The Growing Priority of Sustainable Design, and the Engineer's Role in Promoting a Sustainable Future

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Andrew John Kraemer

Spring 2021

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

Advisor

S. Travis Elliott, Department of Engineering and Society

Introduction

When representatives and leaders from 172 nations convened at the 1992 Rio Earth Summit to jointly discuss and debate environmental initiatives and concerns, it represented a momentous shift in global attitude towards sustainability and environmental health (United Nations, 2019). For more than the past hundred years, rapid industrialization and urban development frequently came with little regard for the safety of the planet, with efforts to promote environmental awareness and sustainability limited to non-profits or independent and disjointed measures by individual countries. However, such attitudes have shifted in modern times, as the greater international community has recognized the severe challenges brought about by global climate change, and the drastic and unified measures needed to confront such challenges and embrace a sustainable future (World Federation of Engineering Organizations', 2002). Such evolutions in environmental awareness are promising, but even with new summits and initiatives, climate change continues to negatively progress; 19 of the 20 hottest years of all-time have happened since 2001, many fossil fuel reserves are predicted to expire before 2100, and biodiversity worldwide continues to be irrevocably damaged, with such problems continuing to escalate (Shaftel, 2020; Kuo, 2019). Lost among government agencies, world leaders, and sustainability pioneers, however, are the everyday engineers who play just as vital a role in shifting the world towards a more sustainable future. Sustainable engineering and sustainable design practices are a vital component of any comprehensive plan to effectively combat climate change, and an analysis of the education, tools, and support provided to engineers at every level will highlight the role engineers play in guiding the world sustainably forward. Paradigm shift framing is being applied to focus on the global shift towards environmental concern and sustainable practices, as well as how these changes in attitude manifest in the work and perceptions of engineers. The ongoing shift towards sustainable engineering provides a strong lens to view how engineers fit into a sustainable future, and what role they currently play in helping guide the world towards that future. To thoroughly explore this investigation, the following research question will be addressed: what responsibility do engineers have in guiding the world towards a sustainable future?

Birth of Sustainability

To properly appreciate the importance of sustainability in engineering and industry moving into the future, it is imperative to understand the history that has led to this point. In particular, it is beneficial to understand the origins of the Industrial Revolution, and the fundamental shifts in both practice and mindset that spawned from it. Prior to the rapid industrialization and machination that characterized the late 1700's through 1800's, nearly all energy and capacity to do work came from either people, animals, or burning organic matter such as wood (Brown n.d.). These sources of energy are all limited to some extent, especially in their lack of ability to store large quantities of energy for future use, restricting how much work people were capable of performing. What changed this status quo, however, was the discovery of fossil fuel, namely coal, oil, and natural gas. Fossil fuels such as these could be readily found in substantial quantities, stored in massive volumes, and provided upwards of triple the energy density compared to burning wood (J.M.K.C. Donev et al. 2018). The rapid proliferation of fossil fuels enabled innovations across industry and engineering, from steam engines to electric grids, both revolutionizing society and exponentially expanding humanity's environmental footprint.

In addition to the rise of fossil fuels, the Industrial Revolution also saw sweeping changes to manufacturing and production. With access to new fuel sources and the nearly limitless potential enabled by them, major economies such as the United States, Great Britain, and other European nations began transitioning from agrarian economies to industrial economies, and with this shift came the rise of the factories and mass production (UShistory.org n.d.). Goods that once required skilled craftsman to painstakingly create could now be produced in vast quantities by relatively unskilled labor, meaning factory owners and business owners could produce a massive volume of products in a fraction of the time previously required. This increase in production capabilities and supply was matched by an increase in demand and transportation, as the development and growth of railroads, and later cars and airplanes, allowed for goods to be distributed across the country and internationally (Foundations of Western Culture 2016). With both supply and demand soaring due to innovations brought about by the Industrial Revolution, the conditions were ideal for explosive economic growth and business opportunity.

While the Industrial Revolution certainly benefited society overall, the sheer speed at which it progressed undeniably led to challenges and problems. In regards to this STS analysis, of particular note was the lack environmental concern or regulation as the fields of industry and engineering exploded in growth during and following the Industrial Revolution. As technologies rapidly developed and unprecedented economic opportunities presented themselves, speed was imperative for entrepreneurs to stake their claim. Such ample opportunity inevitably led to intense competition between business owners, inventors, manufacturers, and engineers, and in their haste to ensure they did not miss out on these opportunities, concerns over environmental challenges and long-term sustainability were frequently never even considered (Brown n.d.). As such, prolific industrial and technological growth spawned by the Industrial Revolution have contributed to accelerating numerous serious environmental problems, pressing issues which now must be addressed in force to correct prior and prevent future damages. Over a century of nearly-unregulated industrialization has led to countless hazards, including water contamination and habitat destruction, air pollution and ozone degradation, and resource depletion (Folk 2018). These are all serious and complex challenges, ones with potentially irreparable consequences which must now be addressed with haste to ensure the earth's longevity. Furthermore, these challenges are not the sole responsibility or fault of industrialists and manufacturers, as there are other stakeholders guilty of environmental neglect. Focusing on the United States, there was very minimal national or uniform environmental regulation well into the 1900's, with the first true regulatory agency, the Environmental Protection Agency (EPA), not being founded until 1970 (EPA.gov). This was also around the time period when various nations across the globe began to seriously attempt to address the multitude of environmental challenges grown during the past two centuries, with the very first international summits to discuss and devise unified plans to combat climate change and address sustainability.

Paradigm Shift

To analyze and understand how the global view on and approach to sustainability has changed, a well-suited framework of analysis is the paradigm shift framework. The idea behind the paradigm shift framework was first proposed by philosopher Thomas Khun in his book *The Structure of Scientific Revolutions*, and the core principle of his framework centered on the idea of great shifts in accepted concepts or standards of viewing the world or a particular field (Khun, 1962). These shifts, during which established norms and frames of view are significantly or fundamentally revised and altered by a new understanding in the field, result in a new prevailing paradigm, which serves as the standard moving forward. A classic example of a paradigm shift is the Copernican Revolution; for centuries a geocentric model of the universe had been the consensus "right" view, but through the works of Copernicus and others, this model was challenged and ultimately replaced by the new paradigm of a heliocentric model, which has been the basis for all scientific exercises since (Spencer, 2020). The idea of a paradigm shift is particularly applicable to this STS analysis due to the nature of sustainability. One of the main criticisms of Kuhn's paradigm shift framework is that it can tend to undersell the validity of scientific knowledge, instead subscribing to the mindset that such facts are nothing more than opinions heavily swayed by whatever viewpoint or mindset is most prevalent at that time (Cohen, 2015). However, in analyzing sustainable engineering, it is evident that discussions and debates on sustainable practices is just as centered on people and their mindsets, motivations, and perspectives as it is on scientific knowledge or theory. As much as any new technology or governmental policy, wholesale changes as to how people think and interact with the environment is equally dependent on people themselves changing their mindsets and view on sustainability, and the realm of engineering is no exception.

In order to understand what role and responsibility engineers play in promoting a sustainable future, and how the paradigm shift framework applies to this analysis, it is important to first understand what sustainable engineering is and how it differs from the traditional view of engineering. For the purposes of this investigation, sustainable development will be viewed under the working definition of "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (World Federation of Engineering Organizations', 2002). Such a definition is broad by design, and allows for the full spectrum of sustainability to be analyzed, not simply specific environmentally friendly technologies or practices. This point is key, as a thorough and comprehensive adoption of sustainable development and engineering principles depends on much more than strictly eco-friendly technologies or penalties for causing blatant environmental harm. In contrast to this, traditional engineering has been the status quo since the earliest days of modern engineering. While the tenants of what is considered traditional engineering can understandably vary greatly across different engineering disciplines, there are several over-arching principles which characterize traditional engineering: a focus on a single object or process, solving an immediate problem independently, and a general concern only for the most immediate and local context (Fedkin 2020). What these all have in common is an overall tendency to focus only on the most direct and immediate of deliverables and stakeholders, approaching a given engineering problem essentially in a vacuum with little consideration, whether intentional or incidental, for how that problem and any proposed solution fit into the greater society around it. A high-level comparison between traditional and sustainable engineering can be seen below in Figure 1.

Figure 1: Sustainability Approaches in Engineering (Fedkin 2020)

Traditional Engineering	**Sustainable Engineering**
Considers the object or process	Considers the whole system in which the object or process will be used
Focuses on technical issues	Considers both technical and non-technical issues synergistically
Solves the immediate problem	Strives to solve the problem for the infinite future
Considers the local context	Considers the global context
Assumes others will deal with political, ethical, and societal issues	Acknowledges the need to interact with experts in disciplines related to the problem

Looking at traditional and sustainable engineering side by side, it is readily apparent how the paradigm shift framework is well-suited for this analysis. With traditional engineering being the well-entrenched standard for how engineering problems were handled, a transition to sustainable engineering principles certainly represents a seismic change in mindset and action. That being said, even with the clear dichotomy present between the two schools of engineering practice, there is an argument to be made that to view them as such a polar dichotomy can actually be counterproductive in successfully promoting sustainable engineering (Gagnon et al., 2010). Instead, a more seamless connection and transition between the two schools is vital to ensuring meaningful implementation of sustainable design and engineering principles, an idea which will be explored in more detail as the idea of sustainable engineering is analyzed.

Sustainable Engineering and Society

As can be clearly seen by reviewing the key principles of sustainable engineering, it is a concept which extends well beyond simply an engineering problem. There are numerous different stakeholder and perspectives which must be simultaneously appreciated and addressed in any sustainable design process, a task which is easier said than done. Take a hypothetical Request for Proposal for a new passenger jet delivered to an aerospace engineering firm. The customer would provide an overview of the final aircraft they desire to the engineers, from flight characteristics to cost breakdown and repair life cycle. Under the traditional approach to engineering, the hired engineers would receive the list of deliverables, analyze the best way to address each of those tasks, and systematically address each deliverable to reach a finished product of a functional aircraft design. Considerations would be made insofar as they serve to directly address or support one of those deliverables, with minimal to no regard given to how design decisions impacted stakeholder groups outside the customer.

It is easy to see how, at least on a surface level, sustainability considerations could be included into this design process, such as how much carbon emissions would be produced by the proposed aircraft design. However, in order to fully embrace sustainable design principles, it is imperative that sustainability is incorporated into every stage of the design process, regardless of how much concern is or is not given in the client's initial deliverables list (Eales 2012). Under the new paradigm of sustainable engineering, merely meeting the assigned deliverables of the project and strict economic targets is no longer sufficient, and it is the engineer's duty to understand how each design decision impacts not only the project at hand, but also outside stakeholders and society at large (Eales 2012). This includes obvious markers such as carbon emissions of the aircraft, but also ranges from where the materials for the aircraft are being sourced, how the aircraft will be manufactured and how that process will impact the local environment, and how the implementation of the solution might impact social groups and stakeholders outside of the customer or company contracting the project. Sustainability must be a constant consideration in every step of the design process, not simply a box to be checked upon the completion of the final design, and to ensure that sustainable design and thought process are treated with such importance, it is vital to understand how decisions are made and influenced in an engineering setting. This will enable a deeper understanding into how engineer's themselves think and go about their work, illuminating the engineer's relationship with sustainability.

When considering outside forces which might impact the engineering design process, perhaps the one that most readily comes to mind are economic factors. In a vacuum, it is fair to assume that given two all else equal options, most people would choose the option with the least environmental impact. However, real engineering and decision-making do not happen in a vacuum, and one of the biggest outside drivers for engineers are economic factors. At its most basic, every design decision has an associated cost and opportunity cost attached to it which engineers must weigh. Sticking with the hypothetical passenger aircraft example used earlier, say an engineer is analyzing the engine options for this aircraft, and whether to use two or four engines. There is obviously a monetary cost associated with including four engines rather than two, but choosing two engines may limit the flight range and speed capabilities of the aircraft, while the additional weight from selecting four engines may limit the cargo weight limit of the aircraft. From the earliest preliminary reviews to the final design, engineers must wrestle with a plethora of different economic and financial decisions during the engineering design process, both internal and external.

Economic considerations can often come into conflict with sustainability considerations, whether or not the engineer has any real say in the matter at hand. Green technologies and sustainable design processes all have a variety of costs associated with them, and when those costs exceed or conflict with existing mindsets and priorities from a more traditional view on engineering, it can be challenging for the engineer to ensure sustainable goals are met, regardless of his or her wishes. A particular client may be skeptical that the merits of a sustainability-driven decision outweigh the additional upfront financial costs to the company, or a boss may be desperate to meet shareholder economic goals and decide to skirt on environmental provisions to meet those targets. Cases such as these may be beyond the engineer’s direct control, which is why it is imperative that engineers and decision makers at all levels buy into prioritization of sustainable design principles.

While scenarios such as those above may give the impression that economic factors can only serve to hinder the engineer and adopting sustainability, this is far from the case. In fact, economic goals and design metrics can serve as a powerful tool to encourage sustainable design, both as encouragement and as discouragement (Franz et al, 2013). Fears of economic losses and profit margins may cause decision-makers to hesitate in embracing sustainability, but by the same token, financial incentives and sustainability-driven design and performance metrics can serve as a vital incentive to encourage sustainable design practices. It is one thing for an engineer to simply approach a design team or boss with sustainability concerns for the good of the environment or human society at large, but when those pleas are accompanied by financial data and economic frameworks which support and reward sustainable design, it can make the pitch that much more powerful (Franz et al, 2013). In this sense, under the new paradigm of sustainable engineering, the engineer's responsibility has grown to having an understanding of the economics that intertwine with the technical knowledge of the job, and being willing and able to leverage that understanding both in the design lab and when consulting with clients.

Similarly, economic sanctions and penalties can serve as incentives encouraging sustainable design and thinking. If the engineer is unable to persuade cohorts or clients to actively embrace sustainability, it may at least be possible to dissuade recklessly dangerous decision-making through the risk of penalties, whether they be financial or reputational in nature. There are numerous case studies which can be used in such a manner, serving of examples engineers can use to show the dangers of disregarding sustainable and environmentally friendly design considerations. One recent case which perfectly demonstrates this is the Volkswagen Emissions Scandal. In this scandal, automobile manufacture Volkswagen deliberately installed software in hundreds of thousands of their vehicles in order to "cheat" on environmental emissions standards testing (MacDuffe 2019). This software detected when the automobile was in a testing environment, and curtailed the vehicle's emissions to meet EPA diesel standards during tests. However, once finished testing and on the road in a regular driving environment, those vehicles would revert to producing emissions several times over the legal limit. Once this scandal was exposed and came to the public light, Volkswagen not only suffered financial sanctions directly related to the violated EPA and international standards, but also saw its public reputation take a major hit, as environmental activist groups and a variety of other stakeholders expressed outrage towards the company (MacDuffe 2019). There are situations where mandates to act in an environmentally damaging or even dubious manner may come from way above the typical engineer in the company hierarchy, and it is unrealistic to assume a lone engineers or group of engineers will be able to always persuade or go against their superiors in such a situation, but cases such as this are yet another tool to demonstrate the risks that a company or executive could face should they not take sustainability seriously in their work.

Thus far, most of the analysis has worked under the assumption that the average engineer is willing and eager to wholeheartedly embrace and promote sustainability in their work and the design process. However, this is far from a given, and a topic worthy of further investigation. To what extent engineers embrace sustainable engineering principles in their work is majorly influenced by both the education they receive and the societal culture they live within. An engineer could have all the necessary tools to fulfill their role and promote sustainable design in all their projects, but all that is for naught if the engineer has no personal motivation to embrace the challenges brought on by sustainable engineering (McIsaac and Morey, 1998). The upbringing of an engineer is paramount in instilling sustainability-driven values in young aspiring engineers, and this can be where numerous stakeholders play a pivotal role in empowering engineers to value sustainability.

A natural place to begin are universities and technical schools, where every year thousands upon thousands of young engineers and professionals receive the educations that serve as the foundations for the rest of their professional careers (Mulder et al, 2012). The education received at these institutions are instrumental in forming an engineer's perspective and work principles, so they are naturally a topic of keen interest when analyzing how best to prepare engineers to adopt sustainable design philosophies. As much as any engineer has the responsibility to implement sustainable design in their career and future projects, such stakeholders have an equally important responsibility to give engineers the tools, perspective, and environment needed to encourage and promote the importance of sustainability. This responsibility extends well beyond the classroom or office, as broad influences such as culture and ingrained societal norms can be equally if not more instrumental in how a person's perspective on the world develops (McIsaac and Morey, 1998). Thus, ensuring a strong societal and cultural basis which values and mandates sustainability and environmental accountability is paramount, and can be viewed as the responsibility of outside stakeholders to the engineer, such that the engineer in turn is able to perform his or her duty in championing sustainable. Even so, there are still efforts engineers can make in promoting sustainable design amongst colleagues and fellow engineers, both in academic settings and in the workplace, in order to keep sustainability at the forefront of discussion.

Why Sustainability Matters

This analysis has explored how sustainable design and has come to the forefront of engineering, and what factors and stakeholders influence the engineer and his or her ability to contribute towards a sustainable future. For some, what this analysis has skipped is an answer to the simple question of "Why does sustainability matter?" Certainly, there are people who see little to nothing wrong with what the status quo has been since the early days of the Industrial Revolution, or who believe that dire predictions about the impending environmental doom of planet earth are vastly overblown, and see little reason to so adamantly and comprehensively embrace sustainable engineering. As sentiments and public perceptions have shifted, the new paradigm of sustainability is one that encompasses far more than simply going green to save nature. Yes, concern over the well-being of the planet now and for future generations is a key driver for sustainability, and doing one's part to ensure that people will be able to safely and healthily continue to enjoy earth is sufficient motivation for many. Now, however, sustainability is an economic problem and a political challenge in addition to an environmental one. People care more about who they buy products and form relationships with, as well as how those companies present themselves and act. Expanding environmental regulations and sustainability-driven policies not only encourage and benefit those who actively embrace sustainability, but can actively hurt those who intentionally flaunt environmental responsibilities. As this new paradigm continues to solidify as the new norm, so too does the prevalence and significance of sustainable engineering and design process, and companies and executives who deliberately try to oppose this will likely suffer for it, whether financially or reputationally. Rather than be dragged along while stubbornly resisting or be left behind altogether, it can be far more advantageous to adopt a proactive mindset towards sustainability, and to offer whatever aid or support possible to engineers working to adapt sustainable engineering themselves. To expect engineers to embrace sustainable design in their work is one thing, but to expect them to also create the foundation and society which demands such is unreasonable, and this "buy-in" from all parties involved is the next great paradigm shift needed to truly maximize sustainable engineering. Engineers certainly have a major responsibility in designing a sustainable future, but it is not their burden to carry alone.

Works Cited

Brown, Cynthia (n.d.). The Industrial Revolution. Retrieved February 22, 2021, from https://www.khanacademy.org/humanities/big-history-project/acceleration/bhp-acceleration/a/the-industrial-revolution

Cohen, Martin (2015). *Paradigm Shift: How Expert Opinions Keep Changing on Life*, *the Universe, and Everything*. Imprint Academic.

Eales, A. (2012). 1.7: The Engineer's Role in Sustainability. Retrieved October 13, 2020, from https://rdmc.nottingham.ac.uk/bitstream/handle/internal/112/Engineering%20Sustailability/17_the_engineers_role_in_sustainability.html

Fedkin, M. (2020). 1.4 Principles of Sustainable Engineering. Retrieved October 13, 2020, from https://www.e-education.psu.edu/eme807/node/688

Foundations of Western Culture (2016). The Railroad's Effect on Time and Distance. Retrieved March 5 2021, from http://foundations.uwgb.org/railroads-time-distance/#:~:text=The%20railway%20allowed%20people%20to,travel%20newer%20places%20as%20well.&text=Business%20boomed%20due%20to%20the,especially%20in%20time%20and%20distance.

Folk, Emily (2018, September 17). Environmental Impacts of Industrialization. Retrieved March 2, 2021, from https://www.ecomena.org/environmental-impacts-of-industrialization/

Franz, K., Risse, K., & Stumpf, E. (2013). *Framework for Sustainability-Driven Aircraft Design* (Rep.). Los Angeles, CA: AIAA. Retrieved October 14, 2020, from https://arc-aiaa-org.proxy01.its.virginia.edu/doi/10.2514/6.2013-4393.

Gagnon, B., Leduc, R., & Savard, L. (2010). "From a conventional to a sustainable engineering design process: different shades of sustainability," Cahiers de recherche 10-09, Departement d'Economique de l'École de gestion à l'Université de Sherbrooke.

https://ideas.repec.org/p/shr/wpaper/10-09.html

J.M.K.C. Donev et al. (2018). Energy Education - Energy density. Retrieved March 9, 2021, from https://energyeducation.ca/encyclopedia/Energy_density.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. Chicago, IL: The University of Chicago Press.

Kuo, G. (2019, May 23). When Fossil Fuels Run Out, What Then? Retrieved October 26, 2020, from https://mahb.stanford.edu/library-item/fossil-fuels-run/

Lewis, Jack (1985, November). The Birth of the EPA. Retrieved March 1, 2021 from https://archive.epa.gov/epa/aboutepa/birth-epa.html#:~:text=The%20official%20birthday%20of%20EPA,rampant%20and%20highly%20visible%20pollution.

MacDuffie, J. (2019, March 21). Why the Volkswagen Diesel Scandal Hasn't Gone Away. Retrieved October 12, 2020, from https://knowledge.wharton.upenn.edu/article/volkswagen-diesel-scandal/

McIsaac, G. F., & Morey, N. C. (1998). Engineers' Role in Sustainable Development: Considering Cultural Dynamics. *Journal of Professional Issues in Engineering Education and Practice*, 110-119. Retrieved October 10, 2020, from https://ascelibrary.org/doi/pdf/10.1061/%28ASCE%291052-3928%281998%29124%3A4%28110%29

Mulder, K.F., Segalàs, J. and Ferrer-Balas, D. (2012), "How to educate engineers for/in sustainable development: Ten years of discussion, remaining challenges", *International Journal of Sustainability in Higher Education*, Vol. 13 No. 3, pp. 211-218. https://www.emerald.com/insight/content/doi/10.1108/14676371211242535/full/html

PBS (n.d.). Who Made America? – Samuel Slater. Retrieved March 2, 2021, from https://www.pbs.org/wgbh/theymadeamerica/whomade/slater_hi.html

Shaftel, H. (2020, July 16). Global Temperature. Retrieved October 26, 2020, from https://climate.nasa.gov/vital-signs/global-temperature/

Spencer, J. (2020, June 24). Copernican Revolution. Retrieved October 25, 2020, from https://www.britannica.com/topic/Copernican-Revolution

United Nations. (2019). United Nations Conference on Environment and Development (UNCED), Earth Summit. Retrieved December 02, 2020, from https://sustainabledevelopment.un.org/milestones/unced

UN Educational, Scientific, and Cultural Organization. (2020, March 3). Do engineers have the right tools to meet the UN Sustainable Development Goals? Retrieved October 14, 2020, from https://worldengineeringday.net/do-engineers-have-the-right-tools-to-meet-the-un-sustainable-development-goals/

UShistory.org (n.d.). Economic Growth and the Early Industrial Revolution. Retrieved February 27, 2021 from https://www.ushistory.org/us/22a.asp

World Federation of Engineering Organizations'. (2002, August). *Engineers and Sustainable Development* (Rep.). Retrieved October 11, 2020, from file:///C:/Users/Student/Downloads/2.pdf