Design a Better Smoke Detector

Section Instructor: Professor Hulbert
Project Sponsor: Kids in Danger
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ME 450, Winter 2022: Team 10

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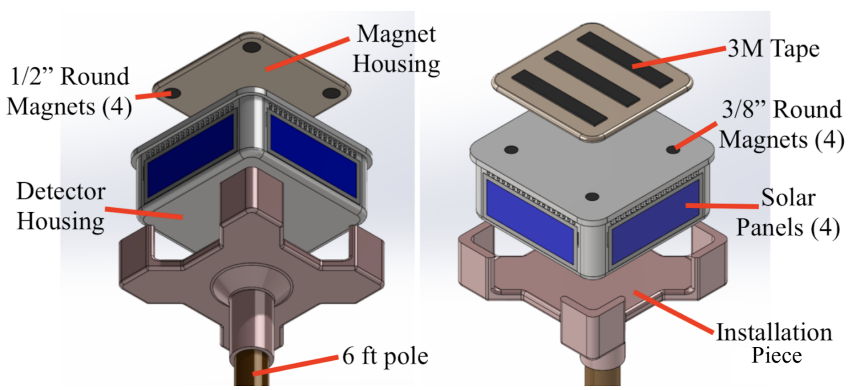
EXECUTIVE SUMMARY

Current smoke detector designs put children at risk in home fires, therefore, the team was tasked with designing a “better” smoke detector. The project is sponsored by Kids in Danger, a nonprofit organization dedicated to protecting children by fighting for consumer product safety. After conducting research and collaborating with stakeholders in the space, the project scope has been narrowed to the improvement of installation and maintenance of smoke detectors. The existing technology of smoke detectors is sufficient and is not contributing to the cause of death for children in home fires, therefore, the team is not focusing on changing the smoke detecting technology. Using research and stakeholder input, the following user requirements and engineering specifications were defined:

- *Quick to Install:* ≤ 3 minutes to install
- *Easy to Install:* 1 required tool, mount to a surface roughness up to 30 microns
- *Easy to Access:* User at 3 ft above the floor can access smoke detector
- *Easy to Maintain:* ≤ 2 minutes to demount
- *Lightweight:* Smoke detector ≤ 0.7 lbs
- *Low Cost:* ≤ $20 (manufacturing cost)
- *Long-Lasting:* Lifespan of at least 5 years

Focusing on the installation and maintenance of smoke detectors, the team was able to generate 160 design concepts. Through analysis and a rigorous selection process, the concept of a solar powered detector with an assistive installation piece was selected. This design ranked the highest in a pugh chart, as the innovative concept best fits each of the user requirements listed above.

The final design is a solar powered smoke detector, removing the need to change the batteries. The magnet housing will be 3M taped to the ceiling and the smoke detector will magnet to the magnet housing. The detector has dimensions of 4.9” x 4.9” x 2” and a wall thickness of 0.08’’. The design will be installed by placing the detector and magnet housing in the installation piece. The installation piece will be raised to the ceiling and pushed to adhere the tape to the ceiling. Then, to de-mount the detector, the detector will be twisted using the installation piece to disengage the magnets. This design, shown below, is aimed to allow seated-users to install and access the smoke detector.



A build solution of the final design was created and used for verification testing. Most requirements were able to be verified by the team through testing, but further testing with a user group is needed for the quick to install and easy to maintain user requirements. The final estimated cost of the final design above is $10.72, and the current plan for manufacture consists of injection molding the detector housing, installation piece, and magnet housing. The remaining parts, such as the battery, circuit board, and tape, will be outsourced.

As for improvements to the final design, the final design does not address manufacturability the greatest, so further research is needed. Additionally, market-based research should be performed to ensure that users want the detector in their home and that it is aesthetically pleasing. Overall, a successful design, prototype, and final solution were created, and future work has been laid out to improve the product.

ABSTRACT
"Design a Better Smoke Detector" is sponsored by Kids In Danger (KID), an organization dedicated to fighting for children's product safety. The need was established due to children being at higher risk in home fires, especially if smoke detectors are not present within the home or not functioning properly. The final design will ease installation and maintenance of smoke detectors to promote safer homes, in hopes that adults will install and maintain their detectors properly. The design will consider the elderly, low-income families, and those with a lack of mobility, since many devices on the market do not prioritize these users.

PROJECT INTRODUCTION, BACKGROUND, AND INFORMATION SOURCES
The following section will outline the project to be completed throughout the semester, as well as necessary information regarding the project sponsor, how a smoke detector works, and what has been attempted in previous designs. Desired outcomes will also be detailed.

Project Sponsor and Project Need
The sponsor of this project is Kids In Danger (KID). KID is a nonprofit organization founded in 1998 dedicated to protecting children by fighting for consumer product safety [1]. KID was established by the parents of sixteen-month-old Danny Keysar, who died when a portable crib collapsed on him in his child care home. KID's mission is to "save lives by enhancing transparency and accountability through safer product development, better education, and stronger advocacy for children" [1].

The need for a better smoke detector design was raised to KID by the U.S. Consumer Product Safety Commision; the goal is to eliminate the amount of children negatively affected by faulty or non-functioning smoke detectors. Home fires kill about 500 children ages 14 and under each year in the United States [2]. Furthermore, only three quarters of all homes in the United States had at least one functioning smoke detector [2]. Additionally, 78% of smoke detectors that did not operate in home fires were due to lack of access and maintenance [3]. Therefore, the objective of this project is to design a smoke detector that is easier to install and maintain than current detectors on the market. If the final design fulfills these requirements, users may be more likely to use and interact with their smoke detectors properly, increasing both children and adult safety in home fires.

Previous Solutions
Previous attempts to ease installation and maintenance have not made it past the prototype stage. For example, a detector that winds down from the ceiling when the battery is low is easy to maintain, however when brought to consumers, this design was regarded as "too silly to buy" [4]. There are successful designs on the market that allow for easy installation, however, these designs are not easy to reach. The Siterwell smoke detector comes with a magnet and 3M adhesive [5], which eliminates the need to drill into the wall for installation. However, given that smoke detectors must be mounted at least 12 inches from the ceiling [6], most users will still have to climb a ladder to mount the detector.

There are previous attempts at low-maintenance and alternative-power smoke detectors. Kidde makes a "10 Year Worry Free" ionization smoke detector that can be either battery powered or hardwired with a backup battery source. The price per unit of this product is $14.99 and $28.48, respectively; these products are relatively low cost as they do not require battery replacements [7]. While these products are low-maintenance, they are not designed for easy or quick installation. To install these products, the user would still need a ladder and drill. Another solution on the market is solar powered smoke detectors. Uniform Warehouse sells a solar photoelectric smoke detector for $29.99. There is limited information on this design, such as the lifespan and functional ability; however, the design does meet Code NFPA 72 [8]. While this design is low-maintenance, again, it is not easy or quick to install.

Existing Design Features
There are current smoke detectors on the market that contain aspects of the final design. The final design includes a square-shaped smoke detector that uses 3M tape and magnets to mount to the ceiling. Square smoke detectors are quite popular amongst buyers. The Google Nest [9] and the BRK FirstAlert smoke detector [10] are two examples of current square-shaped smoke detectors on the market. Both designs are popular, but have relatively high costs of $119 and $54, respectively. As for the magnetic and 3M tape aspect of the design, there is a separate magnetic piece by Siterwell with a 3M tape adhesive that is available on Amazon [5]. Since the Siterwell product does not come attached to a smoke detector (it is sold separately), it may be used for other products and consumers may not know it exists for their smoke detector.

Information Sources
For this project, interviews have been conducted with Nancy Cowles, the Executive Director of Kids in Danger [11], Johnathan Midgett, a Consumer Ombudsman for the U.S. Consumer Product Safety Commission (CPSC) [4], as well as Arthur Lee, an electrical program manager for the CPSC [12]. The CPSC "protects the public from unreasonable risks of serious injury or death from thousands of types of consumer products under its jurisdiction, including products that pose a fire, electrical, chemical, or mechanical hazard or can injure children" [13].

Also, standards for smoke detector placement that are set forth by the National Fire Protection Association (NFPA) have been taken into consideration, along with smoke detector design requirements set forth by Underwriters Laboratories specification UL 217. Details regarding these standards and specifications will be provided later in this report.

How a Smoke Detector Works
Current smoke detectors use two different technologies to detect smoke: ionization and photoelectric. An ionization smoke detector is shown in the left column of Figure 1. When smoke is not present, the circuit within a smoke detector is able to maintain a constant current. When smoke enters the system, the current is interrupted and the alarm sounds. The second method to detect smoke is through a photoelectric detector, which can be seen on the right-hand side of Figure 1. When smoke is not present, the light source is detected by a light sensor mounted on the bottom of the detector. When smoke is present, the light sensor is no longer able to detect the light, thus sounding the alarm [14].

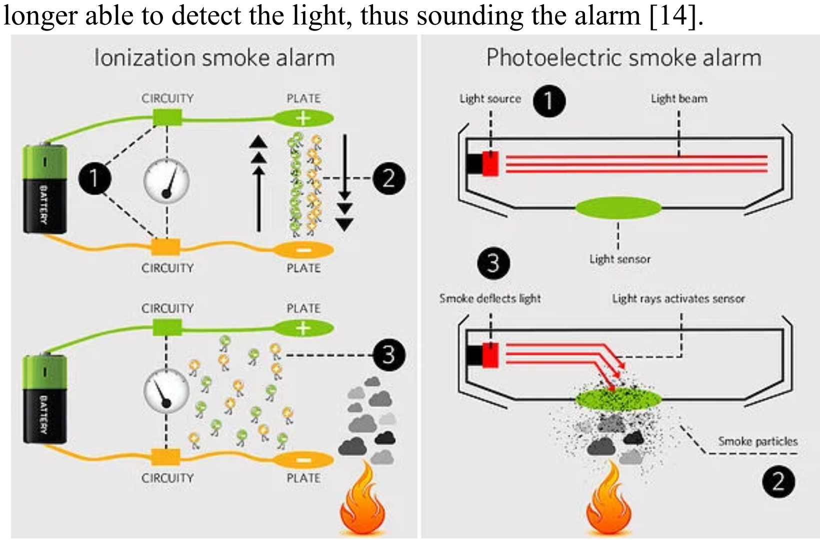


Figure 1: Internal diagram for how smoke is detected in both ionization and photoelectric smoke detectors [15].

Installation and Maintenance of a Smoke Detector

The same installation and maintenance process is required for both an ionization and a photoelectric smoke detector. According to the NFPA Code 72, a certain number of smoke detectors must be placed within a home a specific number of feet from bedrooms/potential fire hazards (i.e kitchens) [6]. Current smoke detectors on the market usually come with two pieces: the smoke detector and a base that holds the smoke detector and mounts to the ceiling. In most cases, a Phillips screwdriver, a ladder, and a hammer will be required to install the mounting piece to the ceiling. Once the smoke detector is mounted, a battery must be installed in the device to power the smoke detector [16].

When replacing the batteries in the smoke detector, the user will need to source a new 9V battery and a ladder to access the smoke detector. The battery cover or a piece of the smoke detector is removed, and the new 9V battery is installed. To complete the replacement, the battery cover is placed back on the device, or the smoke detector is re-mounted to the base on the ceiling [16].

Most smoke detectors should be replaced every 10 years [17], and the batteries are recommended to be changed every six months [18]. The vents on the detector should be routinely dusted or vacuumed to prevent any dust build up which might prevent the device from functioning properly [17].

Intellectual Property

The team owns the intellectual property of the project. The team does not need to consider the role that intellectual property plays in the design moving forward.

DESIGN PROCESS

Since the beginning of the semester, a problem-oriented design process has been used for this project. A problem-oriented design process is when emphasis is placed upon abstraction and thorough analysis of the problem structure before generating a range of possible solutions [19]. According to the project sponsor, the task was to "design a better smoke detector". Currently, there are many avenues to improve smoke detector design, and a variety of people interact with smoke detectors throughout their lifetime. Using a problem-oriented model was essential in narrowing down the scope of the project, primary problem(s) with smoke detectors, and the stakeholder needs and requirements. Also, the problem-oriented design process currently being used is composed of both stages and activities. Using both a stage-based and activity-based approach allows for well-structured, iterative activities within each stage, and as one moves through stages of the process, there are less and less activities, leading to a converged solution [19]. These stages are connected through feedback loops which allow for one to return to the previous stage if necessary, promoting design and problem iteration throughout the entire design process.

Another design model considered was a solution-oriented model with a linear structure. A solution-oriented model is when an initial solution is proposed, analyzed, and repeatedly modified as the design space and requirements are explored together [19]; linear structure eliminates the possibility of design and problem iterations throughout the process. Using this model would create a streamline process in which there is little emphasis on the problem in the beginning, and possible solutions are altered until a final solution is validated; once one stage is completed within the process, there is no return to the previous stage. A solution-oriented model can be both time and cost intensive, due to constant prototyping and testing of the potential solutions. Given that this project is ideally completed in one semester with a relatively low budget, this model was not ideal for the project. Also, the scope of the project was quite large. Using a problem-oriented design process and performing a thorough analysis of the potential problems with current smoke detectors, who is using smoke detectors, who was affected and how they are affected by smoke detectors was essential to meeting the sponsor and stakeholder needs.

Figure 2 on the page below shows the standard design process introduced in the first class lecture. This is the same process chosen for the project considering it focuses on a thorough analysis of the problem, and allows for design and problem definition iteration throughout the entirety of the project. The standard design process provided is both an activity-based and stage-based model: within each stage are certain activities, along with tools and specific outcomes that should be achieved before moving onto the next stage. Given the time constraint (January 5th, 2022 - April 19th, 2022), the “Problem Definition”, “Concept Exploration”, and “Solution Development & Verification” stages will be the primary focus for this project. Since a need for the project was already identified before the beginning of the semester, and the final prototype will not be mass manufactured by April 19th, the “Need Identification” and “Realization” stages of this design process will be neglected.

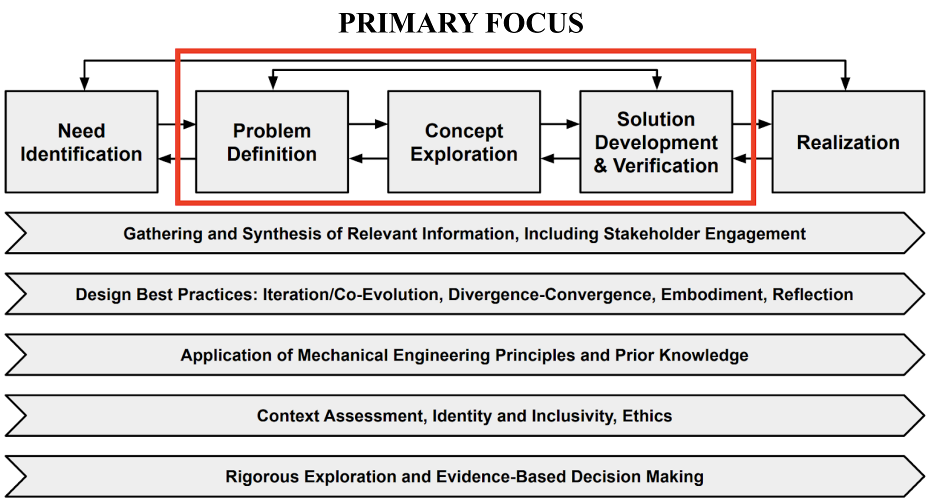


Figure 2: The standard design process proposed at the beginning of the semester, and the primary focus for the project; this figure was reproduced from the ME450 Design Process Block [20].

To complete the “Problem Definition” stage, the activities that were fulfilled included understanding and framing the problem, collecting relevant information and data, determining stakeholder needs and requirements, and translating those requirements into engineering specifications [20]. Tools that were utilized to complete these activities included multiple stakeholder interviews and conducting online research on current smoke detector models on the market (how they work, problems with smoke detectors, and engineering and government regulations for smoke detectors within a home). As a result, the scope of the project was narrowed to easing the installation and maintenance of smoke detectors, specifically for the elderly and those with limited mobility. A list of user requirements and engineering specifications the final design must meet is provided later in this report.

Once the problem was defined and the engineering specifications were established, potential solutions were created in the ‘Concept Exploration” stage of the design process. To complete the “Concept Exploration” stage, the activities that were fulfilled included generating, developing, and evaluating solution concepts, using a variety of tools to encourage divergence, and further develop and evaluate concepts with requirements and specifications in mind [20]. Tools used to complete these activities included brainstorming, sketching, Design Heuristics, a morphological analysis, concept screening/scoring, and prototyping. The ideas generated from using each technique, along with the concept selection process and the alpha design that will be used for prototyping is described later in this document.

Once a prototype was fabricated, the team was able to complete most of the “Solution Development & Verification stage of the design process. To complete this stage, the activities that were fulfilled were the development of a detailed design solution to meet requirements and specifications, the incorporation of best practices for CAD, matertials, and manufacturing, and the development of appropriate design embodiment and verification. Tools to complete these activities included sketching/CAD, engineering analysis, prototyping, engineering standards, texting, and stakeholder feedback. All of the these tools will be described later in this report.

DESIGN CONTEXT

The team must consider the stakeholders and overall impact of smoke detectors, including the public health and safety, social, environmental, and ethical impact.

Stakeholders

The stakeholders of "Design a Better Smoke Detector" have varying interest and power in the final design and project as a whole; Figure 3 below shows the stakeholder map for "Design a Better Smoke Detector". "Power" was defined as control and influence over the final design, while "Interest" was determined as the stakeholders desire for the project itself.

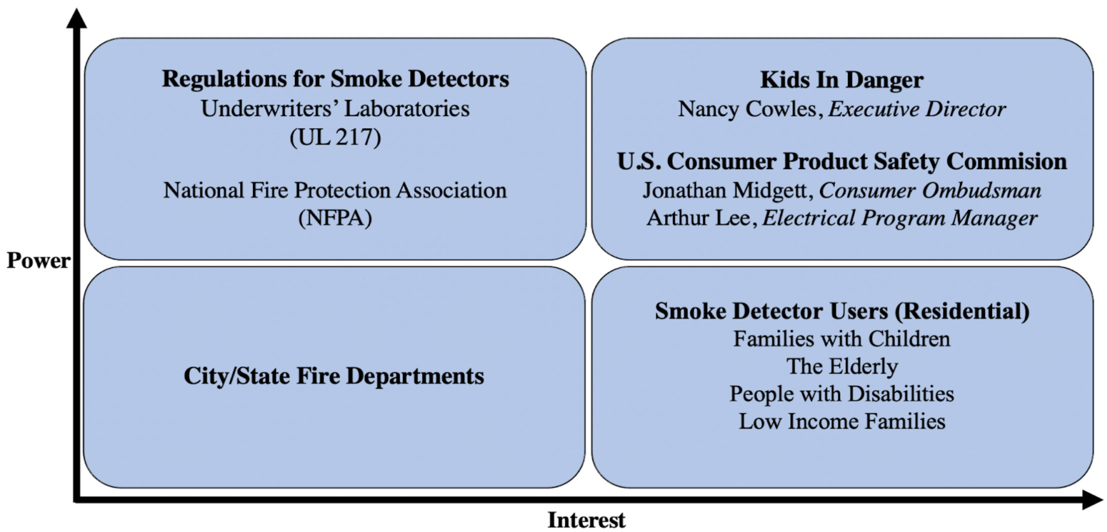


Figure 3: Stakeholder map of smoke detector design

KID has both high power and high interest in the project, since they are the project sponsor and a child safety advocate. The U.S. Consumer Product Safety Commision also has both high interest and high power as they first introduced the need for a better smoke detector to KID, and they work to address consumer product safety in the United States. Smoke detector users have low power as consumers are limited to what smoke detectors are available on the market, however, smoke detector users have a high interest in the project since easier installation and maintenance would result in safer homes. A new smoke detector design with easier installation and maintenance would benefit families with children as it would increase safety by making battery changing easier. The project would be of interest to the elederly and people with limited mobility because not all users can physically reach their smoke detectors or use a ladder. The project is of interest to low income families as the design is intended to be affordable. The local city and state fire departments have both low power and low interest in the project as they focus on fire prevention and responding to emergencies, which are not in scope of this project. The NFPA has high power over the project because they create codes and standards for smoke detectors within the home. Since an interview was not conducted with someone from the NFPA, it is assumed they have relatively low interest in this project. Similar to the NFPA, UL creates standards for smoke detectors. Any design created must comply with NFPA and UL standards for smoke detectors. Specifically, NFPA 72 regulates the placement of smoke detectors [21], and UL 217 regulates the technology in smoke detectors and the ability to detect different kinds of smoke to reduce nuisance alarms [22].

REQUIREMENTS AND ENGINEERING SPECIFICATIONS

The following user requirements and engineering specifications were created from research on current smoke detector characteristics as well as stakeholder interviews with Nancy Cowles of KID, and Johnathan Midgett and Arthur Lee of the CPSC. These requirements center on the installation and maintenance of smoke detectors, not the technology of sensing smoke. The requirements and specifications are listed below in Table 1.

Table 1: User Requirements and Engineering Specifications

User Requirements	Engineering Specifications
Quick to install	≤ 3 minutes to install
Easy to install	1 required tool, Mount to a surface roughness up to 30 microns (wood)
Easy to access	User at 3 ft above the floor can access smoke detector
Easy to maintain	≤ 2 minutes to de-mount
Lightweight	Smoke detector ≤ 0.7 lbs.
Low cost	≤ $20 (manufacturing cost)
Long-lasting	Lifespan of at least 5 years

Conducting both online research and virtual stakeholder interviews was the first step in determining the engineering specifications for this project. After the problem was set, engineering targets were created through an understanding of the user necessities and solutions available on the market. Current products are able to adequately detect fires, however are not accessible to all users. The requirements surrounding ease of installation and maintenance were of top priority; this is due to the fact that the main problem with smoke alarms surrounds the user's ability to mount the detector and change the batteries regularly.

Fire safety laws are met with the utmost importance in the United States. Therefore, the placement of smoke detectors within the home must follow NFPA 72. Additionally, the design of the detector must be in regulation with UL 217.

As this project surrounds the accessibility of smoke detectors, the necessary requirements include "easy to install", "quick to install", "easy to access", "easy to maintain", and "long-lasting". The "long lasting" requirement addresses the need for the end design of a detector to last as long as possible once installed. Having a detector that has a life span as long as it can be designed eliminates unnecessary interaction between the device and the user, saving cost, frustration, and time. The longer the design lasts, the more likely a desired outcome will occur for the end user. The wishful requirements help expand the product availability to a larger audience. For example, retaining a low cost is a wishful requirement as the product can be suitable for lower income users. Overall, all of the requirements carry importance to this project. While some, like the ease of access, follow the problem definition closer than others, all are relevant for the detector design.

"Easy to install" was found to be one of the more important requirements for the project. Current smoke detectors require at least two tools to install the detector to the ceiling (drill and ladder). To make the final design easier to install, there must be at most one required tool and it must mount to a surface roughness up to 30 microns. The surface roughness of a wood ceiling, one of the most rough ceiling types, is around 30 microns. Therefore, if the design does not use nails or screws to fasten to the ceiling, it must still be able to mount to the roughest of ceiling types. The initial consideration of attaching to a surface roughness of 3 mm for "popcorn" ceilings has been changed as design research progressed. It is not possible to use any tapes on "popcorn" ceilings. Additionally, it is not safe to puncture "popcorn" ceilings in homes built before the 1980s due to asbestos. As neither tape nor epoxy can adhere to "popcorn" ceilings, the team has changed the requirement to only reflect homes with drywall, drop tile ceilings, or wood ceilings.

"Easy to access" was found to be one of the most important requirements after discussions held with multiple stakeholders. The ideal design is accessible to as many users as possible, including those who have limited mobility. The requirement that a user 3 ft above the floor can access the smoke detector allows users sitting at chair-height to be able to access the detector on a 9 ft ceiling. The standard ceiling height across homes in the United States is 9 ft.

All of the user requirements have been translated to engineering specifications. The requirements and their matching specifications can be found in Table 1. Each engineering specification has been quantified and assigned an appropriate testing procedure. For example, the specification of "Smoke detector ≤ 0.7 lbs" will be analyzed by using SolidWorks mass properties to estimate the final weight. All of the specifications listed in Table 1 are reasonable. They are reasonable due to the fact that they can be quantified and tested through various means. All specifications are backed by research and current design characteristics of smoke alarms.

CONCEPT GENERATION

Design Heuristics, a morphological matrix, and the S.C.A.M.P.E.R. techniques were used to generate more than 160 potential solutions**.** To generate solutions that met the scope of the project, the smoke detector was broken up into two subfunctions: installation and maintenance (battery changing, easier to access, etc.). This allowed focus on ideas to ease the installation and maintenance of the smoke detector, rather than generating ideas with diffent smoke-detecting technology. Also, the solutions produced in the beginning favored quantity over quality. It was important to generate as many ideas as possible (even if they were not feasible or were considered "crazy") in hopes to produce ideas that were creative rather than ones that already exist. Each of these methods and the corresponding concepts generated are described below.

Design Heuristics provides 77 specific strategies to help generate novel designs that are different from each other, leading to innovative concepts [23]. Design Heuristics advance the creation of new ideas by adapting the current smoke detector design. Design Heuristics #3 (add motion) and #4 (add to existing product) were used to evolve the standard smoke detector into a smoke detector that would move down to the user when the battery life was low, and a smoke detector that was inside of a lightbulb. Figure 4 shows the Design Heuristic cards used and the corresponding sketch of the new solution.

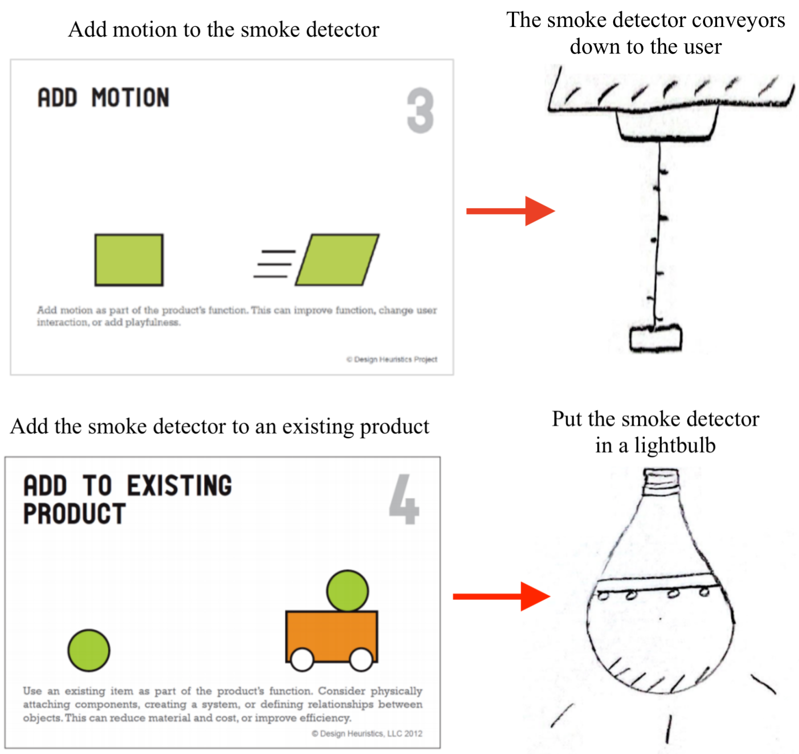


Figure 4: Examples of Design Heuristic cards and the generated concepts.

Another activity used during the concept generation phase was a morphological matrix. In a morphological matrix, the system is broken up into important subcomponents, and different solutions for each subcomponent are listed or sketched. This method allows the user to mix and match one solution from each subcomponent to form one full product. The smoke detector was broken up into four subcomponents: power source, installation/attachment method, the noise/alarm, and the type of smoke sensor. From here, multiple smoke detector designs were created using one solution from each subcomponent. For example, one solution was a battery-powered ionization smoke detector that uses velcro as an attachment method and music as an alarm. Although a lot of ideas can be generated, not all of them are distinct from one another. It is often that the potential solutions suggested using a morphological matrix already exist/are on the market. Figure 5 shows the morphological matrix used for the smoke detector design.

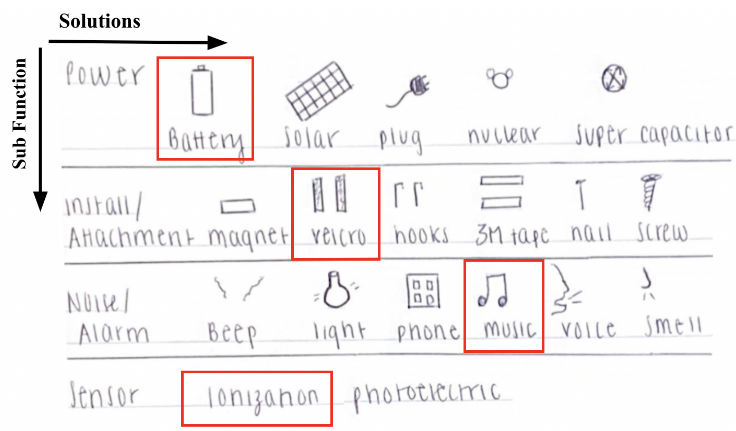
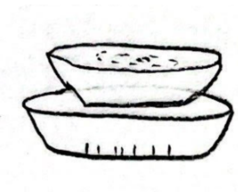
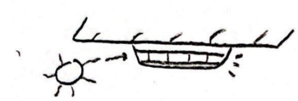


Figure 5: The morphological matrix created for smoke detector design.

The last activity used to generate innovative solutions was the S.C.A.M.P.E.R. technique. The S.C.A.M.P.E.R. technique uses a set of directed, idea-spurring questions to suggest some addition to, or modification of, something that already exists [24]. S.C.A.M.P.E.R. stands for Substitute, Combine, Adapt, Magnify/Modify, Put to other uses, Eliminate, and Rearrange/Reverse. This method generated many creative solutions, since the premise was to iterate on the existing design. Table 2 shows some of the concepts generated using the S.C.A.M.P.E.R technique.

Table 2: Example of the S.C.A.M.P.E.R technique and the ideas that were generated. This figure was adapted from [24].

S	**Substitute**	Think about substituting part of the product or process for something else (components, material, people) Questions: What else is intended? Who else is intended? What other materials, ingredients, processes, power, sounds, approaches, or forces might I substitute?	**Substitute** screws for suction cup 
E	**Eliminate**	Think of what might happen if you eliminated parts of the product or process and consider what you might do in that situation. Questions: What might I understate? What might I eliminate? What might I streamline? What might I make smaller, lower, shorter, or lighter?	**Eliminate** battery change by using solar power to charge battery 

CONCEPT SELECTION PROCESS

After generating more than 160 individual concepts, 20 feasible ideas were selected and evaluated against the user requirements. All 160 ideas can be seen in Appendix A.1. From here, many of these 20 ideas were combined into fewer, more complete solutions using a concept merger; these solutions were then evaluated against the same user requirements. An alpha design was then chosen. The section below will outline the concept selection process and the chosen alpha design.

Concept Evaluation and Merging

To decrease the number of design concepts from 160 to 20, each of the four team members took five of their best concepts and presented them to the other team members. To ensure a wide variety of unique solutions were chosen, each team member chose five ideas that differed from the other members. Each member then evaluated their five concepts against the user requirements using an analysis table. This table included four rankings: green - the concept met the requirement well, yellow - the concept could meet the requirement if designed correctly, red - the concept did not meet the requirement, and gray - the concept was not intended to consider the requirement. The analysis tables for the 20 concepts can be found in Appendix B.1.

From here, the team combined concepts that only met a few requirements to create ideas that met more of the requirements. For example, one concept was to attach the smoke detector to the ceiling using tape. This design only met the "easy to install" requirement. Another idea was to take the detector off of the ceiling using a retractable pole. This design only met the "easy to maintain" requirement. Merging these two ideas together created a concept that is both easy to install and easy to maintain.

Selection of Top Five Concepts
Eight merged concepts were evaluated against the user requirements; these can be found in Appendix B.2. From the merged concepts, the five best-ranked ideas are shown below in Table 3.

Table 3: Final selected concepts evaluated against the user requirements.

	Drone for install and battery change	Tape to ceiling; solar power; access with pole	Tape to ceiling; access with pole	Light bulb detector; access with pole	Tape to ceiling; magnetic charging; access with pole
Quick to Install	Good	Good	Good	Good	Good
Easy to Install	Good	Good	Good	Good	Good
Easy to access	Good	Good	Good	Good	Good
Easy to maintain	Good	Good	Okay	Okay	Good
Lightweight	Good	Good	Good	Good	Good
Low cost	Bad	Okay	Good	Bad	Okay
Long-lasting	Bad	Okay	Okay	Okay	Okay

Some ideas from the concept merger met the user requirements better than others. While using a drone to install and change the batteries of a smoke detector met most of the requirements, it is likely to be costly and not a long-term solution (difficult to develop and maintain). Taping the smoke detector to the ceiling and installing it with a pole fulfills “quick to install”, “easy to install”, “easy to maintain”, and “lightweight”. However, this design is ranked “okay” for both low cost and long-lasting as the cost of the design and lifespan of the tape are unknown at this point. Using solar power to charge the battery of the detector meets the requirement “easy to maintain” as the batteries do not need to be changed. However, solar power only ranks “okay” for “low cost” and “long-lasting”as solar panels are an added cost to the design and solar panels degrade over time. Taping a smoke detector to the ceiling, accessing it with a pole, and using a standard 9V battery considers “quick to install”, “easy to install”, “easy to access”, “lightweight” and “low cost”, but the design may not be easy to maintain as the batteries still must be changed every six months. Putting a smoke detector inside a lightbulb and installing it with a pole fulfills “quick to install”, “easy to install”, “easy to access”, and “lightweight”. This design is “okay” for “easy to maintain” as the batteries may still need to be changed. The design is “bad” for “low cost” as shrinking the technology of a smoke detector may increase the cost. The design also was ranked “okay” for “long-lasting” as the lifespan is unknown at this time. Taping the smoke detector, installing it with a pole, and periodically charging the batteries with a magnetic charger fulfills the requirements “quick to install”, “easy to install”, “easy to access”, “easy to maintain”, and “lightweight”. This design only scores “okay” for “low cost” as magnetic chargers can be expensive and “okay” for “long-lasting” as the lifespan of the magnetic charger and tape are unknown at this point.

As seen in the table and discussed above, the three best-ranked concepts were: 1. Tape to the ceiling, solar power, access with pole, 2. Tape to ceiling, no change to power, and access with pole, and 3. Tape to ceiling, magnet charging, and access with pole. These designs were then compared to a standard smoke detector using a Pugh chart. A standard smoke detector requires a battery change every six months and requires a drill and ladder to install the device. The Pugh chart can be seen in Table 4 below.

Table 4: Pugh chart for final three concepts.

Requirement	Weight	Standard Smoke Detector	Tape to ceiling; solar power; access with pole	Tape to ceiling; access with pole	Tape to ceiling; magnetic charging; access with pole
Quick to Install	2	0	1	1	1
Easy to Install	2	0	1	1	1
Easy to access	2	0	1	1	1
Easy to maintain	2	0	3	1	2
Lightweight	1	0	0	0	0
Low cost	1	0	-1	-1	-1
Long-Lasting	2	0	-1	0	-1
Total Score		**0**	**9**	**7**	**7**

The three designs in the Pugh chart were agreed upon by the team as the top three designs. All of these designs include an assistive pole device that would allow the user to install and take down the smoke detector from a seated position. Each requirement was weighted with a weight of two, except for the slightly less important lightweight and low cost requirements. Although these are important for the final design to have, easing installation and maintenance are the top priorities. Each design was then scored from (-1) to 3 for each requirement. A -1 or 0 was given if the new design met the requirement worse or about the same as a standard smoke detector. A 1-3 was awarded if the design met the requirement better than the standard smoke detector. A solar powered smoke detector scored the highest with a score of nine, and the team agreed that this concept was the best with respect to the user requirements and engineering specifications.

The solar powered smoke detector scored highest for "easy to maintain" because the design removes any need for the user to take the detector down to replace a battery every six months. Additionally, a design that includes some type of an assistive pole for install and removal offers advantages in the installation and accessibility requirements of the project. Some drawbacks of the solar power design include a higher initial cost and a shorter overall lifespan of the detector. The shorter lifespan is due to the lifespan and degradation of the solar panels over time. Keeping these disadvantages in mind, the concept of solar rechargeable batteries is still the best overall concept.

Following a strict design process generated the best possible solution to the problem, as the initial ideas generated were not ideal designs. The initial concepts by the team only included disposable batteries or a detector that had to be taken off the ceiling to be maintained. The first idea was a smoke detector that could be put up and taken down with a pole to change the standard batteries every six months. After receiving feedback from primary stakeholders, it was suggested to leave the smoke detector on the ceiling. There was a slight amount of fixation during the beginning of the design process on needing a dismountable design, but that thought was overcome and did not affect the concept generation process overall. The team also became fixated on taping the detector to the ceiling. This fixation is corrected in the "Concept Iteration" section below. While there are currently solar powered smoke detectors on the market, they are not common in households and do not address the aspect of installation. The team hopes to create a realistic, usable design that fits the needs of the end user.

SELECTED CONCEPT DESCRIPTION AND ITERATION

A solar-powered smoke detector that tapes to the ceiling and uses a pole was chosen for the final alpha design. The alpha design will be described in detail below.

Alpha Design 0

The selected alpha concept will be powered by solar panels and a rechargeable 9V battery. The use of solar panels for the main power source is promising as there is a smoke detector model on the market that uses solar power. The alpha design is square-shaped, allowing for the attachment of rigid solar panels. Although there are flexible solar panels that could attach to a circular smoke detector, they are more expensive than flat solar panels and the design aims to be low cost. The overall dimensions of the design are 5.25" x 5.25" x 2.1". This is similar in size to the diameter of a standard circular smoke detector (6"). The detector will be attached to the ceiling using 3M tape. The alpha design can be seen below in Figure 6.

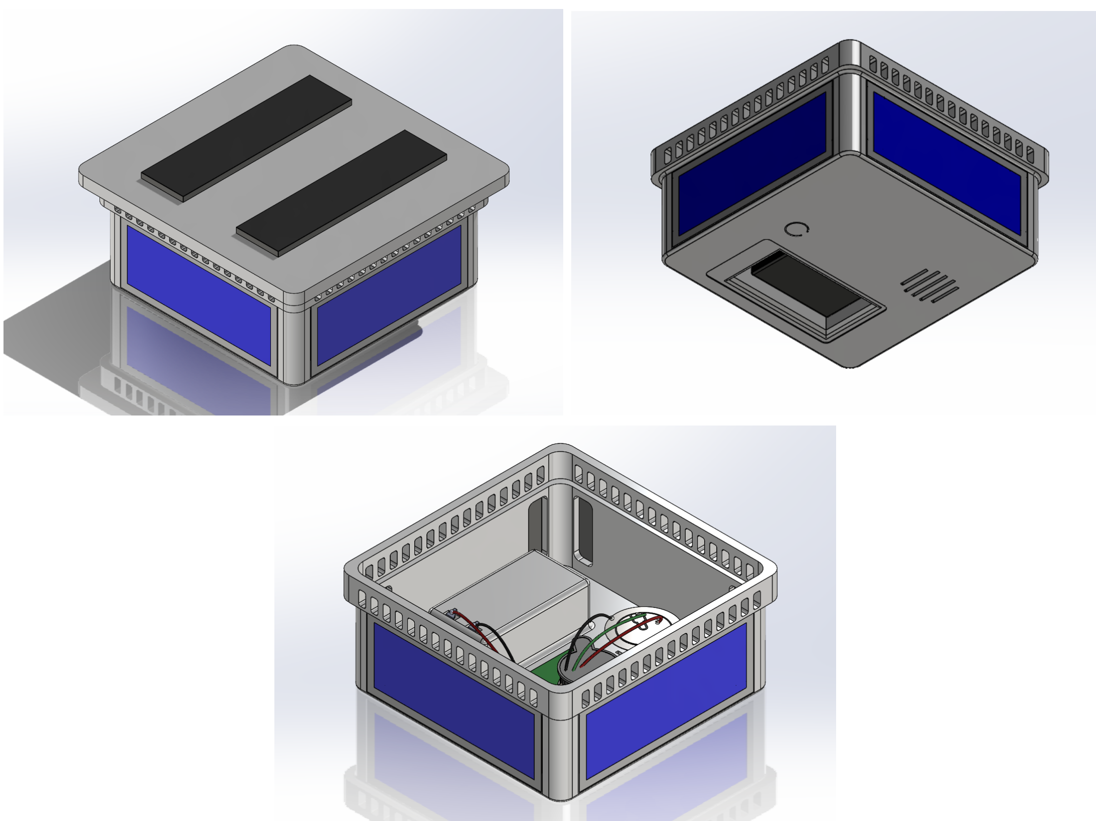


Figure 6: External and internal view of the alpha design.

Another component of the alpha design is the installation piece. The smoke detector will be installed with a cup-shaped installation piece that attaches to a pole. The base of the installation piece is made to fit a standard 0.75" diameter broom handle or extendable pole. Using a pole with the installation cup allows the smoke detector to be installed by a user who is seated. This part of the design meets the requirement "easy to install" and is aimed toward low-mobility and elderly users, as well as anyone who does not want to use a ladder. This installation piece can be seen below in Figure 7.

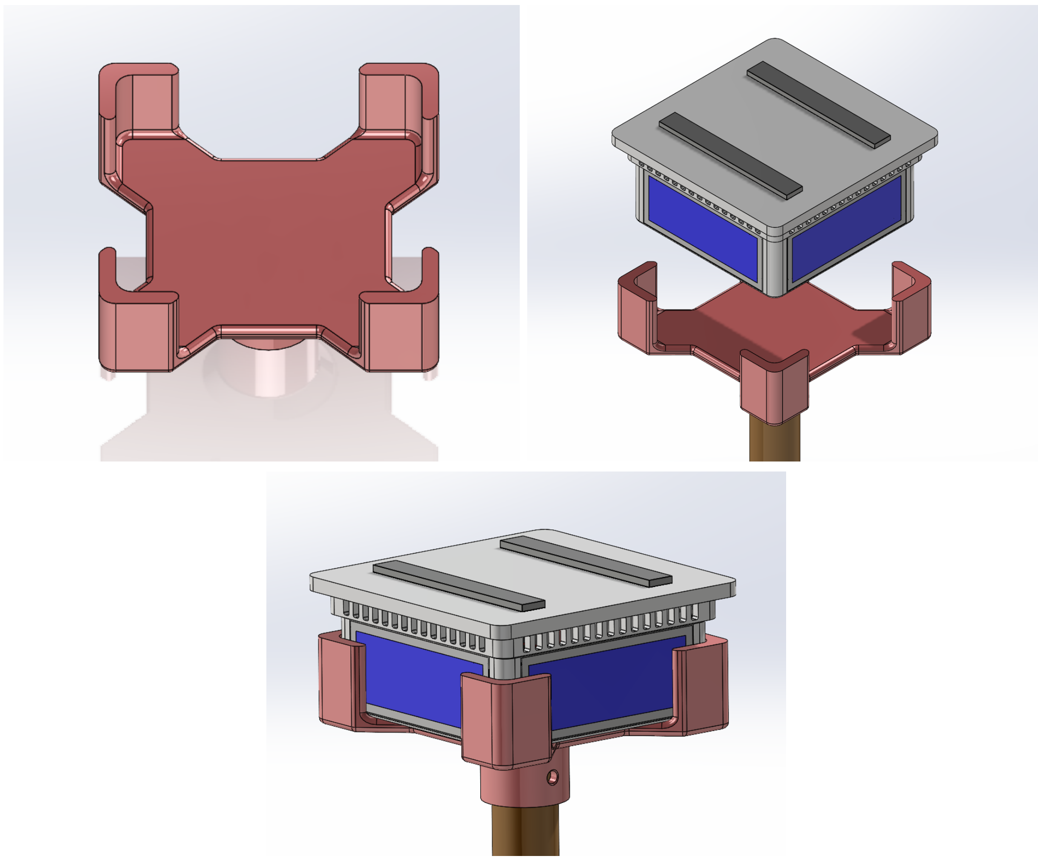


Figure 7: Installation design concept

To install the device, first attach the installation piece to the pole. Then, place the smoke detector into the installation piece and remove the backing from the tape. The user will raise the smoke detector to the ceiling and apply an upward force so the tape adheres to the ceiling. The user can then easily lower the installation piece and pole once the detector is attached. This process greatly improves upon the current smoke detector installation process which requires a ladder and a drill.

Once the smoke detector is installed, it has a lifespan of 5 years, which is limited by the lifespan of the solar panels. This problem will be further discussed in the Concept Analysis section. Since the battery is rechargeable, the batteries do not need to be changed by the user, making the smoke detector "easy to maintain".

To remove the device from the ceiling, the user will raise the pole and installation piece to ceiling and cup the smoke detector in the installation piece. The user will then twist the pole, thus twisting the smoke detector. This will remove the smoke detector from the ceiling by shearing the tape between the smoke detector and the ceiling. The user can then lower the smoke detector down and dispose after 5 years.

This alpha design should fulfill the requirement of "quick to install" as it is expected that taping the device to the ceiling will take less than 2 minutes. The alpha design is "easy to install" as the installation device (pole and installation piece) is the only required tool and the 3M tape is likely to stick to a surface roughness of 30 microns. The design should fulfill the requirement of “easy to access” since the installation piece is designed to allow a seated user to install/take down the detector. The design is “easy to maintain” as the batteries in the smoke detector do not need to be changed. The design is less than 0.7 lbs, which was confirmed using SolidWorks modeling. The design is aimed to be “low-cost” as replacement batteries do not need to be purchased every six months over the detector’s lifespan. The design is “long-lasting” as all parts in the model have a lifetime of at least five years. Whether or not the design actually meets the user requirements will be confirmed during testing.

The alpha design was chosen in an objective selection process without heavy sponsor influence. The team met with Nancy Cowles of KID and Johnathan Midgett of the CPSC to seek feedback only after the concepts were well-thought out. The evaluation in the Pugh chart was not “fudged” to satisfy the sponsor or Section Instructor - the team individually and objectively performed these tasks. The team however became fixated on taping the smoke detector to the ceiling, which may not be the best attachment method. More attachment methods will be considered with testing.

Following the Design Review 2 Presentation, feedback on the first alpha design was taken into consideration. The original method of attachment, taping to the ceiling, was not well received by the class. Using a twisting motion to disengage the detector from the ceiling may rip the paint or damage the surface of the ceiling. Additionally, a large force may be necessary to twist the tape from the ceiling, a force too large for the user to apply from 3ft above the ground. Based on this feedback, the team has decided to test various mounting techniques. The tests include mounting with tape, magnets, and plastic velcro. These designs and tests can be found in the ‘Engineering Analysis’ section below.

Alpha Design Iteration 1: Magnetic Ceiling Attachment

The first iteration of the alpha design is still solar powered and has the same internal design as the alpha design, however, the detector will now be attached to the ceiling using magnets. One set of magnets will be secured to the ceiling using 3M tape or epoxy and the second set of magnets will be attached to the smoke detector using a press fit with epoxy. Using magnets instead of tape gives the user the ability to take the detector down if it is not functioning properly. The orientation, spacing, and type of magnets will be determined with prototype testing. As of right now, it is assumed that round magnets on the device and rectangular magnets on the ceiling will be enough to hold the device. If testing proves otherwise, rectangular magnets can be used on both the device and the ceiling. These magnet types and orientations can be seen below in Figure 8.

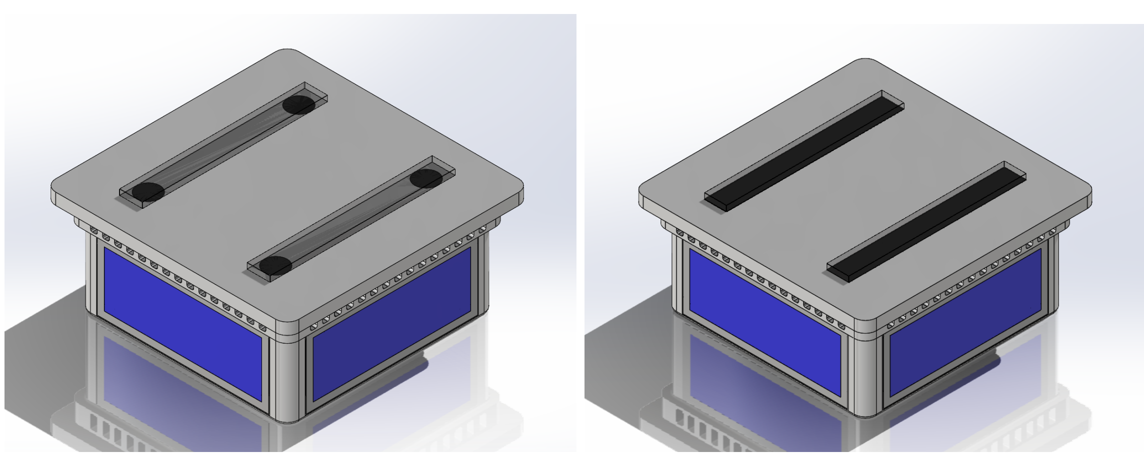


Figure 8: Magnet Orientations to be tested: (left) two rectangular magnets attached to four circular magnets and (right) two rectangular magnets attached to two rectangular magnets

To install the detector, the user will place the smoke detector in the installation piece attached to a pole and remove the backing of the tape or apply the epoxy. Then the user will raise the smoke detector to the ceiling and apply contact until the smoke detector is secured to the ceiling. The time will vary between tape and epoxy, since the epoxy will need time to set and cure. The time needed to properly set the smoke detector using epoxy will be provided with the device.

To remove the detector from the ceiling, the user will cup the smoke detector with the installation piece by raising the pole to the ceiling. By twisting the pole 90 degrees, the smoke detector will turn 90 degrees and the magnets will disengage; this process can be seen below in Figure 9. Once the magnets are repelling, the user can easily lower the smoke detector to the ground. The two bar magnets attached to the ceiling will remain on the ceiling, and the same detector or a new detector can be re-attached. This process is the same if two rectangular magnets were also attached to the detector.

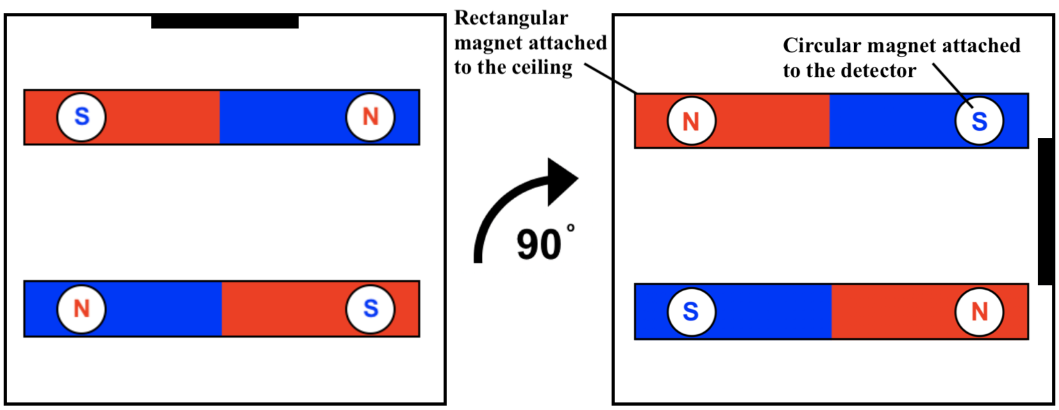


Figure 9: The smoke detector attached to the ceiling using magnets (left) and the magnets dis-engaged and the smoke detector unattached to the ceiling (right). This is the same concept for two rectangular magnets attached to two rectangular magnets.

It is anticipated that two rectangular magnets attached to two rectangular magnets is more secure and long-lasting than two rectangular magnets attached to four circular magnets. However, four rectangular magnets may be too strong and difficult to disengage and remove the device from the ceiling. This must be confirmed with testing along with the use of 3M tape or epoxy.

The use of solar power fits the user requirement of "low cost" as solar panels cost less than replacing the batteries every six months over 5 years. The solar powered detector will result in a cost savings of $26 per detector installation over 10 years; see Appendix C for calculations. Given the average home has five smoke detectors, the cost savings will multiply to $130 over the 10 year period [17].

ENGINEERING ANALYSIS

Aspects of the alpha design were analyzed, researched, and tested to prove the effectiveness of the design. The following steps were taken to further the design process.

Smoke Detector Circuit and Power

The internal circuit diagram of a photoelectric smoke detector can be found bounded in red in Figure 8. This portion of the circuit will be taken directly from the existing photoelectric smoke detector. The added solar charge component of the circuit is labeled in the green segment of Figure 10.

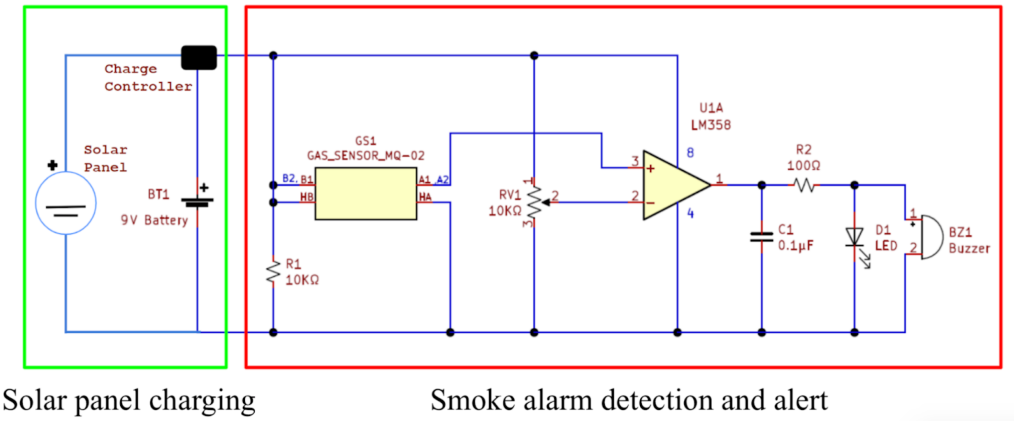


Figure 10: Circuit diagram of solar powered smoke detector design.

The solar charge component of the circuit includes the solar panels and charge controller. The charge controller effectively distributes power to the detector and battery from the solar panel. Per battery manufacturer recommendations, the solar panels will be wired both in series and parallel to supply the correct amount of current and voltage to the system displayed in Figure 11.

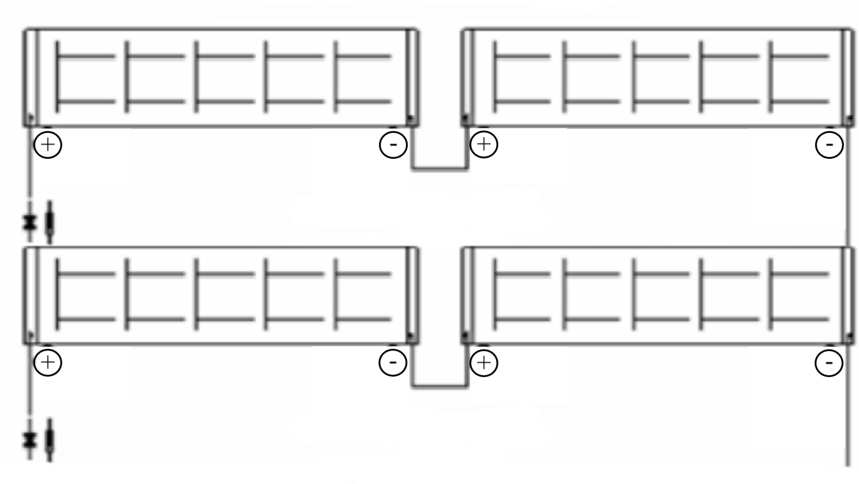


Figure 11: Four solar panel configuration

Smoke detectors require a consistent amount of power to the system to operate [25]. Current detector design requires the batteries to be changed once every six months to maintain these power requirements. To reduce or eliminate this maintenance, a solar panel can be used to supply a sufficient amount of power to operate the detector. To determine the power requirements of a detector to size a solar panel, two energy rate approximations, Equations 1 and 2, were used.

$$Total\ charge\ per\ day = solar\ panel\ power\ generation \times effective\ charge\ time$$

Equation 1: Power generation of solar panels

$$Total\ power\ dissipation = detector\ consumption \times [1/system\ efficiency] \times effective\ dissipation\ time$$

Equation 2: Power consumption of smoke detector

The solar panel power generation, as well as the detector consumption and system efficiency, were provided by the respective manufacturers Solar Made Online [26] and Kidde [7].

A lux is the SI derived unit of illuminance, measuring luminous flux per unit area. One lux is equal to one lumen (one candle) per square meter [27]. The average room receives 200 lux, which is estimated to produce 5.76 mW of power through the selected solar panels. A standard smoke detector consumes 4.84 mW per day. Since the power produced by the solar panel is larger than the power consumption of the detector, the smoke detector should be able to run for its entire lifecycle of 5 years in an average light setting.

In a low light room at about 25 lux, the solar panel will not be able to generate sufficient power to run the detector [27]. The solar panels are estimated to produce only 0.72 mW of power a day in comparison to the 4.84 mW drawn by the detector. Given this loss, the detector will be able to run for approximately 3.6 years before either needing a new battery, or being charged by a more intense light source. To extend the battery life, it is estimated that shining a flashlight or ceiling lights on the device for two days every 6 months will restore the battery life to its full 5 years. This idea will be confirmed with testing.

To validate the power generated by the solar panels, the solar panels must be tested. This will be done by first wiring the solar panel to a multimeter and collecting the voltage and current readings in a low-light room. Then, the orientation of the panel will incrementally change by 15 degrees until it is parallel to the ceiling, each time measuring the voltage and current outputs. Also, at each orientation, the solar panel will be moved closer and farther from the nearest light source as represented in Figure 12. All procedural steps will be repeated in standard room lighting (200 lux).

Figure 12: Solar Panel Orientation to light source

The results of this test will provide empirical evidence of the solar panel operation in both standard and low-light conditions. If power generation and dissipation values are similar to the preliminary analysis, then the currently selected solar panels will be used. If the power generation values are too low, then the orientation and solar panel configuration will be changed.

A typical lifespan of a nickel metal hydride rechargeable battery is around 5 years, and the battery has up to 1000 recharges before significant degradation [28]. Since the battery of the detector will not be depleted 100% every day, the battery lifespan should last up to the 5 year mark established in the design requirements. The solar panels chosen for the design degrade on average about 1-2% per year of use [26]. They are rated to have a lifespan of around 5 years, making them sufficient for the final design.

Power Generation Testing Results

After the second design review, there was concern that mounting the solar panels perpendicular to the ceiling would not generate the most power. To analyze the power generation and the best orientation for mounting the solar panels, one solar panel was mounted to the lid of a box with similar dimensions to a standard smoke detector. From here, the angle between the ceiling and solar panel varied from 0 (parallel to the ceiling) to 90 degrees (perpendicular to the ceiling), and an ammeter was used to read the voltage generated by the solar panel at each orientation. This procedure was conducted in both a standard-light room (~ 250 lux) and a low-light basement (~ 50 lux). The testing setup can be seen below in Figure 13.

Figure 13: Solar panel power generation testing.

The testing results can be seen in Table 6.

Table 6: Solar panel power generation vs. orientation of solar panel from ceiling.

Solar Panel Orientation	0° from Ceiling	30° from Ceiling	45° from Ceiling	60° from Ceiling	90° from Ceiling
Standard Room	0.163 mW	0.169 mW	0.173 mW	0.176 mW	0.178 mW
Low-light Room	0.017 mnW	0.027 mW	0.032 mW	0.046 mW	0.046 mW

From this test, it was determined that there was maximum power generation when the solar panel was 90 degrees (perpendicular) to the ceiling. In a standard light room, one solar panel generated 0.178 mW; in a low-light room, one solar panel generated 0.046 mW. Since the design uses 4 solar panels, 0.712 mW should be generated in a standard room and 0.184 mW generated in a low-light room. The smoke detector requires 0.202 mW to operate, therefore, sufficient power should be generated, especially if the smoke detector is placed near a window in the low-light room.

Ceiling Attachment Method Testing

Tape, magnets, and Velcro were considered for attaching the smoke detector to the ceiling; testing was performed to select the best attachment method. When selecting an attachment method, priorities included the ability to disengage the detector from the ceiling via twisting, and the attachment method must be able to stick to the ceiling for at least 10 years. Since the lifecycle of the smoke detector is about 5 years, the team wanted to ensure the attachment method did not fail prematurely. Also, if the attachment method lasts 10 years, this would allow the user to reinstall a new smoke detector once the old one fails in the same spot. Since the installation piece requires a twisting motion to remove the smoke detector from the ceiling, it is vital that the smoke detector can be twisted without damaging the ceiling. Figures 14 and 15 show examples of testing for each concept.

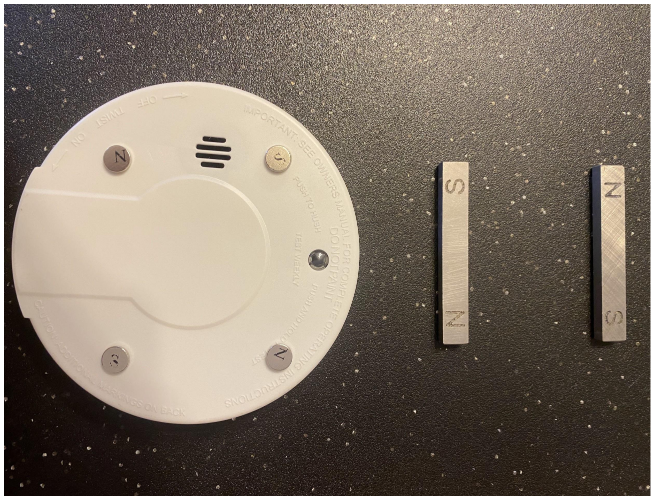


Figure 14: Testing of magnetic installation concept.

To test the magnets, 3M tape was applied to one side of the bar magnets, and the bar magnets were then attached to a flat surface. 3M tape was also applied to four round magnets, which were then attached to the outside of a standard smoke detector. Once the magnets were attached together, a team member then twisted the smoke detector to disengage the magnets from one another. This procedure was conducted with four circle magnets attached to two bar magnets, and two bar magnets attached to two bar magnets. It was found that it was very easy to twist the magnets to disengage the smoke detector with both magnet arrangements. It was also found that the 3M tape between the bar magnets and the flat surface did not fail when twisted.

Figure 15: Testing of velcro installation concept.

To test Velcro as an attachment method, one piece of Velcro was attached to a flat surface and another piece of Velcro was attached to a smoke detector. From here, a team member twisted the smoke detector to try and shear the Velcro from itself. One team member could not move the smoke detector at all, and when another team member twisted, the adhesive failed between the flat surface and the smoke detector. Velcro was then abandoned as an attachment method since the adhesive failed before the Velcro could detached from itself. Using Velcro would make it impossible for someone to use the installation piece to twist the detector off the ceiling.

Ceiling Attachment Method Results

Once the results were analyzed, it was determined that attaching magnets to the ceiling and the smoke detector would be the best method for installation. Using magnets allowed for an easy removal process without damage or failure to the magnets or the flat surface. Although the testing was conducted with bar magnets, circle magnets will be used for both the ceiling and the smoke detector. Bar magnets were a significant cost driver for the final design because they are difficult to manufacture (~ $8.00/magnet). Circle magnets will be used because they have the same strength as the bar magnets at a much lower cost (~ $0.40/magnet). The cost for the magnets and the final magnet arrangement can be found in the 'Final Design' section below.

Ceiling Attachment Lifespan Research

The main concern with the lifespan of the ceiling attachment is the adhesive as magnets essentially do not degrade over time. Magnets with 5 lb pull force are more than sufficient to hold the design with a weight of less than 0.7 lbs. While 3M VHB Tape is only warranted for a shelf life of two years, it is proven to last much longer than that. In testing performed by 3M, it was found that 3M tape retained almost 100% of its tensile strength after 5 years of outdoor weathering in Minnesota. Additionally, 3M VHB Tape still had high performance after 10 years of submersion in water [29]. Since the smoke detector is expected to be in dry, climate-controlled homes, the tape should last at least 10 years.

To ensure the magnets and tape could hold the smoke detector once it is attached to the ceiling, the team also performed physical testing. A standard smoke detector was attached to a ceiling-like structure, and various weights were hung from the smoke detector. The tape and magnets could hold 2.5 lbs without failure, which is well above the 0.7 lb requirement. This test can be seen in Figure 16.

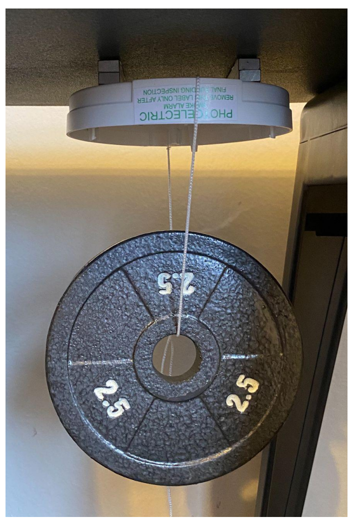


Figure 16: Testing ceiling attachment load

FINAL DESIGN DESCRIPTION

The final design will be a solar-powered smoke detector with an installation piece for easy installation and maintenance. A flat magnet housing with four ½" round magnets (12 lb pull force) will attach to the ceiling using 3M tape. The smoke detector is attached to the magnet housing with four ⅜" round magnets (5 lb pull force). The smoke detector is raised to the ceiling using the installation piece and pole to attach the detector to the magnet housing. The lifespan of the smoke detector is 5 years due to the lifespan of the solar panels. The lifespan of the 3M tape used to attach the magnet housing to the ceiling is expected to last at least 10 years [29]. The final design can be below in Figure 17.

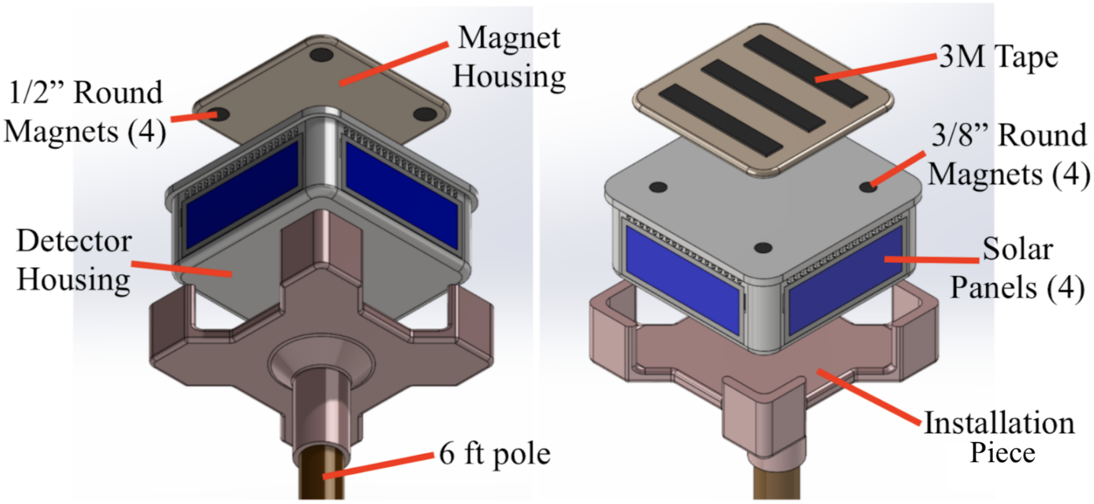


Figure 17: Final smoke detector design.

The design will come with the 3M tape pre-attached to the magnet housing. The magnet housing will be placed on the detector housing and the user will peel the backing off of the 3M tape. Then, the user will raise the magnet housing and detector to the ceiling using the installation piece and apply upward pressure for 30 seconds, as directed by the 3M. Now, the entire set-up (magnet housing and smoke detector) will be attached to the ceiling.

Detector Housing

The detector housing holds the circuit components and battery. The dimensions of the smoke detector housing are 4.9" x 4.9" x 2" with a wall thickness of 0.08 inches. The material of the smoke detector housing is ABS and has a weight of 0.16 lbs. Since the detector housing will likely bear any loading, a uniform, thin wallthickness was chosen (ideal for injection molding). There are vents for the smoke to enter the device, a button to disable the alarm, and a low-battery light. The part can be seen below in Figure 18.

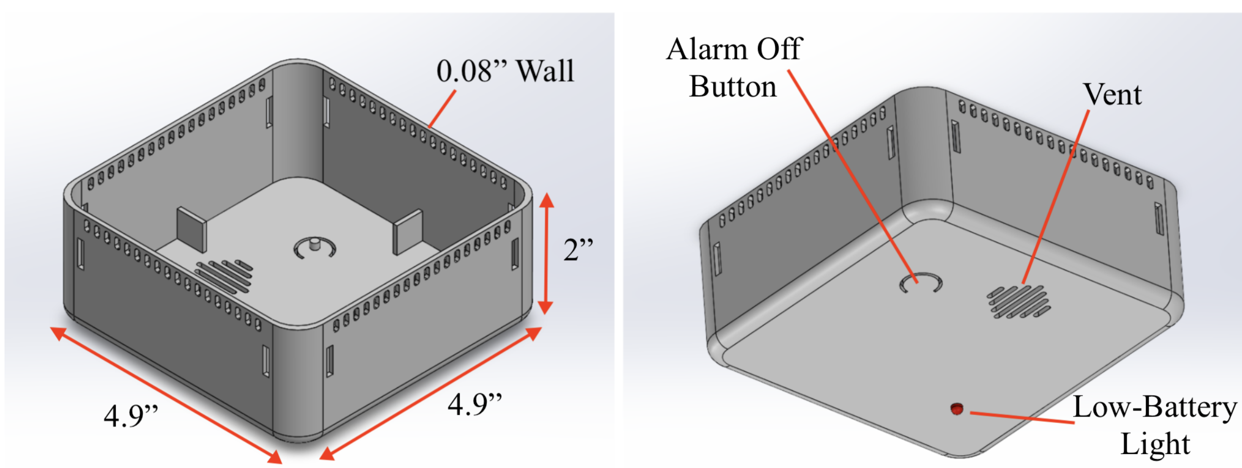


Figure 18: The detector housing.

Lid

The lid will seal the detector housing after the inside circuitry is assembled and installed. The dimensions of the lids are 5.14"x 5.14" x 0.28". The lid is made of ABS and the weight is 0.25 lbs. Although the lid is also made of ABS and will be injection molded, it was given a larger thickness due to the width of the four 3/8” magnets within the lid. The magnets are press-fit and epoxied into the lid. The lid is press fit and epoxied to the detector housing. The part can be seen below in Figure 19.

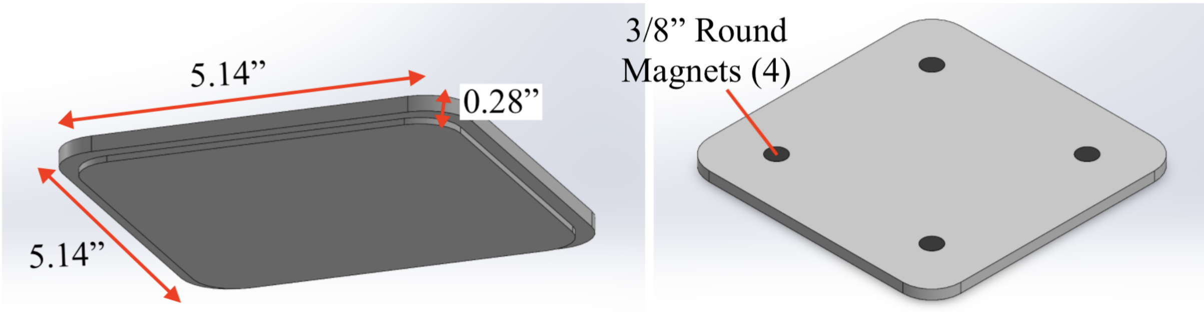


Figure 19: The lid of the detector housing.

Installation Piece
The installation piece attaches to a ¾” diameter pole, which is the diameter of a standard broom handle [30]. The dimensions of the installation piece are 5.4” x 5.4” x 4.0” with a maximum wall thickness of 0.2”. The material of the installation piece is ABS and the weight is 0.46 lbs. The installation piece can be seen below in Figure 20.

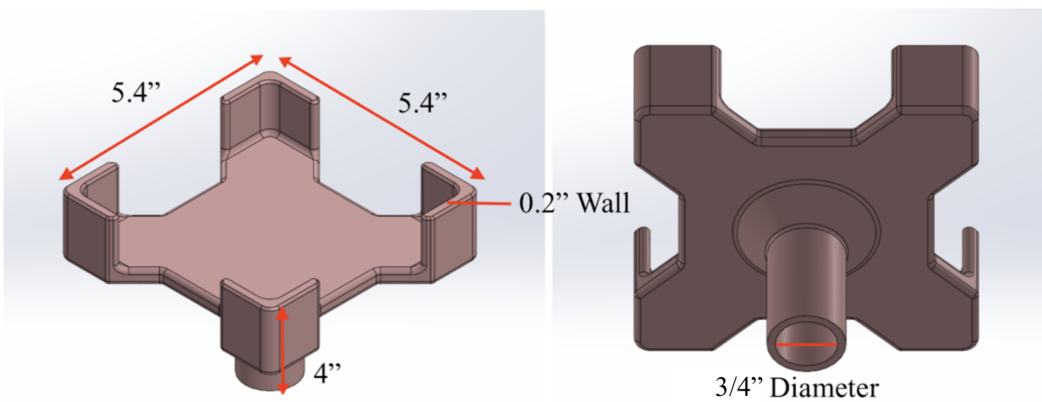


Figure 20: The installation device.

Magnet Housing
The magnet housing attaches to the ceiling with 3M tape and to the detector lid with magnets. The dimensions are 4.25” x 4.25” x 0.2”. The material for the magnet housing is ABS and has a weight of 0.12 lbs. Again, the magnet housing was designed with a larger thickness to properly house the magnets within the part. There are four 1/2” round magnets in the magnet housing. These magnets are press-fit and epoxied into the housing. The part can be seen below in Figure 21.

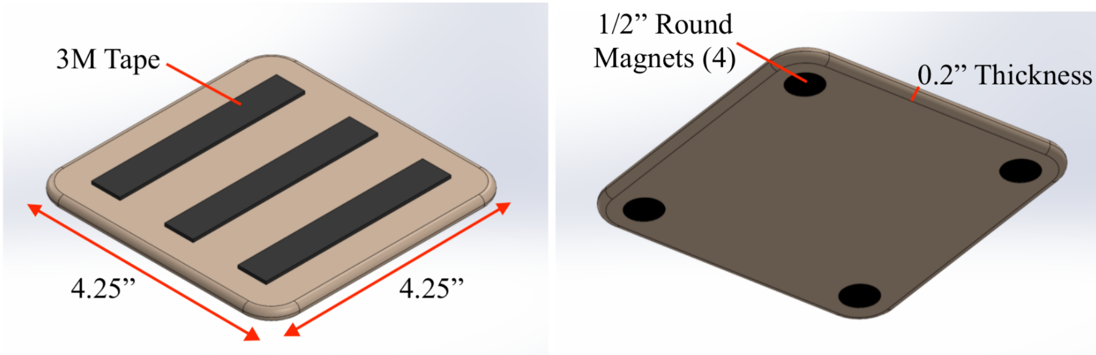


Figure 21: The magnet housing.

The final design will also include a picture-led instruction manual that will walk the user through each step of the installation process. Also, a QR code will be provided in which the user can scan using the camera on their smartphone. This will lead them to a youtube video in which the user can watch how the smoke detector, installation piece, and magnet housing is used and installed.

Mass Manufactured Design Bill of Materials

Below is the bill of materials for high volume production (1 million units) of the smoke detector. As there are almost 140 million homes in the United States [31], this is a conservative estimate of units produced. Ansys Granta-Eco Audit was used to predict the material and manufacturing cost for each component; components with part numbers will be outsourced, therefore there is no manufacturing cost. See Appendix D for the full Eco-Audit. Since most of the manufactured parts will be injection molded, the mold itself was factored into the assessment with an estimated cost of $50,000. Table 7 lists the bill of materials for the final smoke detector design.

Table 7: Bill of materials of the final design.

Component	Material Cost ($)	Manufacturing Cost ($)
Detector Housing (ABS)	$0.16	0.25
Lid (ABS)	$0.09	0.22
Installation Piece (ABS)	$0.37	0.24
Magnet Housing (ABS)	$0.09	0.22
0.5” Round Ni-Cu-Ni Magnets (4) [32]	$1.16 Amazing Magnets, D049C	N/A
0.5” Round Ni-Cu-Ni Magnets (4) [32]	$1.60 Amazing Magnets, D040D	N/A
Solar Panels [33]	$1.02 XRSolar, XRT-12750.8-3V350M	N/A
9V Battery [34]	$2.07 CW, 7.2-1800	N/A
1.5 ft of 20 Gauge Wire [35]	$0.01 Triumph Cable Co., UL2464	N/A
Charge Controller [36]	$2 Shenzhen Electronics Co.,1823232721	N/A
Photoelectric Sensor [37]	$0.20 Shenzhen Technology Co., LM393	N/A
Circuit Board [38]	$1 Shenzhen Electronics Co.	N/A
Diode [39]	$0.005 XUYANG, 1N4001	N/A
Epoxy [40]	$0.0001 Yixing Chemical Co., C39H36O7	N/A
Packaging, Box	$0.0048	N/A
Packaging Foam	$0.0065	N/A
Total	**$9.79**	**$0.93**

The detector housing, lid, installation piece, and magnet housing will be injection molded if mass manufactured. Injection molding the installation piece and detector housing may require multiple pieces that would be attached together later. All other parts will be purchased through various suppliers such as the sources listed in Table 7.

The internal circuit and soldering of the wires to the solar panels will be completed on an assembly line. The solar panels will then be attached to the outside of the detector housing using epoxy. All wires and the battery will be placed into the detector housing and the lid will then be press-fit and epoxied to the detector housing. Four ⅜” circle magnets will then be press fit and epoxied into the lid. The magnet housing will also have four circle magnets that are press fit and epoxied into it. Once each of these pieces are completely assembled, they will be packaged and shipped with the installation piece.

BUILD SOLUTION

A build solution was necessary to verify the power generation of the solar panels and the installation piece; the build solution was created using 3D printing and purchasing ready-to-order parts. The wall thickness of the build design is thicker than the final design as the build design was 3D printed, not injection molded. The build solution can be seen below in Figure 22.

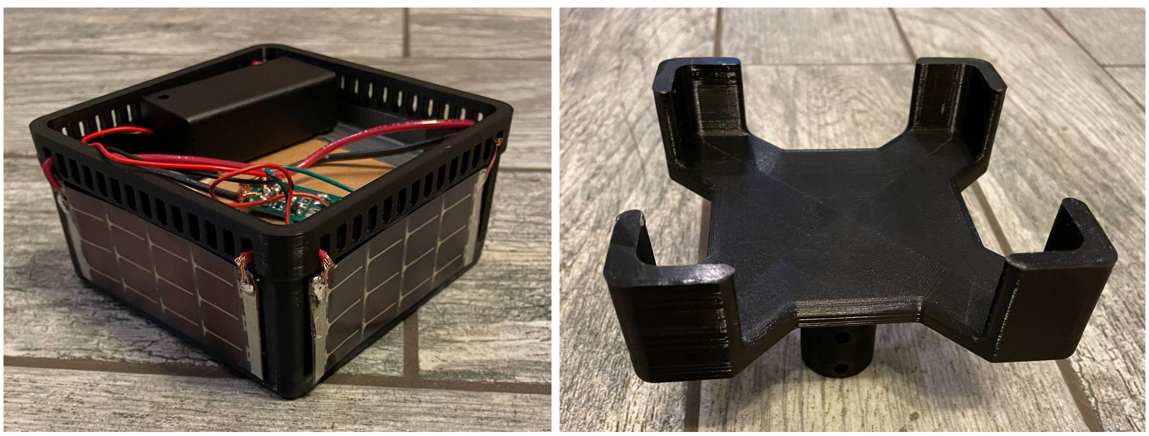


Figure 22: The build solution used for verification plans.

Build Solution Manufacturing Plans and Bill of Materials

The build solution was created by first 3D printing the detector housing, lid, and installation piece from PLA plastic in the north campus X50 laboratory. The remaining parts were purchased either in a local hardware store or from an online retailer. The four solar panels were purchased from Solar Made Online [26], the charge controller from Acxico [41], the bar magnets from Dowling Magnets [42], the diode, the battery, the battery housing, and smoke detector from Amazon [43], and the wiring, circle magnets, and 3M tape were purchased from HomeDepot [44]. The solar panels were attached to the housing using super glue. The solar panels were then soldered to the charge controller, diode, battery housing, and sample smoke detector circuit to complete the closed circuit. These components were placed within the detector housing to complete the build solution. The manufacturing process and material or the supplier, part number, and cost can be found in Appendix E.

The tolerance between the installation piece and the detector housing is critical for the final design to function as intended. There must be ample room so that the two pieces fit together with minimal effort, but there cannot be a gap wide enough that limits the function of the installation piece. Also, the tolerances between the magnets and holes within the lid and magnet housing will be critical. If the holes are too small, the magnets wont fit which will cause the need for re-manufacturing or disposal of the piece (increase in waste). If the holes are too large, the magnets could become detached from the lid or magnet housing which will prevent the smoke detector from functioning properly. A final focus of tolerance will be on the flat plate that houses the magnets. This plate must have a small tolerance to keep the plate as flat as possible, allowing for a secure connection to the ceiling. Places where tolerances are less important include the circuit housing inside the detector, the size of ventilation holes, and the sides on top of the detector. Each of these elements can have a wider tolerance range, as they are not involved with high accuracy components.

The build design was much more expensive than the projected cost for the final design. Creating a prototype was necessary to verify the power generation of the solar panels and the installation process using the installation piece. The build was necessary to verify several requirements: “easy to install”, “easy to maintain”, and “long-lasting”. While some build model testing was performed with different arrangements and shapes of magnets than the final design, the build model was able to prove the concept of magnets and the installation piece.

VERIFICATION AND VALIDATION PLANS

The final design must be verified and validated to ensure the design meets the user requirements and functions as intended. The verification plans and validation plans are described below.

Verification Plans

The following verification methods will be used for each user requirement; the methods are explained in Table 8. Each requirement has either been verified by the team or has a plan of verification in place. The third column in the table indicates the status of each verification plan, with “pass” indicating a successful verification and “not completed” indicating a future test is required for completion.

Table 8: Verification plan and results for each user requirement.

User Requirements	Verification Plan	Results
Quick to install	Timed user trials	Not able to complete
Easy to install - 1 required tool	Demonstration	Pass
Easy to install - roughness up to 30 μm	Physical testing	Pass
Easy to access	Physical testing	Not able to complete
Easy to maintain	User testing	Not able to complete
Lightweight	Virtual testing	Pass
Low cost	Virtual testing	Pass
Long-lasting	Physical testing and research	Pass

To verify that the design is “quick to install - less than 3 minutes to install”, timed user trials will be performed. Users will be giv en an installation guide and the design; they will be timed while performing the installation process. This testing must be done by various user groups to ensure that all users can perform the actions within 3 minutes. This testing cannot be performed by just the team members as they are all the same age and of the same physical capabilities. This method is limited for the project as finding users this semester to test the design is not possible nor expected. For initial verification, team members performed the installation process and successfully met the requirement.

To determine if the design is “easy to install - 1 required tool”, a demonstration test will be conducted with a variety of different users. The participants, each of different age, gender, and mobility will be given the installation piece and a pole and will demonstrate themselves using the installation tool. Feedback about how the design works for their personal ability, including any positive and negative comments, will be recorded by the team and used to verify the success or failure of the design. Letting users test the installation piece and getting their unbiased feedback is the best way to ensure if the design verifies the requirement of easy to install with only one tool. This method is limited for the project as finding users this semester to test the design is not possible. Team members have verified through preliminary testing that the current design is easy to install using one tool.

The requirement of "easy to install - surface roughness up to 30 microns" has been verified by the team through physical testing. The build solution was mounted on several surfaces: a smooth painted surface, drywall, wood, and a drop ceiling tile. After successfully mounting the build design on surfaces up to 30 microns in roughness, it was concluded that the design verifies the set requirement of "easy to install". Further verification was performed through research of 3M tape specifications for various mounting surfaces. These two actions were decided on as the best form of verification for this requirement, and no further verification will be necessary.

To verify the solution is "easy to access - users can access the detector from 3 feet above the floor", each team member used the installation piece and a 6' extendable pole to reach the detector from a seated position. This requirement could be verified without user participation, since it does not rely on the physical ability or age of a user. Members sat in a chair 3 feet above the ground and demonstrated reaching up, taking down, and putting back up the build solution. Each member was able to reach the detector at ceiling height with ease. As a result, the requirement of "easy to access" was deemed verified.

The requirement of "easy to maintain - less than two minutes to demount" was initially verified by team members. Each team member used the installation piece and a 6' extendable pole to remove the detector from the ceiling in less than two minutes. It took an average of 15 seconds for a team member to demont the smoke detector (extend the pole to the ceiling, twist the detector, and lower the detector to the ground). Future verification plans include testing the same process with users of different ages and physical abilities. The testing performed is limited as the team members performing the test were of the same age and physical ability. This would be addressed with further user testing.

Verification of the "lightweight - less than 0.7 pounds" requirement was performed through virtual testing and research. The team used SolidWorks weight simulator to calculate the weight of the injection molded plastic components with a wall thickness of 0.08 inches. The team researched the weight of non-plastic detector parts, such as the circuit board, battery, and magnets. The final estimated weight was 0.43 pounds. This verified that the requirement of "lightweight" was fulfilled. The final weight may change slightly as the design goes through manufacturing phases, but should not have any drastic changes that increase the weight over the required limit.

The requirement of "low cost - smoke detector less than $20 (manufacturing) cost" was verified using virtual testing, and research. Using the SolidWorks cost simulator, the Ansys Granta Eco Audit Tool, and quotes from manufacturers, a final estimated cost for each detector was $9.79. This cost assumes injection molding 1,000,000 parts for each plastic component and a $50,000 injection mold die cost. This verifies the requirement of "low cost - less than $20 (manufacturing) cost". The results of this verification test may be limited due to the high volume of product assumed for injection molding cost calculations.

To verify the design is "long-lasting - lifespan of at least 5 years", research was conducted on the lifespan of all components. The solar panels are the limiting component of the design as they are only rated for a 5 year lifespan. The team also considered the lifespan on the tape used to adhere the design to the ceiling. Through research of 3M tape specifications and tests conducted by 3M, the team concluded that the tape will last at least 10 years [45], and fulfills the requirement of "long-lasting". This verification testing was limited by the information published by 3M.

The final design has either passed the verification testing or is predicted to pass future verification testing that requires a diverse group of users for testing. The specifications that have been met are confirmed with numerical testing results or research. The stakeholders should be confident that the design meets the user requirements as they have been thoroughly tested or planned to be tested.

Validation Plans

While design validation is out of the scope for this semester, several questions would need to be answered using market-based testing. To validate the final design, the questions that must be answered are: do users prefer a five year lifespan for a smoke detector over changing the batteries every six months? Are users willing to buy a smoke detector with these features at this cost? Are users willing to buy and store a tool specifically for their smoke detector? Does the proposed design meet all regulations for smoke detectors? For regulatory compliance, the team must also answer "does the design meet all smoke detector regulations?"

As the stakeholders better understand the solution, the specifications may change to adapt new thoughts and ideas. Part of the validation process involves the team introducing a finalized product to multiple user situations, putting the detector up in homes and buildings across the United States. Many of the questions to validate the design, described above, rely on users interacting with the detector as they would a current detector. Every validation question is not possible with short term analysis. Some, such as a willingness of a user to buy and store a tool, or does the design meet smoke detector regulations, may be answered with a survey or research. Other validation questions such as if users prefer a five year lifespan over changing the batteries every six months and if they are willing to buy the design at estimated costs cannot be answered until the product is on the market for an extended period of time. Thus, ample observation time after the final design is produced must be allotted for complete verification of the smoke detector design.

DISCUSSION

This section will discuss the problem definition, design critique, specification difficulties, further problems, and final deliverables.

Problem Definition

The problem definition started with emphasis on children in homes, then quickly changed to encompass the parents and their actions regarding smoke detectors. If more time and resources were available, there are more questions which could have been answered. The user interactions with smoke detectors would have been further studied as current smoke detectors are not effective due to user error. While the solution from this semester has been intended to increase ease for the user, there are still unknowns. For example, are users more likely to use the nuisance alarm button or do they take the detector off the wall when it beeps? Observational studies and focus groups would be used to explore these questions. Studying how people interact with the final design and currently available smoke detectors would give insight to how to adapt the best solution.

Design Critique

The team was able to perform physical and virtual testing on the design. The physical prototype was used to test the solar panels, the installation process, and the ceiling attachment method. The strengths of the design include the ease of installation and maintenance in comparison to traditional smoke detectors. The magnet design from the prototype was able to be installed in less time and with less tools than current detectors. The prototype also takes less time to take on and off the ceiling as well. The weaknesses of the design include the aesthetics and operation in low light conditions. The prototype is large and boxy, which is not desired by users. Additionally, in low light settings (basements with a few windows) the detector is unable to operate the full five year lifespan. Larger solar panels or a more efficient circuit would increase the lifespan in low light settings. Larger solar panels would provide more power to the detector. However, users may not want a larger smoke detector.

There are aspects of the design that would be changed after reflecting on the semester. The installation device could be adaptable so it would fit on a variety of poles. The installation piece could be adjustable to fit many shapes of detectors. Future modifications also include using thinner wire for the electrical connections. The 14 gauge wire used for the prototype was oversized for this application.

Specification Difficulties

Many of the engineering specifications, such as keeping installation under three minutes, mounting to a surface roughness of less than 30 microns, and keeping the time to change the battery under two minutes required a working prototype that is able to withstand these tests. These specifications rely on the creation of a functioning prototype to put through the testing necessary to verify the proposed specifications. The team must stay strict to desired deadlines to ensure that a prototype will be created in a timely manner. If the decision was made further into the semester that a prototype will not be created in time to test properly, the team will have a couple of options. More in depth CAD modeling and simulations could be conducted, or a less accurate yet functional prototype could be used to make it through testing. Both of these options will be weighed if needed, and decided as a team.

Another difficulty lies in the material required for the analysis of the engineering specifications. With the current specifications, various testing will need to be performed on the prototype. Mounting to various surfaces will need to be tested to ensure the design can attach to surface roughnesses equal to or less than 30 microns. The design must mount to different ceiling types that are found in homes. This means getting access to materials to simulate ceilings such as drop ceilings and drywall to test the design. Having a variety of materials and need for a testing platform might cause issues in time and cost; thus, the specification could have to be simplified to a singular, most common ceiling type. Further problems may arise when testing the quick to install and easy to maintain user requirements. To be tested, these requirements require a mounting surface, which relies on the prototype again and the resources available to the team.

Further Problems

Foreseeable problems also come to mind when thinking about end user engagement throughout the project. To test multiple of the engineering specifications, it would be best to have a realistic user of a smoke detector engage in time trials. The most realistic results would come from actual end users of the product. This may pose a problem due to COVID-19 precautions, and the willingness of participants for in person testing is unknown.

The team also does not know how the end user currently values the importance of a smoke detector, creating further boundaries in gaining valuable testing results. There is a general sense of importance known to the team about having the best smoke detector design, but this may not correlate to getting the desired engagement.

Along with the difficulty of getting valuable user engagement, the team may face a challenge when it comes to a finished design. It is expected to be a long process involving multiple governmental regulations and approvals to implement any new smoke detector design. This may seem unnecessary to focus on as a semester-long project for the team, but it poses a problem when thinking about how the design may impact current smoke detector users. The team thinks it is valuable to receive feedback from users installing the final design in their own homes, but getting results may take years of implementation with the prototype.

Final Deliverables

The final deliverable is a smoke detector design that can store energy from solar capture, detect smoke, and is able to be easily installed and maintained. The deliverable also includes a prototype that is used to perform verification testing. The final design has been verified for most of the specifications. However, further user testing and validation is needed to ensure the targeted user group can install and maintain the device in less than three minutes and two minutes, respectively.

REFLECTION

The following sections outline the societal, environmental, and economic impacts of the design and the factors that have impacted the design process and final design.

Societal Impact

The design of smoke detectors has a large societal impact; a more accessible design would make homes safer for everyone in the home, regardless of age. It is in the interest of public health and safety for every home to have functioning smoke detectors, as it reduces the risk of dying in a house fire by 55% [3]. Any design that makes smoke detectors more likely to function properly in a home will increase safety. Additionally, consumer education on smoke detectors may be important for the project to succeed.

While smoke detector users will be positively impacted by the project, there may be stakeholders who are negatively impacted. The use of non-recyclable plastics and mass manufacturing have a negative environmental impact that affects everyone, not just users of smoke detectors. Ensuring that the design is manufactured with a fair salary and safe working conditions is important, or there could be a negative social impact. Additionally, outsourcing the manufacturing of the design could have a negative social impact for the local community due to less local jobs. The societal impact was visualized through a Stakeholder Map.

The project sponsor, KID, prioritizes social impact and education over other impacts, such as profit and environmental impact. As KID is a non-profit organization dedicated to protecting children, their main focus is safety. The priorities of KID will impact the smoke detector design. The targeted audience of the project has been narrowed down to the elderly, people with limited mobility, and low income families; this is a user group suggested by KID. This suggestion from KID will have a positive societal impact as frequently products are not designed for these users.

Economic Impact

There is both a positive and negative economic impact associated with the smoke detector design. While the solar-powered detector may have a larger up-front cost than a standard smoke detector, there is no cost associated with purchasing batteries. There is a positive cost savings associated with the design. A solar-powered smoke detector would create a new product on the market and manufacturing a new smoke detector design may create new jobs.

Environmental Impact

While there is a positive social impact of the project, there may be a negative environmental impact. According to the latest Census, there are currently 139,684,244 housing units in the United States [31], and in each of these homes there are multiple smoke detectors installed. An impactful design change to smoke detector design could lead to the replacement of some of these 100,000,000+ smoke detectors in the United States. The environmental impact was evaluated using Granta EcoAudit found in Appendix E. The raw materials and manufacturing process of smoke detectors must be considered for the environmental impact of the final design. The manufacturing of smoke detectors also emits pollutants, and ionization smoke detectors contain a radioactive material, americium, that is dangerous for humans in large amounts [24]. There are also many metal components in the smoke detectors such as the circuit board and sensing chambers. The plastic housing of smoke detectors are injection molded which has little plastic waste.

The use of current smoke detectors has a negative environmental impact due to batteries. Most smoke detectors on the market use a 9V battery as either the main power source or the backup power source. The 9V battery is recommended to be replaced every six months. The batteries can be recycled or thrown away after this timeframe. The use of solar power would reduce the total number of batteries needed during the lifetime, decreasing lifetime cost of power and waste during the use of the product.

Current smoke detectors are thrown away at the end of life or can sometimes be shipped back to the manufacturer for disposal. Since smoke detectors are composed of both metal and plastic components, they cannot be recycled though most local recycling programs due to the fact that the metal and plastic cannot be easily separated. Also, ionization smoke detectors contain small amounts of radiation, and must be disposed of properly [46]. This does not change with the use of solar power.

Impact of Identities

All members of Team 10 have the same college education, so it was easy to agree on a concept generation and evaluation process that had been taught in current and previous courses. However, not all members have the same experience level with the design process and prototyping due to extracurriculars and internships. This caused some team members to lead different aspects of the design process.

The members of Team 10 did not have prior knowledge about child product safety or smoke detectors. Designing for child safety was not a concept taught in previous classes, so it was new to all team members. Whereas KID is well connected with families in the United States and advocates for child safety. KID and its representatives were the experts on the topic in the relationship between KID and Team 10, while Team 10 was the expert in engineering. There was a knowledge gap and age difference between Team 10 and all its stakeholders.

Inclusion and Equity

There are various power dynamics between the team and the stakeholders to consider when evaluating the project. Team 10 desired to please KID as they are both the sponsor and a potential end user. KID and the CPSC were able to provide feedback throughout the design process and influence the final design. The Team had to follow all guidelines set by the NFPA and used research and surveys provided by the NFPA. The end users were not able to provide direct feedback on the design but their desires were taken into account during the design process to focus on easing installation and maintenance. See the previous Stakeholder Map on Page 8 for visualization of the power dynamics.

The members of the team do not have the same identities and experiences as the intended end users: the elderly, low-mobility users, and low-income families. This could have influenced the selection of user requirements and engineering specifications as “low cost - manufacturing cost of less than $20” may not fit the description of low cost to everyone. Additionally, using the installation piece was easy for every college-aged, able-bodied team member to use. However, verification testing must be performed to ensure this task is easy for eldery and low-mobility users.

To include diverse viewpoints of stakeholders, the team interviewed a variety of stakeholders, including employees of KID, the CPSC, firefighters, and families. To include diverse viewpoints of team members, the team practiced the ideology that “no idea is a bad idea” to encourage participation and diverse thought. Once the team had collected many ideas and feedback internally and from stakeholders, the team had to balance all the ideas. Feedback from Nancy Cowles of KID and Jhnathan Midgett of CPSC were taken with the highest influence as KID is the project sponsor and they are both experts in their fields. To balance ideas from team members, every team member was allowed to give input and the team would vote.

Ethics

The team does not expect to face many ethical dilemmas during the project, however, some situations can be considered. Current smoke detectors are expensive. A low cost product for the final design may be accessible to low income families, but the product may be manufactured by workers who are paid lower wages. This ethical dilemma could be managed by suggesting an advanced manufacturing technique for the smoke detector that is partially automated. Complex manufacturing techniques require fewer but more skilled workers who may be compensated fairly. Additionally, creating a low cost product must not impact the quality of the smoke detector as they must function properly to protect people in home fires.

The teams' personal ethics are the same as the University of Michigan professional ethics as both prioritize honesty and responsibility. The team values honesty within team communication and communication with stakeholders. The team values responsibility in completing all tasks to the best ability to ensure the best final design. Honesty and responsibility are also professional ethics that any future employer should uphold by the American Society of Mechanical Engineering Code of Ethics [47] and National Society of Professional Engineers Code of Ethics [48].

RECOMMENDATIONS

Throughout the design process, verification testing, and stakeholder engagement, much was learned. There are many things the team recommends to KID and a future ME450 team.

It is suggested that future teams work with KID and utilizes their access to information. KID offers a large network base to families. Close collaboration would lead to quicker results and more accurately focused designs. Team 10 also recommends that future ME 450 teams evaluate their design at every step of the process. The final design for the smoke detector came from the combination of multiple ideas, and was one of the later concepts thought about after collaboration with stakeholders. It is never too late to change the design idea, and better ideas were found to be formed after taking a step back and trying to think about the user's needs.

A second recommendation is to continue forward with the remaining verification and validation testing. Timed trials must be performed for installation and maintenance by a wide variety of users to verify the design. These tests have been preliminarily performed by the team; however, they must be performed by the intended users (elderly, people with limited mobility).

Another recommendation is a kit with different attachment methods that makes the design usable for all ceiling types within homes. Currently the design considers drywall, wood, and drop ceilings. To include "popcorn" ceiling types, the design would need an attachment method that punctures into the "popcorn" ceiling. This design work and testing could be performed by a future ME450 team.

In order for the user to easily perform the installation tasks, an illustrated installation guide should be created. The guide will walk the user step-by-step through the installation process as well as how to take down the smoke detector and replace the smoke detector. An easy to follow guide will increase the number of functioning smoke detectors in homes and make homes safer overall.

Another recommendation is a reconsideration and possible re-design of the final design for ease of manufacturing. The final design functions and meets each user requirement and engineering specification, but does not necessarily conform to the best manufacturing practices. The team spent multiple hours designing around the user needs, but did not deeply explore how manufacturable the final design is. Specific areas of the design that may need attention include the size of the lid and housing walls, as well as the shape of each injection molded piece. It is recommended that further research is conducted, either contacting possible manufacturers or optimizing the chosen design under specified manufacturing requirements. This work would ensure that the final design conforms to best practices and is easy to manufacture.

It was also brought to the team's attention to seek feedback from a large user group about design aesthetics. It is recommended that a survey or in person feedback of some sort is conducted to receive thoughts on how the design looks. As the detector is necessary in every home and is something that sits in obvious visible sight, it is optimal for the detector to look as sleek and un-abnormal as possible. This may include research and feedback on the shape, color, and size of the detector. It is recommended to gain feedback on the aesthetics of the smoke detector before manufacturing anything.

Another recommendation is to make the solar panels and rechargeable battery easy to replace as they are the limiting factor in the lifespan. This would make the detector housing reusable and decrease total waste as it is not recyclable. This could also save cost to the consumer, since they would be buying one piece rather than a whole new detector. Research would need to be conducted if this task is something a user would want to do.

A final recommendation is for KID to continue this project with a University of Michigan team. Non-functioning smoke detectors cause deaths, and any project that would increase safety and the number of working smoke detectors is worth continuing to pursue.

CONCLUSIONS

After meeting with the project sponsor from KID and getting initial background information on what was intended by "design a better smoke detector", the team took multiple steps to narrow the project scope for the upcoming semester.

First, research was conducted on how a smoke detector functions, and what problems have been identified with current designs. Splitting the research up into user-based problems and design-based problems helped the team focus the intended project scope to be completed. Using a problem-oriented design process, potential stakeholders were identified, which included local fire departments, members from the CPSC, NFPA, and end users of a smoke detector. Interviews were conducted, and a list of user requirements were created. These user requirements include quick to install, ease to install, easy to access, easy to maintain, lightweight, low cost, and long-lasting. Each requirement was converted into a quantifiable engineering specification backed by research.

After defining the problem and determining the requirements and specifications, more than 160 potential solutions were generated. Each team member created more than 40 unique concept ideas using a variety of generation techniques such as Design Heuristics, a morphological matrix, and the S.C.A.M.P.E.R. technique. From the 160 collaborative ideas, 20 feasible designs were chosen and narrowed down using the user requirements and a concept merger. From there, three designs were rated against a standard smoke detector using a Pugh chart, and the design with the highest rating was chosen as the alpha design. The alpha design being a solar-powered smoke detector that uses 3M tape to mount to the ceiling and an installation piece to install and take down the smoke detector. The installation piece is designed to fit on a standard 1" broom handle or assistive pole.

After receiving stakeholder feedback on the alpha design, the final solution was iterated. Tests with 3M tape, plastic velcro, epoxy and magnets were conducted to choose the best installation method. Eventually, it was concluded that the final design, still powered by solar panels, would include the use of magnets and 3M tape to mount the detector. Mounting with magnets allows the user to take it down and put it up in case the detector fails to work properly throughout its lifetime.

Throughout the design process, the team analyzed potential problems that may have been encountered. These problems included the difficulty to get testing materials, difficulty to gain valuable user engagement and feedback, and time to produce a functional prototype. The issue of final cost and prototype functionality were also considered.

The team has learned about smoke detector function and what can be improved, in both the design and user engagement space. The team has also learned how to engage stakeholders and hold their needs to a high standard, multiple concept creation techniques, iteration methods, and what a necessary design analysis consists of.

Following the second design review, the team performed multiple tests, worked on a prototype of the selected alpha design, and continued the design progress. Following the third design review, the team continued to iterate the prototype. A final design was created based on these test results.

Testing verified the correct orientation and power output of the solar panels, and the attachment method between the smoke detector and a house ceiling was concluded. The final design consists of a magnetic housing lid that holds four polarized magnets together. This lid is 3M taped to the ceiling. The detector housing also contains four polarized magnets that attach to the housing lid. The installation piece did not see any changes through testing results, but is still included in the final design.

The final solution of a solar powered smoke detector with an easy access installation piece and magnetic housing is the best combination of ideas to achieve successful results. This design meets every user requirement and engineering specification set for the semester, and has hopes of being refined to a finalized product. Future iterations may occur, as the design process is never over until final release of a design, but the progress made is encouraging in the time allotted for work.

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APPENDIX

Appendix A: Concept Generation.

Many unique design ideas were created of the team throughout the concept generation portion of the project. Shown below are twenty unique ideas.

Appendix A.1. 160 Generated Concepts.

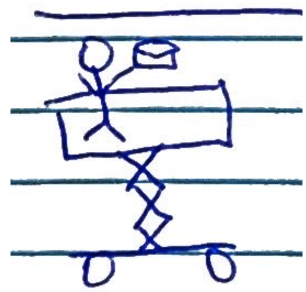
Each team member generated 40 concepts. The designs are labeled and described below.

Concepts generated by Lauren:

1.)

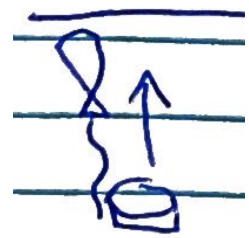
User can throw the detector at the ceiling for installation.

2.)



User is lifted to the ceiling to install.

3.)

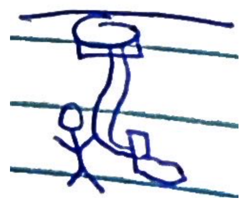


Detector is lifted to the ceiling with a balloon.

4.)

Detector is lifted to the ceiling with a blimp.

5.)

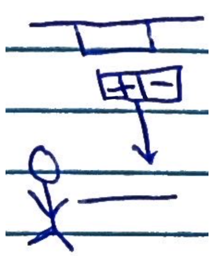


Detector is lowered with a vacuum.

6.)

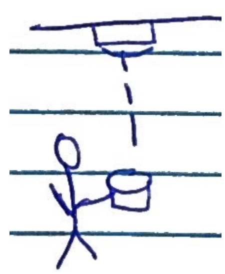
Detector is powered by an outlet in the home.

7.)



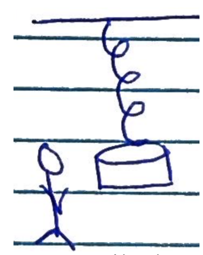
The batteries fall to the user.

8.)



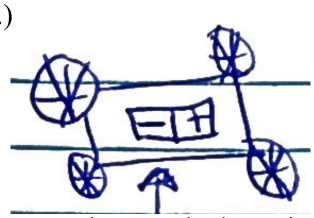
The detector falls to the user.

9.)



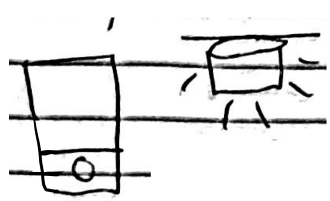
The detector coils down to the users.

10.)



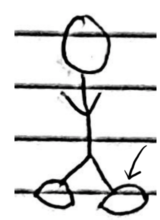
Drone changes the batteries.

11.)



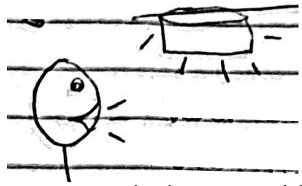
User's phone controls the detector.

12.)



User walks up walls with suction shoes.

13.)

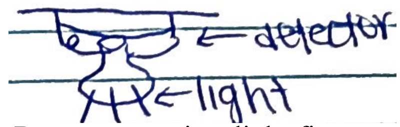


User controls detector with voice.

14.)

Detector speaks to the user.

15.)

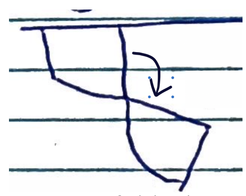


Detector goes in a light-fixture.

16.)

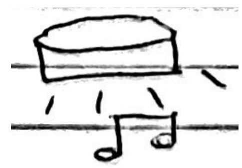
Inside of the detector is replaceable.

17.)



Detector folds down.

18.)

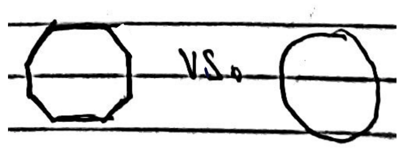


Detector is also a music speaker.

19.)

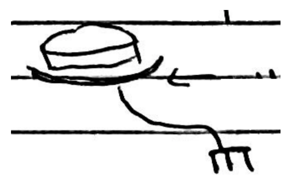
Detector uses hooks (no drill).

20.)



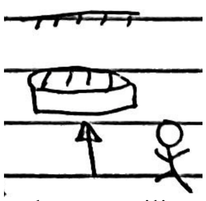
Change the shape of the shell.

21.)



Charging-pad for batteries.

22.)

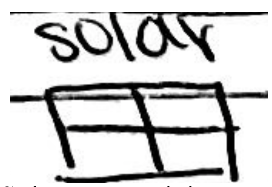


Velcro to ceiling.

23.)

Battery-level display light.

24.)



Solar-powered detector.

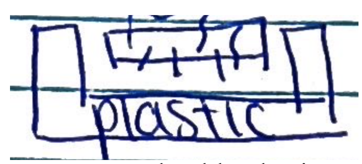
24.)

Crank-shaft power.

26.)

Phone call when the battery is low.

27.)



Use recycle-able plastic.

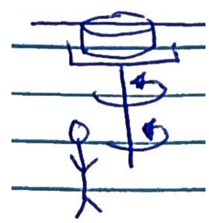
28.)

Magnet to the ceiling.

29.)

Suction to the ceiling.

30.)

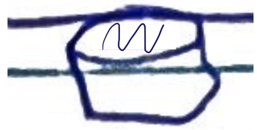


Twist down from the ceiling.

31.)

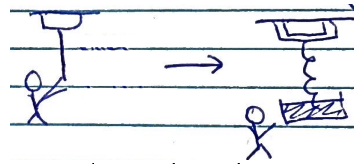
Tape to the ceiling.

32.)



Glue to the ceiling.

33.)

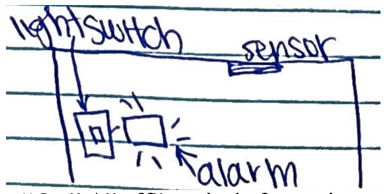


Push-to-release button.

34.)

Voice-record the alert sound.

35.)



“On” / ”off” switch for noise.

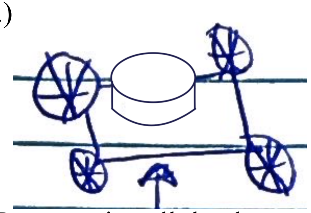
36.)

Two detectors with different battery cycles.

37.)

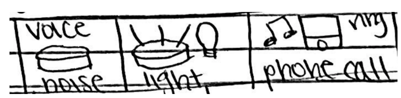
Detachable bracket.

38.)



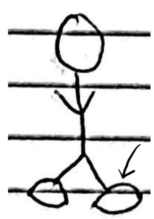
Drone to install the detector.

39.)



Alert the user of a low battery with noise, light, and a phone call

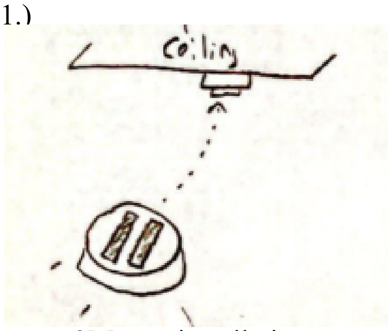
40.)



Users can jump to the ceiling with spring shoes.

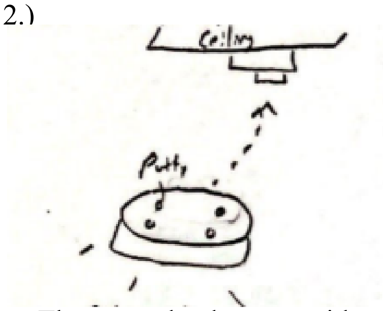
Concepts generated by Matt:

1.)



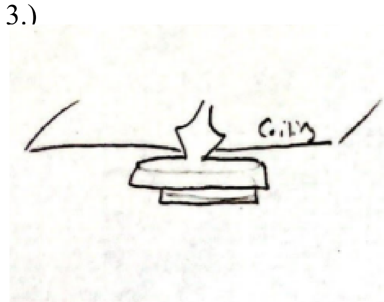
3M tape installation.

2.)



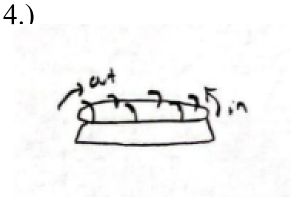
Throw on the detector with putty.

3.)



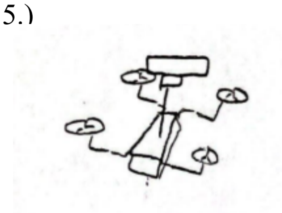
Push through the ceiling with a clip.

4.)

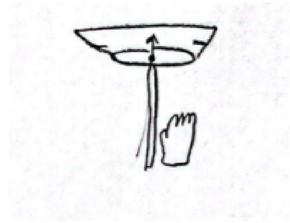


Rotate ceiling spike.

5.)



Battery changing drone.

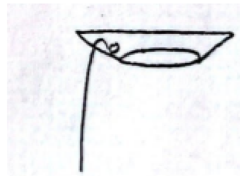


6.) Push pole insertion.

7.)

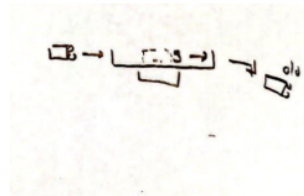
Twist pole device to unscrew from base.

8.)



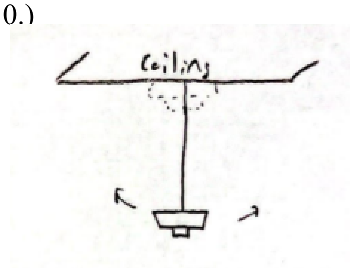
Latch pole.

9.)



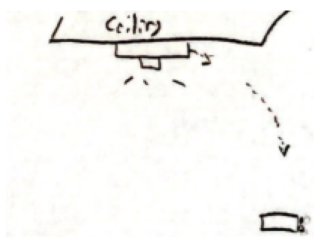
Push a new battery in to replace the old one.

10.)



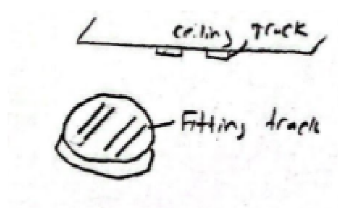
Drop down detector on a string.

11.)



Self ejecting battery.

12.)

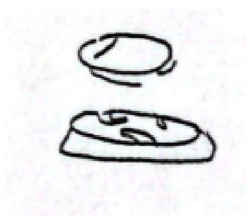


Slide in and out track for detector base.

13.)

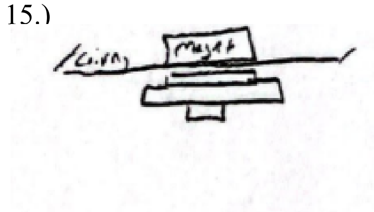
Ladder extending when the battery needs replacing.

14.)



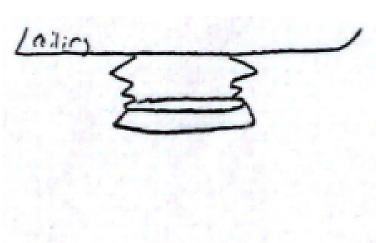
Push in and twist mount.

15.)



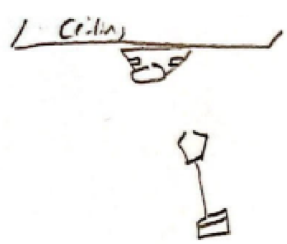
Magnetic ceiling mount.

16.)



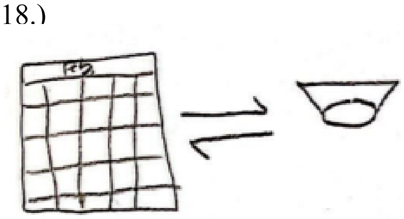
Pop socket detector.

17.)



Reaching clamp.

18.)

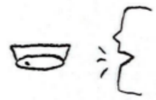


Google calendar link device.

19.)

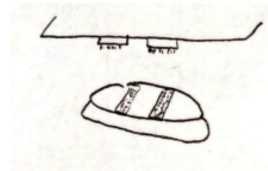
Spaceship sleek design.

20.)



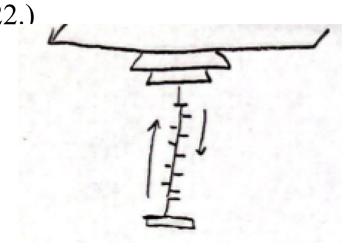
Detector that responds to voice command.

21.)



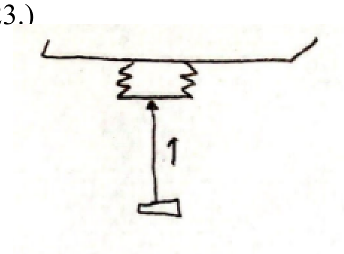
Velcro strip.

22.)



Conveyor belt to lower detector.

23.)

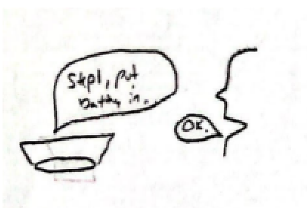


Pop socket with pole to assist.

24.)

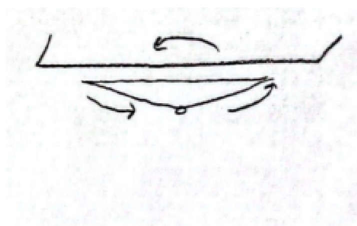
Extension pole with suction cup.

25.)



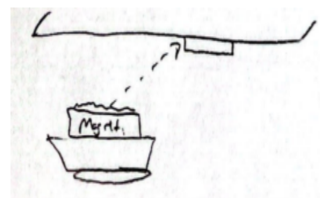
Speaker prompted detector.

26.)



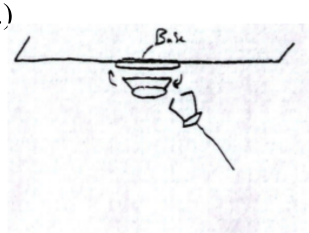
Rotate in sleek design.

27.)



Throw on magnetic base.

28.)

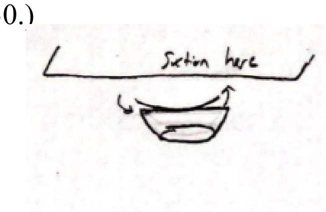


Clamp with suction base.

29.)

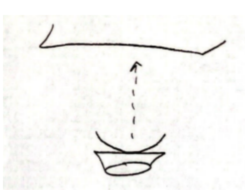
Scheduled drone (i-drone).

30.)



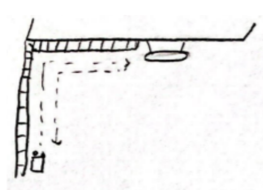
Suction cup base with rotate in housing.

31.)



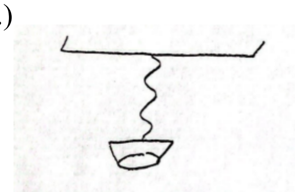
Throw up suction cup.

32.)



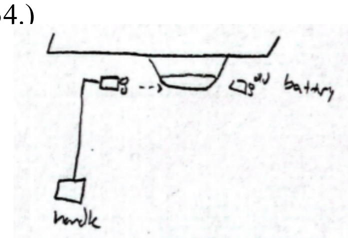
Railroad track automatic changing.

33.)



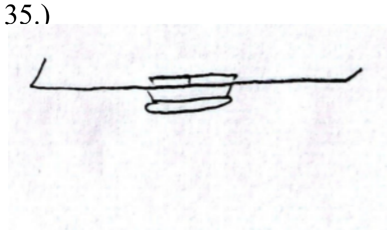
Bungee cord drop down.

34.)



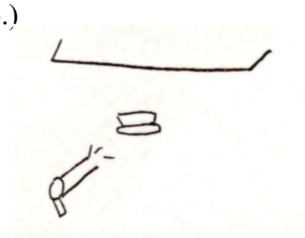
Push out batter with a new one, assisted with a pole.

35.)



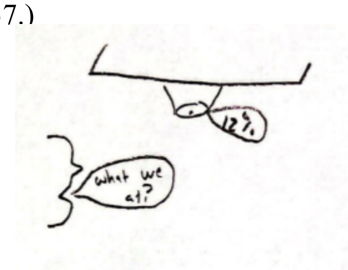
Push in base with drop down clamp.

36.)



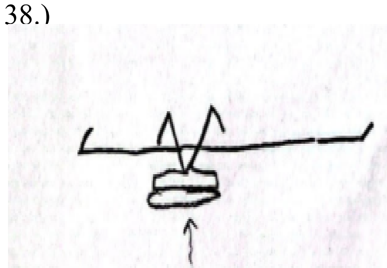
Installation launcher.

37.)



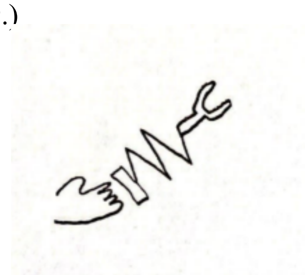
Speak into detector for battery percentage.

38.)



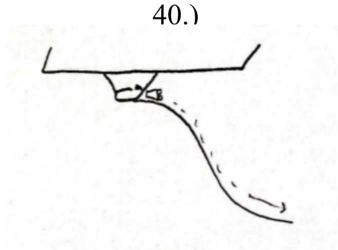
Push through ceiling spike.

39.)



Foldable extension pole.

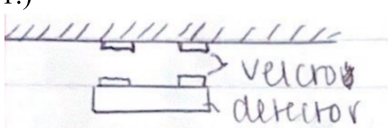
40.)



Slide down battery ejection.

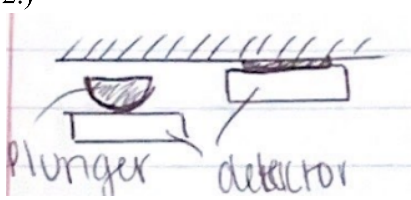
Concepts generated by Ally:

1.)



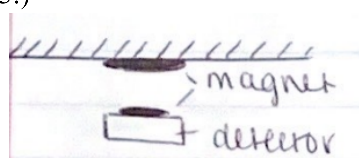
Mount with velcro.

2.)



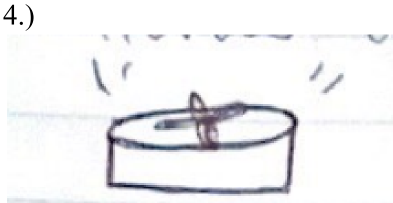
Plunger suction cup to ceiling.

3.)



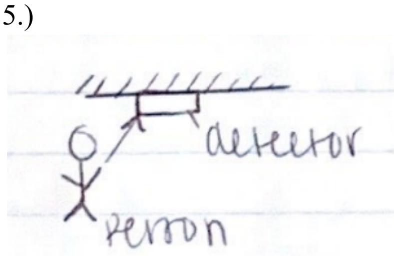
Mount with magnets.

4.)



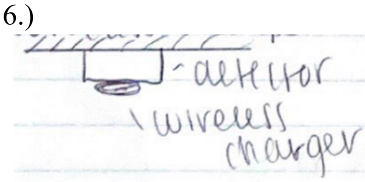
Flies down when batteries are low.

5.)



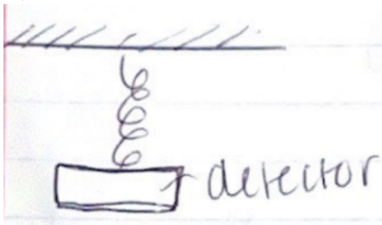
Throw detector onto ceiling.

6.)



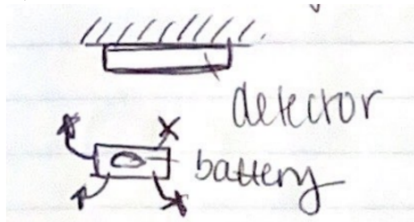
Wireless charger.

7.)



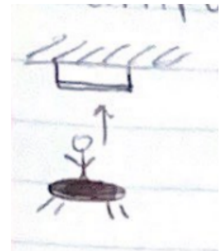
Coils down when battery is low.

8.)



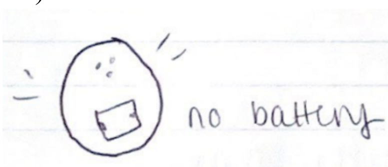
Drone to fly up and change batteries.

9.)



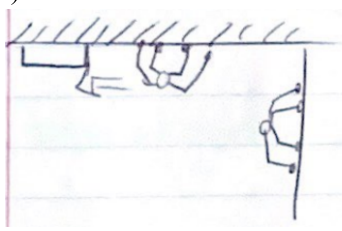
Trampoline to change batteries.

10.)



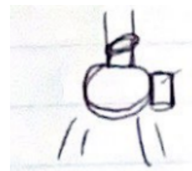
Smoke detector beeps when no battery is present.

11.)



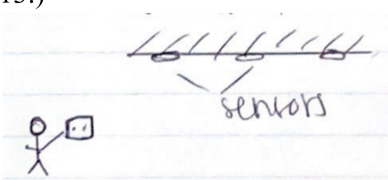
Robot-spider changes batteries.

12.)



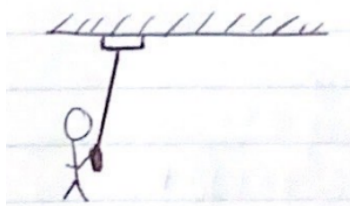
Smoke detector within lightbulb.

13.)



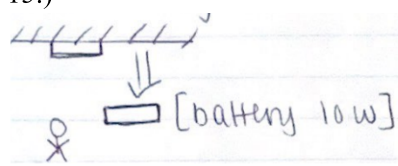
Smoke sensors and separate unit.

14.)



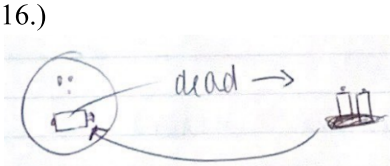
Assistive tool to bring detector down.

15.)



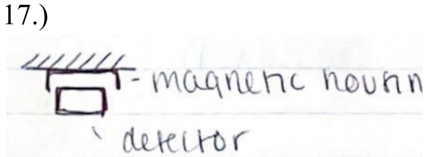
Smoke detector falls off ceiling when battery is low.

16.)



Battery charging dock.

17.)

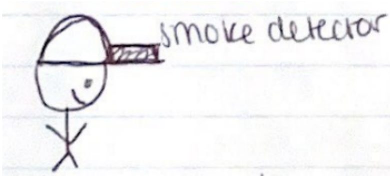


Magnetic housing (stays on ceiling). Insides are removable.

18.)

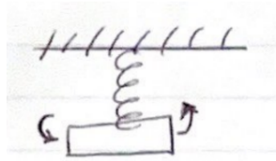
Super thin detector.

19.)



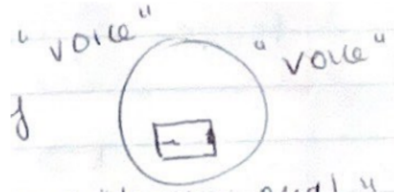
Smoke detector hat.

20.)



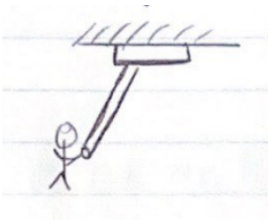
Smoke detector coils down and keeps rotating until the batteries are changed.

21.)



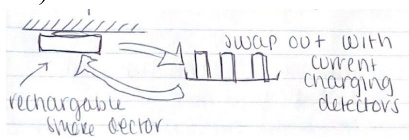
Smoke detector talks until the battery is changed.

22.)



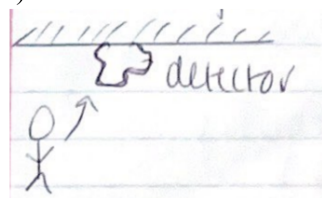
Vacuum to suck battery out.

23.)



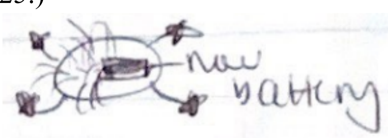
Rechargeable smoke detector.

24.)



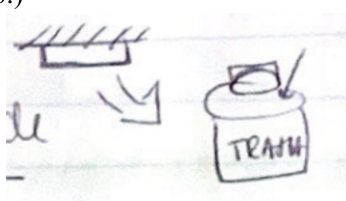
Moldable smoke detector.

25.)



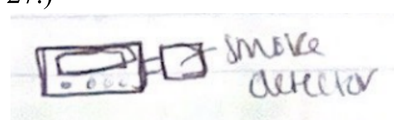
Drone that changes battery and cleans outside of the detector.

26.)



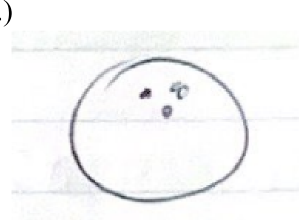
Disposable smoke detectors.

27.)



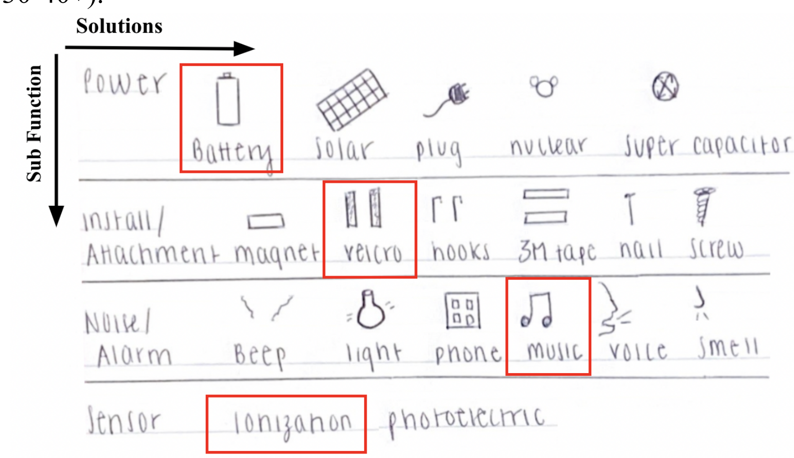
Smoke detector and thermostat.

29.)



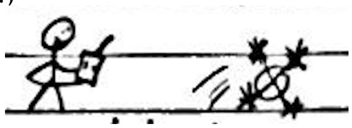
Battery-less smoke detectors.

30-40+).



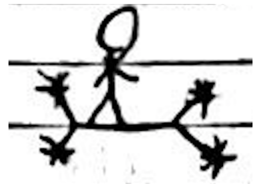
Concepts generated by Austin:

1.)



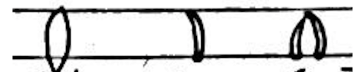
Remote-controlled battery changer.

2.)



User rides a drone for access.

3.)



Customizable drone parts to change smoke detector batteries

4.)

Detector in the ceiling fan.

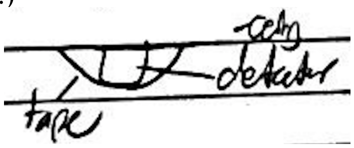
5.)

Blimp to install a detector.

6.)

Detector goes inside a door.

7.)

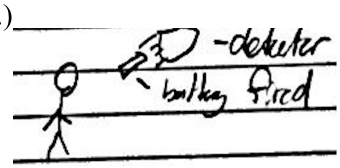


Duct tape to ceiling.

8.)

Balloon to install detector.

9.)

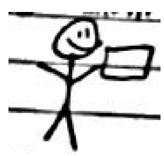


Old batteries fall to user.

10.)

Drywall hook to attach.

11.)

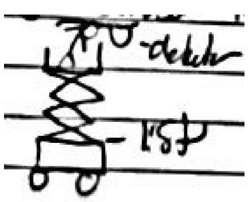


Smoke detector changing companies.

12.)

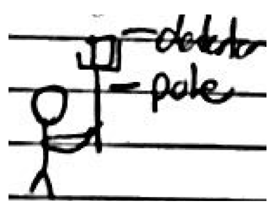
Sling-shot the detector to the ceiling.

13.)



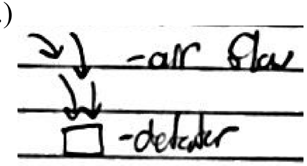
Construction lift to ceiling.

14.)



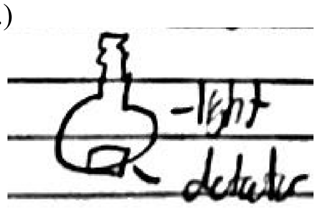
Take detector down with a pole.

15.)



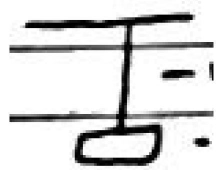
Detector on the floor with ceiling airflow.

16.)



Detector in lightbulb.

17.)

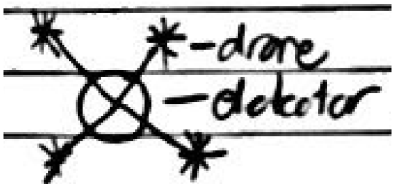


Detector comes down on the cable.

18.)

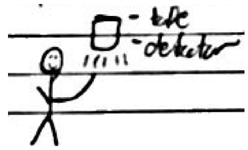
Detector magnets to ceiling.

19.)



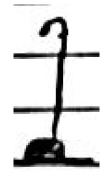
A drone replaces the detector.

20.)



Tape to ceiling when user throws detector at ceiling.

21.)

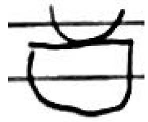


Detector in a lamp.

22.)

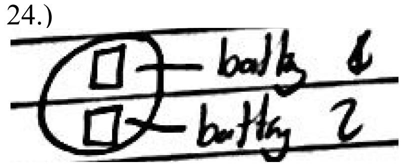
Velcro to ceiling.

23.)



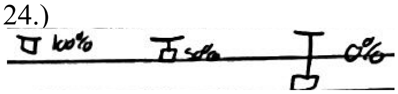
Suction cup to ceiling.

24.)



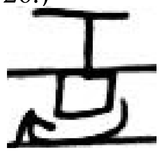
Detector has 2 batteries.

24.)



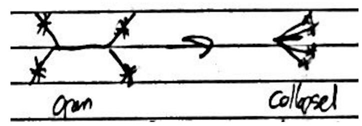
Detector falls as the battery decreases.

26.)



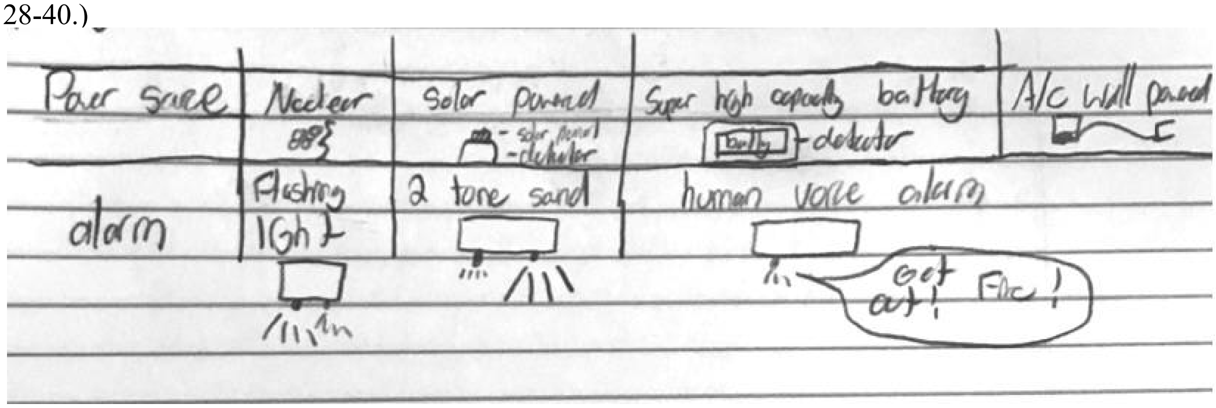
User spins the detector down.

27.)



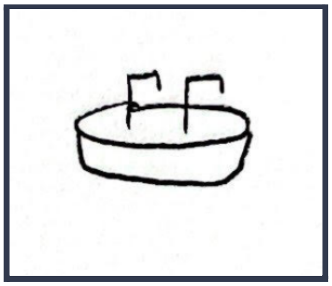
Collapse-able drone to change batteries and easy to store.

28-40.)



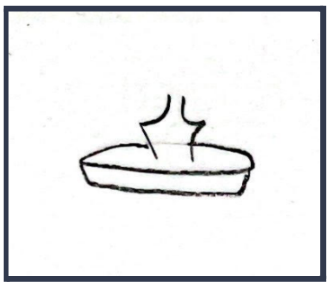
Appendix A.2. Concept Generation for Ceiling Attachment Methods.

Concepts generated specifically to address the installation of the smoke detector. From the shown designs, in numerical order they consist of: 1. Hook 2. Rotation ook 3. Push Clip 4. Velcro 5. Suction Cup.

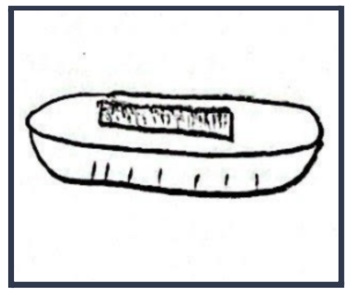


1.)

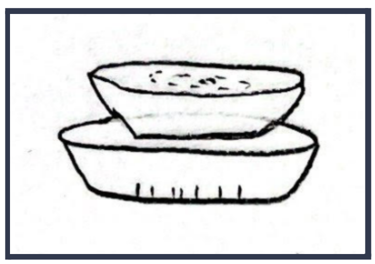
2.)



3.)

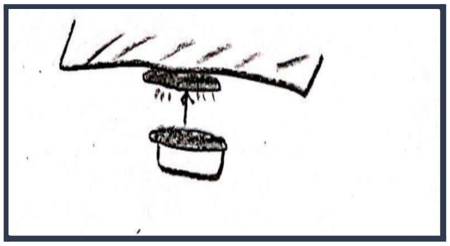


4.)



5.)

Appendix A.3. Concept Generation for Maintenance Methods.
Concepts generated specifically to address the maintenance of the smoke detector. From the shown designs, in numerical order they consist of: 1. Magnetic Mount 2. Vacuum Removal 3. Automatic Twist-Off 4. Conveyor System 5. Replace Insides 6. Magnetic Charger 7. Push-Out Battery.



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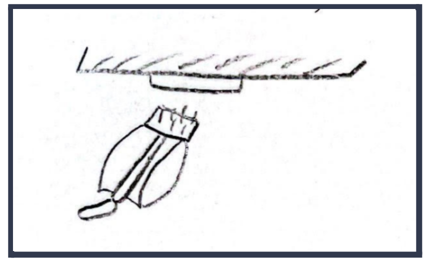

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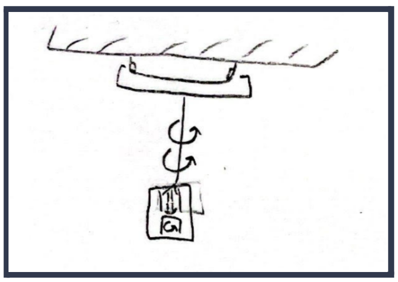

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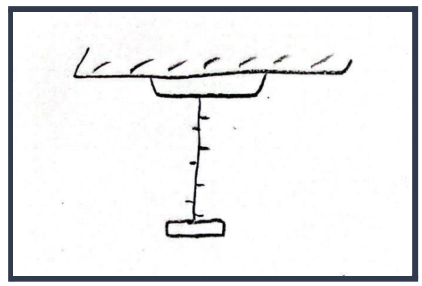

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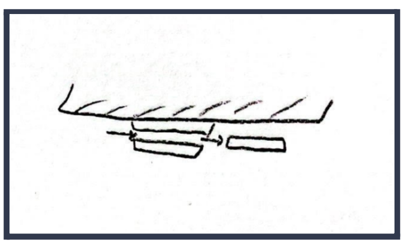

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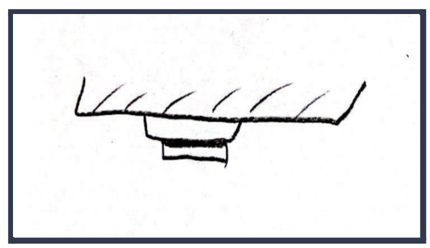

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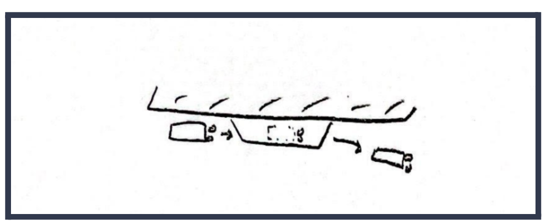
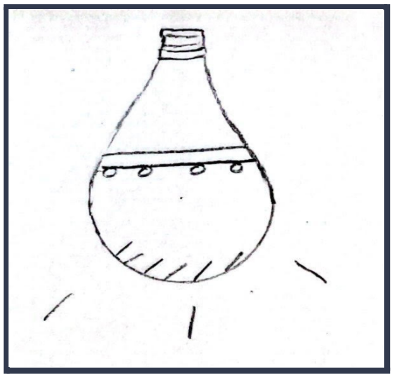


7.)

Appendix A.4. Unique Generated Concepts.

Unique generated concepts. From the shown designs, in numerical order they consist of: 1. Light Bulb Housing 2. Fan Detector 3. Ground Lamp 4. Drone Changer 5. Robo-Spider 6. Solar Powered 7. Rechargeable Unit 8. Switch-Off alarm



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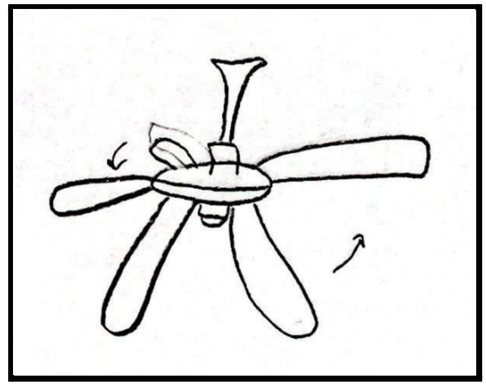

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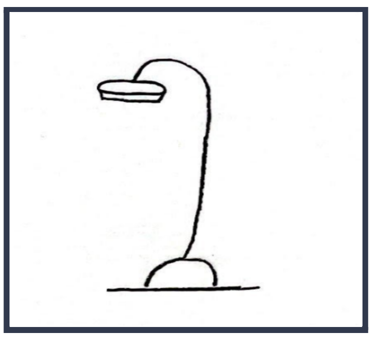

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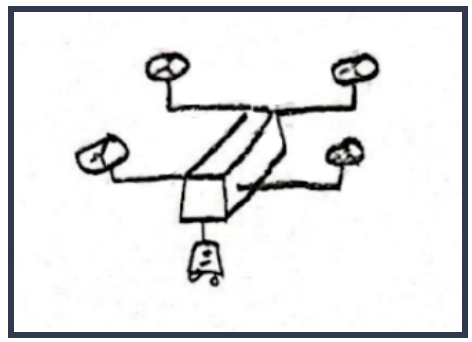

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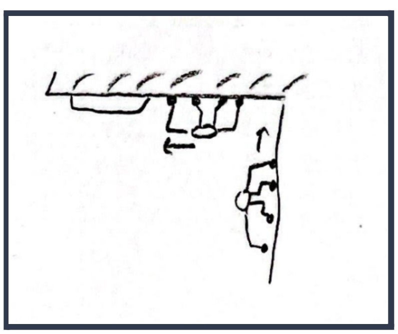

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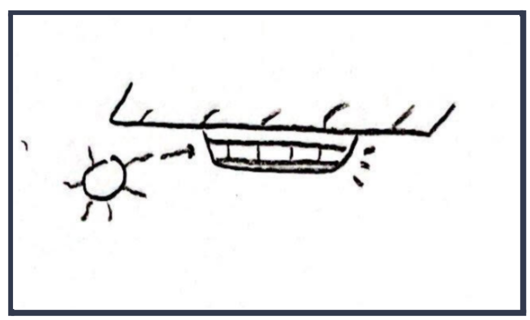

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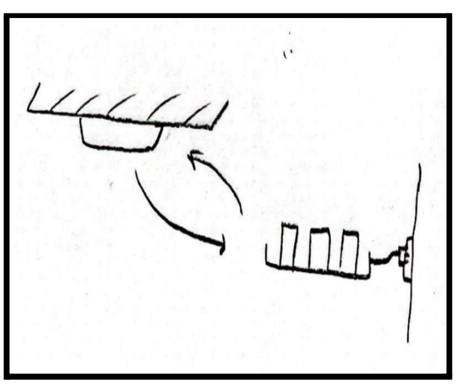

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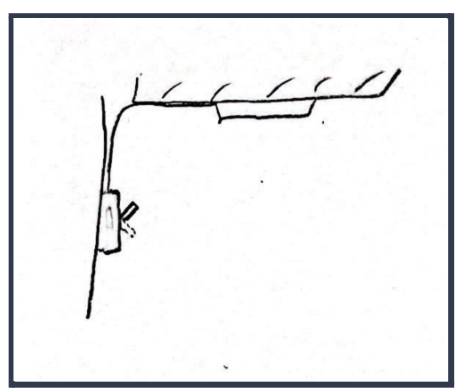

8.)

Appendix B. Concept Evaluation and Merger.
Below in the concept evaluation tables, “good” (green) indicates the concept fulfills the user requirement, “okay” (yellow) indicates the concept may fulfill the user requirements, “bad” (red) indicates the concept will not fulfill the user requirements, and “N/A” (gray) indicates that the concept is not aimed to fulfill the requirements and the team did not consider that requirement with the concept. Many concepts had red and/or gray in the evaluation tables.

Appendix B.1. 20 Initial Designs.
Concept analysis tables of initial 20 designs narrowed down from 160 designs. Five designs were provided by each teammate. The designs are evaluated based on the user requirements.

Table 10: First set of initial design concepts evaluated based on the user requirements.

Requirement	LED smoke detector housing	Lamp detector	Suction cup mounted	Velcro mounted	Ceiling fan
Quick to Install	Good	Good	Good	Good	N/A
Easy to Install	Okay	Good	Good	Good	N/A
Easy to access	Okay	Good	N/A	Good	Okay
Easy to maintain	Good	Good	Okay	Okay	Okay
Lightweight	Good	Bad	Good	Good	Bad
Low cost	Okay	Bad	Good	Good	Bad
Long-Lasting	Good	Okay	Bad	Okay	Good

Table 11: Second set of initial design concepts evaluated based on the user requirements.

Requirement	Rechargeable detector	Wireless charging	Magnetic mount	Vacuum detachment	Robo-Spider
Quick to Install	Good	N/A	Bad	Okay	N/A
Easy to Install	Okay	N/A	Bad	Okay	N/A
Easy to access	Bad	Bad	Good	Good	Good
Easy to maintain	Okay	Okay	Good	Good	Good
Lightweight	Good	Good	Okay	Okay	Good
Low cost	Good	Good	Okay	Okay	Bad
Long-Lasting	Okay	Okay	Okay	Okay	Bad

Table 12: Third set of initial design concepts evaluated based on the user requirements.

Requirement	Pole twist off	Ceiling hook	Drone	Replacement of insides	Manual alarm switch
Quick to Install	N/A	Good	N/A	Good	N/A
Easy to Install	N/A	Good	N/A	N/A	N/A
Easy to access	Good	N/A	Good	N/A	Good
Easy to maintain	Good	N/A	Good	N/A	N/A
Lightweight	Good	Good	Good	Good	Good
Low cost	Good	Good	Bad	Good	Okay
Long-Lasting	Good	Okay	Bad	Good	Good

Table 13: Fourth set of initial design concepts evaluated based on the user requirements.

Requirement	Pole conveyor system	Push replacement battery	Ceiling push through clip mount	Rotating base hooks	Solar Power
Quick to Install	N/A	N/A	Good	Good	N/A
Easy to Install	N/A	N/A	Good	Good	N/A
Easy to access	Good	N/A	N/A	Bad	Okay
Easy to maintain	Good	Good	Bad	Bad	Good
Lightweight	Okay	Good	Good	Good	Okay
Low cost	Bad	Good	Good	Okay	Okay
Long-Lasting	Okay	Okay	Okay	Okay	Good

Appendix B.2. Merged Concepts.

Merged concepts from the initial 20 concepts evaluated based on the user requirements. .

Table 14 First table of merged concepts evaluated based on the user requirements.

Requirement	Suction seal with pole	Drone for install and battery change	Magnetic changing with pole	Stick to ceiling with drop down system
Quick to Install	Good	Good	Good	Okay
Easy to Install	Good	Good	Good	Okay
Easy to access	Good	Good	Good	Good
Easy to maintain	Okay	Good	Good	Good
Lightweight	Good	Good	Good	Good
Low cost	Good	Bad	Bad	Okay
Long-Lasting	Bad	Bad	Okay	Okay

Table 15: Second table of merged concepts evaluated based on the user requirements.

Requirement	In lightbulb with pole	Ceiling hook with pole	Magnetic mount with pole	Tape to ceiling with pole
Quick to Install	Good	Good	Good	Good
Easy to Install	Good	Good	Good	Good
Easy to access	Good	Good	Good	Good
Easy to maintain	Okay	Okay	Okay	Okay
Lightweight	Good	Good	Good	Good
Low cost	Bad	Good	Good	Good
Long-Lasting	Okay	Okay	Okay	Okay

Appendix C. Solar Power Cost Calculations.
Cost savings of using solar power instead of replacing the 9V battery every six months. There are additional time and effort savings of not using a ladder or hardware tools to install the device and not having to maintain the device.

Standard 9V Battery

- 9V battery cost: 2 for ~ $8.00
  - $4.00 Each
- 2 Batteries per year
- Lifespan: ~10 years
  - **20 batteries/10 years**

(20 batteries)*($4.00/battery) = **~ $80.00/detector**

Solar Power

- Small Solar Panel: $7-$10
  - 2 solar panels: ~$20 (conservative)
- 9V rechargeable battery cost: ~$7.00
- Lifespan: ~ 5 years (both)
  - 2 devices ~ 10 years

2((2 solar panels)+(1 battery)) = **$54.00/2 detectors**

(~ $26/detector)*(5 smoke detectors per household) =
~ $130.00 cost saving + CONVENIENCE

Appendix D. Granta Eco Audit.
Smoke detector phase of life vs. energy consumption, CO2 footprint, and cost.

Phase	Energy (kcal)	Energy (%)	CO2 footprint (lb)	CO2 footprint (%)	Cost (USD)	Cost (%)
Material	1.21e+04	86.4	5.99	82.8	4.14	42.9
Manufacture	1.4e+03	10.0	0.972	13.4	5.37	55.6
Transport	63.6	0.5	0.0423	0.6	0.065	0.674
Use	418	3.0	0.215	3.0	0.0777	0.806
Disposal	19.3	0.1	0.0125	0.2	0.00226	0.0234
Total (for first life)	**1.4e+04**	**100**	**7.24**	**100**	**9.65**	**100**
End of life potential	-32		-0.0189			

Material cost breakdown.

Component	Material	Recycled content* (%)	Part mass (lb)	Qty.	Total mass processed** (lb)	Cost (USD)	%
Main body	ABS (injection molding, platable)	Virgin (0%)	0.17	1	0.17	0.16	3.8
Lid	ABS (injection molding, platable)	Virgin (0%)	0.1	1	0.1	0.092	2.2
Installation Piece	ABS (injection molding, platable)	Virgin (0%)	0.4	1	0.4	0.37	8.9
0.375" Magnets	Neodymium magnet N52	Virgin (0%)	0.001	4	0.004	0.061	1.5
0.5" Magnets	Neodymium magnet N52	Virgin (0%)	0.001	4	0.004	0.061	1.5
Solar Panels	Single crystalline silicon, photovoltaics	Virgin (0%)	0.003	4	0.012	0.41	10.0
9V Battery	Ni-Cd rechargeable battery	Virgin (0%)	0.07	1	0.07	2.1	50.0
Circuit Components	Integrated circuit (small)	Virgin (0%)	0.005	1	0.005	0.9	21.8
Packaging, box	Cardboard	Virgin (0%)	0.01	1	0.01	0.0048	0.1
Packaging, foam	PC foam (rigid, closed cell, 0.65)	Virgin (0%)	0.001	1	0.001	0.0065	0.2
Total				**19**	**0.78**	**4.1**	**100**

Manufacturing cost breakdown.

Component	Process	Length (ft)	% Removed	Amount processed		Cost (USD)	%
Main body	Polymer molding	-	-	0.17	lb	0.25	4.7
Lid	Polymer molding	-	-	0.1	lb	0.22	4.0
Installation Piece	Polymer molding	-	-	0.4	lb	0.34	6.2
0.375" Magnets	Casting	-	-	0.004	lb	2.3	42.0
0.5" Magnets	Casting	-	-	0.004	lb	2.3	42.0
Packaging, foam	Polymer molding	-	-	0.001	lb	0.057	1.1
Total						**5.4**	**100**

Appendix E. Build Solution: Bill of Materials

Table X: Bill of Materials on the build design (prototype) created for testing.

Part	Supplier, Part No.	Prototype Part Cost
Housing Piece/Lid	University of Michigan CoE 3D Printing, PLA	$8.20 SolidWorks Cost Estimate
Installation Piece	University of Michigan CoE 3D Printing, PLA	$12.40 SolidWorks Cost Estimate
Charge Controller [41]	Acxico	$2.67
Solar Panels (4) [26]	Solar Made Online, LL 200	$27.00
Wiring [44]	Home Depot Stock Wire	$4.00
Diode [43]	McIgIcM (Amazon), 1N4148	4.99
9V Rechargeable Battery [43]	Tenergy (Amazon)	$4.00
Bar Magnets (4) [42]	Dowling Magnets, DO-731011	$31.78
Battery Housing [43]	LAMPVPATH (Amazon)	$3
Circle Magnets (4) [44]	MagCraft (Home Depot), 6lb ⅝ x ⅛ in	$13.79
3M Tape [44]	3M (Home Depot)	$5.38
Photoelectric Smoke Detector [46]	Kidde (Amazon), P9050	$12.97
Total		**$130.18**

TEAM BIOGRAPHIES

Team 10 consists of four members: Matthew Alexander Waier, Alexandra Danee Roberts, Austin John Kassouf, and Lauren Leeann Siller. Their individual biographies can be found below.

Matthew Alexander Waier (he/him)

I was born and raised in Midland, Michigan. My parents, both University of Michigan graduates of the chemical engineering program, pushed me to explore a variety of interests when I was younger. I enjoyed playing many sports, including football, baseball, and wrestling, and I continued playing them throughout high school. I also played basketball when I was younger, and still continue to water ski. Besides having sports in my childhood, I excelled in my science and math classes. This is what I believe sparked my interest in pursuing a mechanical engineering undergraduate degree. I have always been interested in how machines around me and how they go together. As a kid I would take things apart and try to put them back together from memory. My brother, who just graduated from the University of Michigan with a Computer Engineering undergraduate and masters degree in 2022, also sparked me to join the Wolverine community. I toured the campus, loved everything I saw, and decided this is where I wanted to go. Mechanical engineering tests my problem solving ability and creative thinking around things I find enjoyable, which is why I still have an interest in the mechanical field. Over the past two summers I interned with Dow Inc. and General Motors in their manufacturing department, and gained great industry experience. I plan on graduating this upcoming spring, and coming back to the Ross school of Business here at the university to get a Masters of Management degree. I feel that this will allow me to enter the industry space of project management and expande my overall role in the workforce.

Alexandra Danee Roberts (she/her)

I was born and raised in Royal Oak, Michigan; my immediate family consists of my mom (Michelle), dad (Jason), and my brother, Cole. Cole is currently attending Michigan State University and is studying business. Like my brother, my mother and father also attended Michigan State University and both became physical therapists. I was raised a Spartan fan, therefore, I never actually planned on applying to the University of Michigan. However, after the university came to my high school for a presentation, I was sold on the highly-respected engineering resources and extensive alumni network post graduation. Although I applied and got into the College of Engineering, I had no idea what an engineer even was. Growing up with two parents in healthcare, I initially planned to study biomedical engineering because I enjoyed the idea of using my degree to help people. After attending Northfest freshman year, I joined a biomedical engineering-based project team called Project MESA. Project MESA designs portable, medical examination tables for mobile clinics in Nicaragua. It was here where I realized that I enjoyed the design and manufacturing aspect of the table more than the "biomedical" field of engineering. As a result, by the end of freshman year I knew I wanted to study mechanical engineering. Growing up in the metro Detroit area, I told myself I would never work in the automotive industry, since I have been surrounded by companies like Ford, GM, and FCA my whole life. However, after completing a process engineering internship at an automotive supplier (Kautex by Textron) and a manufacturing engineering co-op at an automotive OEM (Tesla Inc.), I quickly fell in love with the gritty and face-paced environment. My current plan is to graduate in December 2022, since I took a semester off to participate in the spring/summer co-op. I will be participating in another internship this summer as a build and flight reliability intern at SpaceX.

Austin John Kassouf (he/him)

While I was born and raised in Cleveland, Ohio, I was never an OSU fan. I grew up playing a variety of sports from lacrosse, track, pole vault, and snowboarding. I have one twin sister (Alyssa) who attends Johns Hopkins University and is planning on attending medical school after completing her undergraduate career. We grew up with our two dogs Aspen and Angel. Aspen is a rescue golden retriever and Angel is a welsh corgi. I have been fascinated with engineering and construction from a young age. My father would take me to his construction sites and drive around the heavy equipment. From there, I further pursued this passion through restoring cars in high school and into college. While also in high school, I worked as an assistant mechanic restoring tunnel boring machines and fixing heavy equipment from cranes, skid steers, and bulldozers. Most of my family, including my father, two of my uncles, and cousin, studied engineering at Purdue. It was a tough decision to switch paths and pursue my degree from the University of Michigan. I chose U of M because of the immense engineering resources here. I originally wanted to go into the automotive industry, however my Engineering 100 class also gave me an interest in Naval Architecture. I later found a passion for the tunneling industry through two internships at Robbins and Triad Engineering. At Triad I was responsible for creating a system capable of inspecting tunnels in real time. While at Robbins I refined my design skills though investigating current problems and redesigning tunnel boring machines. I am currently undecided on my plans after graduation in May, however I will most likely be working for a tunneling or naval architecture start-up.

Lauren Leeann Siller (she/her)

I am from Ann Arbor, Michigan. I grew up playing soccer and ice hockey. When I was younger, my parents made me do math problems “for fun” everyday after dinner; so, it is not a surprise that my siblings and I pursued a degree in STEM. I have an older brother with a statistics degree from Michigan State University and an older sister with a chemistry degree from University of Michigan. I was raised a Wolverine as I am from Ann Arbor and both of my parents attended the University of Michigan. I was originally interested in attending the University of Michigan for engineering because I liked problem solving and math. Once I got here, I realized that mechanical engineering was the best fit for me. I was drawn to mechanical engineering because I liked how you could take complex systems (such as a motor or thermodynamic systems) and break them down into small and understandable parts. After interning for Walmart as an industrial engineer, I realized that the complex problem solving aspect was also in that field. While at U of M, I have been a member of Society of Women Engineers, Special Olympics Coaching Club, and a Supplemental Instructor for Math 216 (Differential Equations) through the Engineering Center for Academic Success. I will graduate in April 2022 with a Bachelors in Mechanical Engineering. After graduating I will be moving to Hoboken, NJ for work. I am excited to live outside of Michigan for the first time. I have a full time job as an automation engineer for Walmart. My future job description more closely fits a systems or industrial engineer than a mechanical engineer.