Sustainable Welding: Establishing Human-Robot Collaborations Through Implementation in Industry

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

A study conducted by Argonne National Laboratory found that 920 megajoules of energy and 62 kilograms of carbon dioxide are released during the welding phase of a 1532 kilogram vehicle (Sullivan, 2010, p. 18). *Sustainability* magazine reported a comparison study done on manual and robotic welding in small and medium manufacturing companies, finding that robotic welding decreased the arc time by 50.4 seconds, increased the power source efficiency by 0.3%, and increased the annual parts production by 162,560 parts (Epping, 2018, p. 11). This comparison shows the increased efficiency in robotic arc welding, including the environmental benefits of lower carbon emissions.

The implementation of robotic welding in industry involves displacing manual welders and creating new manufacturing systems. Although there is belief that humans in industry lose their jobs to robots that perform the same tasks, according to *Forbes* magazine, when Wing Enterprises implemented robotic welders in their production system, they produced enough parts to enable them to open another facility, expanding their job force from 20 to 400 employees (Ellingrud, 2018). Therefore, the most important consideration is understanding the human-robot relationship through the implementation of sustainable, robotic welding because there are not successful implementation methods and procedures established. In other words, successful robotic implementation methods have not been seen enough to understand and create standards to follow.

Throughout this paper, the human's role in a robotic world is analyzed to understand how to successfully transition to sustainable processes, while upholding human values. Additionally, the multi-dimensional facets of this problem frame are considered by using Frank Geels'

Multi-Level Perspective framework to understand successful sustainable process transitions and Joan Burton's WHO Healthy Workplace model to develop the process of creating and maintaining a healthy work environment. These frameworks will be meaningful because of the difficulty in transitioning to sustainable processes due to cost and administrative responsibility shifts. These frameworks will be used to uncover the truths in Pope Francis' quote from Laudato Si, "a true ecological approach always becomes a social approach; it must integrate questions of justice in debates on the environment, so as to hear both the cry of the earth and the cry of the poor" (Francis, 2016). Through this research, I argue that there is an ethical and successful ability to implement robotic welding in industry for sustainability by evaluating the critical multidimensional facets of sustainable transitions and human needs and values in the workplace.

Part I: The Need for Successful Sustainable Robotic Welders and Implication Methods

The improvements made in robotic welding features create savings in energy and carbon dioxide emissions as explained in the introduction. As shown in Figure 1, TRUMPF, a German industrial machine manufacturer, conducted a study comparing the emissions of manual metal arc welding (manual welding), laser arc-hybrid welding (robotic welding), and gas metal arc welding (manual welding), both standard and modified versions. When comparing the life cycle assessment for each type of welding practice, it was found that the laser arc-hybrid welding emitted the least amount of phosphate, sulfur dioxide, ethene, and carbon dioxide as shown in Figure 1 (Kaliudis, 2017). Due to the harmful environmental effects of these gases, such as their contribution to greenhouse gases, it is important to emit small amounts of these compounds.

Likewise, both comparison studies for each type of welding practice highlight how robotic welding is more environmentally friendly and efficient than the alternative of manual welding.

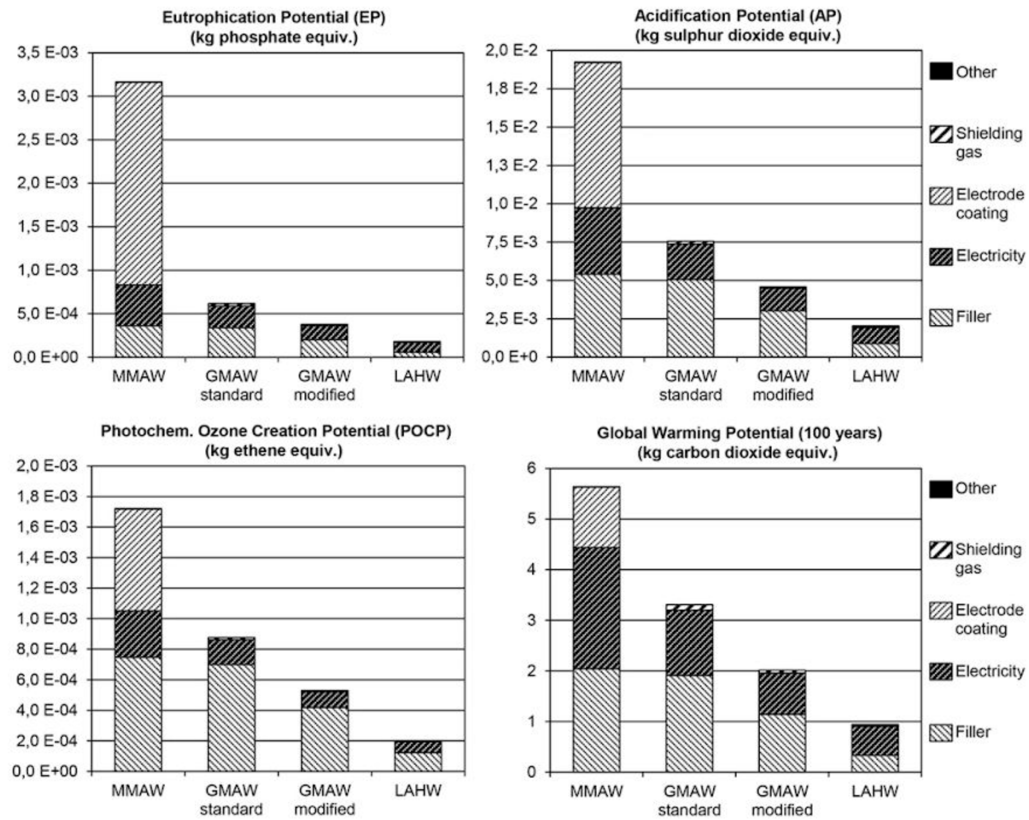

Figure 1: The graphical results of emissions for phosphate, sulphur dioxide, ethene, and carbon dioxide for manual metal arc welding (MMAW), laser arc-hybrid welding (LAHW), and gas metal arc welding (GMAW), both standard and modified versions. From the results, it is shown that manual welding creates the most emissions for all gases measured (Kaliudis, 2017).

Robotics in the manufacturing industry has become a critical factor in daily operations for mass production, safety, and sustainability. Genesis Systems, a specialized robotic integrator company, analyzed the performance of human and robotic welders, noting that although the weld time does not change, human welders have a maximum efficiency of 20%, while robotic welders increase efficiency up to 85%. Further, due to increasing demand in industry, Genesis estimates that by 2024, the United States will be 400,000 skilled welders short (Martinez, 2017). Although there is a potential shortage of human welders, the implementation of robotic welders can combat the demand while improving efficiency. The Information Technology and Innovation Foundation, which is a United States nonprofit organization focused on public policies that spur technological innovation, highlights the increases in national robot adoption, such as, "according to IFR, the global average for industrial robots per 10,000 manufacturing workers grew from 66 in 2015 to 85 in 2017" (Atkinson, 2019). Although there is a national rise in the robotic adoption rate, the success of the payback for the implementation when compared to the compensation levels has drastic variations among various nations as shown is Figure 2 (Atkinson, 2019). Therefore, this results in the need for established human robot collaborations and implementation processes to increase the total of successful robotic adoption cases.

Figure 2: Actual robot adoption rates as a share of expected robot adoption rate19

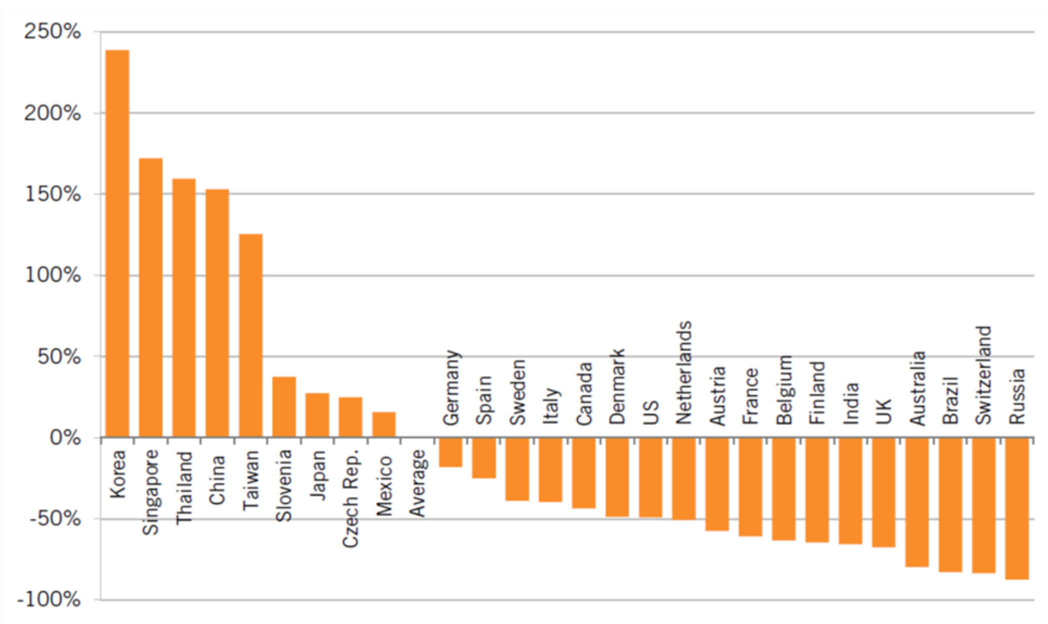

Figure 2: The Information Technology and Innovation Foundation shows the robotic adoption rates in manufacturing by country. "Comparing the ranking of expected robot adoption given differences in compensation levels to actual rates, several patterns emerge. First, East Asian nations lead, occupying six of the top seven positions in the ranking: Korea leads with 2.4 times more robots adopted than expected, while Singapore, China, Thailand, and Taiwan follow. Japan ranks seventh. In contrast, Commonwealth nations lag behind significantly, with Canada ranking 14th (44 percent below expected adoption rates), the United Kingdom 23rd (73 percent below), and Australia 24th (80 percent below)" (Atkinson, 2019).

Through robotic implementation in industry, various human-robot relationships, positive and negative, can develop; however, only a limited number of potential relationships have been noted. Brookings Institution, an American research group, discusses one possible relationship shift between the two actors; when robots are implemented in industry, training for the human workers is needed to further their skills to work alongside robots. The new training would enable the workers to understand the technology behind the robots, allowing them to troubleshoot or complement the new technologies (Casey, 2019). Further, this relationship creates a collaboration between the robots and humans, developing an additional skill set of the human workers.

An article by the *International Journal of Advanced Robotic Systems* demonstrates specifically the potential collaborations that humans and robots performed previously, which can be applied to robotic welders in industry. The journal highlights one collaboration of humans using robots as tools in a harvesting melon experiment where results indicated that a human operator working with a robotic system with varying levels of autonomy resulted in improved harvesting of melons (Green et al., 2008, p.3). To further understand how to create success within human-robot collaboration and project, the journal states,

> "This section on Robots as Tools highlighted two important ingredients for an effective human-robot collaboration system. First, adjustable autonomy, enabling the system to vary the level of robotic system autonomy, increases productivity and is an essential component of an effective collaboration system. Second, situational awareness, or knowing what is happening in the robot's workspace, is also essential in a collaboration system. The human member of the team must know what is happening in the robot's work world to avoid collisions or damage to the robotics system" (Green, 2008, p.3).

An additional relationship that could develop would be master welders training robots how to perform human skills. *Control Engineering* discusses an increase in demand for master welders due to the lack of training in the industry, which creates new opportunities for welders. Master welders who possess the needed skills, such as the sequencing of welding processes, travel angles, and amperage, can train robotic welders through computer coding (Anandan, 2017). The idea of using the welders to train the robots creates a teacher-student relationship, where the robot is taught welding skills by the master welder. An additional outcome shown through the relationship is that the skillsets of the welders would be utilized through two features: training and precise welding. To elaborate on how the mindset of human welders can be instilled into the robotic welders, the International Federation of Robotics (IFR) discusses how encompassing artificial intelligence leads to a successful human-robot collaboration because "advances in artificial intelligence are leading to a growing market for collaborative robots that work alongside humans rather than being housed in cages" (IFR, p.7, 2018). Therefore, to develop the intelligence and human experience that robots need to be successful in the collaborations and daily manufacturing performance, human welders can teach the needed skill sets and thought processes to the robots.

As shown above, although there are documented potential human-robot collaborations that were developed as a result of robotic implementation, it is crucial to further understand what characteristics lead to successful adoptions. Further, as implementation procedures evolve, it is essential to better understand how to uphold human values through policy changes in industry. The Multi-Level Perspective will be used to navigate through the needed steps for sustainable transitions to implement robotic welding. Additionally, the WHO Healthy Workplace

Framework and Model will develop the methods to create and maintain a healthy workplace that upholds human values in various dimensions by considering the psychosocial work environment, which focuses on culture and values of employees. Thus, by using these frameworks together, they will enable the establishment of successful transitions in sustainable robot implementation.

Part II: Maintaining a Healthy Workplace Environment and Implementing Sustainable Transitions in Industry

Multi-Level Perspective

The first framework that is critical to the research of the human's role in a robotic world and how to successfully implement robotic welding is Frank Geels' Multi-Level Perspective (MLP). Overall, this framework provides a basis on how to understand various levels of transitions to incorporate sustainability, which is important because of the various levels, transitions, and actors involved in implementing sustainable robots. MLP revolves around the challenge that transitions to become sustainable involve multiple actors and are multi-dimensional. The various facets representing the multi-dimensionality "makes sustainability transitions unique" because "most 'sustainable solutions do not offer obvious user benefits", such as the human welder benefit (Geels, p. 25, 2011). Therefore, in considering the most efficient processes to incorporate all aspects, including human values, "researchers therefore need theoretical approaches that address, firstly, the multidimensional nature of sustainability transition, and, secondly, the dynamics of structural change" (Geels, p. 25, 2011). Fostering these ideas, the MLP framework includes dimensions from evolutionary economics, science and technology studies, structuration theory and neo-institutional theory to define and theorize the role of regimes and niches (Geels, p.26, 2011).

Crucial for the use of the MLP framework are the roles of regimes, niches, and the landscape. Regimes and niches are the basic building blocks used to navigate through a socio-technical system. A regime "forms the 'deep structure' that accounts for the stability of an existing socio-technical system", meaning it provides the rules followed by the system (Geels, p.27, 2011). In industry, an example of the regime is the job responsibility matrix of the human welder. "Niches are 'protected spaces' such as R&D laboratories, subsidised demonstration projects, or small market niches where users have special demands and are willing to support emerging innovations'" (Geels, p.27, 2011). Relevant to the research, niche-actors are most importantly considered, due to them being "crucial for transitions, because they provide the seeds for systemic change" (Geels, p.27, 2011). In the research, niche-actors can be represented as experimentation projects that implement robotic welding. Involving both the regime and niche, the sociotechnical landscape in MLP acts as the environment that influences and is influenced by the actions of the regime and niche, as shown in Figure 3 (Geels, p.28, 2011).

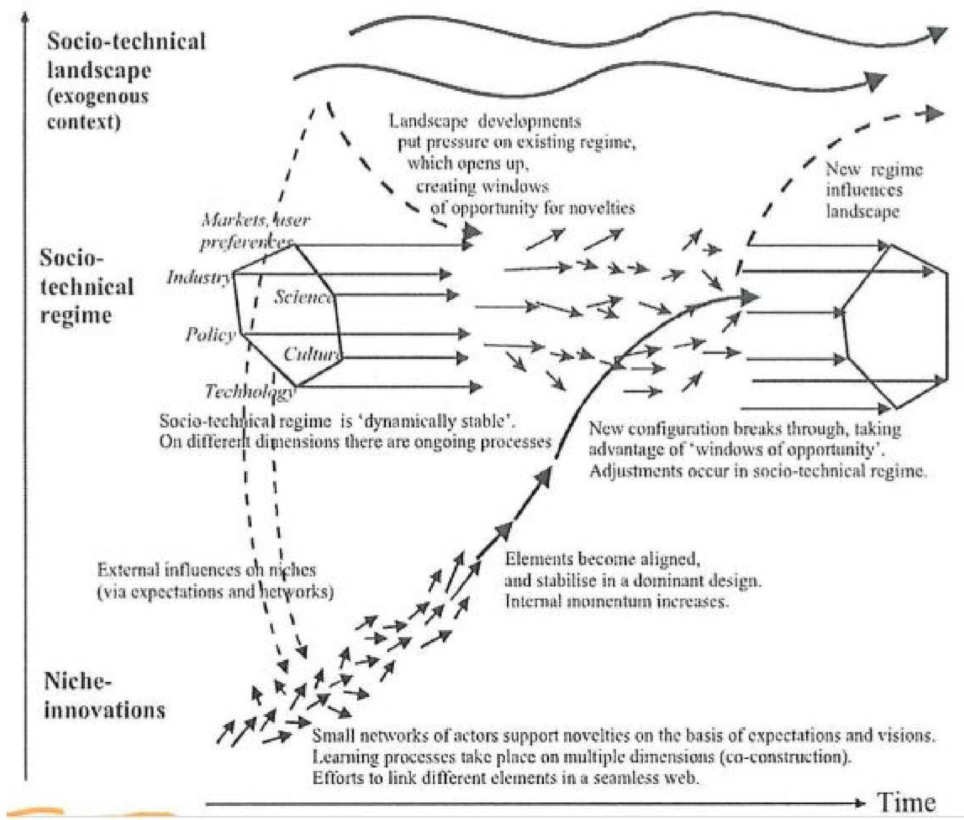

Figure 3: The MLP framework's representation on how the regime, niche, and landscape interact dynamically through socio-technical transitions. By incorporating each level and actor, the MLP provides the ability to analyze which dimensions and actors cause and develop the greatest change (Geels, p.28, 2011).

Further essential ideas used in MLP are the role of agency, equality between transitions, and heuristics, epistemology and explanatory style. Through various levels of structures and power, MLP develops agency by dividing the power and actions between each level. This part of the framework can be applied to establish the responsibilities between the roles of the manual welders, industry executives and robotic welders. MLP does not explicitly look at various actors as individuals, due to the idea that " the trajectories and multi-level alignments are always enacted by social groups" (Geels, p.29, 2011). The role of social groups, such as a workforce, in MLP develops the system of multi-leveled structural actors, which "bridge[s] the social science divide between ‘materialist’ and ‘idealist’ theories” by developing the role of power (Geels, p.30, 2011).

Equality between transitions in MLP eliminates the bias towards bottom-up dynamics initially by creating transition pathways: transformation, reconfiguration, technological substitution and de-alignment and realignment. Transformation addresses how small adjustments in regimes are made as a result of innovation and landscape pressures, such as implementing gradual robotic welding in industry. Reconfiguration proposes that solutions to challenges, which can reconfigure the foundation of a regime, are developed by actors adopting symbiotic niches. Further, technological substitution highlights the opportunities for niche-innovation to replace the regime. De-alignment and re-alignment disintegrate and rebuild the regime, which builds a strong foundation for the new innovation and ideas (Geels, p.32, 2011). By introducing the pathways, MLP focuses on the structural models and allows fluidity between transition methods. As a result of the pathways, four strategic profiles developed: reformists, impatient revolutionaries, grassroots fighters, and patient revolutionaries. Most critical to the research is the reformist profile; “existing elites (in politics and business) gradually change existing institutions in greener directions”, because of the role the industry executives play in implementing sustainable, robotic welding (Geels, p.33, 2011).

Planning and analyzing results of the robotic implementing process is developed through the MLP framework of heuristics, epistemology, and explanatory style. Although the MLP does not provide explicit answers on how to solve challenges through transitions to become sustainable, it relies on “‘heuristic devices’ that guide the analyst’s attention to relevant questions and details” (Geels, p.34, 2011). Utilizing these devices through the transitions of implementing robotic welding allows patterns and mechanisms in processes to be exposed. As a result of the awareness of the patterns and mechanisms, “the analyst thus needs to trace unfolding processes and study event sequences, timing, and conjunctures” (Geels, p.34, 2011). Through this practice, interactions and implementation methods between the human and robotic welder can be developed by providing data to analyze the successes and failures of various processes.

WHO Healthy Workplace

A second framework critical to understanding how to uphold human values in the robotic implementation process is the WHO Healthy Workplace Framework and Model (WHO), established by Joan Burton from the World Health Organization. WHO provides processes to ensure a healthy work environment through four avenues: the physical work environment, psychosocial work environment, personal health resources in the workplace, and enterprise community involvement (Burton, p.83, 2010). Although all four avenues are important in developing a healthy environment, the most crucial aspect in the WHO framework to consider in implementing sustainability in industry is the psychosocial work environment because it “includes the organization of work and the organizational culture; the attitudes, values, beliefs and practices that are demonstrated on a daily basis in the enterprise/organization” (Burton, p.85, 2010). This avenue highlights the need to uphold the human values through transitioning their job responsibilities due to the “fear of job loss related to mergers, acquisitions, reorganizations, or the labour market/economy” (Burton, p.85, 2010).

Essential to WHO is the act of implementing a healthy workplace program, which includes mobilizing the people to become committed and evaluating the results. Highlighted in

WHO are the core principles of "leadership engagement based on core values and ethics, and worker involvement" (Burton, p.89, 2010). Due to the leadership divide in industry between executives and the workforce, engagement from both sides is critical. Additionally, WHO notes "it is critical to mobilize and gain commitment from the major stakeholder and key opinion leaders in the enterprise and community before beginning" (Burton, p.89, 2010). Although the workforce and leadership actors in industry hold different values and value differing ethical frameworks, it is crucial to gain the support of these stakeholders so they are motivated to adopt the sustainable innovation. Beyond commitment, it is necessary to have "the engagement of the key leaders in mobilizing resources for change - providing the people, time and other requirements for making a sustainable improvement in the workplace" (Burton, p.90, 2010). After the implementation process, WHO develops the need for evaluating the results and actions. "Evaluation is essential to see what is working, what is not, and what are the impediments to success. Both the process of the implementation and the outcomes should be evaluated, and there should be short-term and long-term outcome evaluations" (Burton, p.94, 2010). The WHO evaluation step ensures that human worker values are upheld during and after the implementation process, which allows for additional changes to be made to improve the success.

Part III: Individualizing Results and Synthesizing the Multidimensional Results

Multi-Level Perspective

The MLP provides a basis for understanding how each dimension within the system contributes to the overall transition to sustainable robot implementation. Applying MLP alone results in knowing how to consider each facet of a multidimensional challenge to provide a solution. An example of this is revealing that each dimension of implementing sustainability plays an individualized part, but also acts as a whole system. This idea is supported by John Ikerd, a professor at the University of Missouri, because "sustainability is an emergent property of natural, social, and economic communities and societies that have ecological, social, and economic integrity" (Iker, p.2, 2015). Therefore, the MLP develops these communities to act as a landscape where the various integrities act as regimes, which are changed by niche-actors, such as human and robotic welders. Further, although the regimes can act as individual entities, the success of implementing sustainability relies on all regimes and dimensions to act as a whole. For example, Guido Bugmann from the Centre for Robotic and Neural Systems, concluded that the initial cost of an industrial robot is recovered in two years (Bugmann et al., p1, 2011); however, sustainable concerns are not rooted in facts, but in human values (Ikerd, p.1, 2015). Therefore, the implementation of robotic welding can successfully be achieved only if the human value is appealed to, while having concrete evidence to support the other dimension.

Additionally, MLP reveals how successful implementation results from gradual changes. To initially test the outcome of implementing sustainability, a small manufacturing company or individual unit in a larger company needs to be exposed to the robotic welders. The small unit will act as an experimentation group to analyze the sustainable changes. This idea is shown through evidence that a "process may begin with a few collaboratively designed and implemented pilots and a small network of stakeholders" (Bugmann et al., p. 3, 2011). By using and observing the small network, the realistic experiment can be turned "into a scalable body of knowledge", which develops appropriate needs for education and training programs that help maintain or correct the systems (Bugmann et al., p. 3, 2011). Further, by adapting and making changes within these small groups, a Community of Practice can be created to understand the successes and challenges faced by similar organizations through knowledge and communication, as shown in Figure 4 (Bugmann et al., p. 3, 2011). The creation of these groups can lead to successful collaborations, innovative solutions, institutional capacity building, and larger sustainable implementation (Bugmann et al., p. 3, 2011).

Figure 4: Sustainable development contributes to collaboration within a community. Various actors, such as the stakeholders and policymakers, interact to share knowledge to produce increased successes in implementing sustainability (Bugmann et all, p. 3, 2011).

<u>WHO Healthy Workplace</u>

WHO reveals how to incorporate human values into implementing sustainability to create and maintain a healthy work environment. The main result from this framework is human values are a top priority when trying to create psychosocial health. Therefore, implementing robotic welding must appeal to the human value in order for the sustainable transition to be meaningful for them. Specifically, “our most basic human values are reflected in our worldviews; in common terminology, meaning how we think the world works and where we as humans fit within it” (Ikerd, p.1, 2015). To push human welders to understand their role in a robotic world, it is essential to provide them knowledge for the need of sustainability. By increasing this knowledge base, the humans will see a need for sustainability and will be committed to their transitioning role.

Further, WHO reveals the importance for full commitment from both an employer and employee. Therefore, if the stakeholder with more power commits to educating the human welders on their roles and the importance of the sustainable transition, better acceptance of the change will occur. For example, Andrew Arnold from *Forbes* addresses the commitment and adaptability of humans in the workforce to help with sustainable transitions because “they’ll have to be hungry for knowledge and committed to continuing education whether that’s by taking an online MBA, attending conferences, reading books, consuming podcasts or taking traditional advanced degrees” (Arnold, 2018). Therefore, this commitment developed by WHO results in the notion that human welders will not only need to be committed and valued in the sustainable transition, but they will also need to increase and maintain their relevant and advanced skills for the job to be meaningful to them. Specifically, “the dynamics of the 21st century… require education collaboration be at the core of knowledge production and technology innovation” (Bugmann et al., p.3, 2011).

Synthesizing MLP and WHO

Although results were established by MLP and WHO individually, the most essential result was established by considering the frameworks together. Specifically, sustainable transitions can successfully be implemented only if the quality of life in the workplace is not inhibited. By educating human welders about the importance of sustainability and understanding the job actions that are most fulfilling to them, human-robot hybrids can be created, which are "systems that combine the best of the human with the best of the robot" (Bugmann et al., p.3, 2011). Including the best of both the human and robot, such as incorporating the best characteristic that the humans value in their jobs, sustainability can successfully be implemented in industry. Additionally, because restructuring existing systems through de-alignment and re-alignment is used, it is critical to evaluate how the various dimensions impact the overall quality of life because "deep sustainability advocates radical redesigning human economics and societies to reflect the natural hierarchy among ethical, social, and economic values in determining overall quality of life" (Ikerd, p.3, 2015).

Conclusion

Due to the increase in efficiency and decrease in harmful emissions, there is a need to implement sustainable robotic welding in industry. However, due to the large impact on the current job positions of human welders, considerations of the human values and various actors must be taken to successfully implement sustainable transitions because of the lack of established successful robotic implementation cases and methods. The Multi-Level Perspective explained in detail above, develops processes to use the multiple dimensions within the problem frame. Additionally, a crucial detail highlighted in MLP is the need for gradual change versus abrupt changes. As a result, MLP yields the idea that for success, each dimension, specifically non-factual aspects, plays an essential role in the implementation of sustainable welding. The

WHO Healthy Workplace Framework and Model develops the need to focus on the psychosocial environment of the human welder. This framework reveals the commitment aspect by all stakeholders to ensure each actor understands their role and its importance in the total sustainable transition. Although both the MLP and WHO Healthy Workplace frameworks establish important considerations when understanding how to create procedures and methods for successful human robot collaborations and implementation, the most critical results come from analyzing the frameworks together. Synthesizing the MLP and WHO, as shown above, results in the final conclusion that by "including the best of both the human and robot, such as incorporating the best characteristic that the humans value in their jobs, sustainability can successfully be implemented in industry" (Patterson, p.16, 2020).

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