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The realities of achieving a Smart, Sustainable, and Inclusive shopfloor in the age of Industry 5.0.

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Abstract

The employment of Industry 4.0 technologies in manufacturing has paved the way to interlinked machinery, shop floor flexibility and personalised production. However, despite the amplified level of productivity and efficiency, such advances may also take a toll on the operators' skills and well-being. Over and above, worker diversification culminates in the novel ideology of Industry 5.0; where a triad is established between sustainability, human-centricity, and resilience within manufacturing. This broadens the horizon for worker diversification, especially for people with disabilities who may be estranged from the manufacturing shop floor due to an absence of accessibility, stigma, and other lingering challenges. In pursuit of comprehending these hurdles in the form of themes, a set of interviews were conducted with designers and engineers from a range of manufacturing companies, followed by a Reflexive Thematic Analysis Exercise. Three umbrella themes and eight sub-themes revealed an apparent level of friction between manufacturing engineers and the potential of recruiting operators with disabilities, a lack of design knowledge in creating inclusive workstations, and an absence of social sustainability with respect to disability employment in manufacturing. Accordingly, two major areas for future work by engineers, designers and academics are also proposed.

Keywords: inclusion; manufacturing; Industry 5.0; design; qualitative research; sustainability; Reflexive Thematic Analysis; workstation design

1. Introduction

The prospect of a smart, sustainable and resilient Industry 5.0 paradigm moves from a techno-centric Industry 4.0 [1], [2] to a more human-oriented approach mitigating the current potential negative effects on the operators' well-being [3], [4]. This extends the vision for inclusion and social sustainability, fostering the opportunity for individuals with disabilities to participate in the manufacturing industry. This possibility becomes more significant considering that people with disabilities may be excluded from the industrial shop floor owing to lack of accessibility, stigma, or

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other persisting factors. The United Nations (UN) [5] explain the term 'disability' as 'long-term physical, mental, intellectual, or sensory impairment' and this definition shall be adopted throughout this paper. At present, around 87 million Europeans are persons with disability, 50% of which are employed [6]. This scholarly work will thus attempt to comprehend the perception of employing operators with disability on the shop floor from an engineering point of view, commencing with the state-of-the-art on smart, sustainable, and inclusive manufacturing shop floors. This is the first step towards identifying research gaps that provide a solid foundation for primary research with experts in the field Qualitative methods are then applied, conducting interviews with Maltese manufacturing engineers to present a reflection of the current state of inclusion within the Maltese manufacturing industry, including challenges and current accommodations. Reflexive Thematic Analysis is then adopted, and three distinct themes are drawn and discussed in detail. This work concludes by identifying two practical gaps identified through the interviews, therefore fuelling room for future work in the remit of inclusive, smart, and sustainable manufacturing shop floors.

2. State-of-the-art on smart, sustainable, and inclusive manufacturing shop floors.

Academia and industry alike are in pursuit of understanding how Industry 4.0 technologies could mutually complement the strengths of each manufacturing operator, sustaining Romero's Operator 4.0 taxonomy [4], whilst nodding towards the novel Industry 5.0 paradigms. This shall propel a shift from a techno-centric approach to a more human-oriented one, in congruence with sustainability and resilience [7] – [9]. There is a growing appreciation of the window of opportunities that has been broadened for operators with disabilities through the implementation of Industry 4.0 over time [10]-[14]. Mark et al. [15] strove to bring this matter into the limelight, presenting physical, cognitive, and sensory advantages that would be gained when for instance, people with disabilities are introduced to the shopfloor with the intervention of Industry 4.0 technologies such as augmented and virtual reality. On the other hand, Kildal et al. [16], note how collaborative robots can be employed to aid people with cognitive disabilities by assisting them in understanding, following and successfully completing tasks that would otherwise prove too challenging.

Despite its prominence within Industry 5.0, theoretically acknowledging the social sphere of sustainability in manufacturing is not entirely novel. Here, human-centred design, job satisfaction, and a flexible human-machine dyad are enlisted as prime contributors, with authors such as Villani et al. [13] presenting the importance of striking a balance between social sustainability and the traditional manufacturing parameters. Notwithstanding, there lies potential for proper practical implementation and guidance of social sustainability in manufacturing, which has not garnered enough momentum yet [17]. This becomes critical when considering that, in 2020, more than 29 million people were employed within the EU manufacturing sector [18]. Industry 5.0 researchers are also advocating for further practical considerations of the relevant Sustainable Development Goals (SDGs) within a manufacturing context, with special focus on the social and environmental counterparts. Nonetheless, merging social sustainability and manufacturing within the context of operators with disabilities additionally demands comprehension of the quotidian challenges faced by such individuals [19] and how such hurdles may inhibit a manufacturing shop floor that caters for all abilities. Primarily, persons with disabilities may face prejudice, employment discrimination, inferior education and lack of access to information, leading to a higher risk of poverty [20],[21]. There is a shortcoming of practical scenarios that narrow on people with disabilities on the manufacturing shopfloor, and that the absence of incentives at industry and corporate level further these hurdles.

Researchers have strived to piece together the dynamics of the situation, albeit numerous limitations in literature were observed. Primarily, field research in the field does not always clarify which stream of manufacturing (such as: electronics production, food and beverage production, pharmaceutical production and the rest) that particular study would have narrowed on. This may be traced back to literature, where a large body of scholarly work addressing people with disabilities, workstation design and technology, revolves around sheltered workshops [22]–[24] as opposed to actual manufacturing companies. Manufacturing diversified products demands dissimilar tasks and thus, a pool of operators' skills [2]. The latter is of crucial consideration when the intended operators have a disability and thus supplementary care needs to be heeded to in respect of the technologies and arrangements opted for. In the work of Mark [25], the interviews revolve around a case study of a social cooperative in Northern Italy permitting people with disabilities to participate in assembly tasks for external manufacturers. This falls short of providing a true account of how operators with disabilities are included within established manufacturing companies.

Additionally, existing literature may not clearly underline how individuals with a spectrum of disabilities (sensorial, mobility and cognitive) would handle the same task simultaneously. For example, one may consider a noisy environment in which it is custom to wear ear protection for every operator. For an individual with a hearing impairment this would be the ideal occurrence since ear protection inhibits the need to hear commands; yet the same solution would pose a challenge for someone with a cognitive impairment who is easily startled by noise. Engineering researchers sometimes fail to annotate such stochastic elements and subsequently propose solutions revolving around a generic notation that at times may benefit one individual at the expense of the next (for instance – research focusing solely on cognitively impaired workers [16], [26]-[29], or on operators with motor / mobility impairments [24]. Ultimately, comparable interviews debated in literature may deprive the reader of realising the problems entailed in seeking, recruiting, and employing operators with disability on the shopfloor (for instance, health and safety issues, shortage of space and more).

3. Methodology adopted for this research work.

This research work will abide with the methodology exhibited in Fig. 1, qualitatively eliciting the current Maltese manufacturing environment's fostering of inclusion and sustainability (or lack thereof),. An insight into the state-of-the-art lead to gaps in literature to be identified, prompting questions for manufacturing engineers related to (but not limited to) task assignment for physical, sensory, and cognitive disabilities; current accommodations to enhance shopfloor accessibility and prior experience (if any) mentoring operators with intellectual disabilities . Interviews addressing the aforementioned questions were thus conducted and Braun and Clarke's Reflexive Thematic Analysis (RTA) [30], (one of the three approaches to the thematic analysis umbrella explored in contemporary scholarly work [31], [32]) was opted to analyse the interviews.. The choice of adopting RTA for this study stems from RTA's flexibility and engagement of the researcher's recognition of themes from collected data [31]. Unlike other thematic analysis approaches, for instance: codebooks that underline the themes prior to any coding being done, RTA permits the researcher to first decode the data in order to extract any pertinent themes [31]. Thus, RTA cradles the scope of this study – theme identification from collected data. To summarize, this research work adopts an inductive scientific reasoning research approach, whereby research themes are drawn from interviews with engineers from manufacturing companies to found theory on the purported subject.

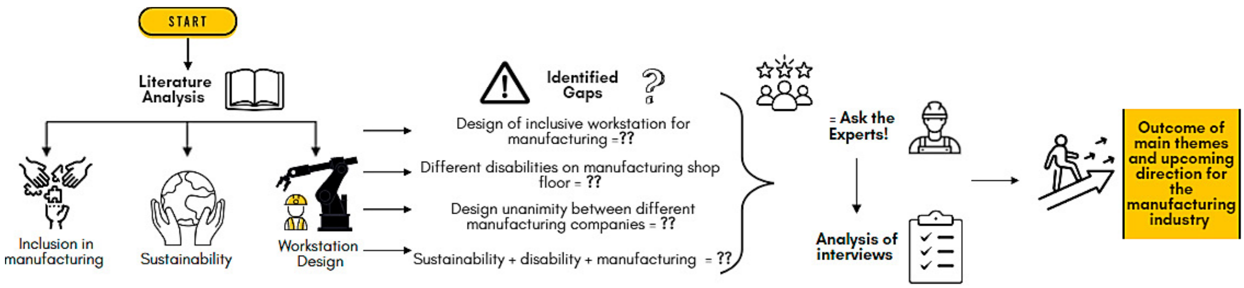

Fig. 1. The methodology developed and abided by throughout the course of this research work.

3.1 Validity and trustworthiness of the research work:

RTA automatically adopts a subjective ontology, detaching itself from constricting the researcher to obtain "'accurate' and 'reliable' coding, or achieving consensus between coders" [33, p.594]. Instead, focus is attributed to the researcher's ability to not solely unearth the main themes during the analysis, but more so reflect and engage with the resulting data. Consequently, on account of inter-rater reliability tests (IRR) not being appropriate for RTA due to the above reason [31], [32], the findings of this study (identified themes and reflections) were instead discussed with several academics and experts in the field. This was carried out in order to ascertain that bias was kept to a minimal. Albeit RTA being subjective in nature, it is paramount to reduce the level of researcher bias, especially since the research team comes from an engineering background. This was undertaken to ascertain that the themes properly depicted the participants' various standpoints as opposed to that of the researchers.

3.2 Recruitment of participants within the study

To generate novel theory following the identification of such gaps in literature, this research work focuses on the consultation affected with people directly engaged in manufacturing engineering (11 interviewees comprising of engineers, directors, and managers) and operator recruitment (4 interviewees from the human resources (HR) department of different manufacturing companies). The interviews fulfilled in this research work bridge this gap, prioritising the involvement of twelve of the most eminent manufacturing companies located in Malta, Fig. 2. All interview transcripts (15 in total, in line with [34]) were processed through NVivo Qualitative Software, and the six stages of RTA were adhered to.

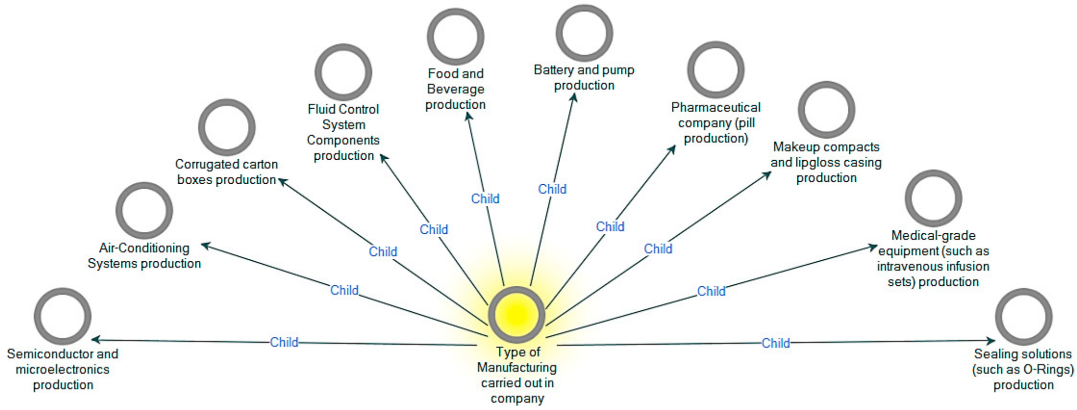

Fig. 2. An array of production carried out in the interviewed manufacturing companies.

4. Main Outcomes of the Reflexive Thematic Analysis

The main outcomes of the interviews have been grouped under three themes following RTA. These emergent themes span the issues relevant to this topic and will be discussed in detail in the following section.

4.1 Theme 1 – Stark discrepancies in manufacturing workstation design for mainstream operators and operators with disabilities.

Sub-Theme 1.1 – Key concepts of mainstream workstation design

The initial queries presented to manufacturing personnel specifically focused on routine approaches adopted by engineers during workstation design. Most interviewees appointed ergonomics and health and safety as two pillars of prominence in the early stages of design. On the onset of planning and design, priority is also given to key features namely the product rate (parts per hour) and material line flow (in and out). An unforeseen concern that prevailed was the location of the workstation with respect to the whole assembly line, especially when the operator has a disability, since improper placement could lead to bottlenecks, as elaborated further in Sub-Theme 2.1. Consequently, the interviewees highlighted the importance of task allocation during workstation design as well as the actual factory flow and shop floor layout (for example, will someone check the work after the operator with disability if that particular workstation forms part of the end-of-line?). This was an aspect which did not results from interviews carried out by other researchers in the field. In addition, unanimous consensus revolved on how the general design of workstations should employ lean manufacturing tools and practices, specifically Single-Minute Exchange of Die (SMED analysis), Man-to-Machine Ratio (MMR), Value Stream Mapping and Time and Motion studies.

Sub-theme 1.2 – Deterrents to workstation design for operators with disability

To back this up, all companies were in agreement that workstation design at their company is targeted towards catering for the mainstream operator (standardised design). Interviewees from eight out of the twelve companies conveyed how they had never designed a workstation for a person with disability; but rather settled for assigning the most suitable available task to suit the abilities of the operator with disability. The rationale behind not having designed workstations for operators with disability lingers in the fact that the task might necessitate certain skills and hence there is a fear of arising injury, or that there are no operators with disabilities available to work. Such reasoning suggests a tight limit placed on possible roles that people with disabilities could be assigned to, thus posing an absence of choice for other tasks. A slight degree of apathy was also observed throughout certain interviews. A misconception revolving around workstation design was identified; most manufacturing engineers were adamant that when the workstation is to be designed, the endmost aspiration is to have all the equipment operating at its full potential to work in par with the daily targets. While this cannot be nor disputed nor negated, a considerable number of engineers have completely overshadowed the possibility that, with slight more thought, research and consultancy, the workstation can address both said targets whilst simultaneously providing an inclusive environment for a broader portfolio of operators. Only one manufacturing engineer shed light on the vital role of interdependency, not confined to collaborations with external stakeholders (government ministries, employment organisations, NGOs) but also internally, such as consultancy between different departments such as Health and Safety, to verify the upholding of safety and ergonomics for the workstations.

4.2 Theme 2 – Operators with disability on the shopfloor – navigating through scepticism, stigma, and a paucity of knowledge from the manufacturing domain.

Sub-Theme 2.1 – Perception of disability within the manufacturing shopfloor.

For an individual whose background lies in manufacturing engineering, it is easier putting a label on disability rather than dedicating effort and time to explore what it entails. Precisely, a set of questions were geared to understand how people in manufacturing perceive disability. The majority tended to picture an operator with disability as someone who is either confined to a wheelchair and thus has restricted mobility, or as someone who cannot carry out quotidian tasks efficiently.

Sub-Theme 2.2 – Current obstacles encountered for operators with disabilities in line with manufacturing requirements.

The interviews were a pivotal point in exploring the potential obstacles encountered by the manufacturing employer as well as also the hurdles endured by operators with disabilities on the manufacturing shop floor. Most interviewees addressed health and safety as the paramount concern. Contradictory outlooks were also drawn out in terms of the effect on quality, time, and product output. Some interviewees dismiss quality as being a function of the operator alone and thus perceive quality as unsusceptible should the operator have a disability. Others esteem quite the opposite; that unless planned with utmost rigour, a workstation occupied by an operator with disabilities could lead to a decline in the degree of quality exercised. A third cohort of interviewees stood on the fence between complete dismissal and approval of an operator with disability's influence on quality, asserting how such a question demands more thought than a mere yes or no answer.

Factors such as a product flow, the number of products to be produced, the availability of assistive technology, the presence (or absence thereof) of a supervisor, the workstation possibly being the ultimate stage before the product reaches the customer were all addressed when this question was prompted. Task allocation (and the option of job rotation) was another bone of contention since this enquiry disclosed a triad of opinions. The first observed opinion surrounded how job rotation should be averted for operators with disabilities since there is no perceived return-on-investment (ROI) on a workstation tailoring solely for one person's abilities especially if that individual is prone to absenteeism. This group of interviewees also believe that people with disability (irrelevant of what disability and the individual's personal ability) would be better off learning one task and excelling in it rather than switching tasks that may instigate a level of confusion.

Conversely, the second ideology drawn from other interviewees is the importance of assigning operators with disabilities to teams (groups) with ample supervision. Ultimately, the third belief disassociates itself from the individual needs of the worker and instead sheds light on the job that is being carried out, the core necessities of the job, the product's flexibility and the general predicted turnover of employees, the product itself and changeovers of equipment. Such responses peel back the layers that surround the misconceptions of employing operators with disabilities and show both the breadth and depth of thought that is demanded within this multidisciplinary field. The interviews allude to an omnipresent grey area, with a few manufacturing engineers (even at higher ranks) explicitly commenting on their lack of knowledge on how the company caters for operators with disabilities. This spens from the interview and recruitment stage up to allocation of task and workstation amendments. For this reason the human-resource departments (HR) of certain manufacturing companies were consulted to obtain a concrete comprehension of the procedures that are entailed, and that could not be attained from the manufacturing engineers alone. An insightful highlight drawn out from more than one HR employee, pertaining to different companies, is the lack of operators (mainstream) available for employment. One interviewee in particular laid prominence to this challenge faced during recruitment and beseeches manufacturing companies to seek operators with disabilities who are available and willing to learn and work as opposed to turning a deaf ear to the possibility of engaging such employees to fill the absence of workers.

A lot of manufacturing engineers, managers and directors have a rooted perception that an operator with disabilities will necessitate accompaniment by a job coach or a social worker to assist throughout both the induction and daily endeavours. A level of scepticism arises since this would indirectly add to a secondary wage (cost) apart from that of the operator himself or herself. Despite comprehending such concerns to an extent, the majority of engineers have not yet explored potential alternatives, such as technology and how existing machinery and workstations could be tuned up and modified to cater for the operator. This would drastically reduce the number of days that a job coach would have to assist the operator for, whilst broadening the awareness of technology's benefits. Another plausible motive which was raised regarding the absence of operators with disabilities on the shop floor, revolves around the employer's security. Manufacturing employers are wary of operators with disabilities getting injured on the shop floor, with some employers pushing for more security and legal binding prior to feeling utmost assurance of employing the operators. When approached with the additional question of how accessibility on the shopfloor could be augmented from a cognitive point of view, the majority of respondents with a strong manufacturing background struggled to provide suggestions for such improvements. This identified another potential challenge that exists within manufacturing: the privation of cognitive awareness and mental support for operators with disabilities.

Sub-Theme 2.3 – Working with operators with disability, a testimony.

Notwithstanding the factors mentioned in the preceding theme, some of the interviewees recounted their experiences working with, recruiting and appointing operators with disabilities. The number of (registered) operators with disabilities who work on the manufacturing shop floor of different companies ranged from no operators to maximum ten operators with disabilities in one company. Despite these numbers, it must be recalled that on average, the companies interviewed have between 150 to 250 operators on the shopfloor; resulting in quite a discrepancy when the number of concurrent operators with disabilities are considered. A supplementary remark yielded from two HR employees (each from a different company) is that the number of operators with disabilities may fluctuate depending on seasonality, thus the ascribed numbers may not be fully realistic. The majority (if not all) of the interviewees ascertained that from experience, catering for certain disabilities is more straightforward than others. Such is the case when employing people with sensorial disabilities, mainly people with hearing impairment. Hearing impairment is perceived as easier to cater for since there are easily accessible options and substitutions to ensure that the work experience is not hindered nor loitered, but instead, the experience is ameliorated. For instance, visual lights are an excellent and simple way of issuing instructions, alerting the user and ensuring safety even in complex scenarios. A similar conception was attributed to another sensorial disability, colour blindness. More than half of the interviewees recollected employing a colour-blind person on the shopfloor. One interviewee prompted how the company had introduced a 2D code for every unique product, so the colour-blind individual could still carry out testing without having to interpret colours for each step. One manufacturing engineer who is currently overseeing an operator with disability working on an inspection station has provided nothing but words of praise for this operator. This admiration was not limited to just the quality of the work done, but extending also to reliability, dedication, and experience. This paves the ground for other future people with disabilities to be integrated fruitfully within manufacturing and operations. Employing a person with disability has enriched not just the life of the individual but has also moulded a more considerate and open-minded workforce. These, of course, are in addition to the excellent quality of work that was being carried out (as per testimony). In addition, liaising with governmental foundations and NGOs was imperative for a third of the twelve manufacturing companies in taking the first step towards employing people with disabilities on the shop floor: with some interviewees commending local and European projects for weaving inclusive opportunities in employment.

Sub-Theme 2.4 – A fusion of present and future accommodations for operators with disabilities.

It is futile presenting generic experiences of employing people with disabilities without relating this to the current accommodations that can be prescribed to future suggestions. This sub-theme therefore touches on what manufacturing companies are currently putting forward to assist operators with disabilities, as illustrated in Fig. 3. About four interviewees commenced by expressing the significance of proper shift and timetable allocation, as this directly affects the performance of operators with disabilities, precisely for an operator who gets fatigued easily, or is on medication that may result in episodes of exhaustion. The morning shift was endorsed by all four interviewees, owing to the higher level of supervision and assistance available.

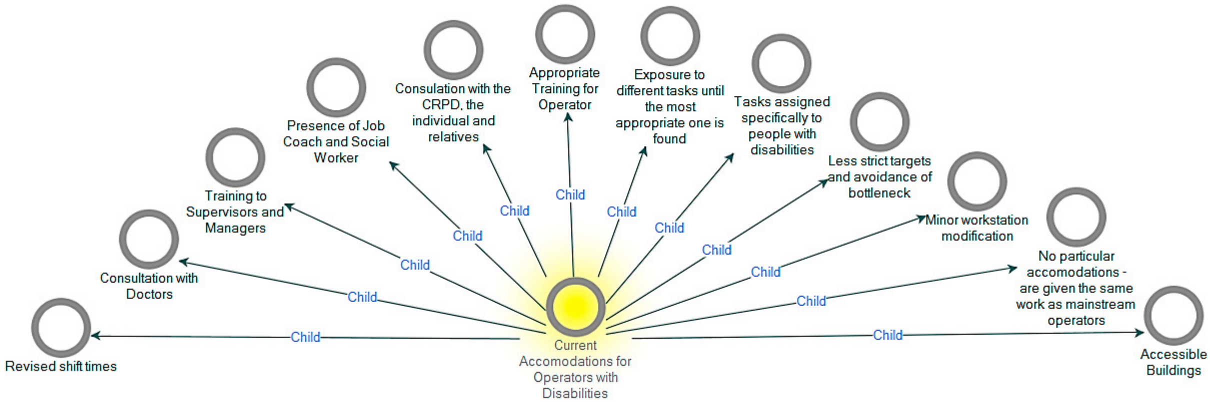

Fig. 3. NVivo Explore Diagram for current accommodations in Maltese manufacturing.

Albeit the current accommodations exhibited in Fig. 3, there was little to no mention of employing assistive technology as a means of being able to provide access to all jobs (as opposed to solely selecting jobs to match the skills). The technologies alluded to were conveyors, foot pedals and visual means, and only two interviewees from twelve companies addressed the use of robotics (collaborative robots – cobots) to assist the individual. When prompted to recommend improvements for people with cognitive disabilities, the answers were generally oriented around ample support provision, yet very few acknowledged how Industry 4.0 could potentially be that stem of support. This presents another industrial problem, where it is common to opt for blinker vision and use technology for its intended purpose only. This thus instigates an aura of awareness evasion and potential lack of understanding of the application of Industry 4.0 technologies. A final insightful facet in light of technology enactment resulted in one interviewee noting how the omnipresence of technology down the line (in say, five years' time), will not hamper the opportunities for people with disabilities to work on the shopfloor. If anything, it will open the door for more ways of accounting for inclusivity on the shopfloor. This ties Industry 4.0 with the social aspect of sustainability, paving the way for a more novel concept, Industry 5.0.

4.3 Theme 3 – Sustainability vis-à-vis inclusivity in Maltese manufacturing companies.

Sub-theme 3.1 – Dominance of the environmental and economical spheres of sustainability

In an attempt to draw relationships between inclusivity and its affiliation to sustainability, all interviewees were asked about how they employ sustainable practices within their daily endeavours. The questions strictly segregated the three sustainable pillars (economical, environmental, and social). There is an undisputed concord between the vast majority of manufacturing engineers and higher rankings, that notwithstanding the relentless drive to achieve environmental and economic excellence (standards and indices, KPIs, carbon neutral goals, waste management and water recycling), the same cannot be reiterated for the social pillar of sustainability. Many commented about the challenge endured to implement social sustainability due to a lack of tangible goals, and thus having to rely on their will and creativity to accelerate things forward.

Sub-theme 3.2 – Scratching the surface of the social pillar of sustainability.

A sense of animosity seems to be present, with some manufacturing interviewees commenting on how corporate social responsibility (CSR) and environmental social governance (ESG) used to be solely related to donations and volunteering, but due to unprecedented economical hurdles not even this is being executed. Thus, the justification for shedding light even on social sustainability within the company walls is not only recommended but encouraged.

5. Discussion of Results

The interviews which were carried out highlighted a number of diverse challenges and views. On the one hand, some manufacturing personnel deem every challenge as an opportunity to reap new rewards and are willing to engage more people with disabilities (without distinguishing between one disability and the other, but rather cater for all disabilities when possible). Having noted that, there is also a small number of manufacturing personnel who deem engaging people with disabilities on the shop floor as delving into unchartered waters and are not willing to adopt a broader perspective which at least attempts to question the status quo. It also appears that these two opinions are rooted even in the age and the experience of the interviewees, with young manufacturing staff exhibiting themselves as more open-minded. The above observations can be summarised into two major aspects that pave the way for future work in this field:

- Lack of guidelines available to adopt inclusive design on the shopfloor with ease and which is not secluded to just accessible shopfloors.

There is a widespread lack of easily available (practical and theoretical) examples and this deters employers and engineers in manufacturing companies from employing people with disabilities and catering for their needs on the shopfloor. The solitary tasks with highest recurrences in all twelve manufacturing companies delegated to operators with disabilities are mainly packing and inspection tasks. Also, most manufacturing companies employ only one class of disability with confidence: the sensorial disabilities class, and in particular – operators with hearing impairment. Finally, it was concluded that the standard (if any) referred to by manufacturing companies when catering for people with disabilities is only the Maltese Standard SM 3800:2015 [35]. Some interviewees pointed out the need of guidelines to overcome the absence of points of referral for manufacturing companies who would like to explore inclusive design within a manufacturing production context. Academics should rise to the opportunity to collaborate with practitioners in industry to formulate such guidelines based on real operators with disabilities and their experience on the shopfloor. This would allow the wellbeing of operators with disability to be the hallmark from the onset of planning, up to proper health and safety and ergonomic evaluation as well as cognitive evaluation. This underlines what social sustainability should revolve around, providing equal opportunities without prejudice, as urged by the sustainable development goals.

- Absence of clarity in the definition of social sustainability with respect to disability employment in manufacturing.

More than three-fourths of the manufacturing interviewees (comprising of engineers, managers, and directors) boasted on the fervent drive adopted by their manufacturing companies to follow sustainable practices and retain competitiveness. Having said that, it is evident that this push was only limited to the economic and environmental pillars of sustainability, with the same interviewees lamenting on the absence of tangible targets and guidelines that clearly define what is entailed by the social aspect of sustainability. This evidently averts manufacturing companies from meshing the social sphere with the glorified economic-environmental duo. Consequently, this exhorts practitioners to foster a culture that respects all three facets of sustainability (not confined to economic and environmental but also social), to track their hotspots and make amends. The first (and most obvious) step forward following this study is to focus on making shopfloors more inclusive for people with different abilities. This should simultaneously extend an invite to academics to provide more case studies for practitioners to follow, as well as identifying scenarios contributing (or hindering thereof) to a smart, sustainable, and inclusive shopfloor.

6. Conclusions

The results of the research work and interviews carried out and analysed testify how society in general is fraught with misconceptions and lack of awareness regarding people with disabilities, especially within manufacturing. The main limitation of this study revolved around the sample chosen for the interviews, comprising only of manufacturing engineers, directors, and managers. Despite the sample size adhering to the recommended number for RTA, future work shall also attempt to encapsulate a second sample comprising of experienced operators on the shopfloor. This would provide a special and novel facet to the topic, permitting first-hand recounts of mainstream operators and their experience working alongside operators with disabilities. Furthermore, a third sample would comprise of operators with disabilities, a current boundary that was not considered for this study but is of extreme importance to harness the values of emancipatory and participatory design for future work.

In conclusion, employing operators with disability on the shopfloor reaps social benefits not only for persons with disabilities, but also for other operators. This is clearly expressed in the solidarity, appreciation and empathy shown, which results in a domino effect and moulding a novel generation of uplifting employees, especially in the age of Industry 5.0. Despite this idea of a utopian shop floor, there is little to no awareness of how to promote social sustainability in the context of operators with disability, as well as a lack of guidelines of how workstations which cater for operators with disability. Nonetheless, not all is bleak; with a fair number of interviewees asserting their confidence in tailoring for operators with disability should more guidance and knowledge be made accessible between all involved stakeholders. Such momentum should ultimately commence from the engineering community itself, where technology and resources could be utilised to bring out the best in every individual on the shop floor. This work has therefore contributed towards a deeper understanding of the challenges and perceptions of employing persons with disability on manufacturing shopfloors. Whilst the results of this research is strictly confined towards the industrial reality within Malta, a European state and island with a small population, the authors of this work hope that this will motivate other researchers in the field to conduct similar studies across the European continent, and beyond. Future work will therefore build on the conclusions of this research in order to develop smart, sustainable, and fully inclusive shopfloors in the age of Industry 5.0.

Acknowledgements

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