A University of Virginia Themed Pinball Machine

(Technical Project)

The Right to Repair Movement and its Environmental Impacts

(STS Research Paper)

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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

Technical Report

For my technical project, I will be a member of a team constructing a UVA themed pinball machine. Upon its completion, we plan to install the pinball machine in the student lounge area of 1515 for UVA students to use and enjoy. The machine is home to a plethora of motors, solenoids, microcontrollers, LED arrays, and digital displays. With its complex construction, moving components, many mechanisms, and microcontroller code, it will be incredibly important to consider its repairability for future engineers. With many of the machine's mechanisms being the team members first attempts at design, the likelihood that future repair work will be necessary is high. Because of this, repair-conscious engineering will be incredibly important.

STS Research Paper

The importance of repair-conscious engineering is ever growing in the age of right to repair laws. With the addition of microcontrollers and complex electronics to common consumer devices, the topic of repairability has been spotlighted. Corporations have traded replaceable and repairable components for single-use and proprietary technology often in favor of profits. As claimed by Aaron Perzanowski in chapter one of his book *The Right to Repair,* "if consumers were more aware of these environmental and human costs, some may be more likely to repair a damaged device," (Perzanowski, 2022). The lack of consumer repairability in modern electronics has been detrimental for its growing carbon footprint and financial impact on consumers. In my STS research paper, I plan to explore the extent that the lack of repairability in modern

electronics has on the environment and consumers as well as the technologies and policies in place serving to mitigate these impacts.

I will analyze this topic through the STS framework of the Social Construction of Technology which views technologies not solely as the result of scientific progress, but instead as the product of social, political, and scientific progress. By using this framework, I will be able to highlight topics such as how the rise in demand for semiconductors has been incredibly taxing on the environment and commanded social and political movements to amend its impact. Additionally, new technologies failing to accommodate for affordable or even possible consumer repair have skyrocketed the amount of e-waste generated annually. This has called for action to be taken regarding the disposal and recyclability of used electronics as well as repairs to extend a products lifespan. Finally, this framework will help me highlight the financial burden that stripping repairability from devices has on the end consumer.

Technical Project – Creating a UVA Themed Pinball Machine for 1515's Student Lounge

For my technical project, I will be a part of a team planning to complete a UVA themed pinball machine. Its design consists of many complex mechatronic systems. In its current state, the frame, playfield, some mechanical components, and general game ideas are already created. The machine was the subject of a previous capstone project from approximately seven years ago. Despite the progress at this point, there are many systems that need optimized or completely reworked. The machine is currently unplayable and many of the mechanical components are not functional. Additionally, with advancements in microcontroller and display technology, many of the electronic components of the game need modernization.

One specific area of improvement is with the solenoids that control the movement of the flippers. Solenoids are inherently inefficient. Requiring huge amperage to initially pull their plunger into the wire core, they are very wasteful of energy. Additionally, the large coils of wire necessary to generate the magnetic field are heavy and add unwanted bulk to the machine. These problems were observed by the previous group of engineers constructing this pinball machine. In search of a remedy, the group turned to modern lightweight and energy efficient solenoids to control the flippers. Unfortunately, these solenoids do not generate enough torque to properly launch the pinball. We plan to return to older, less efficient but more powerful solenoids and design a proper mounting mechanism for them. To achieve this, we will design a coil winding system and a 3D printed spool to be able to create our own solenoids.

Additionally, there is a lot of digital aesthetic work that needs to be completed in the design. There are many instances of LED's being integrated throughout the machine that need microcontroller code to become operable. Another huge hurdle to overcome is the addition of screens to serve as targets. These screens need to be able to vertically raise and lower throughout the game while also being durable enough to survive being hit by the steel ball. These screens provide a place for variable artwork to match the current theme of the game. With the intention of having the players score progress them through the four years of undergrad and then various stages of careers, customizable screens serve as a spot for aesthetic design.

Finally, a solution for removing the top glass and hinging the playfield must be developed for repair purposes. Similar to the hood of a car, pinball machine playfields typically hinge at the back and can be propped up to access and repair their electronics and mechanical components. This will be incredibly important to design as the underlying components of the playfield will need to be accessed frequently throughout its construction.

I feel as though this project serves as a place where repair-conscious design must be considered. Pinball repair has been a profession since pinballs conception due to the mechanical nature of the game. In a VICE interview with New York City pinball repair technicians, one technician stated, “They [pinball machines] were only built to last five years. They were built to suck the quarters out of people’s pockets and then get tossed” (Koebler, 2018). Clearly, pinball machines are not built to last forever. It would be irrational to think that nothing on our pinball machine would break years down the line. As the project will be left on display for public use, it will most certainly need some repairs and upgrades throughout its life. It will be important to consider how future engineers will be able to access and modify our creation.

STS Project – The Importance of The Right to Repair for Consumers and the Planet

Repair is an inherent aspect of mechanical systems. Over time, the technology around us degrades and needs repair. In recent years, the accessibility and ability to repair many consumer electronics seems to have been exchanged for company profits. Repair manuals have been proprietary and controlled through copyright laws limiting them only to those who pay for the ability to access them (Wiens, 2013). Not only is this damaging to the end consumers’ overall repair costs, it also incentives replacing damaged or outdated products with their newest releases instead of promoting device repair and reuse. This has been incredibly detrimental for waste management as e-waste has become the “fastest-growing component of the municipal waste stream in the country” (Meidl, 2023). By replacing instead of repairing, outdated and damaged devices will continue to contribute to the growing e-waste problem. The lack of repairability is becoming evident in the staggering amount of e-waste generated worldwide. The United Nations 2020 Global E-waste Monitor noted that e-waste generation increased 21% in the last five years

(Forti, 2020). Without changing the typical electronic device's lifespan through increased repairability, the environment will continue to suffer.

This issue is one that has been presented to the United States Congress. In 2022, Nathan Proctor, head of the Right to Repair campaigns for the Public Interest Research Group, stood before Congress to deliver his insight on the topic. Proctor claimed, "disposable electronics are incompatible with a livable planet. A phone takes about 122 pounds of carbon to make, mostly from mining and smelting the components" (United States Congress, 2022). A huge portion of this carbon footprint is the result of producing the semiconductors needed for modern electronics. The demand for this technology is commanding serious social and political change. If new device production was decreased and repairability and reuse were promoted, there could be a reduction in the growing carbon footprint.

This sentiment is shared by Pádraig Belton, journalist for The Guardian, in his article highlighting the semiconductor industry's growing carbon footprint. He claims the industry is paradoxical in that "meeting climate goals will, in part, rely on semiconductors," but "chip manufacturing also contributes to the climate crisis" (Belton, 2021). Belton noted that in 2020, the Taiwan Semiconductor Manufacturing Company used "almost 5% of all of Taiwan's electricity" (Belton 2021). Greenpeace, an independent environmental activist organization, predicts that "semiconductor manufacturing is projected to consume 237 terawatt hours of electricity globally by 2030, roughly equivalent to Australia's 2021 electricity consumption" (Greenpeace, 2023). The semiconductor industry is clearly posing serious threats to the environment. Without addressing these issues, we risk irreparable damage to the Earth's climate. By increasing device lifespan and improving consumer right to repair, the demand for

semiconductor manufacturing will drop. Through increased repairability, the strain the semiconductor has been putting on the environment can be somewhat alleviated.

Beyond just environmental impacts, the right to repair has strong economic impacts as well. In Nathan Proctor's speech before Congress, he noted that increasing the ability to repair would "save the average household about $330 per year, which totals $40 billion across the country" (United States Congress, 2022). Despite these facts, many major corporations refuse to make their products repairable. Aaron Perzanowski notes this in his book *The Right to Repair* where he claims, "Accessible, affordable repair presents a threat to the business models of companies that manufacture and sell consumer goods by the billions," (Perzanowski, 2022). Inherently, repair mitigates the consumers need to purchase replacement or new products. This directly contradicts the business models of corporations relying on mass product sales.

Apple, a company selling goods by the billions, relies on consumers replacing phones upon physical damage and upgrading devices yearly. In a letter from Tim Cook, Apple's CEO, to investors, he notes, "While macroeconomic challenges in some markets were a key contributor to this trend [of lower than anticipated iPhone revenue], we believe there are other factors broadly impacting our iPhone performance," including "some customers taking advantage of significantly reduced pricing for iPhone battery replacements" (Cook, 2019). With the CEO of the largest company in the world actively frowning upon the consumer benefits of the new Apple battery replacement program, it becomes clear that repair is not a target of some CEO and investor priorities. Shannon Liao, a technology and culture writer for The Verge, claims in her article about Tim Cook's letter that "in 2018, many of the less pleasant quality of life issues for older iPhone models disappeared, and that may have meant people's main reasons for upgrading to a new phone also vanished," (Liao, 2019). The barriers to repair such as cost and accessibility

were removed, and consumers benefitted financially. By striving to implement policy to increase the right to repair devices and device reusability

There are various theories and solutions proposed to help aid these environmental and economic issues. In a study published in the *Journal of Cleaner Production,* researchers suggested promoting "a CE Repair Society, one in which repair is a cost-effective, convenient, and mainstream activity," (Svensson-Hoglund et. al., 2021). They continue this sentiment by claiming "an upscale with the objective to liberalize the aftermarket through equitable competition is believed to enable more opportunities for consumers to repair," (Svensson-Hoglund et. al., 2021). By allowing repair shops to monetize and compete for repair of consumer products, consumers benefit, and jobs are created. Additionally, this would assist in reducing the compounding e-waste issue as consumers would use their devices for longer periods of time before replacing them.

Finally, there have been advancements from the Environmental Protection Agency (EPA) researchers in understanding the movement of e-waste from consumers to landfills. The EPI has produced the Alternative Disposition of Electronics Planning Tool (ADEPT), "a modeling tool that uses electronics purchasing data to estimate the composition and quantity of electronic materials designated as waste or reuse," (US EPA, 2021). This tool assists landfills in predicting the amount of e-waste they will receive to be able to prepare that waste for recycling. The EPA notes that "e-waste products may contain valuable materials, such as gold, copper and nickel, and rare materials of strategic value such as indium and palladium," (US EPA, 2021), which can often be recovered, recycled, and reused. There also many toxic components of e-waste that require more sophisticated disposal. ADEPT would assist landfills in tracking all this information. While there are clearly advancements in managing the staggering e-waste problem,

repairability serves to keep these devices out of landfills in the first place. By continuing to advocate for the right to repair and keeping devices repairable, we can work to slow the e-waste growth.

Conclusion

By better understanding the incredible impact that removing repairability from devices has on the environment and the economy, engineers and CEO's must be influenced to return repairability to consumer products. Without change, the issues of e-waste, energy consumption, and consumer financial burden will continue to grow. As will be explored through the STS framework of the social construction of technology, the technological advancements of modern electronics and the resultant demand for semiconductors has spawned a litany of social and political movements to lessen their environmental and economic impacts. The importance of repair-conscious engineering is growing simultaneously with the threats impending on the environment. It is our job as engineers to consider the impacts our designs have on consumers and the global environment at large.

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