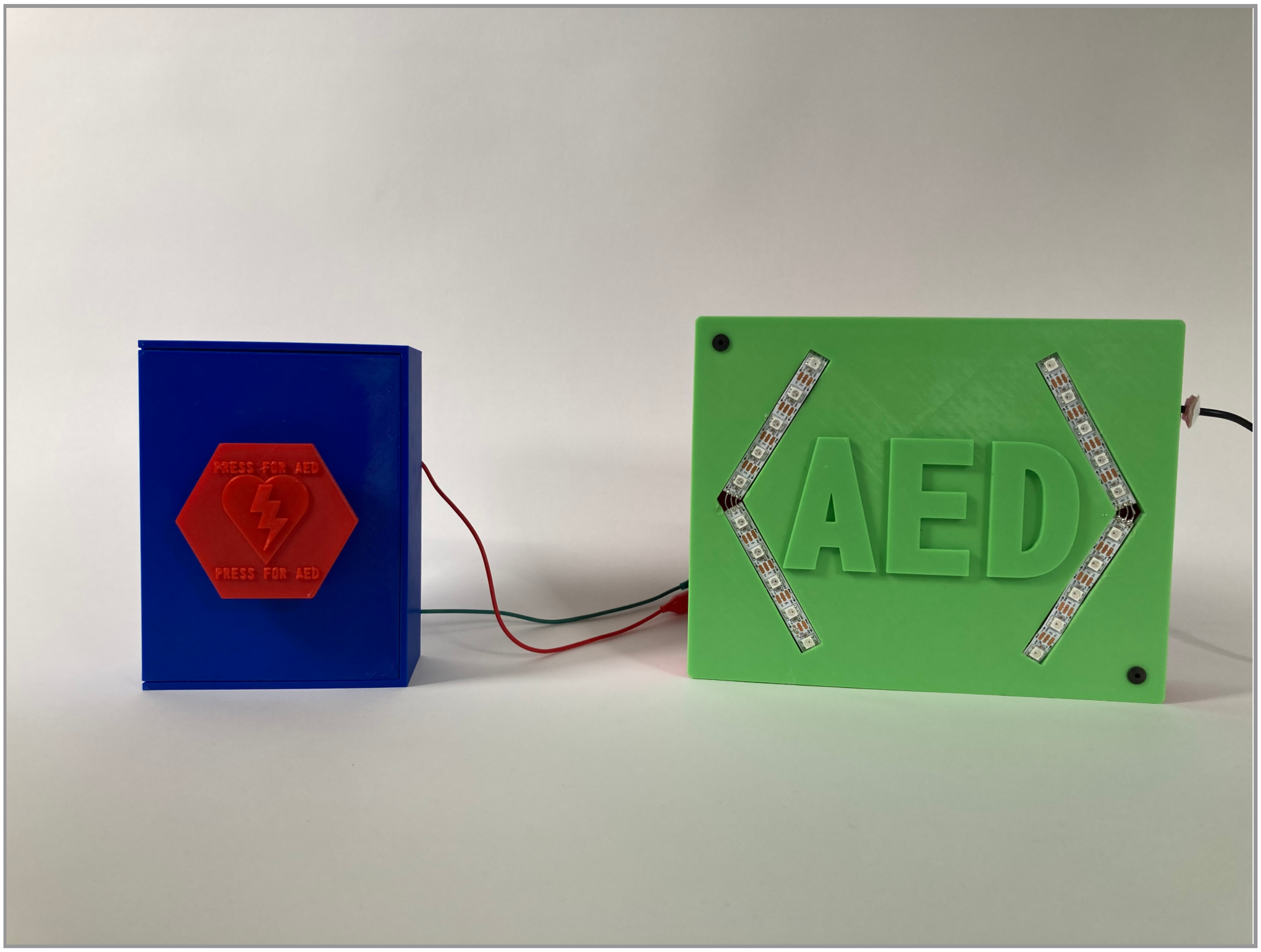
AED Retrieval System

Final Report

ENGS 21 Group 6
Colin Braun
Daniel Ellison
Gavin Burns



Executive Summary

Over 350,000 Americans suffer an out-of-hospital cardiac arrest each year (CDC). While AEDs significantly increase survival rates if quickly applied, all too often the location of an AED is poorly marked leading to significantly increased retrieval times. Even here at Thayer, initial baseline testing revealed a general inability to quickly retrieve an AED even when testers were located in its immediate vicinity.

To solve this problem, we created a modular smart wireless directional sign system after carefully considering multiple alternatives. Once activated by a press of a button, which is attached to every sign, the signs activate their bright LED arrows to direct the user to the closest AED determined via a path-finding algorithm. Additionally a flashing siren on the AED cabinet turns on. Once the user (or other bystander) opens the AED cabinet, a magnetic break switch detects the action and the sign arrows reverse, leading back to the call scene. Once the emergency has been handled, pressing the call button again will return the system to its idle state. This system will thus decrease the retrieval time by eliminating the guesswork of finding an AED and cutting retrieval time should someone already be near the AED at the time of the call. Additionally, it can serve to help bring others (such as paramedics) to the emergency scene who may be able to further assist.

Users of our product would be any bystander in the event of a cardiac emergency. Emergency services take a minimum of five minutes to respond to a call, which falls outside of the three-minute window to administer an AED. Thus, bystanders are a victim's best chance to be administered an AED in time, and our system seeks to help any person easily locate one. Purchasers of our product would be any large institution with publicly available AEDs looking to make them more accessible. Systems would be installed on a price-per-square-foot basis, with other revenue coming from continued maintenance of systems. Costs include parts, outsourcing production, and human resources.

We came up with this solution by first looking into current state of the art products. These include AED alarms and mobile apps that all work to source external help and cut down on overall retrieval times. Although flawed, we saw what each of these products hoped to accomplish and tried to approach their solutions from an alternative angle.

We further refined our product by evaluating and reducing its environmental impact. We began by closely examining our current prototype and rating its environmental impact. Afterwards, we worked to fix our high-impact areas through materials and process research. Next, we devised a program to potentially save costs and reduce our overall wastes. We then reevaluated our new product and questioned what further advances we could make.

Through testing, we found our prototype to be power efficient, draining less than half a Watt per sign, meeting our energy efficiency specification. The software scaled well on installations up to 10,000 signs. The product also met our specifications for legality, safety, and ethical use, as well as our affordability criteria with each sign using less than $9 dollars of materials. Pricing did not include the Raspberry Pi microcontrollers, which are simply being

used for the prototype phase and would be replaced with much cheaper custom controllers in production.

Problem & User

Each year in the United States over 350,000 Americans suffer from an out-of-hospital cardiac arrest with overall survival rates less than 12% (CDC, AHA). Use of Automated External Defibrillators (AED) can significantly raise chances of survival up to 38% but is highly time-sensitive (Weisfeldt and et. al., AHA). AED should be applied within 3 minutes of the incident with each additional minute lowering the survival rate by 7 to 10% (AHA). **However, AED locations are often poorly marked, significantly increasing retrieval times.** Studies show that less than 22% of the surveyed public are able to locate an AED (Smith and et. al.). Further surveying conducted by the American Heart Association in conjunction with Edelman Intelligence found that over 50% of employees across industries did not know the location of AEDs in their workplace (Edelman Intelligence).

According to interviews conducted with members of Dartmouth's Emergency Medical Service team, their minimum response time to an incident is five minutes, while Hanover Fire Department takes between 10-15 minutes to respond. Both of these times are the best-case scenario and still far exceed the three-minute window for addressing cardiac incidents. As a result, bystanders of cardiac incidents are a victim's best chance of being administered an AED within the ideal time window. Using an AED does not require certification and AEDs provide step-by-step audio instruction, so the one of the largest remaining barriers to AED administration is finding the AED itself.

We are initially focusing on the workplace setting with the users including employees and students. Primary purchasers are institutions seeking to enhance AED accessibility in their buildings again with an initial focus on schools and universities. Although younger people are at low risk for sudden cardiac incidents, a school's faculty and staff as well as adults attending school events can still be at high risk. We hope to eventually extend to other indoor facilities such as hotels, sports stadiums, and casinos where there is a higher probability of cardiac incidents. These locations in particular host visitors who are not familiar with the building layout and the locations of AEDs.

State of the Art

When our group began this project, we first looked into existing solutions to see different approaches to this problem. There was no system that was marketed to cut down on AED retrieval times, but there were some products that highlighted AED locations. These mostly included AED signs that bore the typical AED symbol (a heart with a lighting bolt running through it) and arrow stickers that gave vague directions to the nearest AED. In this search we did happen upon two promising systems that worked to both bring in bystanders' help and cut retrieval times.

This first line of products were AED cabinet alarms that could be installed on or near AEDs. These alarms would activate after a cabinet was opened, creating an alerting noise and a flashing light sequence to notify surrounding persons that an AED has been retrieved. This system does a great job at alerting bystanders of an emergency but does little to actually direct its user to the AED.

The other system we found was the *PulsePoint* application for mobile devices. This system gave its user the ability to notify emergency services and other surrounding users that an AED is needed in the area. This system is effective in how it directly alerts people who may be closer to the AED than the actual requester. This can greatly reduce AED retrieval times and alert essential personnel at the press of a button. However, this system is only as strong as the community that uses it. If someone requests an AED from the app and there are no other users in the area, then their alert will not reach anyone. Likewise, there are many places in the US that are not supported by this application. This means that using the app in those areas does not even alert the necessary emergency services.

Despite their downfalls, we did find that these state of the art products offered a great amount of insight into how other people have gone about solving this problem. With this information we can work to brainstorm our own solution and attempt to create an even greater state of the art.

Specifications

From what we've learned with the current state of the arts and from what users and purchasers might anticipate from our product, we assembled a list of specifications that we would strive to design around. The foremost goal of our system is to speed up the process of finding and delivering an AED to a medical event. Since our system directly interacts with the user (via lights, noise, notifications, etc.), it is important to focus on an intuitive and accessible system for its users. This means that our device can be used and understood by nearly all persons, even in circumstances that limit the senses, like crowds or loud spaces. Additionally, to make our product a staple of public areas we must convince buyers to make a commitment to our system. Our system must therefore represent a long-term, affordable solution that is within the law. The first step in that direction is making sure our product is energy efficient during its lifetime. Furthermore, our solution must be environmentally sustainable to reduce further destruction and pollution of the environment.

Specification	Justification	Quantification	Test
Legal	It must not be illegal or a legal liability	Copyright laws Building Violations	Review NH AED and building laws
Safe	It must not be dangerous to use	Complete safety when in use	Survey tests

Ethical	It must be morally unambiguous to use	No one should hesitate to use our system. We should not cause it to take longer to find an AED using our system	Is it ethical? [Y/N]
Noticeable	Directions must be easily identified and understood	Spottable from across Atrium hallway	Test runs and student surveys
Energy Efficiency	Low power consumption to increase product's lifetime	≤44kWhrs per year (power consumption of Exit signs)	Power tests P = I*V
Sustainable	Our product should not pose a significant threat to the environment nor should it add to the pollution problem	<1 impact point/hr	Okala impact survey and material research
Affordable	It must be within the budget of public institutions	Cost less than purchasing additional AEDs (<$1000)	Part lists and cost tables/market research

Table 1: Specification List

Problem Solving

With our specifications defined, we began detailing potential solutions to the need. Our group decided on our top solutions which are represented in the table below. Brief descriptions of the alternatives are as follows:

Phone Signalling: When triggered, phones with proximity to the medical event will receive an alert to retrieve an AED.

Call Location AED Display: A display near the AED will indicate where an AED has been requested so a bystander could expedite retrieval by bringing an AED to the scene..

Noise/Light Locationing Alarm: AEDs will utilize sound localization and flashing lights to help navigate responders to their location.

AED Retrieval Robot: A robot that will bring the AED to the specified location.

Increased AED Placement: Placing more AEDs in the building.

Smart Bi-directional Signage: Signage will direct the user to the nearest AED. Once the AED is removed (either by the original user or another bystander), the signage will switch direction and direct back to the scene.

Directional Stickers: Traditional stickers (ubiquitous because COVID) that show the direction to an AED. For instance: arrows or footprints.

Specification	Legal	Ethical	Safe	Intuitive	Energy Efficient	Sustainable	Affordable	Sum
Weight	Y/N	Y/N	Y/N	x4	x2	x2	x3	
Phone Signalling (Amber Alert)	N	Y	Y	3	4	5	5	45
Call Location AED Display	Y	Y	Y	5	3	2	3	39
Noise/Light Locationing Alarm	Y	Y	Y	3	4	3	4	38
AED Retrieval Robot	Y	Y	Y	3	2	3	1	25
Increased AED Placement	Y	Y	Y	4	4	4	1	35
Smart Bi-Directional Signage	**Y**	**Y**	**Y**	**5**	**4**	**4**	**4**	**48**
Directional Stickers	Y	Y	Y	3	5	3	5	43

Table 2: Alternatives matrix

Looking at our solution matrix we can see the clear winner is the Smart Bi-directional Signage. This solution offers an intuitive method of guiding a requester or bystanders towards the closest AED and then back to the medical event. Likewise, this solution is also one of the most accessible ideas, as it will be easily visible in crowded, dark, or loud scenarios.

Additionally, following initial in-person surveying and interviews, it was revealed that there is a general lack of awareness of AED locations: more than 63% of respondents did not know the location of the closest AED. Timed retrieval trials show over a quarter of respondents taking over a minute to locate an AED and over 18% taking more than two minutes. These results are particularly concerning as the surveys, interviews, and time trials occurred within just 30 feet of an AED. Such prime location is unlikely to be replicated in an emergency and AEDs become increasingly difficult to find with distance. Respondents reported difficulty arising from the coloring of the AED box (prototype was white, users expected red), poor line of sight, and lack of prior knowledge. These results indicate that locating an AED is a real issue, even when a user is directly adjacent to one, and emphasize the importance of making our system as intuitive as possible.

Prototype & Implementation

We approached this problem by creating modular signs with LED arrows and multiple mounting options. When the signs are placed at hallway intersections and networked together, they can guide a user along the shortest path to an AED. In addition we designed a siren and magnetic break sensor system to be placed on an AED cabinet that flashes when the system is activated, and when the cabinet is opened, the signage reverses back to the incident. Thus, anyone who sees the active system can retrieve the AED and be guided back to the incident. Provided that people are present at the time of the incident, this system has the ability to cut retrieval time in half. The system is activated by pressing a prominent button that is wired to each of the signs. Each sign and cabinet is connected to a Raspberry Pi 0 W for computational power and networking. Schematics for the components are shown below:

Cabinet Circuit　　　　　　　　Sign Circuit

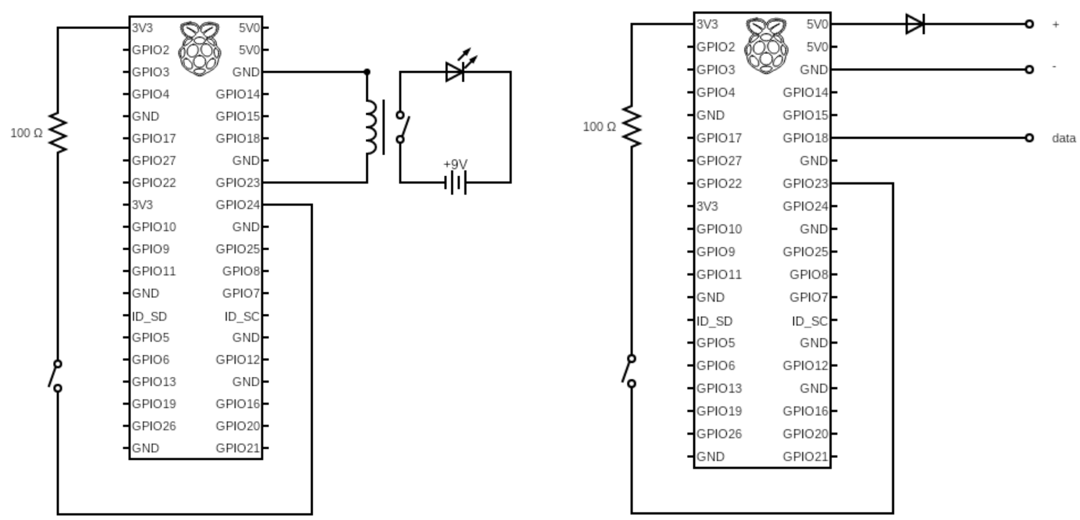


Figure 1: Circuit schematics for the cabinet and sign components. Wireless connectivity is built into the Raspberry Pi 0 W's. The three nodes coming out of the sign circuit are connected to the NeoPixel LED light strips on the signs.

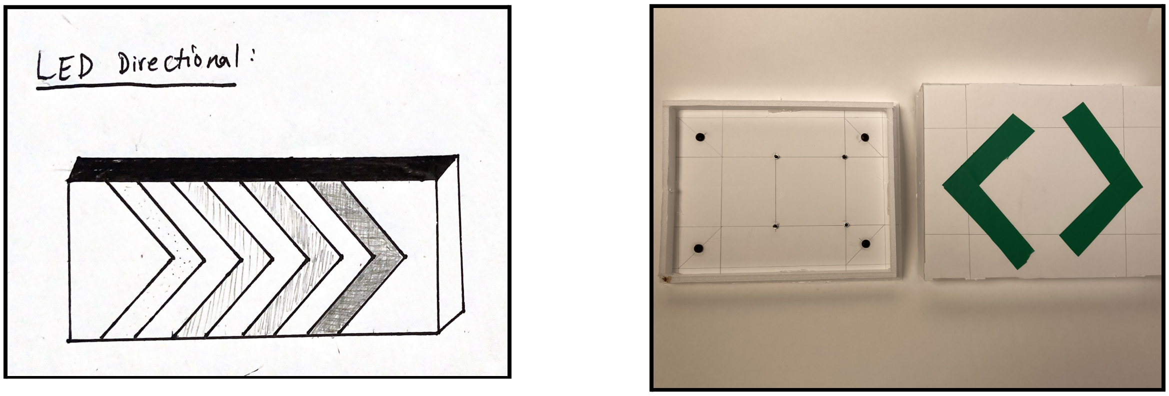


Figure 2: An early concept drawing of the sign and subsequent foam board mockup.

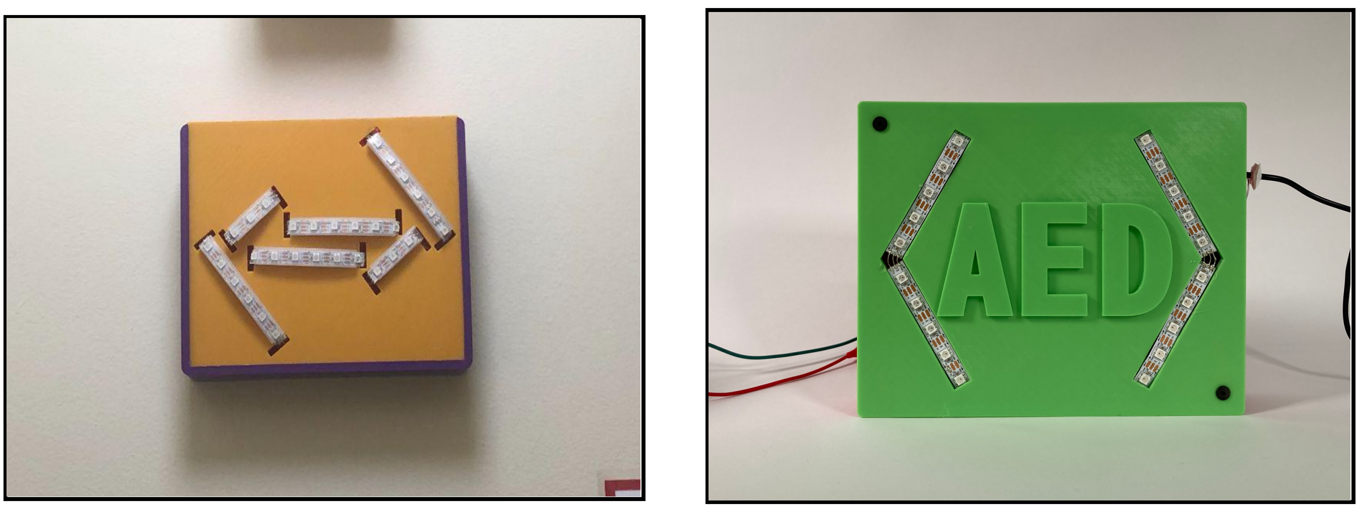
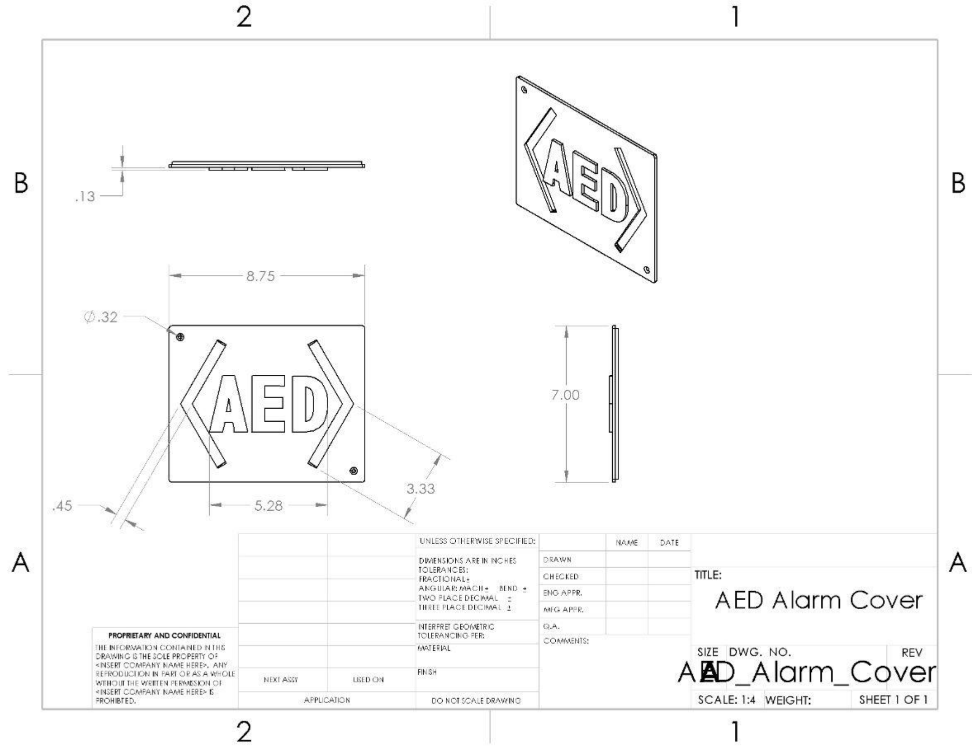


Figure 3: Left: First working prototype with LED strips. Right: Final prototype with wireless connectivity. Note AED subsequently made white to further increase contrast.

Since this system is modular, we wanted to make the signs as adaptable as possible. The signs come in various configurations, with the sign frame being at the core. The frame has mounting holes on the top and side to allow for a ceiling or perpendicular wall mount. 2 faces can then be mounted on the frame, each of which can be either the AED directional face, or a blank mounting face to mount the sign flush to a wall. The button to start the system is wired directly to the sign and can thus be mounted to the wall at a more user-friendly height while the sign remains high and visible. Various schematics of portions of the case are displayed below: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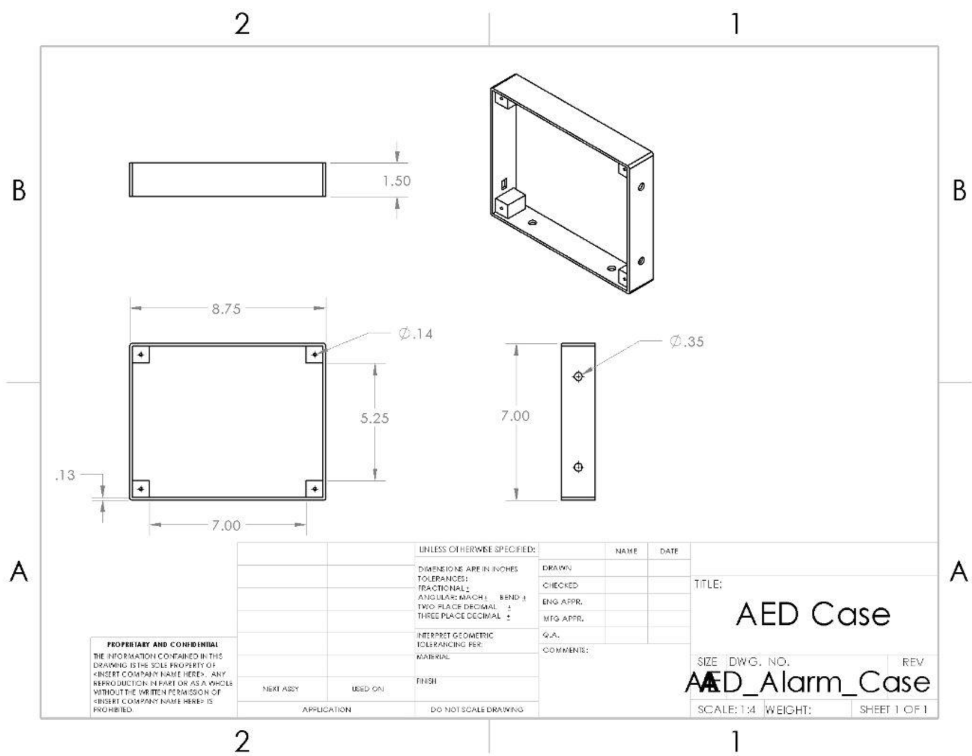
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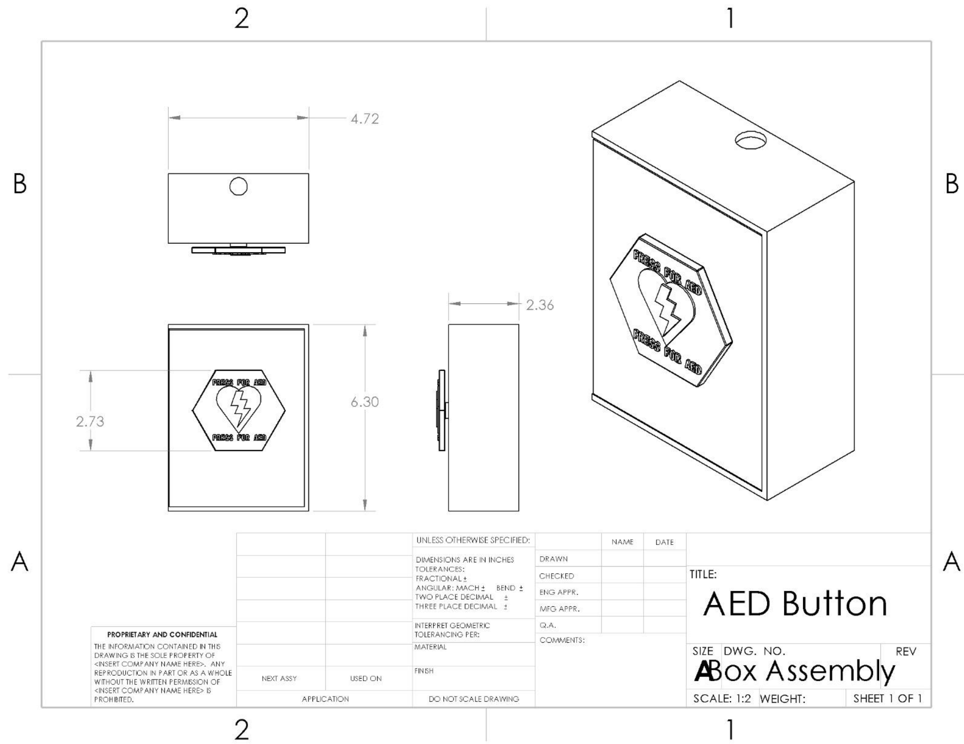

Figure 4: Various schematics of the AED directional sign face, the sign frame, and button box. Blank mounting face not shown.

To actually implement this system, the layout of the building must be represented in a computer readable format. To do so, we graph the floorplan of the building as a network of vertices (hallway intersections) connected by edges (hallways). Each edge is assigned a weight based on the length of the hallway. In the case of stairs, an extra weight can be added to represent the increased time to traverse. Measuring hallway distances and constructing the graph can be a tedious task, so we created a simple graphical user interface that lets a user add a floor plan as an image and then simply click and drag to add edges and vertices. The program automatically calculates the distances of the hallways (which can also be manually modified for more bespoke installations). Creating the graph of a portion of the Thayer Complex in the interface is shown below.

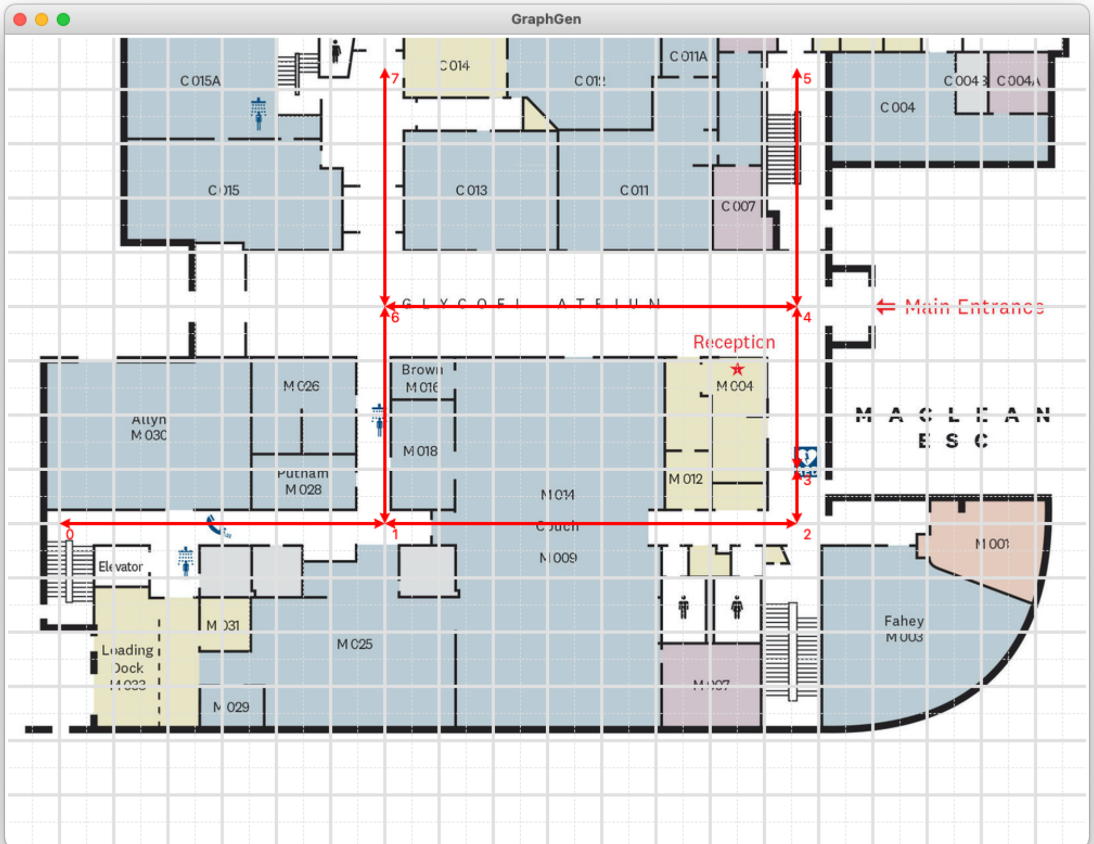

Figure 5: A screenshot of the drag and drop interface.

Each sign is placed at a vertex, with each of its arrows lying directed along an edge. Placing signs at every vertex in a building is costly both financially and environmentally and is often unnecessary. To help us optimize our sign placement, this same program runs an analysis on the edges to find which edges are the most critical to mark with arrows on our signs. A sample analysis for the same portion of the Thayer complex is shown below.

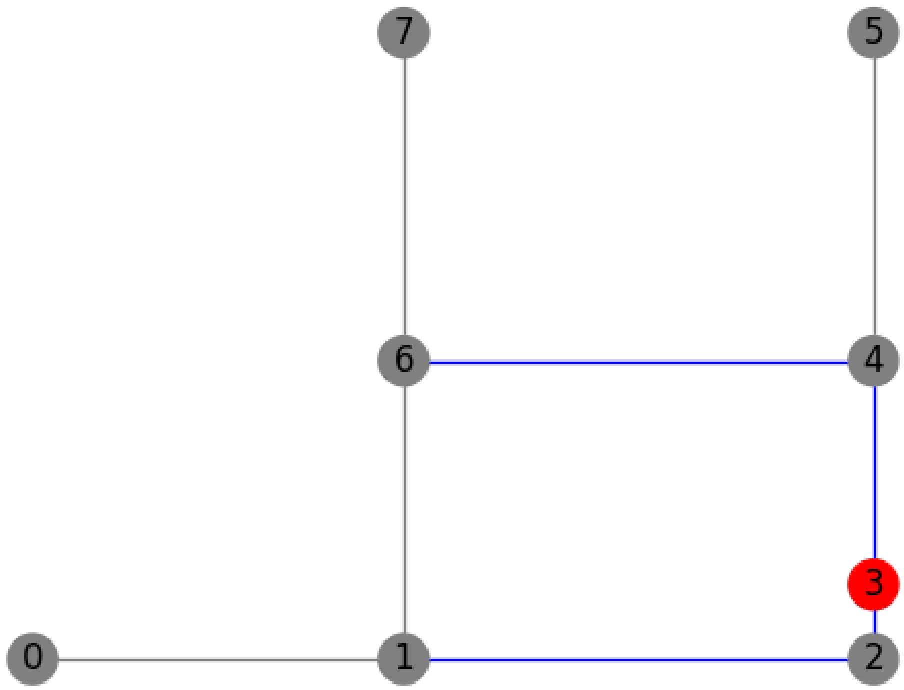

Figure 6: Subsequent automatic analysis of the graph created above. Red marks AED locations, and blue edges mark critical edges.

The blue edges represent these especially critical edges, and the red "3" represents the location of an AED. Intuitively, this marking of critical edges makes sense. For instance it is clear that no matter what vertex you start at, the shortest path to an AED never traverses the edge connecting vertices "1" and "6". Similarly the edges connected to vertices "0," "7," and "5" would only be traversed on the shortest path to the AED if one starts at those vertices. Furthermore, as these are the only directions one can go from these vertices, signage would be superfluous. Extending on and formalizing this idea our program calculates the normalized betweenness-centrality of each edge as defined:

$$c_B(e) = \frac{2}{n(n-1)} \sum_{s \in S, t \in T} \frac{\sigma(s, t|e)}{\sigma(s, t)}$$

Where $\sigma(s,\ t)$ denotes the shortest path from vertex "s" to "t", "S" represents the set of all vertices that are AED and "V" represents the set of all other vertices. In essence, the betweenness-centrality is calculated by calculating by for each edge summing the portion of shortest paths from "s" to "t" that contain that edge for all vertex pairs "s" and "t". We note the number of "s" "t" pairs is at most $n(n\ -\ 1)/2$ where n represents the total number of vertices and so we can normalize the output as shown in the equation. Depending on budgets, we can modify the cutoff centrality to qualify as a critical edge to determine the ideal sign layout.

Once the sign layout is finalized and installed, the system can find the shortest path to the AED from any incident using a pathfinding algorithm. Our system utilizes Dijkstra's algorithm, a classic algorithm. Descriptions of Dikstra's algorithm are readily available online (for instance: [Dijkstra's algorithm - Wikipedia]), but in essence it calculates the shortest distance from a given vertex to the closest AED and is able to trace out the path it took to find this minimal distance.

Testing & Analysis

Once we had our system fully operational, it was important to test our system against our baseline surveying and comparable products. The first attribute we chose to test was the power of our system and its overall energy consumption. Using a multimeter, we took measurements of the average voltage running across the system and its total resistance while idle. With these measurements we were able to use the Power Law Equation to calculate the system's power draw.

$$P = \frac{V^2}{R}$$

From our measurements we found that our average voltage was just under 5V and we had a resistance of 115Ω. Plugging these values into our equation and we get that the power draw of our system was roughly 0.22 Watts. This was confirmed with a power meter from the instrument room which gave a reading of <.5 Watts. This is the power required for each individual sign in our system and from it, we can calculate the amount of energy consumption needed to run this system. Over the span of a year, we estimate that our system consumes roughly 1.8kWhrs of energy. Now, we can compare this to similar low energy systems such as exit signs and smoke alarms to benchmark its energy consumption. Both of these systems are rather low-power-use systems, with exit signs typically consuming roughly 44kWhrs of energy per year and smoke alarms consuming 3.5kWhr. Evaluating these numbers against our system shows that our system is comparably energy efficient; which leads to a longer lifetime and lower cost of operation.

The cost to manufacture the signs is quite low and consists mainly of the cost of the LED. A double faced sign (LED directional arrows on both sides) costs $8.88 in electronic components, and a single faced sign costs $4.72. In addition each sign currently uses $26.50 of Raspberry Pi hardware for prototype purposes. If we were to move forward with this product, the Raspberry Pi's would be replaced with cheaper custom hardware, and the LED cost would go down as we would be purchasing at scale.

In order to determine the effectiveness of our solution we conducted user testing on an installation in the Thayer Atrium. We started users by the lower entry to Spanos and had the signs guide them to the physical location of the Atrium AED which is by the reception desk. Out of the 20 users tested, every participant was able to locate the AED within 35 seconds, with an average time of 26 seconds. For baseline testing, we timed how long it took for participants within the immediate vicinity of the AED (~20 feet) to locate the nearest AED. For comparison, in the baseline testing only 65% of participants had found the AED within 35 seconds even though they were in its immediate vicinity. Thus, we see a significant improvement in the time to retrieval for our system. Baseline and product testing are shown below with the graph showing the portion of surveyed participants who had found the sign within a given amount of time:

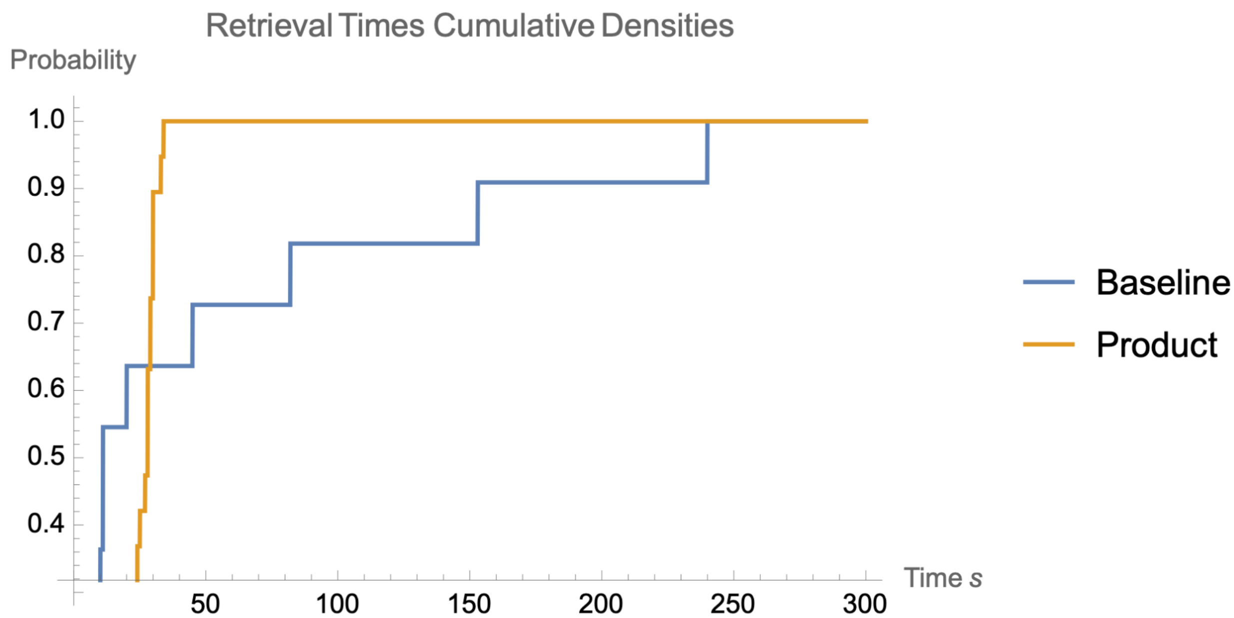

Figure 7: Baseline versus user testing. Higher on the graph is better.

Speed is of course of primary importance for our system, and so it is important to analyze the efficiency of our algorithms. On the Raspberry Pi 0 W, we timed how long it would take to find the shortest path on a hypothetical installation of 10,000 vertices, each at a four-way intersection with 10 AEDs in the building. Each of the 20,000 edges in this generated floor plan were also given 4 significant figures of weight randomly. The average time to calculate the shortest path to an AED from a random start vertex over 1,000 trials was just 0.734 seconds. 10,000 vertices is much larger than any real installation, which shows that our system is sufficiently fast even for the most extreme cases. For a much smaller but still overly-large installation of 1,000 vertices, the algorithm took an average of 0.060 seconds (with all other parameters the same as the 10,000 vertex graph). We believe an actual physical implementation would have far fewer than 1,000 vertices, and thus we see the computational time is more than fast enough, and that the system scales well. Another concern is computer storage. Storage can be expensive, so we want our data files for the graph of the floorplan to be space-efficient. Testing shows that for the 10,000 vertex the file size of the graph was just 86 KB, which is extremely efficient. For reference, a smartphone picture is around 6 MB. Based on these tests, the software side of the system performs satisfactorily.

Ethics & Sustainability

To benchmark the sustainability of our product, we first evaluated its lifecycle using an Eco-Design Strategy Wheel. As seen below, this chart rates each aspect of our product's life cycle beginning with material extraction and ending with disassembly and disposal.

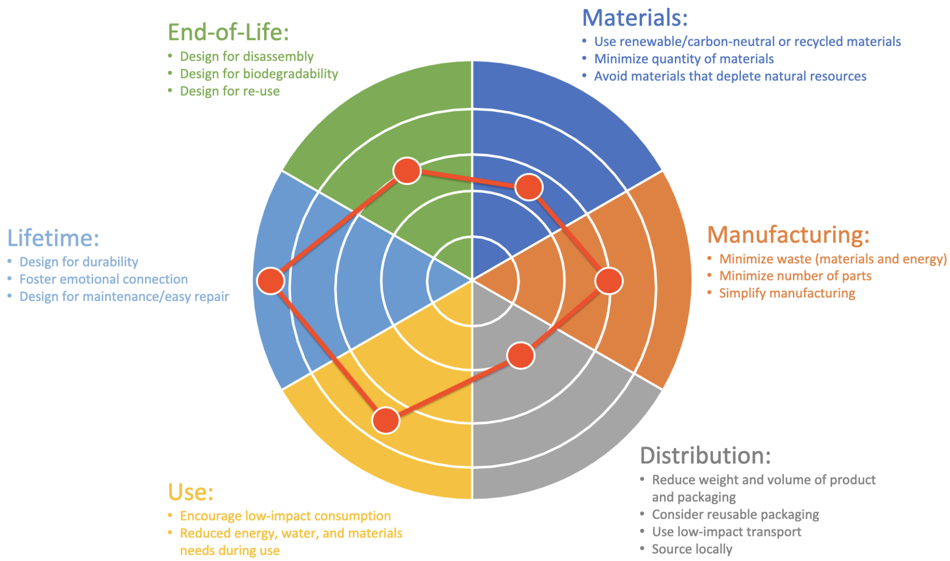

Figure 8: Environmental impacts of our product. Further from the center is lower impact..

Our prototype's main components were made of PLA, LEDs, and other electronic parts (wires and perfboards). As a group we felt that these materials did not reflect the most renewable options, and further, in our product's design we felt that the housing we designed used more plastic and space than was necessary. This led us to rate our prototype on the lower end of the sustainability spectrum. We also found that 3D printing processes and potential overseas distribution do not lend themselves to be sustainable options.

Conversely, we felt our prototype had a low environmental impact during its lifetime and use. Power measurements show that our product runs on less than 0.5W and we estimated that the lifetime of our product would exceed 8years after installation.

Lastly, when we looked at the eventual disposal of our prototype, we decided that it was not the lowest impact it could be, but it wasn't excessively wasteful. The biopolymers used to make PLA have a relatively low environmental impact when thrown out, but we did wish to do more research into a more recyclable option.

After conducting some research into how similar products are produced, we decided that our finalized product would use secondary Acrylonitrile Butadiene Styrene (ABS) if put into commercial production. This is a recycled version of primary ABS that is used to mass produce other products such as exit signs and toys. Furthermore, using a plastic such as ABS lets us utilize mass production techniques such as injection or thermal molding which have a lower environmental impact than traditional 3D printing.

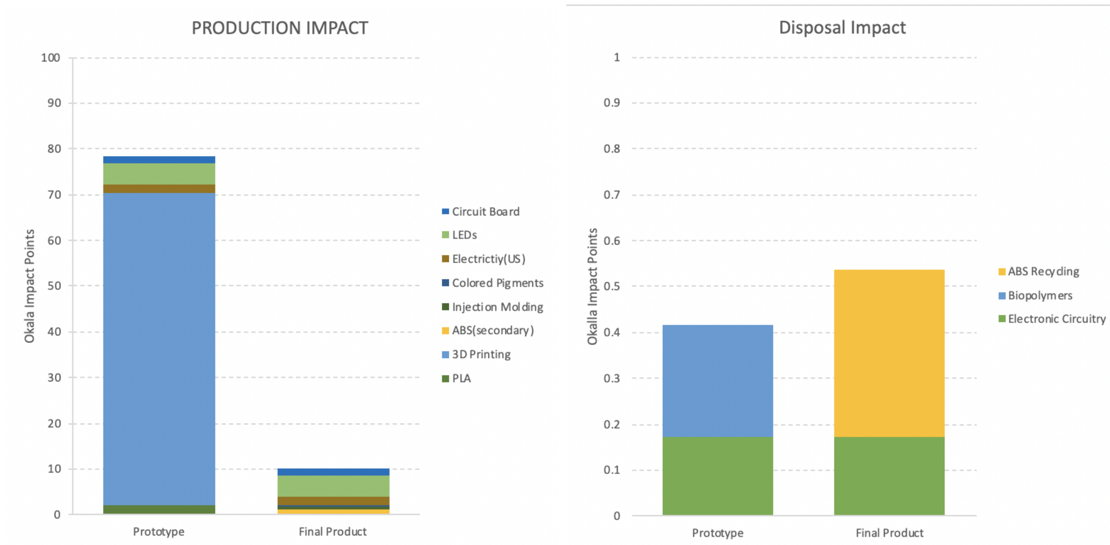

Figure 9: Okala impact scores for manufacturing of current versus hypothetical finished product as well as disposal scores.

To quantify this change, we conducted an Okala impact test to assess the changes we hope to make. Using the data provided by the 2014 Okala Impact Factors Form, we assessed the impact of the change of materials in both the production and disposal of our product.

As you can see in the figure on the left above, our current prototype has a large environmental impact compared to our revised final product. The main source impact came from 3D printing, and making the switch over to injection molding helped reduce this impact by over 80%. Oddly enough, when we look at the disposal end of our product we can see an increase to the overall environmental impact as we switch over from PLA to secondary ABS.

In an attempt to alleviate this issue we devised a reclamation program for our product. In this program we would purchase old, broken, and unused signs back from our purchasers to directly recycle back into our products. Electronic parts from repurchased products would be assessed to see if they could be salvaged, and the reclaimed ABS materials could be remelted and immediately reused into new signs. This would circumvent the need to source new materials and potentially cut some costs.

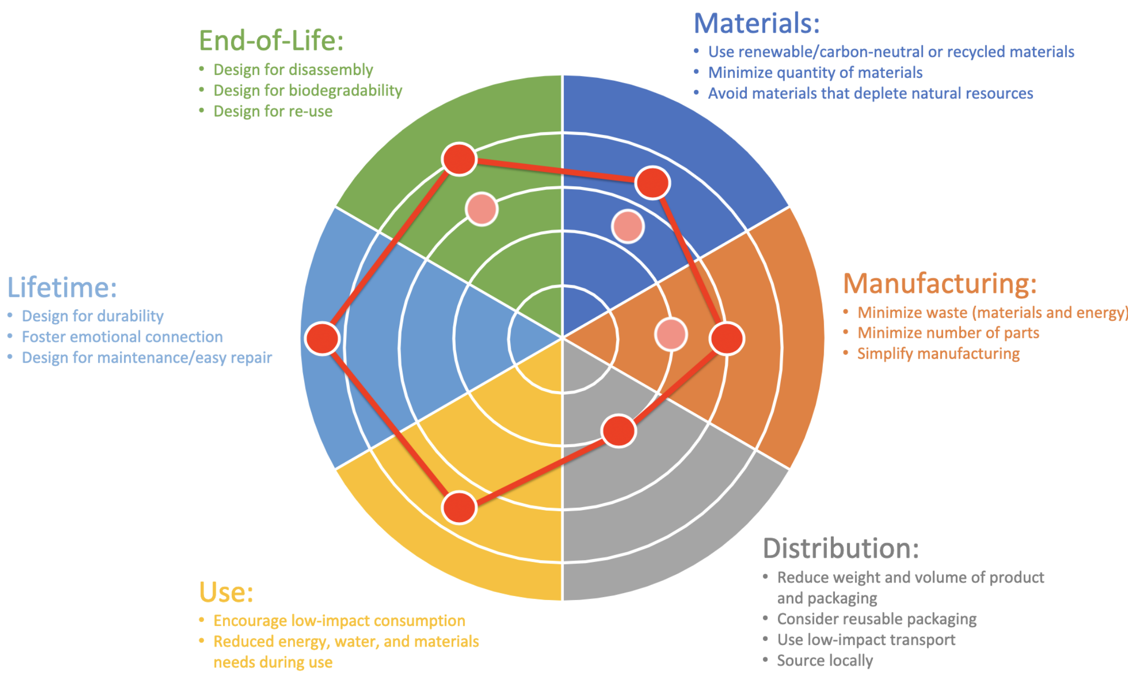

Figure 10: Revised environmental impacts with product changes. Further from the center is better.

When we reevaluated our product's life cycle, we decided that our finalized product would have much lower environmental impacts in terms of materials, manufacturing, and End-of-Life. The new materials, processes, and programs offer many added benefits to the sustainable design of our product, but, as you can see, our distribution process still has a significant environmental impact. Following full scale production and more research, we hope to find solutions to this issue.

Economics & Business Plan -

We imagine our business to be primarily driven by installation and maintenance revenue streams, with the actual production of the sign being outsourced. As such, our costs consist of purchasing parts, manufacturing, and human resources needed to install and maintain our installations. We plan to partner with AED manufacturers so that our product can be more effectively integrated with existing AED cabinets. We also plan to partner with builders and contractors to integrate our product into their supply chain, and with lawmakers to hopefully make AED retrieval systems required in building code.

For institutional customers, our company would send trained professionals to determine ideal sign placement, install the signs, and set up the proper networking between the signs. To keep pricing simple, we plan to charge by the square foot of building, following the pricing models of similar products like fire alarms. The price point would also be similar to fire alarm systems, costing $1-2/sqft for simple installations, moving towards $3-6 for more complex floor plans, and finally up to $4-12 for installations that require retrofitting, most commonly found in older buildings (Ackerman Security). We also hope to increase educational efforts to both make people aware of our system and also about the importance and use of AEDs. Our business canvas is below:

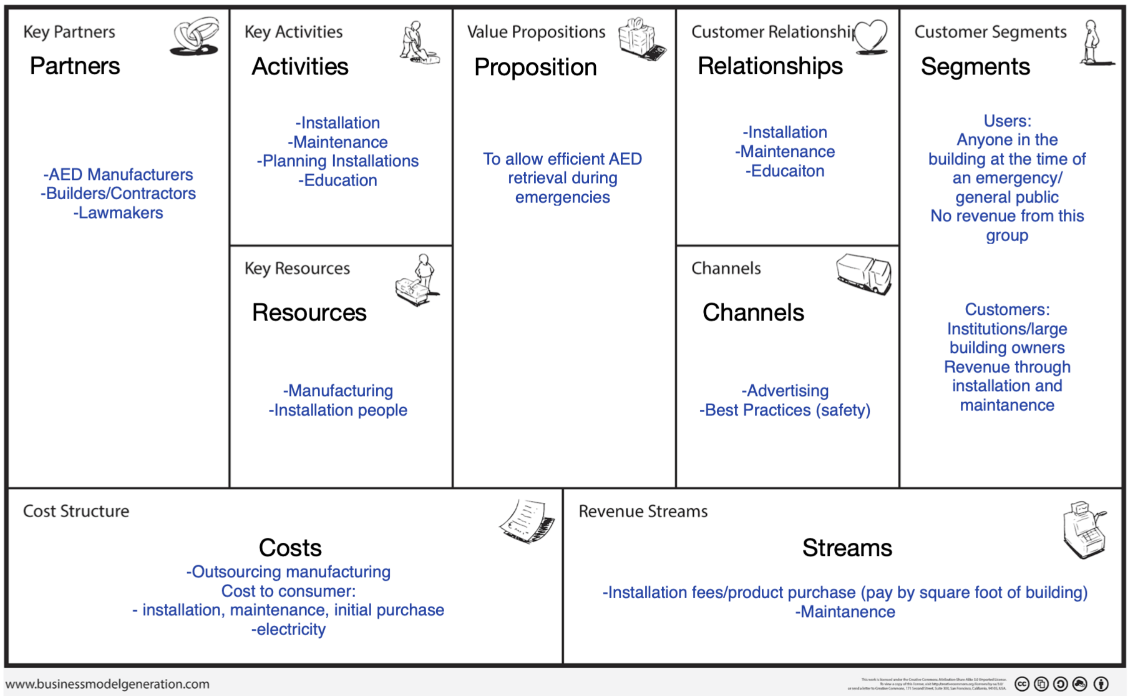

Figure 11: Business plan canvas

Reflections

Moving forward with the project, one of the main objectives we'd like to accomplish next would be a backup battery pack for when the power goes out in a building. As our system stands, every sign and alarm is wired directly into the building's power supply. In the event of a blackout or power outage, our system would be offline, rendering our system useless. One way to circumvent this worry is to install a separate battery to the system. Ideally, the backup battery could runa sign for at least an hour; and when not in use, it could be recharged passively using the building's electricity.

We'd also like to add an audio component to the signs. The lights on our system do a great job at indicating direction and are noticeable from far away, but having an audio cue in addition to the light sequences would add another layer of noticeability.

Coming out of this project, we've learned a lot of new things about the iterative design process and working as a team. It takes effective and intentional communication to work with a team of individuals with different backgrounds and ideas for how a problem can be solved. The process of combining all of these ideas can be difficult, but when it is done well, the final product is significantly better than what any one of us could have developed on our own. We also learned about the process of presenting ideas to a group, and how to most effectively communicate what we developed and prototyped to people who had never seen or thought about our product before.

We also learned about creating business plans, and the importance of considering how a product could go to market. The best ideas in the world still need an effective business strategy in order for the product to become widely used and appreciated, making this process as important as developing the product itself. On a different note, we were forced to consider the environmental impacts of our product, all of the way from production to disposal. It is easy to overlook the impact of something seemingly as miniscule as a few signs and buttons, but the reality is that these products and the processes required to bring them to market add up quickly. Our product is one of countless other ideas in the world, and as engineers we need to consider the impact of our work on the environment in the larger context of the world.

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Appendix A: Python Scripts

Scripts can be found at https://github.com/Daniel-Ellison/AED. Specifically final_sign_driver.py for the sign driver, final_cabinet_driver.py for the cabinet driver, and graphgen_new.py for the drag and drop graph generator.