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# Workplace 4.0: Exploring the Implications of Technology Adoption in Digital Manufacturing on a Sustainable Workforce

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**Abstract:** As part of the Industry 4.0 movement, the introduction of digital manufacturing technologies (DMTs) poses various concerns, particularly the impact of technology adoption on the workforce. In consideration of adoption challenges and implications, various studies explore the topic from the perspective of safety, socio-economic impact, technical readiness, and risk assessment. This paper presents mixed methods research to explore the challenges and acceptance factors of the adoption of human-robot collaboration (HRC) applications and other digital manufacturing technologies from the perspective of different stakeholders: from manufacturing employees at all levels to legal experts to consultants to ethicists. We found that some of the prominent challenges and tensions inherent in technology adoption are job displacement, employee's acceptance, trust, and privacy. This paper argues that it is crucial to understand the wider human factors implications to better strategize technology adoption; therefore, it recommends interventions targeted at individual employees and at the organisational level. This paper contributes to the roadmap of responsible DMT and HRC implementation to encourage a sustainable workforce in digital manufacturing.

**Keywords:** human-robot collaboration; workforce sustainability; responsible technology adoption; digital manufacturing; Industry 4.0; ethics; smart manufacturing

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## 1. Introduction

The fourth industrial revolution introduces the integration of digital technologies into the manufacturing process to increase productivity and efficiency. Digital manufacturing technologies (DMTs) refer to the use of smart, digital, autonomous, and intelligent technologies, including sensor technologies, virtual and augmented reality, distributed networking technologies, additive manufacturing, artificial intelligence and analytics, simulation, and cloud computing [1–4]. This new wave of industrialization is expected to enrich the quality of work by creating a more interesting working environment and greater autonomy for self-development because employees are expected to act as strategic decision-makers and flexible problem-solvers [5,6]. With an automated production system, the operator can transition into a more creative role rather than "assisting or monitoring non-discretionary work flow steps or processes" [7] (p. 3). It is viewed that applications of computing technologies will play a key role in empowering industrial operators [8]. For example, new types of industrial robotics, such as collaborative robots (cobots) (In this paper, collaborative robotics (cobots) is a range of robots in reference to the Technical Specification of ISO 15066) [9,10], emerged where physical barriers are no longer required, allowing for a more flexible and lean process and maximisation of efficiency at work. With human-robot collaboration, the advantages are the combination of high levels of accuracy, strength, precision, speed, endurance, and repeatability from the robot and the flexibility, sensitivity, creativity, and cognitive skills from the human [11–14]. Recognizing the potential of human-machine collaboration, the emerging concept of 'Operator 4.0' aims to promote human-centric technology design for operators to augment their powers and capabilities [6]. Some of the research in this area includes: understanding individuals' learning curves and operator's cognitive processes to deliver better system design [15,16], proposed strategies for better design of cognitive automation solution interfaces used by Operator 4.0 [17–19], and tested conceptualisation of Operator 4.0 typologies to provide guidelines for a human-centric approach to build production systems [20]. It is evident that the technology advancement is moving towards complementary-to-operator tasks, equipping the advanced manufacturing environment with more sensors and systems supporting intelligence analytics.

However, the transformation of business operations brings forward new challenges, including a shift in the workforce from recruiting new talents to modifying daily tasks. The public and academic debates centre around the impact of digital technologies on employment [21]. In particular, the economics debate of technological unemployment is explored by various scholars who focus on the quantification of the impact of computerisation on the workplace. A study by Frey and Osborne investigates this 'technological unemployment' whereby they estimated that 47% of all US occupations are susceptible to being replaced by computerisation in the next 10 to 20 years [22]. The Scientific Foresight Unit STOA of the European Parliamentary Research service emphasizes that "it is hard to quantify the effect that robots, AI and sensors will have on the workforce because we are in the early stages of the technology revolution" [23] (p. 634). According to a study by Smith and Anderson [24] economics experts believe that robots and AI would displace both 'blue' and 'white' collar workers, leading to an increased number of unemployed people and vast income inequality. However, Arntz, Gregory, and Zierahn argue that various studies overestimate the share of automatable jobs because they fail to recognise the "substantial heterogeneity of tasks within occupations as well as the adaptability of jobs in the digital transformation" and by applying their method, they found that the automation risk of US jobs dropped to 9% [25] (p. 157). Moreover, digital transformation introduces unprecedented levels of skills gaps and shortages where some of the traditional jobs are left unfilled and the new 'digitalisation' jobs require skills that older employees do not have. A report conducted by Deloitte and the Manufacturing Institute forecasted that over the next decade more than 2.6 million baby boomers in the US are expected to retire, which could lead to a demographic challenge for the manufacturing industry [26]. Workers will need higher qualifications as their profiles are becoming increasingly more complex with tasks shifting from routine process to controlling the machines in real-time by incorporating analytical information given by new software systems [27].

Notwithstanding the economics debate, research shows that human operators will remain vital elements of the manufacturing industry. Technologies will need to be designed to support and work with the workers. Therefore, workforce issues and acceptance of new technologies need to be addressed [28]. However, very few Industry 4.0 studies focus on the human resources and organisational impacts, with the majority of the research concentrating on technological or infrastructural aspects [27]. There is also a lack of research on the legal, ethical, and social consequences and impact of digital manufacturing technologies on the workforce from a human factors viewpoint [29]. There are some studies dedicated to understanding the barriers to adoption that focus on technology acceptance within SMEs [29–31]. Particularly, a study by Kildal et al. identified key concerns and attitudes towards collaborative human-robot systems [32]. Their results show that a lack of knowledge is the principal barrier to adoption, followed by workers' acceptance, cost, and regulation. The study was conducted in the form of a workshop with one hundred industry professionals that were already users of cobots or were considering introducing them in their processes in the future. However, it is unclear whether the study reflects the perspective of different stakeholders. In addition, Lotz, Himmel, and Ziefel conducted in-depth expert interviews with five industrial employees (three workers and two heads of department). From the employers' perspective, an inherent problem stems from the lack of certainty in regulation, whereas the employees' main concerns are about their safety to work alongside robots and worries about their job security fearing that robots will take over their positions [33]. Another study found workforce skills, resistance to change, and anxiety to be challenges to technology adoption [34]. Legal obligations and finance appear to be the common concerns from a business viewpoint, although impacts on employees are equally important. To get a better understanding of these impacts on employees, Tabrizi et al. argue in their article 'Digital Transformation is not about Technology' that it is important to leverage insiders to transform organisations because staff have an "intimate knowledge about what works and what doesn't in their daily operations" [35]. Despite the potential of digital technology to improve working conditions and job satisfaction, it can also have aspects that have a negative impact on employees and thereby impede a sustainable workforce. As stated by LeBlanc and Oerlemans, highly innovative sectors that have to cope with constant technological changes as well as strong international competition are in need of a sustainable workforce [36]. Initially, a sustainable workforce was conceptualized as employees being able to keep on working while retaining their health and well-being or in terms of adaptability to a multitude of work-related changes [36,37]. However, LeBlanc and Oerlemans indicate that being healthy and able to keep on working is not enough; employees have to be pro-active and demonstrate creative and innovative work behaviour [36]. This personal initiative is key to employee sustainability and of vital importance for the viability and competitive advantage of contemporary organisations.

Therefore, this paper presents a different focus on technology adoption and acceptance, emphasizing the need to look beyond organisations' technology readiness assessment and starts to address the potential impacts based on empirical data. There are many theories that set out to explain technology acceptance, with the most popular one being the classical technology acceptance model (TAM), which predicts people's intentions to adopt a technology based on its perceived usefulness and ease of use [38]. TAM has been proven to have valid and reliable constructs; however, a meta-analysis of the literature identified that the theory does not sufficiently consider external variables such as age, gender, level of education, and prior experience that have been found to influence people's perceptions and usage behaviour directly and indirectly [39]. Furthermore, most technology adoption research that uses the TAM approach to predict actual use focuses on commercial spheres where people have an individual choice in embracing technologies. These studies mainly examine individual users' attitudes towards, and beliefs about, using the latest technology-based products or services in their daily lives [40]. The opinions of experienced users (or non-users) of advanced manufacturing technologies where acceptance is not an individual choice but forced upon the workforce are often overlooked. Hence, we decided not to apply the technology acceptance model or its extensions and adaptations (e.g., TAM2, UTAUT), and a mixed methods approach was applied in this paper to explore the attitudes and concerns from both experts' perspectives and workers' perception towards cobots and DMT acceptance and adoption in this paper.

The paper is organised as follows: Section 2 presents the research methods. the findings based on interviews with experts and a survey among manufacturing employees are discussed in Section 3, leading to the determination that changes are required in work design and organisational culture and models to ensure an enhanced role for humans rather than replacement of human roles in manufacturing. The conclusions and individual and organisational interventions to accomplish a sustainable workforce in a digital manufacturing setting are put forward in Section 4. We discuss the limitations of our study in Section 5.

## 2. Materials and Methods

### 2.1. Expert Interviews

Objective: We conducted a study to identify the legal, social, and ethical challenges and implications of the implementation of emerging technologies, particularly collaborative robotics in digital manufacturing. We found the expert interview [41] approach to be the most suitable method for the purpose of this study, which is to gain in-depth insights from different experts involved in technology development and implementation and their outlooks on the subject matter.

Recruitment: The participants were recruited using the snowball sampling method. To start, emails were sent to colleagues and project partners to help distribute the recruitment request to potential participants who are experts in fields relevant to the implementation of emerging technologies, particularly robotics. As experts are often networked people, many of the participants were recruited through their connection. Because we set a clear objective that participants would be asked about the current challenges and emerging potential ethical, legal, and social risks in implementing digital technologies, particularly human-robot collaboration, we only pursued participants that were, to a certain extent, involved in either decision-making related to the development, and/or implementation of digital technologies, and/or acting as expert advisors for companies, and/or governmental agencies, or involved in establishing robotics and AI standards. As a result, we were able to obtain a well-mixed sample of professionals in different roles and from a variety of industries providing a broad picture of the topic. A total of 15 professionals participated, consisting of practitioners, and researchers: three manufacturers, five lawyers, two technologists, four technology and business consultants, and one robot ethics researcher (see Appendix A or the participant's expertise). The study was conducted between May 2019 and July 2020. It is acknowledged that a minimum of 12 participants is recommended for qualitative studies to reach data saturation [42–44]. The analysis showed that the prominent themes emerged after 10 participants. New codes were identified from the 11th to 15th participants, however, they only added to the existing themes, demonstrating that data saturation was reached. Therefore, the sample size of 15 participants was deemed sufficient for the qualitative analysis of this study and further recruitment was not required.

Procedure: The Computer Science Research Ethics Committee of the University of Nottingham approved the study. Participants were given an information sheet and a privacy notice form that addressed how their data would be handled. Participants signed a consent form before the study began. Participants were asked to fill out a survey to capture their background and expertise, as well as their experience with technology and their knowledge of cobots. We chose a semi-structure interview approach, using a conversational style of interview as well as open-ended interview questions. The participants were asked about their background, expertise, their understanding of cobots, and their opinion on the legal, ethical, and social challenges of emerging technologies, and the general concerns or challenges in adoption of emerging technologies. The emerging technologies include smart embodied autonomous systems for the application of human-robot collaboration. Providing that some participants were not extremely familiar with manufacturing industries, we used the term 'workplace' to provide a context for human-robot collaboration to avoid bias of the conventional manufacturing setting. In the conversation, the participants also revealed overall challenges in adoption and acceptance of digital manufacturing technologies including collaborative robotics. All participants were assigned a unique number and an acronym to identify their expertise, e.g., P1M is a participant who represents manufacturer (T—technology, L—law, M—manufacturer, C—consulting, R—research). Each interview lasted between 45 min and one hour.

Analysis: We used Nvivo 12 software to organise the material and followed Braun and Clarke's thematic analysis approach to analyse the data and identify themes concerning the research questions [45]. We followed their six-phase approach to thematic analysis: (1) data familiarization; (2) generate initial code; (3) code clustering; (4) review potential themes; (5) define and name themes; (6) produce report. Accordingly, an inductive coding approach was chosen to analyse the data. Inductive coding refers to a process where themes are inductively defined from the codes based on the raw data being explored without drawing from any predetermined or theoretical constructed framework. The codes are either descriptive or interpretive. Finally, ten themes were formed based on 62 codes (see Appendix B for an illustration of selections of codes, descriptions, and examples.) The ten themes are: adoption of new technology, trust, risk, safety, due diligence, regulatory, ethics and social challenges, data and privacy, design, and insurance. In this paper, we draw upon the findings in relation to three themes: adoption of new technology, trust, and data and privacy (Figure 1).

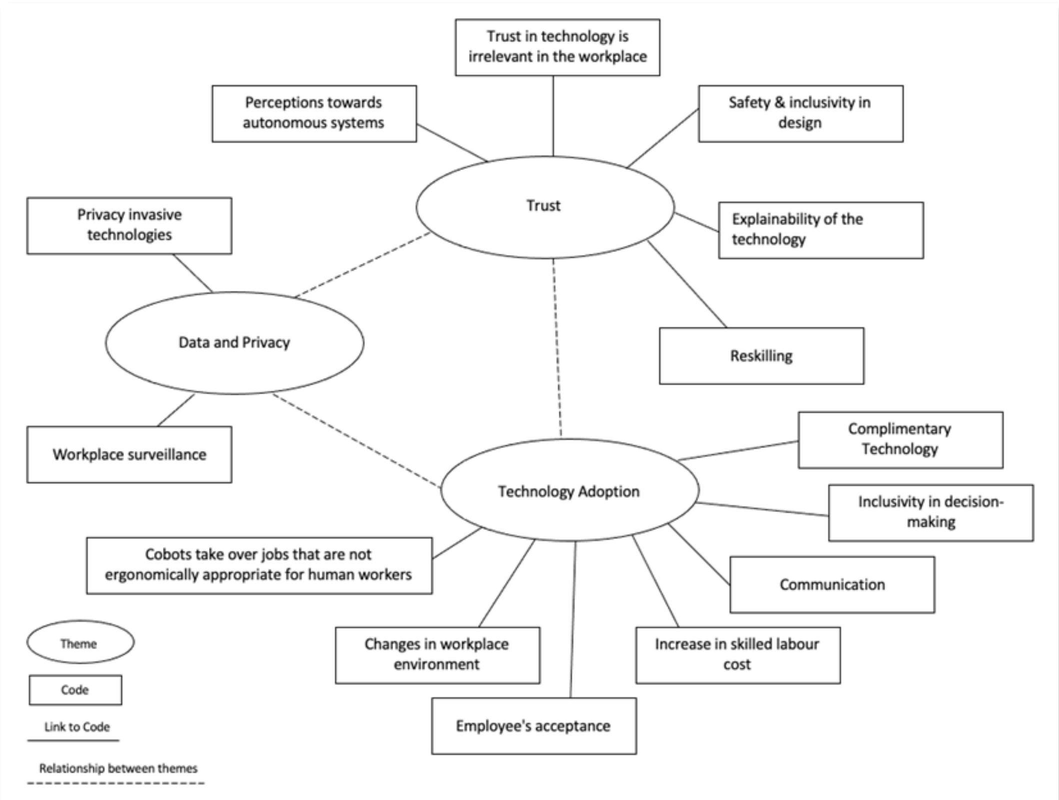


**Figure 1.** Thematic map representing the three main themes underlying Section 3.

Validity: An iterative process was taken three times. We performed the first code clustering (Braun and Clarke's Phase 3) based on the first six interviews. With each new analysed interview, more codes were formed; therefore, we repeated the code clustering process after the 10th transcript and again after the 15th transcript. We conducted a triangulation process whereby two researchers with different backgrounds (law and computer science) separately performed the coding process of 30 quotes. The quotes were coded in a similar manner by both researchers, thus, validating the reliability. Finally, three researchers performed Braun and Clarke's Phases 4 and 5 together to define and discuss relevant themes.

### 2.2. Survey

Objective: Following the qualitative data collection performed via interviews to capture the depth of attitudes and opinions about industrial collaborative robots, we wanted to explore whether these opinions could be generalized to the population level. We developed a survey study to gather experiences of people working with digital manufacturing technologies (DMTs) to inform us on the acceptance and adoption of industrial collaborative robots and other DMTs in British manufacturing. The survey questions presented in this paper focus around the opinions expressed by the participants in the interview stage and provide inferential statistics to give further insights about DMTs adoption. We addressed different stakeholders working within UK manufacturing companies such as operators, production managers, production technicians, engineers, maintenance technicians, quality inspectors, Human Resources personnel, middle management, senior management, and CEOs. The participant sample is a subset of a larger survey investigating the perceptions of 313 manufacturing employees (both DMT users and non-users) on digital manufacturing technologies.

Recruitment: We used the recruitment platform Prolific Academic to recruit participants. The platform offers the opportunity to filter certain demographics to pre-screen the participants. In our case, we needed UK participants working in manufacturing. The platform allowed us to easily integrate our Qualtrics survey tool and collect our data between 14 and 15 October 2020. Participants completed the survey online, which was timed to take no longer than 12 min. The survey was organised in three parts. The first section investigated the perceptions on digital manufacturing technologies. In the second part, employees who worked in organisations that use DMTs such as robots, virtual reality, or sensors were questioned about their actual experiences with these technologies and other related issues. In the final section, the participants provided demographic information.

Procedure: Cranfield University's Research Ethics System (CURES/12146/2020) approved the research. Each participant provided informed consent prior to taking part in the study.

Participant's profile: Out of 184 participants, 129 were male, 54 were female, and one did not indicate their gender. The majority of the participants were either from the age groups of 25–34 (31.1%) or 35–44 (31.1%); 45–54-years old represented 18.6% of the sample, and 12.6% were in the 55–64 year range. Only 6.6% of participants were from the age group of 18–25. Participants work in different manufacturing industries (27.2% transportation, 16.8% metal and machinery, 12% food and beverages, 10.9% electrical/electronics, 9.8% plastic and chemical products, 6.5% wood, leather, or paper, 5.4% clothing and textiles, 5.4% medical/pharma/cosmetics, and 6% indicated that their industry was 'other'). We also asked participants about their role in the company and initially had 13 answer options. These roles were condensed into three main roles: 50.6% shop floor workers (i.e., operator, production manager, production technician, engineer, quality inspector, maintenance technician), 44% managerial roles (i.e., middle management, senior management, CEO) and 5.4% customer facing (customer service, marketing, sales), with an average of 8 years (STD = 6.9) in their current position. The survey sample had an uneven distribution of company size, with 19% of participants working in small companies (<100 employees), 29.9% working in medium sized companies (100–500 employees), and 51.1% working in large companies with over 500 employees. Over half of the participants had a college or university degree (57.4%), 21.3% had higher or secondary or further education, 18.6% had a post-doctoral degree, and 2.7% had secondary school up to 16 years of education.

Analysis: The collected data were exported to SPSS Statistics 26. The data were checked for incomplete responses and completion times shorter than 3 min. The first step for the data analysis was an overview of the participants' responses as a whole group. A non-parametric Wilcoxon signed rank test with hypothetical median of 3 (middle score on all answer options) was used to establish whether participants' responses differed significantly from the neutral answer option. Following this, we compared shop floor employees with managerial employees with a non-parametric Mann–Whitney test for two independent samples.

## 3. Results and Discussions

### *3.1. Employment Paradox*

The manufacturing industry continues to grow and requires more human capital and advanced technologies to cope with the increase in demand and emerging markets [46,47]. Certain manufacturing sectors are facing difficulties to fulfil emerging roles due to a low interest from suitable candidates. For instance, acquiring new shop floor workers is challenging because manufacturing tasks tend to be mundane and repetitive and unattractive to employees. Thus, manufacturers resort to the adoption of new technologies such as collaborative robots to cope with the labour shortage and maintain production quota. However, many manufacturing sectors struggle to attract highly skilled labour and compete with other industries for digitally skilled employees. At the same time, the introduction of new technology causes current employees to fear the loss of their jobs because they do not possess the right skills and experience to supervise and maintain the machines. These contradicting issues of having to acquire new technologies to solve a labour shortage, while also having to let go of unskilled labour is an employment paradox emphasized by our study.

#### 3.1.1. Technology as a Solution to Labour Shortage

Manufacturing industries are experiencing a shift in the workforce. One of the key reasons that motivate firms to innovate and adopt emerging technology is labour shortage. Our interviewed experts cited the difficulty in new recruitment and retaining employers due to the unattractive working conditions of the manufacturing plants. Research found that people do not want to perform tasks in the final assembly lines of car manufacturing because the tasks are repetitive, physically demanding, and often result in several costly health problems [48]. From our expert interview, innovation manager P14M describes a similar experience where people choose not to do jobs that are boring and monotonous, especially in cold factories. The expert continues to explain that the manufacturing industry does not appeal to the next generation and, because the current workforce is heading towards retirement, their organisation considered technology adoption as a solution to cope with industry expansion and labour shortage, "*We've got people who have got the clock card number 007 and the lady was very proud as she was the seventh employee. She's been there for 25 years, but with that comes the other risk that those people are going to be retiring in the not too distant future […] and our labour pool is restricted because of low unemployment in the area [...] we have a turnover of staff that is challenging to keep the feed. We see automation as a way to supplement our recruitment as well as maintain the number of people that we need because we're growing as well*". The innovation manager emphasizes that technology is brought in to do tasks that people do not want to do rather than to replace the current employees, "*We have demonstrated that over the years we actually tend not to bring automation to reduce the amount of people overall. Those people are distributed somewhere else to do jobs that are actually a little bit more interesting or in a more pleasant environment*".

However, the introduction of technology inevitably leads to the fear of job loss. Although P14M's experience with technology implementation is rather positive, "*We have got various systems and operations automated with robots; people tend to take those quite well*", robot ethics researcher P5R found that a heightened fear around robots taking over people's job is the first concern people bring up, worried that automation will remove the need for humans. This is also reflected in the opinions of the surveyed manufacturing employees, with 72% of the participants agreeing with the statement that robots and other digital manufacturing technologies will replace unskilled workers. Furthermore, all respondents agreed that the job security for people working directly with newly introduced digital manufacturing technologies has decreased (mean decrease of 3.33 (20.49), $t(154) = -2.02$, $p = 0.045$). Interestingly, the shop floor workers feel this less strongly than the managerial group (shop floor mean decrease 1.04 (21.02) and managerial role employees indicated a decrease of 6.03 (19.65)), although the difference in opinion of these two roles only approached significance ($U = 2475.50$, $p = 0.068$). Technological unemployment is a pressing issue as research has shown that the implementation of certain digital manufacturing technologies may result in a decreased number of low-skilled workers because it only requires few skilled workers to maintain the machines [49,50]. Experts also found that the danger of job displacement may not only apply to unskilled labourers. Technology lawyer P9L argues, "*A skilled craftsman that teaches machines how to replicate work is effectively doing himself out of a job or perhaps not getting the full value of that skill and experience*".

Arguably, workforce inclusivity and sustainability could be in jeopardy depending on the approach taken by manufacturers introducing technology into the production line. Some of our interviewed experts observe that in many cases firms are likely to uptake full automation as opposed to human-robot collaboration due to cost and safety reasons. Senior lawyer P11L argues that it is more likely that companies will choose automation over human-robot collaboration because it is legally easier to demonstrate that a safe system of work is in place when there is a clear separation of workers and robots. Manufacturing expert P15M also recognises the complexity in incorporating new technologies into the workplace to do tasks currently performed by human workers. The expert advises that organisations should not design technology to do the same task in the same way as people are doing them. Instead, organisations should redesign the process completely and only consider technology capability to reach the desired outcome, as stated, "*Go back and look at the process as in, 'what are you starting with? What is your driving end result? Look at those individual activities that we currently do that you might not need to do […] You need to understand the difference in what you achieve via a human versus what you can achieve by a process […] if you mechanize the wrong human, you've created more issues*". However, P15M only speaks for machines performing existing tasks, not explicitly implying that human roles are fully eliminated or will be replaced by machine for future tasks. In some tasks, it may be that full automation is more efficient and safer, but opportunities where humans and machines can operate effectively together should also be considered.

#### 3.1.2. Lack of Skilled Labour

Although manufacturers are moving towards robotics and automation as a solution to combat labour shortage, many manufacturing companies find the lack of skills a serious limitation to their ability to implement Industry 4.0 technologies and practices. The increased prevalence of digital technologies within workplaces is dramatically altering the demand for certain skills, with employers requiring operational staff to have a wider knowledge of different technologies and production methods [51]. Organisations need employees with specialist skills, which may be difficult to find. For many organisations (in particular SMEs), it is too costly to innovate in-house given that the need for such skills is specific to certain technologies and projects [52]. When introducing new technology to the workplace, it is expected that a company hires talents with different skills, or trains their existing workers to acquire these new skills. Quality control director P2M explains that within their own organisation, new talents need to be employed because current workers lack the expertise to deal with advanced machines such as cobots. P2M sees some challenges training current operators to control machines and be able to problem solve on the spot "*I'm not sure if they will have the expertise in dealing with cobots but they need to know how to conduct a good analysis to find the part that fails. The challenge will be to have a good explanation to the operators and to train the operator that would be working in this environment*". However, some of our experts state that if the introduction of a new technology is minimal it may not be economical to have such expertise in-house. As explained by P15M, "*For a robot, you teach it the fundamentals, but if you change from fundamentals, then you've got to reteach it. It's a very expensive skill that you need to keep in house. If you have two or three robots, you wouldn't necessarily have that skill because it's not worth it*".

Organisations cannot expect to be able to extract the full capabilities of advanced machinery merely by installing them correctly and "flipping the switch". One also needs to look at the effectiveness of use, as there will be inevitable operational problems when adopting new technologies (breakdowns, adjustments, debugging). Economic geographer

Gertler explains that "machinery and production process innovations are often so complex that successful implementation post-adoption cannot be assumed" [53] (p. 25). Our survey showed that there are indeed many operational problems to deal with and issues requiring adjustments (84%) after implementing DMTs, such as hardware (47%) and software failures (52%). Often the technology is under-utilized (37%), misused (9%), or avoided altogether (15%). Gertler determines that there is a need for much greater emphasis on worker training, given a tendency for Anglo-American firm owners to under-invest in this important function relative to their European and Asian counterparts [53]. Employers see a clear need for operational staff to have wider knowledge and understanding of different technologies and production methods [51]. Industry 4.0 also requires this knowledge to be continually developed with periodic training every few years to renew and expand skills [54,55]. Surprisingly, we found that people who have not yet worked with digital manufacturing technologies in their organisation feel that they do not need to acquire new skills to be able to work with these innovations. This is in contrast to employees who already have experience with these technologies.

In addition to training or hiring workers with skills required at the level of programming and maintaining technology, another crucial point to address is that organisations will need to maintain employee satisfaction so that they stay in their jobs. About a third (35%) of DMT users participating in our survey noted workforce dissatisfaction with the new technologies. As P15M puts it, "*as you start getting a mass [referring to robots], how many people do you train? And how do you maintain the interest for that level of labour, that expensive labour?*" Similarly, P14M noted that the industry is not very attractive and has a high turnover rate. Skilled workers may leave the job easily, so it is important that employees are engaged and remain interested in their work.

Nonetheless, although new skills are required to work with smart technologies, in some roles the skills of experienced workers are more valuable and harder to be replaced by modern technologies. Human workers can more easily adapt to new environments and tasks than robots. Robotics expert P1T, states "*I don't need to reinvent a human being in order to achieve the sort of tasks that we're trying to achieve*". The robot expert sees that for a multi-step process a single human worker can do all the tasks whereas it might require different types of robots to complete the whole process as robots still do not have the physical and mental dexterity to solve problems the same way humans can. As industry focuses on recruiting new talents, it is equally important to consider the value of the non-transferrable skills of the current workforce before introducing new technologies to do similar tasks.

### *3.2. Changes in the Nature of Work*

The adoption of DMTs changes the nature of work for shop floor workers. It is evident that employees find the introduction of DMTs to be beneficial from a safer working environment to a decrease in stress level. Equally, there are certain drawbacks such as an increase in mental workload, an augmentation of performance monitoring, and reduced social interaction with colleagues. Particularly, privacy is viewed as a significant trade-off given the intensification of sensors and computing power relying on data from workers' interactions with the machines (including their physical location and movement patterns in the workspace), which possibly introduces a higher degree of workplace surveillance. Such concerns need to be addressed, as they can lead to a detrimental impact on the sustainability of the workforce.

#### 3.2.1. Improved Work Environment

With regard to the changing conditions of manufacturing work, our survey showed that there are many benefits of implementing new digital manufacturing technologies for the employees working directly with these newly introduced technologies. Clear benefits are, for instance, a significant decrease in fatigue, stress, and anxiety (Figure 2). Furthermore, both shop floor and managerial employees state that safety concerns and physical workload have gone down and that the number of occupational diseases such as noiseinduced hearing loss has significantly declined. Despite the many benefits of digital manufacturing technologies, the respondents also identify some disadvantages. As we already noted, all respondents agreed that mental workload (MWL) [56] and performance monitoring have significantly increased, whereas job security has decreased. Despite these negatives, shop floor workers do not indicate that their job fulfilment has lessened.

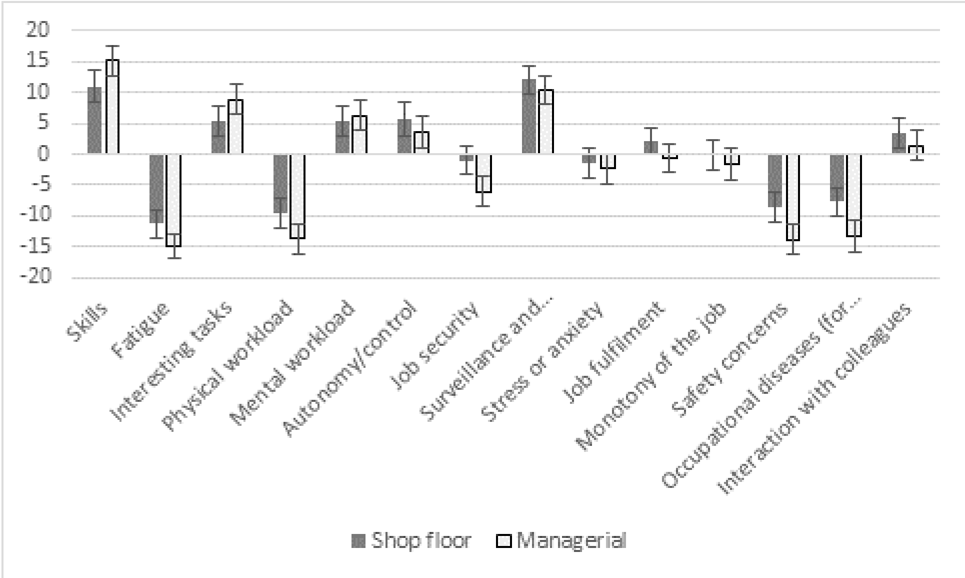


**Figure 2.** Issues around DMT and robots after technology introduction as a function of the employees' job role.

Interestingly, our experts anticipate that one of the potential negative impacts on workers' well-being due to change in the work environment could be the absence of human contact or a lack of social interaction, P12L commented, "*I think when you start to introduce robots, you start to remove the opportunity to have those social connections. For example, we often have to work really late and part of how you deal with that in the workplace is you have people that you work with and there is camaraderie. So on a purely human level, how do you replicate that if you introduce robots?*" Whether this often-expressed fear of loss of camaraderie and social interaction will be a true effect of the introduction of robots in the workplace remains to be seen, as our survey showed that DMT users did not experience a lower level of interaction with their colleagues after the adoption of new (robotic) technology. P5R points out that with all technology introduction a transition period can be difficult, particularly when adapting to different forms of interaction (from co-workers to robots/machines) and the consequences of that have not been explored enough, "*I think the habits that we have about how we interact are very ingrained, but certainly I don't think you could very easily sort of launch a cobot into a workplace and just say 'there you go.' You would expect some kind of issues to arise, but you'll probably find that after a series of time people will be able to kind of develop practices that would be able to accommodate the robot. It'll be an empirical question about whether it's possible to train humans to adapt their interactive style to meet what a robot does or to create a robot that interacts like a human*". P5R also raises a concern where people may interact with robot 'co-workers' in a similar manner to the way they would behave towards each other, but with the difference that the robot does not return any emotions. Such interactions could lead to a negative impact on the workforce. Researchers conducted a study to investigate the behavioural and psychological effects when replacing a human advisor with a machine advisor, and they found that participants "experienced more negative emotions, lower reciprocity, and faulted their advisor more for mistakes when a human was replaced by a machine" [57] (p. 1). Other research found that because humans are social creatures, there could be serious long-term consequences such as diminished organisational commitment and lower productivity when positive emotions that come from social interactions are lost [58]. Therefore, it is important that the identified disadvantages and concerns are addressed for the utmost benefits of the introduction of DMTs to be capitalized.

#### 3.2.2. Privacy and Surveillance as Trade-Offs

The use of sensors has become crucial in robotics to let the technology gather data to perform its tasks and interact in a safe way with its environment [59–61]. However, this leads to increasingly problematic privacy issues given the constant interaction of robots with humans [62]. Technology consultant P4C voices the following concerns: "*anything that brings more sensors, cameras and microphones close to the human person has a privacy challenge because what you are doing is you are starting to gather more and more types of data. As you do that, that data is radioactive, that data is very revealing and intimate*". Several experts are cautious about the potential metadata that can be gathered by technology and discuss how DMTs and cobots may increase surveillance in the workplace in a similar manner to other security technologies used to monitor employees. Data protection lawyer P12L states "*I think with robotics you start to introduce more opportunity for data to be collected in different ways. And knowledge is power. Even if the technology is not meant to be there as your workplace surveillance, it will be interacting with people and potentially roaming around the workplace and indirectly you can still obtain data about the employees*". This concern is also voiced by our survey respondents with both shop floor and managerial employees agreeing that surveillance and performance monitoring has increased. Although shop floor workers think that surveillance increased more than managerial respondents, this difference was not significant (U = 2907.50, $p = 0.889$; Figure 2).

Although one could argue that as required by data protection legislation, people should have a choice on how their data are being collected and used, data processing at work is a complex issue determined by the power imbalance between employers and workers. Despite their concerns of how emerging technology can become privacy invasive, employees may not be in a position to make choices without any ramification. Senior legal scholar and adviser P7L explains that, "*in the traditional data protection problem like Facebook and Google there's still an element of choice. It might be a very limited element of choice, but [people] typically have to do something for [their] data to be collected, [they] have to make use of a service. But in the workplace, employees increasingly involuntarily have to collaborate in the data gathering. There's a massive and more problematic use of privacy invasive methods which can't any longer be dealt with adequately through consent or some of the other legal mechanisms*". With DMT's reliance on sensors and cameras to collecting data, employees may perceive that their employer tries to monitor and gain control over every aspect of their moves through overly invasive surveillance. Research found that constant over-monitoring of employees can also lead to an increase in stress, anxiety, burnout, and overwork—adding to more psychological and physical welfare issues [63–65]. On that account, privacy and surveillance concerns need to be unpacked and addressed, as they can negatively impact employees' well-being.

### *3.3. Acceptance Challenges: Inclusivity in Technology Design and Adoption*

In consideration of employees' acceptance of the adoption of DMTs, safety and trust are presented as the key concerns. A lack of employee involvement in technology design and adoption hinders the safety and confidence level in the innovation. It is recognised that clear communication and engagement with all stakeholders can improve workforce acceptance.

#### 3.3.1. Safety and Design

The interviewed experts recognize that managing safety risks can help employees feel more comfortable adopting new digital manufacturing technologies. Technologies like collaborative robotics receive much scepticism. Accidents involving robots are regularly reported in the mass media, further increasing the safety concerns people might have [66,67]. According to P4C, people often question whether robots can injure them. Employees are concerned whether the robots are adequately inspected for safety before being put into service, as noted by P14M "*I think they would need to be confident that this robot isn't going to knock them out with a left hook*". P5R shares a similar viewpoint: "*safety is a huge component of trust. If you don't feel that a robot is safe, you're very unlikely to trust it when you're interacting with it*".

Ironically, although safety contributes to employees' acceptance and trust, experts raise a very important issue that inclusivity of different stakeholders, particularly the end users, is required to make sure the technology is safe. Such inclusivity is not being practiced enough by industry. According to P7L, there is the tendency to use technology that works sufficiently well and then expect humans to adapt their behaviour. Although this might work for the 'average' person, it might pose problems for people who have been marginalized in the datasets used for training and design. The expert continues with an example of voice recognition that enables cobots to interact with people; the lawyer sees that there is a risk that it will not understand a wide range of people, such as those who have a strong foreign accent, speakers with a regional dialect, or people who speak minority languages such as Gaelic or Welsh. We observe that this could also lead to indirect discrimination in hiring if the robot only works efficiently and safely with some groups of people, as businesses may exclude certain groups of applicants with the justifications on grounds of safety. P3T made a similar remark related to this bias, "*If you're designing systems for mass production, one of the key things in the design process is to have diversity of viewpoints. From a person deploying that kind of technology perspective, what I would be most worried about is other human actors operating within the same domain space. When you are talking about reinforcement learning you are taking knowledge from observing one particular human, and then you're trying to replicate that in a physical space collaborating with a different human. There's obviously ethical concern that have you considered the differences between those humans and what if it's a disabled person? How do you make sure that not only the one person that the robot is focusing on is free from harm, but anyone else that the robot is not focusing on but is in the same space*".

Consequently, lack of understanding of the end users can lead to significant safety risks in the implementation. People tend to have higher standards and unrealistic demands towards robots and other autonomous systems. When researchers tested individuals' tolerance for mistakes made by artificial intelligence software, they found that people demand a much higher success rate from robots than from humans [68]. This can lead to safety problems as people may become less vigilant when interacting with autonomous systems because they expect them to make no errors; whereas technology designers place their expectation on the operator to ensure that the system performs as it should. These are expectations that operators cannot satisfy. P11L states, "*The technology being designed almost under the expectation of humans cannot fail, which is completely wrong. We see accidents where one of the emerging issues appears to be a fundamental misunderstanding of the technology*". P11L emphasises that risk manifests itself when either the limits of technologies are clear but not communicated properly or when the limits are unclear or not understood. Product safety is the minimum requirement for technology adoption. However, in the case of collaborative robotics, there is an additional layer of complexity as the technology is designed to be adaptive to work with or alongside human workers. Having inadequate understanding of the end users can result in serious consequences. Hence, inclusivity of different groups of end users in design and adoption is key to ensure safety of the employees when interacting with robots.

### 3.3.2. Trust

Although trust is one of the key topics for technology acceptance and particular the uptake of robotics [69], it is a complicated subject in a workplace setting. The interviewed experts approached the discussion around trust from two different angles: 1. Trust in a specific context of human interaction with autonomous systems; and 2. Trust as a socially constructed concept and its significance in the workplace.

On the first discussion, experts are of the opinion that human-robot collaboration requires trust at a level similar to how one would interact with their colleagues. P1T states, "*That team has to trust each other, or I should say that humans have to trust the robots. There's some closer degree of collaborative work where there's a significant element of trust in or from the human*". P12L also agrees, "*I think it is about trust, and personally I think a lot of good in the workplaces is based on trust and how you make assessments about people. From a human perspective it's probably going to be harder to make assessments about robotics in the workplace if you've not been given the information about what it is that they're doing, and the information that they're collecting*". P2M adds that human employees work well together because they communicate with each other, and such interaction will be required between human and robots. On that ground, P5R highlights that transparency and explainability need to be the key elements in design to build trust, "*people can't trust something if they don't know how it works. And that creates a difficulty because a lot of the time with this very complex AI stuff we don't know how the decisions are made*". He poses the following questions: "*Should we try to create tools that are explainable to people? And if we can't explain them, should we be using them? I think that's kind of a question that comes up with automated decision making. So transparency is a big issue in relation to trust*". This is the same argument mentioned by P3T: "*Another aspect to this is 'explainability'. Let's take a health care robot, a cobot is collaborating with a senior citizen to make them move around or take their medication. Imagine that you are that person, you are alone with that robot and it does something that you don't understand or expect. There is a very strong argument that in order for people to trust these kinds of robots, there needs to be a way to understand why it did what it just did*". Nonetheless, P1T argues that it is important to build the right level of 'trust' to prevent over-trusting, "*there are some situations in which humans have a tendency to trust machines when they perhaps shouldn't*".

On the second discussion about trust in the technology, some of the experts are of the view that only acceptance, and not trust, can be achieved in the workplace. P5R remarked, "*in order to trust something, you have to have a choice of whether to use it or not. If we're kind of talking about robots in the workplace, trust is only relevant if it's a choice to have those robots there or not. If they're kind of enforced on people, then they just have to rely on them as being safe. If people have no choice, whether or not they trust them is kind of irrelevant in that sense*". P8L noted a similar argument, "*Trust is only relevant to discretionary action, isn't it? Because if I am being told by my employer 'this the way the factory is going to operate', I have two choices: to leave or to accept it. I might not trust it at all, but my only choice is to stay or go. It isn't to work with it or not work with it. It's also about power structure because if corporations have the ability to bring [robots] in, it might not matter whether the people accept it, trust it, or want it. Frankly, if they are in the lesser bargaining position economically, those resistant factors are less relevant and that is not a social or political comment, it is just a fact, reality*". Trust is a complex and delicate matter. Striking the balance between building trust and preventing over-trusting in technology needs to be achieved. The discussion on the relationship between trust and acceptance still needs to be unpacked despite the controversial findings on the irrelevance of trust in the workplace.

#### 3.3.3. Communication

Our experts found that external factors can also contribute to employees' fear and lack of acceptance of new technologies. Several of the interviewed experts feel that there is a misunderstanding of what emerging technology can do. If technology has not been properly communicated to the users, it can lead to an unrealistic fear. An example noted by chief technology officer P3T relates to the overselling of artificial intelligence technology: "*Because there is a lot of money floating around in the AI market, making a lot of promises. But from what I know about AI and the state of technology, we are decades away from meeting what some people will promise*". P3T explains that there are different approaches to artificial intelligence. Initially, AI decision-making that was based on empirical evidence turned out to be too complicated, which resulted in what is known as the 'AI winter'. An AI winter is a period of reduced funding and interest in artificial intelligence research, brought on by pessimism in the AI community and followed by pessimism in the press [70]. As P12L remarked, "*I think a lot of people's perceptions will depend on what's put out in the media over the next however many years. People will be, as we all are, influenced by what they read and what they see*". The promotion of products or applications can be unintentionally misleading, thereby raising false expectations of those users with limited knowledge or experience. Proper communication is needed so that people will not buy into false promises or develop irrational fears.

Consequently, to accomplish employee acceptance of new technologies, it is imperative to include as many different stakeholders in the decision-making as possible, as well as ensuring that the benefit of technology is communicated properly. In addition to offering employees direct input in the decision-making, it is key to take them along the process of implementation in other ways to help them accept new digital manufacturing technologies in their workplace. For instance, people are more likely to accept new technology when they are given the information they need about the transition as well as the reassurance that their jobs will not be negatively impacted. P12L remarks: "*If people don't understand the benefits that technology can deliver, they're unlikely to run to adopt it […] Whenever you're talking about robotics, or AI you have to take people along on the journey. Obviously, most people have to understand what it is and what the impact is. No one will question it if it's working. But if it's not, people are going to have lots of questions and to be able to explain that to everyday users is going to be a really important part of creating an acceptance*". This is also noted by P14M, "*Taking them on the journey. You just don't choose morning and it's there overnight. It tends to scare people when you turn up and there's a new machine there*". P2M confirms the importance of informing their workers and maintaining their morale by illustrating how their company implemented new technology into the manufacturing line and managed to reassure employees that the introduction of new technology would not replace them, "*We always have the plan of what to do, why we want to do that kind of change in the process, how they will be impacted, and how we have to reorganise the activity. I will say in our activity, we have no issue with that. In fact, nobody has gotten fired. And this is why it's easy for us just to explain what we want to do and what are the reasons such as our company will be more profitable so they are not afraid that they will be fired*".

According to our survey, 78% of shop floor respondents and 70% of managerial role respondents agreed that the long-term objectives of the new technology were explained in detail to the workforce. In addition, we also asked participants whether they have any input in the decision-making on new digital manufacturing technologies. We found that influence on the decisions does not only take place at management levels, but also at other levels within the company and that employees in different roles felt in varying degrees that they had a say in the acquisition of new systems. Although only 10% of the operators and 9.1% of the quality inspectors confirm that they have 'a great deal' or 'moderate amount' of input, a much larger percentage of the engineers (40%) say they have influence. However, the maintenance technicians and production technicians do not play a role in technology acquisition decisions at all. Managerial employees indicate different levels of decision-making: from middle managers (23.9%), HR, admin, and finance role respondents (30.8%), to production and senior managers (41.7% and 77.8%, respectively), and finally CEOs (100%).

Some of the experts, including manufacturing experts, are aware that inclusivity in decision-making is key and indicate that such practices are already adopted in their firms to ensure employee acceptance. Other experts feel that there are not enough organisations who represent workers and that impacts of new technology implementation are not being fully assessed. One of the lawyers, P7L, stated that there are consumer protection organisations that speak for the user of the product, but that there is not enough labour representation in the workplace: "*We have seen a massive drive to delegitimize and disempower union movement and at the moment it seems to be as trivialities rather than the big issues. But in principle, I think there needs to be a massive pro-organised labour and all of that*". P10C shares a similar view, "*I suppose the representation needs to be from the point of maximum impact wherever that falls in our society. If you're in Germany, you have workers' councils and trade unions and to understand the impact of robotics, they'll need to, without being Luddites, understand that technology will change the customer demand and will put the firm that you work for out of business if you don't adapt in some way. So, we have to have the impacted represented. You can name all the usual stakeholders, the institutions, the government, but I'd really like some sort of independent arbiter, someone who can bring about all those softer issues that we've talked about*". Our survey is in accordance with the experts' view that there is a low level of labour representation. It shows that only 24% of the organisations where DMTs were introduced had trade union involvement in the acquisition of the new technology.

Besides having input into the technology acquisition, it is important for workers to have a continued dialogue with the technology designers and producers because involvement in the technology implementation process can lower their resistance. The survey results show that participants indicate they were able to express their needs and requirements to the technology producers extremely or very well in 48.6% of the cases, whereas 25.1% said that they either expressed their needs slightly well, or not well at all. Looking at the respondent's involvement with the producers during the integration of the new technology, we separated it into three stages: (i) the design/development stage, (ii) the installation/start-up phase, and (iii) the normal operation phase. Participants' involvement is highest in the third phase (see Table 1).

**Table 1.** The three stages and degrees of respondents' involvement with the producers during the integration of the new technology.

| | Design/Development Stage | Installation/Start-Up Phase | Normal Operation Phase |
|---|---|---|---|
| A lot | 20.2 | 24.6 | 26.2 |
| A moderate amount | 15.3 | 21.3 | 27.3 |
| A little | 64.5 | 54.1 | 46.4 |

To investigate whether shop floor workers' involvement in the design process brings positive consequences, we conducted a non-parametric between-subject test. We separated participants who indicated that they have "a great deal" and "a lot" of interaction with technology producers during the design stage vs. participants who indicated a "moderate amount" of interaction to "none at all". The respondents who were engaged with the technology producers during the design stage reported more job fulfilment (U = 552.00, $p$ = 0.060) and less surveillance and job monitoring (U = 598.00, $p$ = 0.098) at trend significance. Nonetheless, it is evidential that communication and employee's involvement in technology design and adoption process present favourable results for improving acceptance and job satisfaction.

### *3.4. A Route Forward: The Experts' View towards Responsible Adoption*

The impact on the workforce starts with addressing the questions of "*what kind of role robotics will take in the workplace and their role in replacing individuals and how it will work*", states data protection and cyber security lawyer P12L. The lawyer also points out that it is crucial to reflect on how to distribute the responsibility between human and machines and that this needs to be made clear to the employees.

Based on experience, technology implementation consultant P10C supports this view, arguing that even though job displacement is almost unavoidable when it comes to the implementation of technology in the workplace, there is still a very important conversation to be had on how to mitigate the negative impacts on the workforce and evaluate the benefits and costs of technology implementation, "*In our view, whatever stage of maturity you're at, the human roles will sort of start to diminish. There are some questions there for government and others; how quickly they want this to happen and where exactly the benefit should be* *sought and are people protected from it?*" For example, P10C suggests that an environmental impact assessment that is mandatory for the steel and coal industries to protect towns and workers should also be required for DMTs and robotics adoption.

P5R shares a very similar concern on how technology can be used to benefit the whole of society: "*everyone is worried about robots taking people's jobs but that's the wrong way of framing it. It's about robots supplementing the job we have already, or if they are taking away jobs, it's done in a way that those who've lost their jobs have a chance to do something different, so it's not a loss for them, it's something that's also a benefit for them*".

When the benefits outweigh costs, it could be rationalised that technology is adopted to help rather than replace people. The ethical questions about job loss may likely be discussed in the light of the purpose of the technology. As P11L points out "*Some probably suggest that cobots would free humans to do more creative stuff or less tedious stuff. There are very few ethical questions about things that assist you*". The lawyer continues, "*there are ethical questions about the loss of jobs. Although those are kind of balanced to an extent by some developing compelling arguments about how many additional jobs you get from doing this*". The justification is that some of the tasks that are replaced by robots are either not ergonomically best for humans, are undesirable, or require a high level of precision where errors can easily occur if done by human workers [71]. Similarly, the industrial revolution also created a radical change in the industry, although Bejarano et al. argue that this change gave "*new opportunities and better living standards to the working class since [the] population could focus on areas with superior impact*" [72] (p. 558). It is important to clarify that adoption of technology in response to employment issue depends on the tasks DMTs contribute to. Quality director P2M expects that there will always be a role for human workers "*People will be needed for programming the software and to teach the robots what to do. We will need people to implement new activity and new parts*".

Ultimately, job loss due to technology integration will depend on the organisations. The company's organisational culture and its shareholders and/or stakeholders influence how technology will be used and the consequences on the sustainability of the workforce. Technology ethics expert P6C emphasises that organisations can choose to augment the workplace with robotics, or they can choose to supplant all human activity with robotics, "*then it really becomes 'what are they intending to do?'*" Technology consultant P4C raises another concern: "*as you start to push skilled robots into place that collaborate with humans, the other humans who used to work with them may find themselves out of a job. In which case the question is, is the company re-skilling that employee?*" P15M notes that their current organisation has a plan for re-skilling workers who are permanent employees, "*within our business, we use directly employed staff and we use agency [staff]. Our trained people that have been with the agency that work for us, but for over a year, they then can become members of staff. In the event that you put robots in, all it does is move our guys from the repetitive and the mundane, to something that is more interesting. It is not added cost, but it is added value, and then the agency [staff] are the ones that move out*". The ultimate goal should be that technology adoption complements the workforce rather than substitutes it.

## 4. Conclusions and Recommended Interventions

Overall, our survey showed a positive reception by the workforce of robotics and other DMTs, which is encouraging for the future of these technologies. Digital manufacturing technologies are predicted to free workers from boring and repetitive jobs to focus instead on more joyful, interesting, and rewarding tasks. Other benefits that increase the well-being of the workers are reduced levels of stress, fatigue, monotony, anxiety, physical workload, safety concerns, and occupational diseases. However, there are some negatives that need to be addressed to result in a sustainable workforce. As we discussed in the Introduction, workforce sustainability is related to happiness, health, and well-being, but also to personal initiative and having the opportunity to be strongly involved in the work. Ways to accomplish worker retention, health, and well-being with the introduction of robots and DMTs are to promote increased worker engagement, to recognize employees as experts, to encourage management and representatives of employees to cooperate, to build employee skills by offering training and education opportunities, to reduce stress, and to stimulate self-efficacy (a person's belief that they can be successful when carrying out a particular task) [36]. Broadly speaking, a distinction can be made between interventions that are primarily targeted at individual employees and interventions that are primarily targeted at the organisation. Based on our interviews and survey we suggest several interventions to stimulate a sustainable digital manufacturing workforce, both on an individual level as well as an organisational level.

### *4.1. Interventions at the Individual Level*

Several interventions are targeted at individual employees. First, a strategy to enhance workforce inclusivity and sustainability is to encourage more input of the workforce on the acquisition and safety decisions of the technologies, especially from the people who will have hands-on experience with the technologies (e.g., operators and maintenance technicians). If technology is just forced on workers, they might experience feelings of dehumanisation and devaluation of their profession resulting from this technological innovation, engendering the feeling of being removed from the tasks they undertake. The goal is to augment human capacities instead of replacing them by introducing robotic coworkers. Second, it is key to increase the job security through better training of employees working in manufacturing. We have seen from our study that employees genuinely worry about losing their jobs because robots might replace them. After all, the emphasis of digital manufacturing technologies is usually on reducing time and costs, despite such a workflow often being perceived as a threat to the skills and livelihoods of shop floor workers. As Van der Heijden noted: "Lifetime employment is no longer guaranteed, as the qualifications that are required for jobs are becoming increasingly complex while, simultaneously, the 'half-life' of these qualifications is becoming increasingly shorter" [73]. The "half-life of skills or qualifications" measures how long skills are relevant in the workforce. Research suggests that skills generally have a "half-life" of about five years, with more technical skills at just two and a half years [74]. Therefore, one can assume that every five years skills will become half as valuable. This means that without additional upskilling or reskilling, the people that are being trained now will not be suitable for the jobs we need them to do by 2026. The new robot–human team collaborations give workers the ability to focus on less repetitive tasks that require a higher degree of cognitive abilities and different skill sets, such as creativity, logical reasoning, and problem sensitivity. Organisations must develop their workforce and provide deeper and more intensive re-skilling experiences and provide their employees relevant time for this learning as part of their change management and future workforce planning efforts. However, these efforts need to consider that the future with robotics and artificial intelligence will bring disruptive change, and the provided training content cannot be primarily based on today's requirements or on past successes [74]. Third, it is important that organisations stimulate better communication between managerial levels and shop floor workers. They need to have regular talks with the workforce to explain the benefits of newly introduced technology to reassure those jobs will not be negatively impacted. As other have previously noted, it is important for a sustainable workforce to "encourage employers to maintain a stable employment relation with their workers, characterised by job security, opportunities for worker involvement in shop floor decision-making and provision of training required for workers to learn how to extract the maximum effectiveness from a machine or production system" [53] (p. 39).

### *4.2. Interventions at the Organisational Level*

Other possible intervention strategies are targeted at the manufacturing organisations. First, organisations need to address the privacy concerns that employees voice in relation to an increased use of sensors and other data-gathering technologies in manufacturing by reducing surveillance and monitoring of the workforce. Employees' performance and well-being will decrease when employees feel that they are being heavily surveilled. Although workplace surveillance is already well established, modern technologies introduce even more precise ways to monitor every activity performed by the employees, especially technologies equipped with sensors. Therefore, apart from walking employees through the technology adoption journey as discussed in Section 3.3.3, communication on privacy and data protection is required. Although it can be argued on the grounds of safety and functionality that sensors are required for machines to perform the designed functions and to safely operate and interact with workers, at the organisation level it is about setting a boundary on what data are necessary strictly for operational purposes and what data should be erased if they could potentially be used against the employees. Although compliance with regulatory requirements should be a given, the requirements of the General Data Protection Regulation (GDPR) [75] should be seen as an opportunity to ensure that privacy concerns are addressed and employees' trust in DMTs is improved. First, a data protection impact assessment (DPIA) should be seen as an opportunity to deeply interrogate and manage the privacy risks posed by DMTs. Methods of employee involvement in the DPIA process should be considered, and completed DPIA need to be shared with employees. Second, in order to ensure data privacy for employees and in accordance with Article 25 of the GDPR, when introducing DMTs, employers must put in place appropriate organisational and technological measures that are designed to implement data protection principles. This requirement to ensure data protection by design and default must both influence choices about the technology to be adopted in the workplace and animate the design of processes surrounding the implementation of these technologies. For example, principles of 'data minimisation' should provide a basis for policies governing sharing and retention of data regarding employees; the principle of 'purpose limitation' should influence the ways that collected data are utilised. Third, once a DMT is adopted, employers must provide information to employees regarding the purposes for which data are processed, along with details regarding the employees' rights as data subjects. For instance, if certain data will be used for performance improvement or process optimisation, employees must be informed of such activity. The communication needs to be delivered in a simple and short format and it needs to be easy to understand. This information should be seen as the minimum, and employers should continuously communicate with employees regarding adopted technologies, the data that are collected, and the uses that they are put to. Clear communication and transparency can help ease and mitigate privacy concerns on perceived heavy workplace surveillance. In addition to the standard data protection training in relation to handling personal data, training specifically on the interaction with the robots and sensors should be provided.

Second, organisations need to understand and manage the change in mental workload experienced by employees due to the adoption of DMTs and robotics. Our survey findings showed that, although mental workload (MWL) increased after the implementation of new digital manufacturing technologies, stress, fatigue, and anxiety decreased. It can then be argued that an increase in mental workload does not necessarily have a negative impact on an individual's well-being [76]. For example, higher MWL can have a positive influence over an individual's engagement with the tasks by improving their concentration, as they must be attentive and agile when performing the task whereas low MWL may lead to boredom-causing mistakes if people's minds start to wander. However, in some cases, if MWL is too high, the task may become unmanageable as employees cannot cope with the demand and fail to complete their tasks. This is on a case-by-case basis, for instance, a shop floor worker may thrive when MWL is high, whereas a manager may start to get anxious as MWL increases. One may suggest that in order to understand an individual's MWL, constant MWL monitoring could be helpful, as this will allow the system to adjust the workflow in real time according to employee's MWL in order to maintain the optimal workload. However, there is a counter argument to constant MWL monitoring; although the purpose might aim for maximizing adaptive technology adjusting to individual's MWL, employees may feel like they are being constantly monitored and surveilled, which could lead to negative effect on employee's morale and performance. We recommend that organisations should be aware that people have an MWL limit and that it is expected that the implementation of DMTs will increase individuals' cognitive processing as the tasks are shifted to more system-monitoring as opposed to traditionally physical work [77]. Therefore, before integrating DMTs into manufacturing environments, companies should conduct a task analysis and incorporate MWL measures to understand how the technology impacts employees' performance or their ability to cope with new task demand. This approach will help employers design a process more appropriately or at least have a better idea of what level of productivity or performance should be expected. For example, a company may choose to monitor the workload involved in a task over a one-week period, performing the task when the new technology is first implemented to capture data to adequately evaluate expected task performance. Another solution could be to provide a virtual space for employees to try out the new technology prior to the implementation to analyse the change in cognitive demands required by the new system or process and how it may have potential impact on fatigue and stress. Nonetheless, if employers choose to monitor workload, it needs to be implemented in a way that respects employees' privacy.

Third, employees need to be recognised as experts whereby the overarching aim is to involve the workforce as end-users in the co-creation of a highly technical and user-led workflow. This can be accomplished by assessing how different types of technology can enhance workers' practice and by facilitating a dialogue with stakeholders in the technology industry. There needs to be a dialogue between industry workforce and technology developers by feeding back data on workers' use of and attitudes towards robotics technology to tool developers. End-users' personal narratives will actively inform the technologies' evaluation process to co-create a workflow where technology works with manufacturing workers rather than instead of them. This involvement of the workforce ties in with the earlier noted strategy of giving employees a say in the technology acquisition phase.

Finally, organisations should strive to reduce the lack of worker representation. Human-centric approaches could emerge that focus on giving the workforce more control over the process, enhancing their practice, and generally representing a more sustainable option than technology-centric approaches. One way to increase the level of involvement of workers in the workplace and give them more control over processes when introducing new technology is through trade unions. Interest in trade unions from manufacturing workers has declined by almost half (48%) since 1995 and new research suggests that by 2040 less than 10% of manufacturing employees will be members of a trade union [78]. The impact on employee rights and well-being of this trade union decline across the UK is worrying because these unions are of great importance for protecting workers' jobs, securing adequate work facilities, and ensuring satisfactory work conditions (e.g., working hours, health and safety, equal opportunities). Balaji [79] points out that workers whose jobs are insecure need advice, support, and help with getting training so that they have the skills to make them more "employable" if their jobs are restructured or disappear. Furthermore, a 2016 report shows that there are 50% fewer accidents in unionised workplaces and that trade union members are more likely to stay in their jobs longer (on average 5 years longer) [78]. Unions allow workers to come together in a collective voice to communicate to management their dissatisfaction and frustration.

We acknowledge that the impact of DMTs on employment is difficult to be quantified without considering sector specific contexts and the diversity of tasks performed within the same field of occupation. Hence, our proposed interventions advise on understanding the impact of the transition into digital manufacturing in order to stimulate a sustainable workforce.

## 5. Limitations

This study has certain disadvantages, such as bias in sampling and interviewer and interviewee bias, therefore certain topics might have been explored more during the discussion. We do not claim that the presented findings are conclusive, and they should not be used for generalizations. We recognise that the interviewees from the expert interview study are not necessarily representative of all stakeholders involved in the decision-making process. It should also be noted that many of the interviewees have worked with connected autonomous vehicles. However, it is to be recognized that this technology, as a form of human-robot collaboration, already has various use cases in real-world commercial applications. Importantly, there is an availability of regulatory frameworks and legal analysis for autonomous vehicle technology, which makes the experts' experience valuable and relevant to the UK digital manufacturing sector where human-robot collaboration is still developing.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data is stored on the servers operated by the University of Nottingham and Cranfield University.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** Participants.

| Unique Codename and Classification | Role in the Organisation | Area of Expertise | Years of Experience in the Field of Expertise | Years of Experience in Dealing with Smart Technologies | Types of Smart Technologies |
|---|---|---|---|---|---|
| P1T | Deputy Director | Robotics and autonomous systems | 30 | 25 | Human Robot Interaction |
| P2M | Quality Director | Automotive industry—quality control | 15 | 5 | Industrial robots, cobots |
| P3T | Chief Technology Officer | Quality management, software, artificial intelligence, standards development | 20 | 4 | Machine learning/AI |

| | | | | | |
|---|---|---|---|---|---|
| P4C | Founder and Director | Privacy, data protection, public policy | 15 | 15 | Industrial robotics, consumer IoT |
| P5R | Senior Researcher | Human centred computing | 4 | 4 | Ethics, responsible innovation and governance of robotics, AI, IoT |
| P6C | Consultant | Digital technologies, social responsibility, sustainability, and ethics; organisational behaviour; standardization | 39 | 20 | Most of the smart technologies |
| P7L | Research and teaching | Law and technology | 25 | 25 | Legal expert systems; machine translation, robotics, AI |
| P8L | Partner | Law and connected autonomous vehicles | 23 | 5 | Transport tech, CAVs |
| P9L | Director | Connected and automated vehicles | 5 | 5 | Connected and automated vehicles |
| P10C | Founder and Owner | Connected and autonomous vehicles infrastructure | 30+ | 10 | Traffic and transportation systems, LiDAR and camera technology on vehicles, robot concept |
| P11L | Director (senior lawyer) | Law and connected autonomous vehicles, specifically transport regulation | 18 | 5-6 | Aspects of robotics, HMIs, AI, IoT, connected and autonomous vehicles |
| P12L | Senior Associate | Law, technology, and data | 8 | 8 | From a legal perspective: AI, IoT, connected and automated vehicles |
| P13L | Professor | Law and technology | 7 | 10 | Robots, AI, AR, VR, IoT |
| P14M | Innovation Manager | Manufacturing | 20 | 3 | Automated guided vehicles, robotic arms |
| P15M | Projects | Automation | 30+ | 30+ | Robotics, vision systems, sensing systems |

## Appendix B

**Table A2.** Description of code.

| Theme | Code | Description | Example |
|---|---|---|---|
| Adoption of new technology | Acceptance of new technology | Elements that influence people to accept or not accept new technology (user perspective) | P14M: "*We have got various systems and those operations automated with robots. People tend to take those quite, quite well. Jobs that are boring and monotonous then people will choose not to do to be fair. And particularly it's cold in our factories*". |
| Adoption of new technology | Change management | Approaches that can help prepare, support organisations in adopting new technology | P2M: "*I will say in our activity, we have no issue with that. In fact, nobody has gotten fired. And this is why it's easy for us just to explain what we want to do and what are the reasons such as our company will be more profitable. They are not afraid that they will be fired*". |
| Trust | Trust | Key contributions of forming trust in new technology and robots | P5R: "*So then you have issues around explaining ability, should we try to create tools that are explainable to people, and if we can't explain them, then should we be using them? And I think that's kind of a question that comes up with about automated decision making. So transparency is a big issue in relation to trust*". |
| Data and privacy | Data and privacy | Different aspects surrounding the role of data and privacy in technology design and adoption | P4C: "*Anything that brings more sensors, cameras and microphones close to the human person has a privacy challenge because what you are doing is you are starting to gather more and more types of data. As you do that, that data is radioactive, that data is very revealing and intimate*". |

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