connected sensors or input devices, processes the data and triggers outputs based on pre-programmed parameters. A PLC can monitor and record real-time data such as machine productivity and water temperature. It can also automatically start and stop processes and generate alarms.
RFID/RFID tag	RFID (radiofrequency identification) uses electromagnetic fields to extract codified information from objects and track their location. Frequently, this is used in 'RFID tags', small objects (most commonly employee badges) that validate the identity of an individual to grant access to certain areas or systems.
Smart factory	A smart factory is a highly digitised shop floor where data are collected, transmitted and shared in real time by means of connected machines, devices and production systems.
Smart farming (and precision farming)	Smart farming is the use of ICT in agriculture. IoT-based smart farming is the use of sensors in agriculture to manage and monitor crops and livestock, ensure country-of-origin and product traceability for customers, and collect a wide range of data that can be leveraged to optimise production and distribution and reduce waste and costs. A related concept is precision farming, which refers to the use of technologies and data to determine at what stage of farming a treatment is most needed.
Social dialogue	Social dialogue refers to 'discussions, consultations, negotiations and joint actions involving organisations representing the two sides of industry (employers and workers) (European Commission, undated-b).
Supervisory control and data acquisition system	A system of software and hardware enabling the remote control and monitoring of industrial processes. It collects and processes real-time data, provides feedback to field devices, and controls processes by interacting with smart devices locally or at remote locations and recording events into a log file.
Technology readiness level	A scale that assesses the level of maturity and applicability of a technology. It goes from level 1, where a technology is in its preliminary phase and only its basic principles have been observed and reported, to level 9, where the technology is fully implemented and has been proven in a production environment.
Virtual and augmented reality	VR is a computer-generated scenario that simulates a real-world experience. AR combines a real-world experience with computer-generated content (Eurofound, 2020a).
Wearables	Devices comprising electronics, software and sensors that are designed to be worn on the body (Billinghurst and Starner, 1999). Examples include smartwatches, head-mounted displays, body cameras and smart clothing.
Work organisation	Work organisation is a broad concept that refers to 'how work is planned, organised and managed – via production processes, job design, task allocation, rules, procedures, communication, responsibilities, management and supervisory styles, work scheduling, work pace, career development, decision-making processes, interpersonal and interdepartmental relationships' (Eurofound, 2017c).

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Research into the transformative potential of the digital revolution tends to take a quantitative approach in an attempt to monitor changes in employment levels due to digitalisation. The fear of potential job losses and negative disruption brought about by digital technologies has permeated the policy debate on digitalisation. In contrast, this report, based on case study research, takes a more qualitative approach to exploring the impact of selected digital technologies (internet of things, 3D printing, and virtual and augmented reality) in the workplace. While digital technologies can bring many opportunities and have been shown to be beneficial for both workers and organisations, there is a need to put safeguards in place to ensure employee data protection and privacy. A well-functioning social dialogue is also key to reaping the benefits of digital technologies and preventing – or minimising – any negative outcomes.

The European Foundation for the Improvement of Living and Working Conditions (Eurofound) is a tripartite European Union Agency established in 1975. Its role is to provide knowledge in the area of social, employment and work-related policies according to Regulation (EU) 2019/127.

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