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SUSTAINABILITY IN ENGINEERING AND ENGINEERING EDUCATION: A COMPARATIVE STUDY OF GERMAN AND SAUDI ARABIAN INDUSTRIES

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ABSTRACT

Sustainability has become a major concern in the fields of engineering and engineering education. Organizations such as UNESCO have defined goals for sustainable development in engineering. As engineers design, develop, and implement products and processes that impact the environment and society, their role in promoting sustainable development is vital. Addressing sustainability in engineering curriculum is needed to equip engineers with the knowledge, skills, and attitudes required to develop sustainable solutions in their respective areas, and it involves merging the teaching of technical skills with a systems-based approach that considers the broader environmental and economical context of engineering. This

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requires collaboration between different disciplines and stakeholders, including engineers, educators, policymakers, and industry.

This study investigates the industry practices regarding sustainability goals and measures in two countries. Another point of inquiry is to find practical recommendations from engineers and project managers to inform engineering education curriculum in terms of knowledge and awareness of sustainability. Qualitative case study protocol was followed in this research, and participants from Germany and Saudi Arabia were interviewed online. Thematic coding was performed to extract meaning making descriptions from the interview transcripts.

In response to the interview prompts, the participants shared their perspectives of sustainability in their area of engineering. Their recommendations towards the curriculum development included making UN sustainability goals a part of engineering curriculum, while still teaching students to adopt a ‘lean product development approach’ in their course projects, so that they learn the practical implementation of sustainability in engineering projects as well as in life.

1 INTRODUCTION

1.1 Background and Literature Review

The need for sustainable development is a very immediate one, defined and explained initially by the World Commission on Environment and Development (WCED) (WCED 1987) as utilizing the planet's current resources in such a way that future generations may also be able to benefit from them. In that sense, sustainability is an important issue to be addressed in engineering education (Glavič 2006).

Regarding engineering, sustainability has many dimensions, including environmental considerations for ensuring a safe and secure future for generations to come, countering global warming and reducing carbon footprint (Matthews, Hendrickson, and Weber 2008) to name a few. Globally, industries are investing a lot in how to make their material products sustainable. The emphasis is on increasing the quality of products to make them long lasting and durable, using biodegradable materials to manufacture equipment, finding renewable energy sources to run factories and workspaces, and reducing carbon footprint, chemical waste and plastic waste (Evode et al. 2021).

The world is facing a plethora of environmental, social, and economic challenges, such as climate change, resource depletion, and chemical waste which are intricately interconnected and can potentially lead to an uncertain future in terms of habitability of the planet. Governments, trade markets, companies, and engineers working in various disciplines have the responsibility to address these challenges in their respective capacities (Wilkinson, Hill, and Gollan 2001) and create solutions that promote sustainable development. Achieving sustainability requires a holistic approach that considers the entire life cycle of a product or system from raw material extraction to its recycling or disposal (Jawahir et al. 2006).

There is a growing body of academic research that highlights the importance of sustainability in engineering. For example, a study explored the integration of sustainability principles called life cycle sustainability assessment (LCSA) into the design process and building information modeling (BIM) process of buildings (Llatas, Soust-Verdaguer, and Passer 2020) in an attempt to achieve significant reductions in energy use, water consumption, and greenhouse gas emissions from the buildings. This research demonstrates that sustainable engineering practices can have a positive impact on the environment and help mitigate the effects of climate change. In addition to the benefits of sustainability in engineering, there is also a growing need for sustainability in engineering education. A study by Ramirez emphasized the importance of integrating sustainability principles into industrial design curriculum (Ramirez Jr 2007). The author argued that sustainability should be a core part of engineering education to teach students about the ecological impacts of their designs and how to minimize these impacts (Ramirez Jr 2007).

Another study explored the impact of sustainability education on the attitudes and behaviors of engineering students towards sustainability (Tang 2018). The authors found that students who received sustainability education had a greater understanding of the importance of sustainability and were more likely to consider sustainability in their future engineering projects as a moral obligation (Tang 2018). This research highlights the positive impact that sustainability education can have on students and their future engineering careers.

There are several challenges to integrating sustainability into engineering education, including the lack of resources, time constraints, and resistance to

change (Markvart 2009). However, there are also opportunities, such as strategies proposed for integrating sustainability into engineering education, including curriculum redesign towards sustainable development goals by United Nations Educational, Scientific, and Cultural Organization (UNESCO) (UNESCO 2005), project-based learning, and interdisciplinary collaborations (Guerra 2017).
In conclusion, sustainability in engineering and engineering education is a critical issue that cannot be ignored.

The researchers intend to address sustainability through a curricular approach by interviewing experienced engineers in Germany and Saudi Arabia, which as countries are far apart in terms of geographical locations, education systems, and industries. Germany is advancing towards automated industry through the industry 4.0 project (Lasi et al. 2014). On the contrary, Saudi Arabia holds an oil-based economy (Abuhjeeleh 2019). It would be interesting to see how engineers working in both the countries describe their companies' efforts towards sustainability. The goal is to learn about their perspectives regarding the importance of sustainability in engineering and their suggestions towards curricular reforms for better awareness of young individuals in undergraduate engineering programs.

1.2 Theoretical Framework

The research questions in this study are informed by the 'Education for Sustainable Development' (ESD) framework. ESD is defined as "a process of learning how to make decisions that consider the long-term future of the economy, ecology, and equity of all communities" (UNESCO 2005). The ESD framework provides a holistic approach to education that integrates social, environmental, and economic perspectives. It emphasizes the development of knowledge and awareness for students that enable them to participate in sustainable development.

Several studies have applied the ESD framework to engineering education, highlighting the importance of integrating sustainability into engineering curricula. For instance, Bergholm (Hofman-Bergholm 2018) recommended the interlinking of ESD with systems thinking approach to inform the practical implementation of sustainability in education. Comparably, in their implications for curriculum change, Kagawa (Kagawa 2007) reported that students associate the concept of sustainability to be against economic and social aspects, and therefore proposed an engineering curriculum overhaul to overcome such barriers in an attempt to let students realize their preferred futures (Kagawa 2007).

Overall, the ESD framework realizes the challenges of inculcating a sustainability mindset in students through engineering curriculum and provides practical solutions to achieve that goal.
This study aims to realize the full-time engineers' and project managers' knowledge and awareness about the issues pertaining to sustainability and looks at how the industry is implementing sustainability goals. Following are the research questions:
RQ1: How do experienced engineers and project managers perceive the issues relating to sustainability?
RQ2: How does sustainability relate to engineering education and how can sustainability be integrated into the engineering curriculum?
These research questions attempt to explore the concept of sustainability in industry of two countries and bring the industry best practices to inform engineering curriculum in academia.

2 METHODOLOGY

2.1 Study Design

This research is designed as a comparative case study, in which a ‘case’ represents a choice of what is to be studied (Creswell and Poth 2016). Furthermore, this study is not chronological in nature and is based on examining particular scenarios bounded by a limited timeframe (Creswell and Poth 2016). Approaching the issue of sustainability through a case study approach makes sense for this research in a way that researchers want to investigate how the issue is addressed in industry and academia at different geographical locations. Through this study, the researchers aim to shine light on the importance of including the teaching and awareness of sustainability-related concerns in the curriculum of all areas of engineering.

2.2 Sample

Sampling for this study constituted experienced engineers and project managers who worked in Germany and Saudi Arabia. The sample size was 8, including 4 participants from Germany and 4 from Saudi Arabia. Recruitment was done by forwarding recruitment emails to academic and professional connections as well as through snowball sampling, meaning that the recruited participants were requested to find further participants from their professional connections and circles. Certain criteria were set to make sure that participants were aware of the current industry best practices around sustainability. In order to be eligible to participate in the study, following criteria were to be met by the individuals:

Engineers: Engineers were required to have graduated within the past five years from their university in Germany or Saudi Arabia, and to have full-time industrial experience of at least 4 years.

Project Managers: Project managers were required to have full-time industrial experience of at least 15 years and to have served in a corporate-level management position for a minimum of 5 years.

2.3 Instrument and Protocol

The protocol followed in this case study was semi-structured interviews. Participants were contacted remotely via Zoom and their audio and transcriptions were recorded. Interviews started with a brief introduction of the researcher and participant in terms of area of research and industrial experience, followed by open-ended prompts regarding sustainability definitions and practices in their respective companies. Participants were also asked for their recommendations towards improving the engineering education curriculum to cater to the awareness of sustainability among engineering students. Care was taken to maintain the anonymity of participants by assigning pseudonyms to them and their companies.

2.4 Analytical Method

This case study implemented a thematic coding approach to analyze interview data collected from participant audio transcriptions. The analysis involved assigning codes and subcodes to specific groups of information in the transcripts, followed by a holistic determination of repetitive and similar codes appearing in multiple participant transcripts. The information relevant to those codes was then regarded as ‘emergent’

which led to ‘themes’ from the data that answered or tended to answer the research questions for this study. Those emergent themes were used to report the findings as well as inform the discussions section of this article. As a whole, only the participant perspectives have been reported in the findings section, while researchers’ perspectives have been discussed in the later sections.

3 RESULTS

As this is a comparative study, findings have been divided into two groups based on the geographical location of participants. Initial codes indicated that participants defined sustainability in varied ways depending on their area of engineering. However, several participants had similar experiences regarding their companies’ efforts towards sustainability goals.

3.1 Participants from Germany

A participant is a senior mechatronics engineer with a master’s degree working in the German automotive industry for the last five years. His daily work involves autonomous driving systems and advanced driver assistance systems such as adaptive cruise control and lane assist. The participant believes that sustainability is a hot topic in the value chain and that the life cycle sustainability of products such as electric vehicles (EVs) and active hybrid cars should mainly involve minimizing the overall carbon dioxide emissions. Even for the traditional combustion engine technology, the automotive companies are finding ways to reduce emissions. In terms of the European laws about sustainability, a participant explained that Germany plans to discontinue diesel engine production by 2030 and petrol engine production by 2035. Simultaneously, companies are investing in improving fuel cell technology and also making it more affordable. In that regard, Toyota has built a prototype fuel cell powered car whereas Mercedes is developing a fuel cell powered bus. Similarly, Mercedes has replaced original leather seat covers in cars with synthetic alternatives and traditional plastic parts in cars with recyclable alternative plastics in an effort towards a more sustainable system. Although that participant’s current role in the company is not a corporate-level decision making role, he still believes that ample background knowledge and awareness about sustainability is very important for every engineer and should be addressed properly in the university curriculum. He recommends that engineering students should be thought to adopt a ‘lean product development approach’ in their course projects with focus on minimizing expenses and maximizing market value and profits, but at the same time care about the durability and sustainability of the product as important concerns.

Another participant with three years of experience in avionics-related software exclaimed that he was not taught about sustainability in his undergraduate and master level courses. However, his current company is working on a data transfer simulation module for Field Programmable Gate Array FPGA chips and mostly deals with software and coding aspects. In his area of engineering, sustainability efforts involve reducing and optimizing code to use minimum memory resources on microchips. This helps in conserving the natural resources utilized to make microchips which is an important aspect of sustainability towards saving natural resources for future generations.

3.2 Participants from Saudi Arabia

Most of the participants from Saudi Arabia worked at some of the biggest oil companies in the world, in part since crude oil and petroleum products are the biggest exports of the region. A project manager with over 25 years of experience at Saudi's 2nd largest construction company, linked sustainability in his company with the UN sustainability goals defined in 2004, saying that sustainability became the cornerstone of all big engineering projects in the world after that. In another participant's view, engineers need to radically shift to a sustainable mindset in all areas including plastics, batteries, chemicals, and electronics. He warned about an issue that needs immediate attention on a global level, which is that permafrost is rapidly melting in the Arctic Circle due to global warming, and the process is releasing greenhouse gasses, especially methane gas which is 40 times more potent than carbon dioxide. While this is a big problem in the current scenario, the earth as a planet is on the verge of even bigger issues if the average global temperature increases by 1.5 degrees Celsius, such as runaway heating of the planet. In that case, methane hydrates found at the bottom floor of deep oceans and containing more than all the hydrocarbons that humans have been burning from the last 100 years, might rise to the surface, posing everlasting threats to the living ecosystems. The participant explained that recent developments in his company's sustainability policy have resulted into efforts towards decarbonizing operations, electrification, heat pump usage in terms of energy generation, addressing global warming by shifting methane-based steam cracker towards electrical based steam cracker, maintaining a circular economy with the plastic waste reduction and plastic recycling process, and improving resource and energy efficiencies.

In his recommendations toward improving the engineering education curriculum, a participant mentioned that the UN sustainable development goals should be a part of curriculum regardless of the area of engineering. The students must always think from a sustainability perspective, such as while designing and developing a product, think about where it will end up after its lifetime. The focus should be on earning carbon credits and reducing the carbon footprint on the planet by utilizing minimum resources from natural reserves and maximizing the efficiency as well as lifetime of the products. Mark also mentioned that the students need to be aware of the long-term sustainability concerns such as if the whole world moves to electrical energy generation through nuclear, it will only last 75 years; thus, we need renewable sources of energy such as solar, hydel, and wind.

Another participant, working in the drilling department of an oil company for 16 years, defined sustainability as a responsibility of our generation to secure the future of generations to come. His concerns regarding sustainability included minimizing environmental impact of material product wastes, reducing pollution and carbon footprint, carbon capturing, maximizing asset values, and circular economy. Sid emphasized that the issues regarding sustainability are so important that not only the engineering curriculum but also the elementary school curriculum should aware students and develop innate sustainability sense in them from childhood.

4 SUMMARY

4.1 Discussion

Regarding sustainability, the perspectives of engineers and managers working in Germany were quite different from those working in Saudi Arabia. This might be a consequence of different industry focus for the two countries. Germany has been

working on an automated model of industry for a long time, (Lasi et al. 2014) minimizing the human input while maximizing the machine output, which is a step toward enhancing machine efficiency and life cycle and thus contributes to sustainability research. On the other hand, Saudi Arabia has remained an oil-based economy for a long time (Abuhjeeleh 2019) and only recently started investing in tourism, non-oil exports and renewable energy (Waheed, Sarwar, and Dignah 2020) which is apparent from the participant perspectives indicating a relatively recent shift towards sustainable economy, renewable energy, and other sustainability dimensions. Furthermore, the findings indicate that engineers in Germany are well aware of the sustainability challenges specific to their areas such as reducing the lines of code for microchips as a software sustainability concern and replacing automotive batteries and body materials with sustainable alternatives. In contrast, engineers and project managers in Saudi Arabia view sustainability in a more global sense, with less concerns relevant to their specific areas of engineering.

Nevertheless, knowledge and awareness about sustainability must be provided to engineering students throughout the course of their degree programs, and special attention should be given to the practical implementation of sustainability goals in their course projects.

Scholarly Implications: In authors' perspective, gaps do exist in the engineering curriculum of universities that can be informed of through more nuanced research in different areas of engineering, such as chemical, civil, electrical, material, computer science, software, and so on. Sustainability in engineering is a broad area and the relevant perspectives of engineers can be explored more by subdividing it into categories such as robotics, automotive industry, automation, aircraft industry, petroleum industry, and so on. It is expected that the implementation of sustainability goals would be very strict in the automotive and airplane manufacturing industries as compared to a software company per se, as a consequence of fuel consumption of cars and airplanes linked directly to the global carbon footprint and pollution. That might provide interesting perspectives about how important sustainability goals are to a particular industry.

Practical Implications: This study hopes to inform practical changes in the engineering curriculum pertaining to sustainability concerns. The findings from engineers clearly indicate a need to immediately address the lack of awareness about sustainability goals in engineering programs. On a larger scale, this study may be utilized to render educational policy makers more aware of the issues regarding sustainability in academia.

4.2 Limitations and Future Directions

This is a qualitative study and the sample size is appropriate, still more participants might affect the findings and conclusions of this study. Moreover, only male participants were inducted in this study. The reason for that is not the researchers' bias toward a specific gender; rather the sampling strategy used which was snowball sampling resulted in male participants referring their same-gender industrial connections and collegues. Thirdly, the issue of sustainability is worldwide, whereas this case study investigates the industry in two countries only. Not purposefully so, but that depicts only one piece in the complex puzzle, and thus the results of this study are not generalizable to all scenarios regarding sustainability. These limitations, however, could be addressed in future studies to include a more inclusive sample and hopefully inform more practical approaches to engineering curricular reforms in terms of sustainability.

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