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Synthesis of Universal Workplace Design in Assembly – A Case Study

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Abstract. To form an inclusive and sustainable society, workplace design that can be used by different individuals, regardless of sex, language, background, and body function variations is needed. Such workplaces can also give economic benefits to companies if they provide a more accessible, safer, more productive and error proofed working environment. This aim of this paper is to evaluate a universal design concept developed at a company aiming at providing an "easy job"-workplace design for manual industrial operations. The study investigated key factors from 8 interviews and compared it to theoretical constructs such as WHO's ICIDH-2. A synthesis was formed that included the following factors: personal factors, environmental factors and outcomes of universal work. The study has resulted in new insights regarding universal workplace design and the vision is that the synthesis can be used by other production companies that want to increase the universal design in assembly work.

Keywords. Assembly, design, standards, poka-yoke.

Introduction

1.1. Background

There is a societal need for increased universal design in the working life. Ensuring workplace inclusion is part of Agenda 2030 and considered a human right for persons with disabilities [1]. As an example, workplaces are generally not adequately adapted to support demographic changes [2]. In addition to functional variation, a social "disability" may be experienced by migrants and others with lack of language or industry skill in industrial workplaces. The Swedish government presented a societal need for "simple jobs" ("enkla jobb" in Swedish) [3] after the large number of immigrants received in 2015. People with different functional variations experience a disability to participate in many workplaces. The issue of including more people in the working life is also driven by the need that exists in many sectors of the labour market: The challenge of a long-term sustainable supply of skills [4].

A challenge in the manufacturing industry is a growing lack of competent work force. The challenge of providing skills to private companies as well as municipal, regional and state activities consists of several parts, but the most prominent are the

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demographic development, urbanization and technological development. This is especially true for small and medium sized enterprises. The prognosis is that they will suffer competence loss when the aging population goes into pension.

Although digitalisation and automation is often said to ”take jobs”, that is not always true for manual assembly tasks. Contrary, manual work can be supported by digitalisation and automated quality assurance [5]. Machining operations are often automated and requires less amount but highly skilled labour. However, assembly is one type of work where manual labour is still often chosen before automation, due to humans' superior flexibility. Digitization can transform traditional work so that it is adapted and becomes user-adapted [6]. Trends in development of Industry 4.0 into 'Industry 5.0' point towards human centred digitalisation that support all types of sustainability goals.

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 [7]. This type of design thinking can be used to form an inclusive sustainable society, work and workplaces should be designed so that they can be used by different individuals, regardless of sex, language, background and body function variations. Well-designed ergonomic work in assembly can increase physical safety as well as increase productivity of workers [8].

To support development of an inclusive sustainable society, with workplaces that welcomes different individuals, regardless of sex, language, background and abilities is the aim of a project “Universal design of workplaces - manual assembly” in which this study was performed. A knowledge gap for industrial companies lies in understanding how work and workplaces can be designed to support everyone [1]. Historically, much work has focused on supporting the working population. However, it lacks focus on supporting people with function variations. Such workplaces can also give economic benefits to companies if they provide a more accessible, safer, more productive and error proofed working environment.

1.2. Aim

The aim of this paper is to evaluate findings from the case study at a company Husmuttern AB and suggest a synthesis of how universal design could be carried out in industry. The model is based on relevant theory regarding individuals and work methods i.e. WHO's standard for functioning and disability, universal design, productivity assessment, standards and poke yoke.

1.3. Previous work with the company Husmuttern AB

The project Universal design for manual assembly (UUAAMM) is based on previous empirical experience at the company Husmuttern AB. The empirical experience started with developing industrial workplaces for people with low education and without language skills in one of Tillväxtverket's funded project, "Husmuttern's development of simple jobs 2.0" with manual assembly operations that were easy to perform and learn, in line with govt. intentions without being govt. run 'emergency jobs' [3]. The basis of development was Lean methodology (including visual standards and so-called poka-yoke) together with digital visual instructions to develop a system where people with

foreign background and without previous industrial experience could be included in industrial working life, work productively, risk-free, and with assured quality [9]. After successful development the scope was extended to include people with functional variations.
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 [10], but also set up workstations for other assemblies from packaging material assembly to tool-board and door assembly. Husmuttern uses digitized animated visualization of standardized work instructions that are free from text and thereby linguistic restrictions in combination with poka-yoke, templates and a fail-safe process of work operations. During the project, the company has adapted its workstations for house module assembly according to the motto "including without excluding". The workstations have a high degree of visualization and digitization but low degree of automation and mechanization, which we have seen is a key to inclusion. In addition to developing their own production of house modules, they also have successfully sold the service, ”to develop an industrial workplace for staff without language skills”, in one case.

2. Theoretical frame

2.1. Universal design and personal ability/ functioning

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 [7]. 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 stigmatizing; (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, pictional) and clearly feedback if you use it right or wrong; (5) tolerance for error; design minimize hazards and errors and opportunities to make mistakes; (6) low physical effort; and (7) size and space for approach and use.

To understand the nature of a person’s function variation i.e. health condition WHO has classified functioning and disability in ICIDH-2 (International Classification of Functioning and Disability). Figure 2 shows the model for functioning and disability. It describes how a person’s functioning and disabilities interrelate with one another. The relevant aspect for this article is to demonstrate the importance that environmental factors have on a person’s health condition. This model is used in the article to discuss results from the interview study and will form a basis of the synthesis of the results.

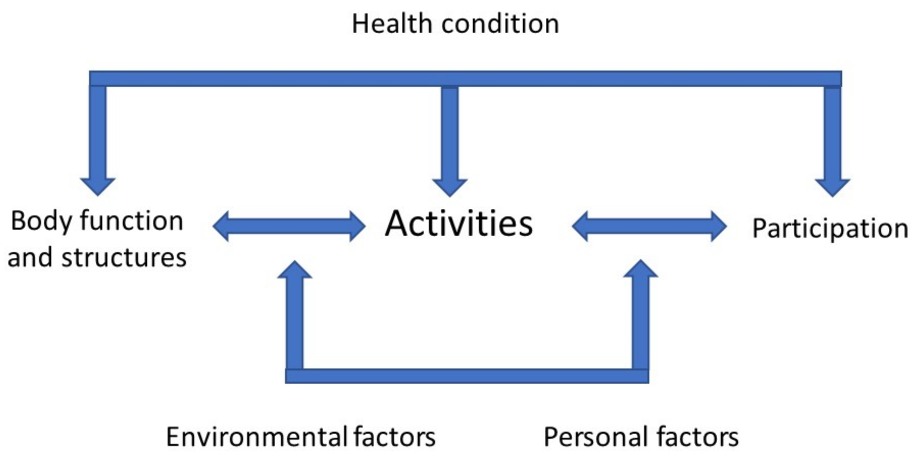

Figure1. WHO standard for health conditions for functional and disability consists of the factors: body functions and structure, activity, participation, environmental factors and personal factors (adapted from WHO ICIDH-2).

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, will environment factors, such as workplace design, as well as personal factors moderate the person's ability to perform the activity. The model has three main dimensions: i) body functions and structure which include both the physiological functions and anatomic parts of the body, ii) activity which is the performance that is associated with a task or action that is performed by the individual and iii) participation which is the individual's involvement in life situations. The contextual factors: environmental factors and personal factors are features of the physical, social, and attitudinal world. This also includes attributes of the person, according to the model. To further build on the model additional aspects are described: assembly tasks, productivity and standards.

2.2. Assembly tasks

In Mattsson et al. [11], 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 five interrelating roles of system operators: Plan, Teach (programming), Perform, Intervene, and Learn [12]. The three modes: Learning, Operational and Disruptive (L-O-D) are presented in Table 1 together with work modes (adapted from Stahre [13]) and the suggested cognitive processes (from Mattsson et al., [11]).

Table 1. Assembly task modes

Assembly 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 & Intuition

To support the operator in the assembly task support should be developed so that it fits the ongoing cognitive processes.

2.3. Productivity in manual assembly

To make sure that the production is profitable it is necessary to measure productivity. Productivity is general measures as the output from a production process divided by the input. Productivity can be measured on different levels and the output and the input can be different entities [14]. It is therefore important to clearly define. In the context of this article, we are concerned about productivity on the shop floor level and a proper productivity measure in assembly work can be for example the number of assembled products per work hour [15]. On the shop floor level and for a certain activity the productivity is built up and can be improved by three factors [16]: The method factor is the ideal productivity rate that depends on the design of the workplace and the intended work procedure. The method factor is modified by two multipliers: The performance factor and the availability factor. 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) [17]. MTM is by agreement 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. That wage system means that workers get more paid if the work faster, i.e., have a performance rate over 100%. The performance rate is also temporarily affected by the skill level of the worker, a not yet 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 three sub factors: Need based availability rate, system designed availability rate and disturbances. Since humans can't work all the time the availability rate never be 100%. System designed losses are for example balance losses in a production flow, which is something that the worker can't affect, but will result in waiting time. The final factor are disturbances such as broken tools or lack of material from suppliers. This affects productivity but is 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 an activity.

2.4. Standards, poka-yoke and safe work

To have lean and sustainable operations in assembly type of operations, training settings get high requirements of the safety of equipment and efficiency of standardised work

[18]. Standardized work and fault-proofing and to do the right thing from the start are basic parts of Lean production and are tools needed to improve e.g. productivity of an operation. In *The Toyota Way*, Liker [19] describe standardized work as based on the staff's unique ability to understand a task, –as a standard as the best method right now. Standardizing 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 standardized work is that "it should be easy" to do things "the right way", i.e. you must design the workplace so that it is easier to perform the work in the standardized 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 standardized 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 [18]. To work effectively, the standard needs to be designed so that all risks are considered.

A first steps in standardized work is to have the workplace in order, "A place for everything and everything in its place" are key words used in this and 5S is a method to reach an appropriate order. A visual standard is common for showing where tools and work items should be placed. Next step is often to note all the work steps that need to be performed, in order, in a standard operation procedure (SOP). In the SOP notes on which sub-steps may go wrong and may risk health of the staff or quality of the product. A classic SOP can be complex to read and understand, but visualised SOP that include pictures can be used as visual instructions. One challenge regards information exchange where both too much information and not enough information can be problematic [20] Personnel then need to be trained in the specific job skills following the SOP [18]. An SOP is not enough to train unskilled personnel in all details of the work, but. is necessary for both efficient continuous improvement and job training. Critical issues and risks for mistakes that still occurs can be handled by error proofing or 'poka-yoke' as a problem-solving resolution [9].

It may be important to consider lean principles in specifying and designing the production equipment and to link sustainable and lean equipment design. Safety of operators, flexibility, quick changeovers, error proofing, reliable maintenance, energy efficiency and one-piece flow are mentioned as important to account for when designing production equipment in general [21] and physical ergonomics influence the quality result of an assembly operation [22]. In inclusive work 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 [23]. 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 workspace and work tasks fault proof Reduced speed of work or productivity can often be compensated for financially, but requirements for quality and safety are not can usually not be compromised. In industry, fault protection has long been developed to make it "impossible" or at least difficult to make mistakes. In the lean sphere, these solutions are called poka-yoke [24]. To find solutions for effective inclusive work, one can use a process that involves well-known techniques for standardized work processes, visualization, and user-centred design [5]. In lean "training within industry", each job element is trained under supervision of an instructor. The instructor shows how to do the job correct and safe, then coach the employee in their attempts. Daily repetition of the job-instruction with the instructor is recommended [25].

3. Methodology

This is a case study and includes a) a qualitative study on key factors for universal design b) improvement suggestions based on a) and c) a draft for universal design. The qualitative study at Husmuttern consisted of an interview study and observation and trials which are presented in 3.1 and 3.2.

3.1. Interview study

Eight interviews with nine participants 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 (in one interview two participants were interviewed). Six women and three men were interviewed remotely; during a conversation, two people were sitting in the same room. Three of them work to get people into work who have had difficulty finding work themselves for various reasons (work in, for example, the labour market unit and occupational therapist), and four of them were employed by Region Västmanland. Due to the pandemic, Husmuttern's concept was used to develop a design for the installation and manufacture of protective coats for Västerås Arena. Therefore, leaders for the work were interviewed, three of whom were newly hired supervisors who taught and further developed the standardized way of working to volunteers and then also to holiday workers. The interviews were conducted in June-August 2020.

The analysis collected 111 statements in line with content analysis [26] 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 were 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: Personalization, 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.

Table 2. Key factors for universal design

Key factors for universal design	Type of factor	Number of times identified in interviews
Personalization	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

The key factors are presented in the results section.

3.2. Observation and trials

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.

4. Results and synthesis

The result section summarizes the interviews and observations. It is structured according to the WHO model, in personal and environmental factors. A section about outcomes was added since that perspective is relevant in a production context.

4.1. Personal factors

The design of a workplace needs to be adapted, i.e. personified, for the different conditions the individual has. 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). The personal factors in the model consists of three parts: i) skills, ii) health conditions and iii) 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 i) explained in a simpler and faster way ii) explained at a certain pace and then give time for questions or iii) to have a short intro, then work together. 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 person who trains or who is to learn, which means that it becomes 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.

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 recognize themselves.

4.2. Environmental factors

The workplace is an important aspect of work seen both in literature and interviews. The following parts were found relevant: 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 various ways of working which may introduce errors. Working with standardized 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 reach lean principles like; flow-efficiency, shorter lead-times, improved teamwork, and resource utilization. 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 [9], 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.

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. [11]. In the context of universal design this means that the layout and environment should be adapted so that it supports the persons active cognitive processes e.g. when intuitive work is performed pictures should be used instead of having a lot of text. From a psychical perspective by implementing small changes, it is possible to adapt the working method to the functional variation. 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. 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 AB 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. 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.

4.3. Outcomes

The productivity factors are important to understand how the outcome is affected by the workers different and often lower ability to produce. Both average values of the factors and the variation in the factors are of importance to reflect upon. There is probably a certain lower limit for productivity for a certain person at a particular work task, where it is of more harm than benefit to the production system, even with subsidized salaries. The productivity model clearly shows how 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 predictable. The system designed losses cannot generally be affected by the workers, it is more of a management issue to deal with. The disturbance affected availability rate can in some cases be affected by the worker, if the worker is causing break downs by for example using equipment the wrong way. That can be avoided by an extra focus on these issues during training.

4.4. Synthesis – A model for universal workplace design

Based on the WHO standard, theoretical frame, the key factors and improvement the following model the Figure 2 was suggested. The model consists of three levels: i) the person, workplace and outcomes. The outcomes depend on the personal factors and are affected by the workplace factors.

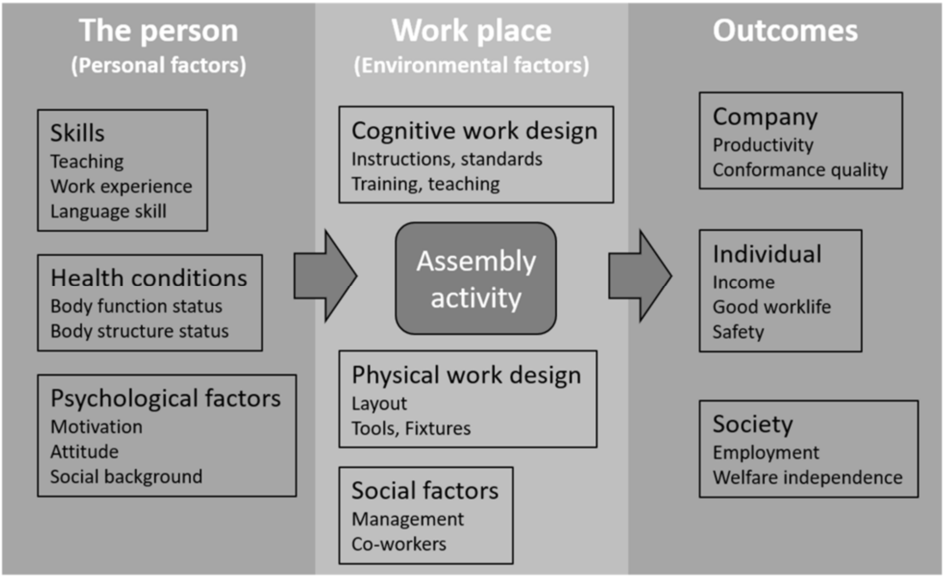

Figure 2. Synthesis of universal design in assembly with the following factors: personal factors, environmental factors and outcomes of universal work.

The first two levels originate from the WHO standard model i) personal factors and ii) environmental factors and includes aspects found in the literature review. 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 seem to benefit to be evolved in core business continuous improvements rather than a parallel project (Skagert & Dellve, 2020) and it might be the same for universal design of workplaces. That is a strength of the Husmuttern concept.

4.5. Reflections - How should companies use this?

It is difficult to ensure that everyone wants to participate and there may be reasons why an individual may not want to participate. On the other hand, it is possible to create an inclusive environment, where as many people as possible feel welcome. One way to do this is to create a learning environment which can enable several different types of individuals to be included. The individual's characteristics i.e. personal factors can both be enabling or limiting for learning [28]. A well-conducted analysis phase can create good conditions for the content part of an acquisition process, however, the individual's driving force and motivations must be understood and supported. This can be beneficial for the basic understanding of how people work and how they learn, but it is not easy to teach in a simple way for SMEs; it would take too long. It can also be difficult and time consuming to examine individuals' drive and needs. By focusing on different obstacles, it may be possible to identify and understand the symptoms of *why* an individual does not want to participate.

5. Conclusions

Universal design regards several aspects that needs to be included in a solution for manual assembly. There are many trade-offs that needs to be considered. In this paper several research areas were combined to form a synthesis that could support companies in reaching a more universal design strategy. In addition, ethics and safety are relevant demands and laws and its relation to efficiency is crucial for production. Therefore, the suggested model should be used to discuss universal design and set a strategy for how companies can design manual assembly in a more universal way.

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