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Framework for universal design of digital support and workplace design in industry

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Abstract: The aim of this paper is to propose a framework for universal design of manual assembly workplaces. Workplaces that are adapted to different individuals, regardless of gender, language, background and functional variations, also support the fundamental goals of the Industry 5.0 concept and an accessible, safer, productive and error-proof work environment. The study included: 1) a qualitative study on key factors for universal design and comparison with universal design theory; 2) improvement suggestions to the company based on observations, interviews and theory; 3) a framework for universal design. The framework included the following areas: personalisation and context, activities/tasks and output, and methods/standards and factors were suggested so that companies could start their analysis work for the design. The study resulted in new insights and empirics regarding universal workplace design.

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Keywords: Industry 5.0; assembly; inclusive design; universal design; poka-yoke; standards.

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This paper is a revised and expanded version of a paper entitled 'Synthesis of universal workplace design in assembly – a case study presented' presented at Proceedings of the 10th Swedish Production Symposium, Skövde, Sweden, 26–29 April 2022.

1 Introduction

The focus of this paper is to support manufacturing companies in reaching Industry 5.0 by suggesting a framework for assembly workplaces through universal design. Industry 5.0 has the vision to go beyond efficiency and productivity and use new technologies, in a human-centred way, to ensure a sustainable society, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the centre of the production process (Xu et al., 2021). 'Industry 5.0' state that human-centred digitalisation should support all types of sustainability goals (EC, 2022) and has three core aspects:

1 human-centric and socio-centric approaches to implementation of digital technology

2 sustainability

3 resilience (Breque et al., 2021).

Universal design aims at creating environments and products that can be used by as many persons as possible, regardless their age, 'normal' abilities, or disabilities (Null, 2013). Design for all people is a similar concept that means that a design should disregard aspects of age or ability and address the needs of the users in the widest possible sense (Clarkson and Coleman, 2015). Such design thinking can be used to form an inclusive sustainable industry (Correia de Barros, 2022). Well-designed ergonomic work in assembly can increase physical safety as well as productivity of workers (Hambali et al., 2021). This could also increase cognitive ergonomic aspects.

One aspect of having a socio-centric perspective on digitalisation is ensuring workplace inclusion; this is part of Agenda 2030 and considered a human right also for disabled persons (UN, 2023). In addition to functional variation, a social 'disability' may be experienced by migrants and others lacking language or industry skills. The relevance of performing research in this area is also strengthened due to the Swedish Government presented a societal need for 'simple jobs' after the large number of immigrants received in 2015. The issue of inclusion in the working life is also driven by the need of a long-term sustainable supply of skills that exists in the labour market (Pyke, 2018), driven by the demographic development. The ratio, 57%, of the Swedish population between 18–64 years are expected to decline to 53% during the next 50 years (SCB, 2019). The decline may be larger if net-immigration will be lower than expected. A solution for industry is to include people that currently are excluded on the job market, e.g., by functional variation, language skills and lack of education. People reporting functional variation are 16% among 20–64-year-old and almost half of these (7%) claims decreased work ability (SCB, 2021).

Previous research has supported workplace design in assembly by trying to automate work tasks or by aiming at the higher skilled workers, e.g., according to the Operator 4.0 definition. Industry 4.0 was said to transform the production processes and the organisation of work practices in manufacturing industries (Lasi et al., 2014) and to use automated solutions in combination of physical equipment and uniquely created software for the specific system that must meet the production requirements and conditions in the factory (Becker and Stern, 2016). These systems should assist and support the human capabilities and operators working in Industry 4.0 are often defined as Operator 4.0 (Romero et al., 2016). The operator 4.0 is "understood as a smart, skilled operator who performs not only cooperative work with robots but also aided work by machines as and if needed by the means of human cyber-physical systems, advanced human-machine interaction technologies and adaptive automation towards achieving human-automation symbiosis work systems" (Romero et al., 2020).

Although digitalisation and automation may be said to 'take jobs', that is not always true for manual assembly tasks. Assembly is one type of work where manual labour is still often chosen before automation, due to humans' superior flexibility (Fast-Berglund and Stahre, 2013). Instead, manual work can be supported by digitalisation and automated quality assurance (Romero et al., 2016) and transform traditional work to make it user-adapted (Mattsson et al., 2020).

Historically, workplace design efforts have focused on supporting the normal functioning working population, while ignoring support of people with functional variations. There is hence a knowledge gap about how work and workplaces can be designed to support all (Fundación ONCE and ILO Global Business and Disability Network, 2019). In addition, workplaces are today generally not adequately adapted to support demographic changes (Keates et al., 2000).

This paper will use universal design theory combined with empirical findings of practically working with universal design to develop a framework for designing human-centric workplaces. The scope is designing assembly workspaces since there is a knowledge gap in how they can be designed to fit manual assembly workers that has functional variations.

1.1 Aim and objectives

The aim of this paper is to propose a framework for universal design of manual assembly workplaces. The framework intends to increase practitioners' understanding of how universal design of manual assembly work may contribute to individual needs for adaptation and performance, i.e., supporting individual needs supporting the universal design concept. This way, guidelines, methods and tools can be chosen to be able to better reach Industry 5.0 according to the principles of universal design.

The framework has its base in the evaluation of a case at a unique 'easy work' Swedish company called Husmuttern AB (hereby called Husmuttern). Husmuttern provides assembly work for persons with disabilities and develops station equipment and work instruction software to facilitate other companies to employ people with functional variations. The objectives are to:

1 further develop the Husmuttern concept by introducing scientific literature such as WHO's standard for functioning and disability, universal design, productivity assessment, standards, and poke yoke

2 adding relevant factors by studying what factors experts use when supporting individual needs

3 combine factors from 1–2 into a framework

4 suggest how companies can work with the framework.

2 Theoretical frame

The theoretical frame includes the following areas:

1 universal design

2 the assembly operator

3 productivity in manual assembly work

4 standards and poka-yoke

5 safe work.

2.1 Universal design

To support development of an inclusive sustainable society the workplace should be designed to support everyone (Fundación ONCE and ILO Global Business and Disability Network, 2019). Universal design can be defined as a 'design for all people' and seeks to create environments and products that can be used by as many people as possible, regardless their age, 'normal' abilities, or disabilities (Null, 2013). The Center of Universal Design define universal design as "the design of a product or environment to be usable by all people, to the greatest extent possible without the need for adaptation or specialized design" (Burgstahler, 2020). There are seven principles of universal design:

1 equitable use, i.e., regardless diverse abilities, the design can be used by everyone without additional tools that might be stigmatising

2 flexibility in use; one can for example use it with right or left hand, adjust height, etc.

3 simple and intuitive use; it is easy to understand regardless language, experience, skills, ability to concentrate

4 perceptible information; different ways of information (verbal, tactile, pictorially) and clearly feedback if you use it right or wrong

5 tolerance for error; design that minimise hazards, errors and reduces opportunities to make mistakes

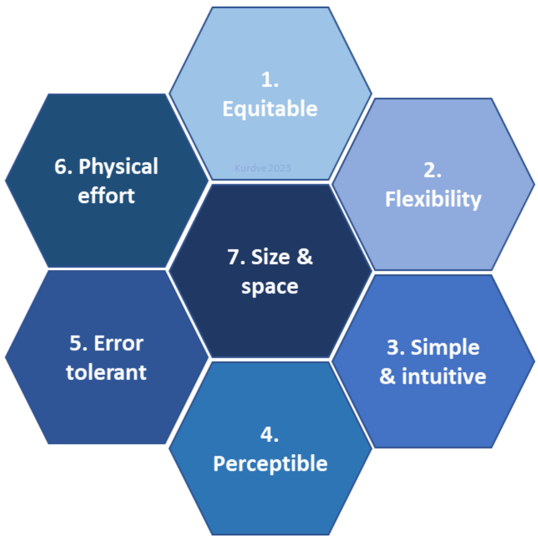
6 low physical effort

7 size and space for approach and use, see Figure 1.

The concept of universal design has its origin in architectural design and theory but has also been used in workplace setting of offices. There are varying terms and interpretations for universal design within the research community. Despite differences in phrasing (such as inclusive design and design for all), the ultimate objective is to achieve the accessibility and usability for the most diverse range of users (Story, 2011). Universal Design is proposed to be useful in future development of all types of workplaces that focus on including people with disabilities in the workforce (Mueller, 2011).

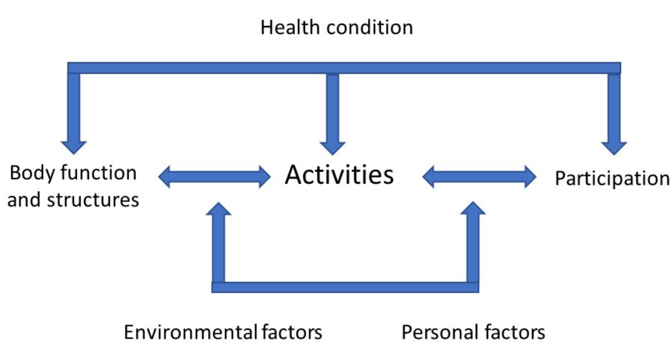
Countries that have ratified the 'UN Convention on the Rights of Persons with Disabilities' recognise the right of persons with disabilities to work on an equal basis with others in a work environment that is open, inclusive, and accessible to persons with disabilities (UN, 2022). There are several different definitions regarding people with disabilities used in different official statistics. According to EU have 87 million or around 19% of the total population disabilities (EC, 2022). However, the share of the population ranges from 10% to more than 30% depending on which definition is used and how the questions to the respondents are formulated (MFD, 2022). In the working age span between 16 and 64 years old are 16% disabled or have a reduced function of the Swedish population according to Statistics Sweden (ibid). The share of the population that get financial support from the government is much smaller, only around 1% of the total population (ibid). It is not easy to define who is disabled and who is not.

Figure 1 The seven universal design principles (see online version for colours)



Source: Adapted from Burgstahler (2020)

Figure 2 WHO standard for health conditions for functional and disability consists of the factors: body functions and structure, activity, participation, environmental factors and personal factors (see online version for colours)



Source: Adapted from WHO ICF

To classify the nature of a person's function variation or health condition, WHO has developed a classification system for functioning and disability in International Classification of Functioning, Disability and Health (ICF) (WHO, 2013). Figure 1 shows the model for functioning and disability. The ICF standard can be used to assess functioning of a person at “the level of the whole human being, in day-to-day life” [WHO (2013), p.8]. It describes also how a person’s health condition, environmental factors, and personal factors interrelate with one another. The relevant aspect of the standard is to use factors from the ICF specifically to the context of assembly workplaces which includes working with digital support.

An individual’s health conditions determine what body function variety is present as well as the individual’s social ability to participate in a particular work activity. Moreover, environment factors, such as workplace design, as well as personal factors, affect the person’s ability to perform an activity. Personal factors have not been classified in the ICF and therefore in this context includes the following: job training and knowledge, personality/type, intelligence, cultural background, and willingness/motivation to work (Li and Wieringa, 2001) as included as factors contributing to perceived complexity in human operations control. The ICF model has four main dimensions:

1 body functions and structure which include both the physiological and psychological functions and anatomic parts of the body

2 activities and participation which is the capacity and performance that is associated with a task or action that is performed by the individual

3 environmental factors

4 personal factors.

The environmental factors are features of the physical, social, and attitudinal world, i.e., understanding the context of assembly design which is presented in the next section.

2.2 The assembly operator

The digitalisation focus of Industry 4.0 has been criticised for not considering health and safety issues and the workers well-being (Badri et al., 2018; Zorzenon et al., 2022). The operator working in Industry 4.0 is called Operator 4.0 and is defined by its ability to become a smarter operator by being assisted by the technology advances offered (Romero et al., 2016). Therefore, to facilitate the transition, it is important to understand how Industry 4.0 technology affects work tasks, and how a balance can be created between tasks made by humans and automated tasks. Operator 5.0 is similarly described as a skilled operator that is supported by automated systems but in addition the operator should be supported by a system that is socially capable. In essence the industrial Operator 5.0 should incorporate not only the attributes that Operator 4.0 had but should also be able to manage increasing complexity, simultaneous tasks, being open to change, effectively communicate with technology and be a creative problem solver, have digital literacy, ability to use AI and data analytics, critically interpret the results, have a strong entrepreneurial mindset, work physically and psychologically safe with technology and have a mindset that is inter-cultural, inclusive and diversity oriented (Mourtzis et al., 2022). Operator 5.0 should, in this sense be resilient in two ways: self-resilience and system-resilience, i.e., that the systems need to support humans working with technology to be in symbiosis with technology (Romero and Stahre, 2021). The systems should both support operators in terms of self-resilience, e.g., health, cognitive functioning as well as support operators in terms of system-resilience, e.g., that the system can share and trade control with the human to guarantee system continuity.

To support all operators working in Industry 5.0, e.g., having a universal approach to human-centricity something more is needed; the technology and processes developed needs to be adapted to the individual and his/her functions. To support Operator 5.0 in the assembly task the workplace should be developed so that it fits the activities that are carried out, e.g., in learning several other cognitive processes are included, e.g., supporting the operator in all types of tasks.

In Mattsson et al. (2020), a model for assembly tasks was presented based on assembly modes which were identified as important for Operator 4.0. The three modes were based on Sheridan's (1987) five interrelating roles of system operators, i.e., plan, teach (programming), perform, intervene, and learn. Based on the five roles three modes were combined based on that they had similar cognitive processes associated to them. The three modes: learning, operational and disruptive (LOD) are presented in Table 1 together with work modes, adapted from Stahre (1995) and the accompanied cognitive processes, from Mattsson et al. (2020). There are two types of cognitive process: intuition and reasoning (Smith and Kirby, 2004). Intuition is automatic, effortless, and fast (Kahneman and Krueger, 2006). Reasoning is the analytic system (Tsujii and Watanabe, 2009), and require energy and takes time. Understanding what cognitive process is active is relevant in order to support the operator in accordance with Operator 5.0. The model is used as a guide for company practitioners to think about what types of digital or physical support tools that can be implemented to support the operator work (Mattsson and Fast-Berglund, 2016). For example, to support learning which involves reasoning, a digital learning tool could be suggested where the learner can click to find manuals and explanations of standards in a simple way or that operators working with operational work in production should be supported by signals such as Andon, pick-by light or light tool systems that support their intuition (Mattsson and Fast-Berglund, 2016). Digital support that is developed without considering active cognitive processes can cause unnecessary cognitive load and lead to poor performance (Sheridan, 2002). The work modes within assembly include several types of work tasks that are included in a typical assembly work in manufacturing industry.

Table 1 The learning, operational and disruptive assembly work modes model (LOD-model)

Assembly work modes	*Work tasks*	*Cognitive processes*
Learning	New work tasks, technologies, routines, or strategies are learned	Reasoning
Operational	The operator monitors machines, does manual assembly, handles small disturbances, teaches, i.e., program robots or operators, handles material and orders and does set-up or maintenance	Intuition
Disruptive	Tasks unknown to the operator, e.g., handling bigger disturbances such as lack of components or machine failures, problem solving or strategy planning	Reasoning and intuition

The Activity in the ICF standard, Figure 2, can be described using the work modes in Table 1. These modes can help increase awareness of what adaptations is needed to ensure a more predictable output, e.g., to support operators reaching a certain tact time or a certain level of product quality. In addition, aspects of situational awareness could be used to further describe a person's personal factors. Endsley (1995) described in her model for situation awareness (SA) that tasks and system factors, perception and decision making as well as individual factors are relevant in understanding a person's understanding of a situation. This way an individual person's situation, learning ability and needs could be included to develop the best possible digital support. Looking at the individual factors there are several aspects affecting a person which are: goals and objectives, preconceptions (expectations), information processing mechanisms, abilities, experience, and training. This could complement the personal factors suggested in Section 2.1. In addition to the environmental factors suggested in Section 2.1 the SA model also includes aspects of the system, i.e., system capability, interface design, stress and workload, complexity and automation, which are relevant when understanding the interaction between the operator and an automated system. In addition to the personal factors, the health condition influences activities and the output of the assembly, e.g., productivity and safety. Productivity and safety are described in the next section.

2.3 Productivity in manual assembly

To assure production profitability and plannability of any type of production it is necessary to measure productivity. This study is concerned with the shop floor level and one proper productivity measure in assembly work could be, e.g., the number of assembled products per work hour (Günter and Gopp, 2022). On the shop floor level and for a certain activity the productivity is built up and can be improved by three factors (Almström, 2013): the method, performance, and availability factor. The method factor is the ideal productivity rate that depends on the design of the workplace and the intended work procedure. Performance is the speed of the work measured as a percentage rate of a normal speed. The normal speed can be determined by a predetermined time system like method time measurement (MTM) (Kanawaty, 1992). MTM is the normal speed in the Swedish manufacturing industry determined by the collective agreement (between industry owners and union). The performance rate, i.e., how fast someone works is determined by the physical ability of the individual as well as motivation. In several industries, such as the construction industry, it is common to have piece rates, where workers get more paid if they work faster, i.e., have performance rate over 100%. The performance rate is also temporarily affected by the skill level of the worker, a not fully trained worker cannot be expected to work at 100% speed. The third factor that will affect productivity is the availability rate. This rate is affected by need-based availability rate, system designed availability rate and disturbances. Since humans cannot work all the time the availability rate will never be 100%. System designed losses are for example balance losses in a production flow, which is something that the worker cannot affect, but will result in waiting time. Disturbances such as broken tools or lack of material from suppliers affect productivity but are usually out of control. The productivity factors can be used to explain in detail how different disabilities (both physical and psychological) will affect the output of a task.

2.4 Standards and poka-yoke

To have lean and sustainable assembly operations, training settings means high requirements of the safety of equipment and efficiency of standardised work (Liker and

Meier, 2006). Standardised work and to do the right thing from the start and 'poka yoke' or error-proofing are basic parts of lean production and are tools used to improve, e.g., productivity of an operation. In *The Toyota Way*, Liker (2003) describes standardised work as based on the staff's ability to understand and perform a task, – as a standard for the best method right now. Standardising a work step so that everyone performs work in the same way every time, regardless of who does it or when, provides benefits both in training, analysis of errors and ensure that work is performed correctly. A basic rule in standardised work is that 'it should be easy' to do things 'the right way', i.e., design the workplace so that it is easier (for everyone) to perform the work in the standardised way than in an incorrect way. When we work with people with less industry experience, language skills, hearing, sight, or cognitive function variation, it becomes extra beneficial with the clarity achieved with standardised work, even if it naturally benefits everyone. An advantage is that with an agreed standard, it is also easier to detect any incorrect ways of performing work steps (Liker, 2003). To work effectively, the standard needs to be designed so that all risks are considered.

A first steps in standardised work is to have the workplace in order, and 5S is a method to reach an appropriate order. 5S (sort, set in order, shine, standardise, sustain) is give a workplace that is safe, orderly and easy to find things in Liker (2003). A visual standard is common for showing where tools and work items should be placed (Liker and Meier, 2006). Next step is a standard operation procedure (SOP). A classic SOP can be complex to read and understand, but visualised SOP that includes pictures can be used as visual instructions. One challenge regards information exchange where both too much information and not enough information can be problematic (Bruch and Bellgran, 2012). An SOP is not enough to train unskilled personnel in all details of the work, and critical issues and risks for mistakes that still occur can be handled by error proofing or poka-yoke (Kurdve, 2018). If the part, operation, or workplace is designed in a way that not only makes it easier to perform the task the right way but makes it impossible (or at least very difficult) to perform the task in the wrong way, the solution is a poka-yoke for that error.

2.5 Safe work

For universal designs aiming at designing workstations for personnel unaccustomed to industrial shop floor work, safety of operators and error proofing is particularly important. Human failures connected to error proofing include, e.g., slips, perceptual errors, rule based, mistakes and violations (Hobbs and Williamson, 2003). In manual assembly with inexperienced workforce, mistakes can be dangerous and thus be pinpointed safety and simplicity as a critical factor in designing the workstation.

Variation involving decreased physical or mental capacity of the workforce emphasise the need to design the workplace and design work tasks to be fault proof. Reduced speed of work (i.e., lower performance factor than 100%) can often be compensated for financially by subsidiaries from the government, but requirements for quality and safety can usually not be compromised.

3 Methodology

Both an explanatory and exploratory approach was used in this paper. Initially, explanatory research was performed to describe universal design in a case study by applying theoretical constructs from the theoretical frame. Empirical data, i.e., interview results was captured to find key factors that could further explain universal design in practise. Exploratory research was performed through, observation and trials to suggest improvements of the concept. After evaluating improvements and the first suggested synthesis a framework was suggested, thereby building theory based on empirical results and triangulated data.

The case study included:

a a qualitative study on key factors for universal design and comparison with universal design theory

b improvement suggestions to the company based on observations and theory

c a framework for universal design.

The empirical study is based on one case, with in depth learning of how inclusion was implemented in the case company, still with the ambition is to draw general conclusions. That might seem contradictory, but the motivation for this single case is that Husmuttern is a unique company. There are no known similar examples of development of assembly workstation concepts with inclusion in mind at any other company in Sweden. The Husmuttern concept was assessed on raising inclusiveness for persons with functional variation, migrants and temporary personnel.

Eight interviews with nine participants (one interview was with two persons at the same time) were conducted in the project where the aim has been to find key factors and principles that can be used to improve Husmuttern's concept. Six women and three men were interviewed remotely. Three interviewees work with getting people into employment who for various reasons have had difficulty finding employments themselves (in, for example, the labour market unit and occupational therapist), and four of them worked during the COVID-19 pandemic, used Husmuttern's concept to develop a design for the installation and manufacturing of protective coats. Therefore, work leaders were interviewed, three of whom were newly hired supervisors who taught and further developed the standardised way of working to volunteers and student vacation employees. The interviews were conducted in June–August 2020 using an unstructured questionnaire focused on how the experts perform their work and how they support the people they meet in the best way and what teaching means for them. The analysis was performed in line with content analysis (Hsieh and Shannon, 2005).

In addition to the interviews, observations and trials of the production concepts were performed. Three of the authors have done observations on others working in the system and tried some operations to get a deeper preunderstanding of the important parts of the concept. One author has also done extended trials of the assembly system for both minor assembly operations with process time of a couple of minutes and more complex assemblies of tool board with a process time over an hour (for an untrained person) and studied the development of the standardisation and poka-yoke of the system.

Based on the theoretical frame with a starting point of the ICF WHO framework and the empirical results a framework for universal design in assembly work is suggested and discussed in context of its relevance to Industry 5.0.

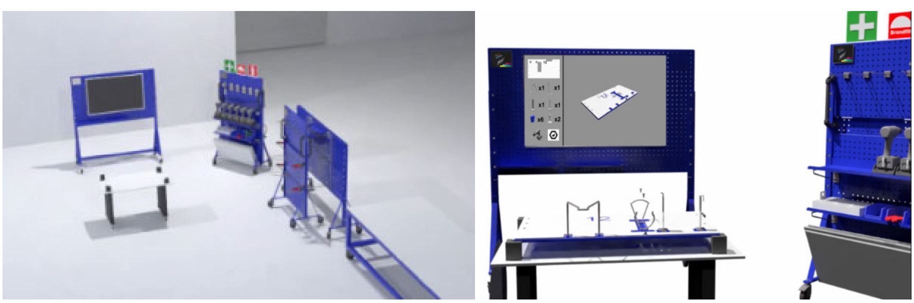
4 Results

This section will first describe the Husmuttern single case, the results from the evaluation of the concept, the interview results, and a synthesis of the framework.

4.1 The case

Husmuttern AB is an SME that develops assembly systems and man these with people that are far from the usual job-market. The company developed a system for manual assembly, first practiced on building modules for modular houses (Kurdve and De Goey, 2017), but also set up workstations for other assemblies, from packaging material assembly to tool-board and door assembly. In combination with poka-yoke, templates, and a fail-safe process of work operations Husmuttern uses digitised animated visualisations of standardised work instructions that are free from text, and thereby linguistic restrictions. During the project, the company has adapted its workstations for house module assembly according to the motto 'including without excluding'. The workstations (Figure 3) have a high degree of visualisation and digitisation, but a low degree of automation and mechanisation, which in the case seem to be a key to inclusion. In addition to developing their own production, they also have successfully sold the service, "to develop an industrial workplace for staff without language skills" to other assembly industries who wish to employ new immigrants or people with functional variation.

Figure 3 Flexible workstations with poka-yoke templates and visual instructions from Husmuttern (see online version for colours)



In addition to supporting social sustainability through introducing inclusive work the system ensures economic sustainability through a business model where the social welfare system contributes to a part of the salary that compensates for lower productivity which is gradually decreased as workers develop their skill and get more productive. The system also contributes to eco-efficiency by improving material and energy efficiency through standardised and modularised work and mistake-proofing. The first batch of people training in the system consisted of three people (one male and two female) who had no previous industrial experience, did not know Swedish and did not read and write in Swedish or English. Two of these completed the program and of them, one quit due to personal reasons and one remains at Husmuttern. In the second and third batches additionally around a dozen people were trained in the system. The second and third batch included mainly people (both migrants and Swedish) with hearing, concentration and or social functional variation. Although industrial work does not fit everyone, the experience is that the work system can be used to include much more people than those who normally are eligible for a job in industrial assembly. A fourth batch of around eight people with functional variation were trained at a customer company producing doors.

4.2 Husmuttern AB's universal design concept

The universal design principles were found in various ends of the Husmuttern concept. The design of the digital tool was developed for equitable use with flexibility and perceptible information. Thanks to the design to fit people with diverse abilities, it accommodated people with a wide range of preferences (universal design principles 1 and 2 see Figure 1). The video tool and puzzle in assembly were simple and intuitive (principle 3) and was designed to fit people independent of size, posture, or mobility (principle 7). The concept included a sequence where individuals first see, then try with a trainer and then assembles independently without help. The instructions were perceptible given by animated video running continuously, supporting the assembler by being intuitive and required low effort to replay or hurry (principles 4, 2 and 6). In addition, the concept was robust against errors (principle 5) since its poka-yoke system made it difficult to make mistakes. In this sense the concept is accessible, usable, and inclusive.

The concept cannot in the strict sense follow standardised work nor universal design in full. However, they have worked accordingly with the principles that form the basis of universal design, standardised work, error-proofing and visualisation. SOPs in the format used in Lean mature operations are not used. Instead, a script is made for operation steps and a 'story line' is drawn containing all operational steps, their sequence and whether something is safety or quality critical. All operative steps are carefully worked through with each person who will work at the workstation. The visualisation system for the tools is presented, how different work steps are described in the animations, and the poka-yoke system of templates to prevent incorrect assembly. Coaching is used to give the individuals positive energy and feedback in learning and execution.

The concept also included a culture utilising the following value-statements: "do good, be good and fair deals". Do good means to treat each other well and with respect, aim to use environmentally friendly choices in their production and product, and to create a good working environment. Be good means to develop a production system where most people can work in and to develop a product that most people can use. Fair deals mean to create a workplace with good conditions for hired/employed staff, respect to suppliers and customers, and useful products available to as many people as possible. The value statement also supports the universal design concept since it should fit as many as possible and include good working conditions and it supports Industry 5.0's sustainability focus since the company should do business that is fair and not choose components that are produced or transported in a wasteful or unethical way.

4.3 Interview results

The analysis collected 111 statements in line with content analysis (Hsieh and Shannon, 2005) and 32 categories of factors were found. According to the method, some of the synonymous categories were combined into 12 key factors (as some of the categories were similar and had few statements). The factors with the least number of statements were then screened out. The final number of statements was then 89. Six key factors were divided into two main headings: individuals and work methods. The key factors that were most important for universal design are: personalisation, structured approach, learning, physical and cognitive variation, motivation and everyone can be involved. See Table 2 for the key factors and the number of times they were identified in the interviews. The key factors are presented further in the following section.

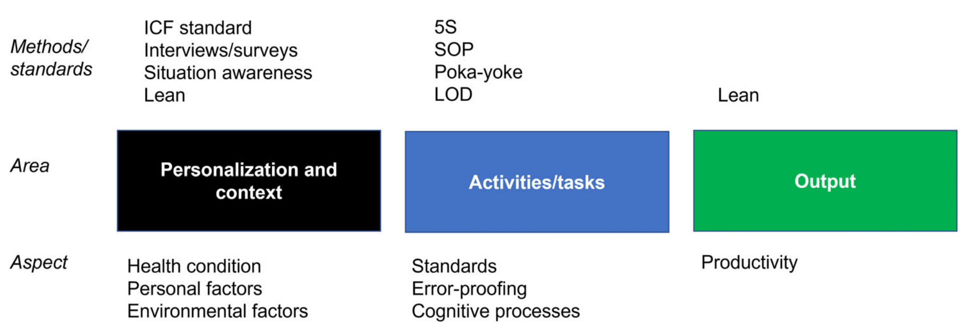
Table 2 Key factors for universal design

Key factors for universal design	*Type of factor*	*Number of times identified in interviews*
Personalisation	Individuals	26
Structured working methods	Working method	19
Teaching	Working method	13
Physical and cognitive variation	Working method	13
Motivation	Individuals	10
Everyone can join	Individuals	8

4.4 Framework

The framework synthesis is structured according to the WHO ICF classification standard. Since the aim was that other companies should be able to use the model to better design assembly workplaces it includes a description of what should be included in an investigation of key factors respectively to achieve a better universal design. The framework is presented in Figure 4. The main areas of the framework are: personalisation and context, activities/tasks and output. Personalisation and context include relevant aspects from ICF, i.e., health condition, personal factors, environmental factors. The three areas of the framework are associated with methods suggested for analysing them as well as its relevant aspects suggested in methods, empirical results, and relevant theory.

Figure 4 Framework for universal design in assembly includes the areas: personalisation and context, activities/tasks and output (see online version for colours)



A discussion of each of the aspects includes a justification where empirical results are included.

4.4.1 Personalisation and context

This area includes health condition, personal factors and environmental factors. *Health conditions* from the WHO standard are relevant since functionality is used to describe the body function and body structure status. Psychological factors are relevant in universal design, which was highlighted by the key factors found in the interviews. When an individual goes back to work, motivation is one of the most important aspects. This applies both in an investigation, for a successful introduction of work and for the individual to develop further. Therefore, it is important that the individual is constantly involved in the assessment and feels that it revolves around his/her needs. An adaptation that, for example, the labour market unit makes when they write their assessments of the individual is that they formulate it so that the individuals themselves understand and recognise themselves. This is where the analysis should start; to focus on individual needs.

The design of a workplace needs to be adapted, i.e., personified, for the different conditions the individual has. Therefore the *personal factors* are a big part of the design of the assembly system. Individuals have different personalities, pace, training time, habit of taking in information, working methods that suit them best, and different languages. It therefore varies not only with any functional variations but also with how accustomed people are to taking in information. It is then important to adapt the information to an individual, to see what he/she needs, to then try and adapt and be careful to choose a design that enables the person (and not limits then). As an example, the first interviewee stated that "... we've had to be pretty flexible and feel in what does this person need" (interview 1). An adaptation that, for example, the labour market unit makes when they write their reviews about the individual is that they formulate it so that the individuals themselves understand and recognise themselves. "We kind of say, what do you want to do then? What is your dream job? And they say but I've worked with metal before… It would be a fun to work with that… and then they will be like, HUH, do I get to decide?" (edited, interview 2). Hence, it is about meeting the individual where they are. Going into too high a level can mean a failure and it can mean that the person completely loses motivation.

The personal factors in the framework consist of three parts:

1 skills

2 health conditions

3 psychological factors.

To ensure that the individual produces good outcome, skills are needed. This was seen in the interviews where teaching and work experience were discussed.

There were many ideas about learning where those we interviewed described the learning process in their own way. Instructions can be:

1 explained in a simpler and faster way

2 explained at a certain pace and then give time for questions

3 to have a short intro, then work together.

Either way the tutors had strategies for how they would adapt their teaching so that their trainees could follow. One interviewee stated that "we're doing the same thing. If they're going to paint, I'll paint them clean and I'll clean it. I jump in the clothes that are appropriate for that workplace. If there is to be food served, I serve also food. If they are going to cook food, I stand there as a chef…" (interview 7). Another strategy is to see-hear-do means that you show them and tell them, and then they get to do it themselves and you stand by and give the same support: "the learning doesn't occur until you've got to do it yourself… just that see-hear-do…... Just watching it doesn't help everyone. You have to hear and explain and all the time when you show, talk them through why am I doing this way – why am I starting here. This why part makes it clink, then it sinks deeper in" (interview 4).

To create good conditions for learning, there are some keys: self-esteem, focus on the action of, for example, walking/driving, working with them and explaining why. Two different methods have been described: the accordion model and see-hear-do. The accordion model involves performing alternating work together. Each step is done together with the trainer, which means that it gives a community, security and strengthens the conditions for a good experience. In the see-hear-do method the trainee first looks at what should be done and explains it, then the trainee should do it themselves while getting support if needed. In addition, language skill was important. Individuals that have language difficulties do not have the same ability to work in the assembly as those that know the language. This is due to many aspects, e.g., language skills are sometimes needed to read assembly instructions or get trained by a trainer.

The workplace is an important aspect of work seen both in literature and interviews. The following aspects were found relevant for the *environmental factors*: cognitive work design, physical work design and social factors. When new ways of working are to be developed, they need to have structured rules that everyone can relate to. If there is no structured way of working, it allows for variation which may introduce errors. Working with standardised working methods enables clear instructions and creates a space for improvement where everyone can be helped. In assembly systems, layout and method changes are introduced to improve productivity. Here we notice in observations, trials and interview answers that in order to become more inclusive and more sustainable in addition to 'hard' principles such as 'safety first' and implementing tools like poka-yoke, standardisation and digital visual instructions (Kurdve, 2018), there is also need for the 'soft' principles of 'teamwork' and 'inclusive culture' where coaching leadership and daily team meetings are typical methods to implement. It is also important to assure that implementation of the methods and tools of the 'hard' principles are not contradicting the methods and principles of the 'soft' principles. One example from the interviews is that an error, working with standards, always will be acknowledged: "You can't do it many other ways and if you do it wrong" … it will be noticed (interview 3).

In the interviews, cognitive variation was not often mentioned. This may be because physical variation is a more established and visible variation. However, it is important that both types of variations are included in a change work. From a cognitive variation perspective, instructions should be adapted to the assembly activity and LOD-model as described in Mattsson et al. (2020). In the context of universal design this means that the layout and environment should be adapted so that it supports the person's active cognitive processes, e.g., when intuitive work is performed pictures could be used instead of having text that requires effort and time to read.

Looking at physical factors it is possible to adapt the working method to the functional variation by implementing small changes. An example is in the manufacture of protective coats when the table was lowered for a volunteer in a wheelchair and that material had to be delivered there to avoid contamination of the protective coat. As an example, interviewees stated that "... it's been fitting for just about anyone. You can sit and you can stand and you can raise and such" (interview 1). In addition, an interviewee stated that they had worked with someone having a hearing aid "... she said it though this works great... I (interviewee) can read a little on my lips, because the interpreter couldn't be there all the time, but she was there at the beginning so we could instruct her how to do it and where she was needed. We found a way to communicate with her. It worked out great" (interview 1).

Table 3 Factors relevant when analysing personalisation and context.

Aspect	*Factor*	*Reference/description/analysis*
Health conditions	• Functioning • Disability • Body function and structures • Impairments • Participation • Activity limitations	ICF standard
Personal factors	• Job training and knowledge • Personality/type • Intelligence • Cultural background • Willingness/motivation to work	Li and Wieringa (2001)
	• Goal and objectives • Preconceptions (expectations)	Situation awareness model, individual factors (Endsley, 1995)
Environmental factors	• Culture	Lean (Liker and Meier, 2006)
	• System capability • Interface design • Stress and workload • Complexity • Automation	Situation awareness model, system factors (Endsley, 1995)

Another time, the folding procedure had to be changed. Some elements, on the other hand, were physically demanding work, which is difficult to work with for a long time, regardless of physical variation. Social aspects are also relevant here as seen in the Husmuttern case. That all individuals are included, and everyone can join was argued by interviewees to be important. Every individual is different and has different conditions. Even if the same instructions are used and that certain adjustments need to be made for them to be carried out in the right way, it is possible to relate to the vision that everyone should be able to participate. As one of the interviewees stated that it is key "...to meet people where they are and kind of see opportunities and see what they can do instead of what they can't" (interview 7). In working with protective coats, the first interviewee stated that "we've been trying to be solution-focused and thinking that there's something that everyone can help and you help based on your circumstances" (interview 1).

This is an important part of being an 'attractive employer' today according to the interviewees. It is about solving problems and at the same time looking after the individuals. Although, there are work steps in the workplace that are not suitable for everyone, but as described in the other factors, it may be important to see opportunities and not obstacles.

In summary the following factors are relevant when analysing personalisation and context is presented in Table 3.

4.4.2 Activities/tasks

In the centre the framework is the activities and the assembly tasks. This area is important since its description is the basis of understanding and performing a task (Liker, 2003). According to lean standardised work should be used to design work so that it can be performed in the right way and it should be easy which fits well with the universal design concept. Having a *standard* can decrease risks and 5S is a good method to start from (Liker and Meier, 2006). *Error-proofing* can be achieved through poka-yoke solutions on critical issues (Kurdve, 2018) which could also help to reduce safety issues that are, e.g., perceptual, slips, violations (Hobbs and Williamson, 2003). In addition, the description of the task is connected to active *cognitive processes* that according to the LOD model can be used to support the operator in the best way (Mattsson and Fast-Berglund, 2016), e.g., by suggesting if the task is intuitive or if the person should be supported in his/her reasoning. Depending on the active cognitive process a suitable digital support can be assigned if needed. Designing without understanding this could result in poor design and performance (Sheridan, 2002). See Table 4 for factors that are relevant when analysing and improving the workplace in terms of activities/tasks.

Table 4 Factors for analysing and improving the workplace in terms of activities/tasks

Aspect	*Factor*	*Reference/description/analysis*
Standard	S5	Liker (2003)
Error-proofing	SOP, poka-yoke	Liker (2003)
Cognitive processes	Intuition and reasoning	LOD-model, Mattsson et al. (2020)

4.4.3 Output

The main point of the framework is to show how companies can include persons with functional variation in their workforce. Here the output factors are key. All companies (with some odd exceptions) need to make a profit that is their reason for existing. To be able to predict the output of their production is crucial for the profitability, the *productivity* of each person does not need to be high if the output can be predicted and used for planning. The profitability is often assessed output factors that companies are familiar with and use everyday, e.g., profitability, capacity, right quality. A lower performance factor due for example physical ability to perform certain tasks for an individual, can be compensated by a subsidised salary from welfare authorities. Using the productivity factor the difference from 100% performance can be measured objectively and be the basis for subsidiary. By single out the performance factor it also becomes clear what the company needs to do to improve the workplace design. According to the productivity model from Section 2.3 a lower physical ability to work fast can be compensated by all other factors. The most important factor is the method factor, to design the workplace to be efficient despite disabilities of the workers is a key. However, without motivation and proper training there is no point of investing in a better workplace design. The availability factors are very much about reducing variation. The need-based availability rate can be different for different individuals due to the physical condition of the person, but it should be consistent to make productivity and thus the output predictable. In Table 5 a description of suggested factors for assessing output is added.

Table 5 Factors for analysing and improving the workplace in terms of activities/tasks

Aspect	*Factor*	*Reference/description/analysis*
Productivity	Method, performance and availability	Almström (2013)

5 Discussion

This section discusses the framework and its areas. It also includes reflections and challenges as well as a future research section.

For both larger and smaller industrial companies there are a lot of challenges connected to reaching a human-centric and socially sustainable Industry 5.0. Human-centred digitalisation means to work with the individual in focus to support operator well-being in centre (Xu et al., 2021) as well as focusing on societal need (EC, 2022). One of the main points in this part of the framework is the specific focus on the individual and his or her needs. Industry 4.0 was criticised for not including health and safety issues and well-being (Badri et al., 2018; Zorzenon et al., 2022). Compared to previous work of the smart and skilled Operator 4.0 or Operator 5.0 this framework supports an operator that can be supported according to his or her needs through the detection of Individual resources. Here skills, health conditions and psychological factors are in focus. In addition, historically workplace design efforts have been focusing on the functioning working population (Fundación ONCE and ILO Global Business and Disability Network, 2019) and one aspect of making workplaces more human-centric is to make it personalised and user-adapted (Mattsson et al., 2020). This is where the framework suggested a start in the analysis: by focusing on what the individual needs are and this is also why the ICF standard was important to include in the framework. The ICF standard can be used to assess the functioning of a person and the relation between a person's health conditions, personal and environmental factors. It provides the link between the health condition and personal factors to the environmental factors and the activities, which we in the framework connect to the production outputs. After the health condition is analysed the workplace and the design of digital support should be designed. The environment, e.g., digital support and the workplace could then be designed and developed accordingly. At the same time the individualisation does not imply that common standard work procedures should be abandoned, instead they should be developed in an inclusive way with the individuals' needs and skills in mind. Therefore, a special emphasise is on the work itself, e.g., that the process, organisational routines, continuous improvements, quality aspects should work in conjunction with what is needed from an individual perspective. In the areas presented in the framework there are a lot of trade-offs. Having standards is sometimes seen as the opposite of having a personalised workplace or a personalised digital support but standards and SOP regards in its foundation something else. It provides a support for better describing what should be carried out at a station and presents that so that anyone could better understand it. This framework therefore can be used to set appropriate requirements for a sustainable workplace, i.e., by both considering individual needs as well as organisational ones.

5.1 Reflections and challenges

This empirical study highlights strengths and adds substantial knowledge on how environmental factors, in a concrete way, can create a workplace where every person's individual resources can contribute to the outputs not only in terms of better life for the person, but also the company and society in general. This framework could strengthen the work of having a human-centred digitalisation and towards creating a sustainable society in Industry 5.0.

The framework is based on the unique success of the Husmuttern case, to make it useful for other contexts, the framework needs to be interpreted and merged into other companies' assembly system design processes. In similar manner as successful lean implementation cannot merely copy Toyota production systems (Liker and Convis, 2011) the authors suggest that others need to understand the concepts of the Husmuttern implementation and why they have implemented it in the way they did. With that as an inspiration, the authors argue that the same concepts can be adapted to other companies' situation and develop their inclusion capabilities.

Universal design is theoretically related to workplace health promotion and might meet the same type of challenges when putting strategies into practice. Workplace health promotion seems to benefit to be evolved in core business continuous improvements rather than a parallel project (Skagert and Dellve, 2020) and it might be the same for universal design of workplaces. That is a strength of the Husmuttern concept.

5.2 Future research

Multi-disciplinary research is needed to support and implement ideas presented in this paper. More empirical case studies at other companies where the Husmuttern assembly system or similar is used is needed to evaluate results of applying the proposed model in practical implementations at companies. For future research, step by step design guidelines based on the framework should be developed for companies who want to develop more inclusive workplaces especially in line with Industry 5.0.

6 Conclusions

Universal design regards several aspects that needs to be included in a solution for manual assembly. Universal design principles for assembly workplaces have the potential to create work opportunities for persons with functional variation. There are many trade-offs that needs to be considered. In this paper several research areas were combined to form a framework that could support companies in reaching a more universal design strategy for assembly workplaces according to Industry 5.0. The framework included the following areas: personalisation and context, personal factors, environmental factors, activities/tasks and output.

To be included in the work life and earn a salary is important for anyone. Good workplace and good design of digital support tools lowers the risk for accidents and improves ergonomics, leading to a safer work environment. In addition, it is also important to get as many as possible into work to decrease dependence on welfare programs and to increase the health in a broad sense in the society.

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References

Almström, P. (2013) 'Productivity measurement and improvements: a theoretical model and applications from the manufacturing industry', *Advances in Production Management Systems. Competitive Manufacturing for Innovative Products and Services: IFIP WG 5.7 International Conference, APMS 2012, Revised Selected Papers, Part II*, 24–26 September, Rhodes, Greece, pp.297–304, Springer Berlin Heidelberg.

Badri, A., Boudreau-Trudel, B. and Souissi, A.S. (2018) 'Occupational health and safety in the Industry 4.0 era: a cause for major concern?', *Safety Science*, November, Vol. 109, pp.403–411.

Becker, T. and Stern, H. (2016) 'Future trends in human work area design for cyber-physical production systems', *Procedia CIRP*, Vol. 57, pp.404–409.

Breque, M., De Nul, L., Petridis, A. (2021) *Industry 5.0: Towards a Sustainable, Human-Centric and Resilient European Industry*, European Commission, Directorate-General for Research and Innovation, Publications Office, https://data.europa.eu/doi/10.2777/308407.

Bruch, J. and Bellgran, M. (2012) 'Creating a competitive edge when designing production systems-facilitating the sharing of design information', *International Journal of Services Sciences*, Vol. 4, Nos. 3–4, pp.257–276.

Burgstahler, S. (2020) *Creating Inclusive Learning Opportunities in Higher Education: A Universal Design Toolkit*, p.47-8, Harvard Education Press, Boston.

Clarkson, P.J. and Coleman, R. (2015) 'History of inclusive design in the UK', *Applied Ergonomics*, 6 April, Vol. 46, pp.235–247.

Correia de Barros, A. (2022) 'Inclusive design within Industry 4.0: a literature review with an exploration of the concept of complexity', *The Design Journal*, Vol. 25, No. 5, pp.849–866.

EC (2022) *Employment, Social Affairs & Inclusion*, European Commission [online] https://ec.europa.eu/social/home.jsp (accessed 26 October 2022).

Endsley, M. (1995) 'Toward a theory of situation awareness in dynamic systems', *Human Factors: The Journal of the Human Factors and Ergonomics Society*, Vol. 37, No. 1, pp.32–64, DOI: 10.1518/001872095779049543.

Fast-Berglund, Å. and Stahre, J. (2013) 'Task allocation in production systems – measuring and analysing levels of automation', *IFAC Proceedings Volumes*, Vol. 46, No. 15, pp.435–441, ISSN 1474-6670, ISBN 9783902823410, https://doi.org/10.3182/20130811-5-US-2037.00032.

Fundación ONCE and ILO Global Business and Disability Network (2019) *Making the Future of Work Inclusive of People with Disabilities* [online] https://www.ilo.org/global/topics/disability-and-work/WCMS_729457/lang--en/index.htm (accessed 11 November 2022).

Günter, A. and Gopp, E. (2022) 'Overview and classification of approaches to productivity measurement', *International Journal of Productivity and Performance Management*, Vol. 71, No. 4, pp.1212–1229, https://doi.org/10.1108/IJPPM-05-2019-0241.

Hambali, R.H., Mohamad, E. and Ito, T. (2021) 'Ergonomic design for assembly manufacturing workstation based on universal design principles', in Shin, C.S., Di Bucchianico, G., Fukuda, S., Ghim, Y.G., Montagna, G. and Carvalho, C. (Eds.): *Advances in Industrial Design. AHFE 2021. Lecture Notes in Networks and Systems*, Vol. 260, Springer, Cham [online] https://doi.org/10.1007/978-3-030-80829-7_106 (accessed 11 November 2022).

Hobbs, A. and Williamson, A. (2003) 'Associations between errors and contributing factors in aircraft maintenance', *Human Factors*, Vol. 45, No. 2, pp.186–201.

Hsieh, H.F. and Shannon, S.E. (2005) 'Three approaches to qualitative content analysis', *Qual. Health Res.*, November, Vol. 15, No. 9, pp.1277–1288, DOI: 10.1177/1049732305276687, PMID: 16204405.

Kahneman, D. and Krueger, A.B. (2006) 'Developments in the measurement of subjective well-being', *Journal of Economic Perspectives*, Vol. 20, No. 1, pp.3–24.

Kanawaty, G. (Ed.) (1992) *Introduction to Work Study*, International Labour Organization, Geneva.

Keates, S., Lebbon, C. and Clarkson, J. (2000) 'Investigating industry attitudes to universal design'. *Proceedings of the RESNA 2000 Annual Conference: Technology for the New Millennium*, RESNA Press, Orlando, Florida, pp.276–278, ISBN 0-932101-42-9, ISSN 0883-4741.

Kurdve, M. and De Goey, H (2017) 'Can social sustainability values be incorporated in a product service system for temporary public building modules?', *Procedia CIRP*, Vol. 64, No. 2017, pp.193–198.

Kurdve, M. (2018) 'Digital assembly instruction system design with green lean perspective-Case study from building module industry', *Procedia CIRP*, Vol. 72, pp.762–767.

Lasi, H., Fettke, P., Kemper, H.G., Feld, T. and Hoffmann, M. (2014) 'Industry 4.0', *Business & Information Systems Engineering*, Vol. 6, No. 4, pp.239–242.

Li, K. and Wieringa, P.A. (2001) 'Structured operation environment and perceived complexity in human supervisory control', *Asian Journal of Control*, Vol. 3, No. 3, pp.181–189.

Liker, J.K. (2003) *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*, McGraw-Hill, New York, NY.

Liker, J.K. and Meier, D. (2006) *The Toyota Way Fieldbook: A Practical Guide for Implementing Toyota's 4Ps*, McGraw-Hill, NY.

Liker, J. and Convis, G.L. (2011) *The Toyota Way to Lean Leadership: Achieving and Sustaining Excellence through Leadership Development*, McGraw-Hill, USA.

Mattsson, S. and Fast-Berglund, Å. (2016) 'How to support intuition in complex assembly?', *Procedia CIRP*, Vol. 50, No. 2017, pp.624–628.

Mattsson, S., Fast-Berglund, Å., Li, D. and Thorvald, P. (2020) 'Forming a cognitive automation strategy for Operator 4.0 in complex assembly', *Computers & Industrial Engineering*, January, Vol. 139, p.105360.

Myndigheten för delaktighet (MFD) (2022) *Statistik om personer med funktionsnedsättning*, in Swedish [online] https://www.mfd.se/resultat-och-uppfoljning/statistik-om-personer-med-funktionsnedsattning/ (accessed 26 October 2022).

Mourtzis, D., Angelopoulos, J. and Panopoulos, N. (2022) 'Operator 5.0: a survey on enabling technologies and a framework for digital manufacturing based on extended reality', *Journal of Machine Engineering*, Vol. 22, No. 1, pp.43–69, https://doi.org/10.36897/jme/147160.

Mueller, J.L. (2011) *Office and Workplace Design in Universal Design Handbook*, 2nd ed., edited by Preiser, W. and Smith, K., Mac Graw Hill, 0071629238Universal-with-cover-page-v2.pdf [online] http://d1wqtxts1xzle7.cloudfront.net (accessed 11 November 2022).

Null, R. (Ed.) (2013) *Universal Design: Principles and Models*, CRC Press, Boca Raton.

Pyke, F. (2018) 'Managing technological change for inclusive growth', *Cambridge Journal of Economics*, Vol. 42, No. 6, pp.1687–1695.

Romero, D. and Stahre, J. (2021) 'Towards the resilient Operator 5.0: the future of work in smart resilient manufacturing systems', *Procedia CIRP*.

Romero, D., Stahre, J. and Taisch, M. (2020) 'The Operator 4.0: towards socially sustainable factories of the future', *Computers & Industrial Engineering*, Vol. 139, p.106128.

Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, Å. and Gorecky, D. (2016) 'Towards an Operator 4.0 typology: a human-centric perspective on the fourth industrial revolution technologies', *International Conference on Computers and Industrial Engineering*, October (CIE46).

Sheridan, T.B (2002) *Human and Automation: System Design and Research Issues*, Vol. 3, John Wiley & Sons, Inc., Santa Monica, CA.

Sheridan, T.B. (1987) 'Supervisory control', in Salvendy, G. (Ed.): *Handbook of Human Factors*, pp.1243–1268, Wiley, New York.

Skagert, K., and Dellve, L. (2020) 'Implementing organizational WHP into practice: obstructing paradoxes in the alignment and distribution of empowerment', *Front. Public Health*, Vol. 8, p.579197, DOI: 10.3389/fpubh.2020.579197.

Smith, C.A. and Kirby, L.D. (2004) 'Appraisal as a pervasive determinant of anger', *Emotion*, Vol. 4, No. 2, pp.133–138, https://doi.org/10.1037/1528-3542.4.2.133.

Stahre, J. (1995) 'Evaluating human/machine interaction problems in advanced manufacturing', *Computer Integrated Manufacturing Systems*, Vol. 8, No. 2, pp.143–150.

Statistiska centralbyrån (SCB) (2019) *The Future Population of Sweden 2019–2070* [in Swedish: *Sveriges framtida befolkning 2019–2070*] [online] https://www.scb.se/contentassets/24496c5905454373b2910229c29001ec/be0401_2019i70_sm_be18sm1901.pdf (accessed 1 March 2023).

Statistiska centralbyrån (SCB) (2021) *The Labour Market Situation for Persons with Disabilities, 2020*, Statistical News from Statistics Sweden 2021-03-31 9.30 [online] https://www.scb.se/en/finding-statistics/statistics-by-subject-area/labour-market/disabled-persons/the-labour-market-situation-for-people-with-disabilities/pong/statistical-news/the-labour-market-situation-for-persons-with-disabilities/ (accessed 1 March 2023).

Story, M.F. (2011) 'Principles of universal design', in Preiser, W.F. and Smith, K.H. (Eds.): *Universal Design Handbook*, 2nd ed., McGraw-Hill, New York.

Tsujii, T. and Watanabe, S. (2009) 'Neural correlates of dual-task effect on belief-bias syllogistic reasoning: a near-infrared spectroscopy study', *Brain Research*, Vol. 1287, pp.118–125, ISSN: 0006-8993, https://doi.org/10.1016/j.brainres.2009.06.080.

United Nations (UN) (2022) *Persons with Disabilities Have Equal Rights to Work and Gain a Living*, UN Convention on the Rights of Persons with Disabilities (CRPD) [online] https://www.un.org/development/desa/disabilities/convention-on-the-rights-of-persons-with-disabilities.html (accessed 26 October 2022).

United Nations (UN) (2023) *Sustainable Development Goals, Goal 8* [online] https://sdgs.un.org/goals/goal8 (accessed 1st March 2023).

World Health Organization (2013) *How to Use the ICF: A Practical Manual for Using the International Classification of Functioning, Disability and Health (ICF)*, Exposure draft for comment, October, WHO, Geneva.

Xu, X., Lu, Y., Vogel-Heuser, B. and Wang, L. (2021) 'Industry 4.0 and Industry 5.0 – inception, conception and perception', *Journal of Manufacturing Systems*, Vol. 61, pp.530–535, ISSN: 0278-6125, https://doi.org/10.1016/j.jmsy.2021.10.006.

Zorzenon, R., Lizarelli, F.L. and Moura, D.B.A.d.A. (2022) 'What is the potential impact of Industry 4.0 on health and safety at work?', *Safety Science*, September, Vol. 153, No. 105802, pp.1–18.