University of Central Florida

Department of Electrical and Computer Engineering

Senior Design EEL 4914

Advanced Breadboard

Group 20

Research Paper

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3 November 2023

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2. Project Description

2.1 Introduction

The breadboard is an engineering tool that allows the building of a temporary circuit without the use of solder. Without solder, the components on the circuit can be easily assembled and reassembled. The breadboard typically consists of a plastic chassis and lines of metal strips to connect the nodes. Circuits built on breadboards are for demos rather than final product. The simple design of the breadboard makes it so that it serves only one function to its user, but this simplicity allows it to be improved upon.
The Advance Bread idea is to redesign the breadboard so that it has advanced features to assist the user in creating a successful circuit.

2.2 Project Motivation and Explanation

The idea for the project came from the team's time in the Linear Circuits Labs. The correct use of the breadboard was integral to success in the laboratory. Understanding how to use the breadboard was straightforward, but applying it in practice proved to be more challenging than expected. Two major challenges of using the breadboard were translating the schematic to a physical board and debugging for components placed incorrectly. The first issue comes from connecting the idea of nodes in a schematic and nodes on the breadboard. Many mistakes come from a lack of understanding of nodes, especially when ground is involved. The second issue consumes a significant amount of lab time because open or short circuits can be hard to spot. Labs are designed to give an application to theory, but unfortunately the majority of the time is spent trying to learn how to use the hardware. The Advanced Bread project aims to resolve these issues by adding a graphical user interface (GUI) that will simplify the process of transitioning a schematic to components on a board and identifying open and short circuits.

This new smart-board will include a GUI that a user can use to draw their schematic. An algorithm will then decide how to place that schematic on the breadboard which will also illuminate which nodes to occupy. The breadboard will be made to house LEDs under all the nodes and connect to a laptop with the software. This breadboard will also have fewer nodes than a typical board to make it easier for the user to learn how to use it. The overall deliverable is a breadboard with LEDs and an open/short circuit test along with a GUI and algorithm for design planning. This project will serve as a stepping-stone for others to develop the breadboard. There is a need for hardware to be more advanced to keep up with the ever-evolving software and advanced algorithms. With the increased accessibility and affordability of microprocessors, at-home projects are on the rise. This project will allow untrained users to become more familiar with circuit designs. The conclusion to this project will show how the breadboard can become an advanced feature in teaching of circuit design and integration.

2.3 Goals and Objectives

Objectives:

- Schematic to breadboard wiring algorithm
- LED activation for component placement
- Open/Short circuit detection

Goal

- Redesigned breadboard with advanced features to assist students in learning how to use the breadboard.

This redesigned breadboard aims to reduce the errors that can come from designing and testing on a regular breadboard. This will include five objectives, or deliverables, with three being software focused, and two being hardware related. The first objective is to create a GUI where a user can easily draw a schematic. This GUI will limit what the user can make including how many nodes are available. The focus will be on node configuration rather than what specific components are used as there will not be options for different values. Instead, a list of components will be available including resistors, capacitors, and inductors. The second objective will be to create an algorithm that can transform the schematic into components on a breadboard. The focus will be on accuracy and speed so that the program does not take time away from the user. The algorithm should ensure that the number of nodes in the schematic are not more than what is available on the breadboard. Will it include other checks to make the translation as accurate as possible. The third objective is for the software to send this data to the breadboard to prepare for hardware integration. It will be able to accurately send the virtual breadboard layout to the physical board through a connection between the laptop and board.

The fourth objective will be for the LEDs in the breadboard to illuminate based on what the algorithm provides it. If nodes A and B are expected to be used then only those nodes should light. This will make it easier for the user to place components on the board without mistake. The LEDs will be bright enough and spaced to not confuse one node for another. The fifth objective is to have a check for open and short circuits. To the untrained-eye that can be difficult to spot, so this check will allow the user to identify this mistake and fix accordingly. This final objective should be able to let the user know that this test failed. Figure 1 shows how the GUI and LEDs will work together to make a guide for the user.

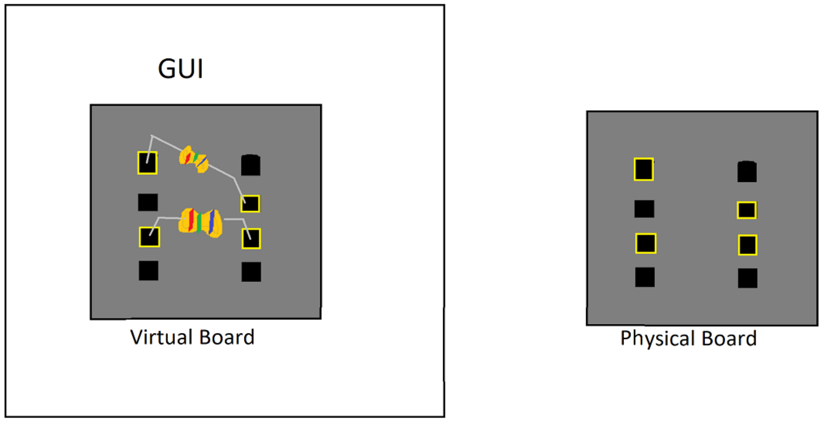

Figure 1: Virtual and Physical Board Relation.

To make this project more portable there will be a limited number of nodes as compared to a regular breadboard. With only a handful of nodes there will only be a few holes associated with each. This will create a constraint on the GUI because the schematic will have to consider this limit. The software will have checks to ensure that the user is not building a design that is incapable of being made. These checks will be known to the user if any of them are failed so that a redesign can be made. The breadboard will also need to be designed and built to include the LEDs, PCB, and communication with software. This new board will allow the project to be encompassed with fewer separate parts.

2.3.1 Prior Related Work

An important part of this project is to create new features to make the breadboard more advanced. Breadboards in most labs are simple solderless boards that allow the user to place components as needed. The goal is to improve on this in a way that has not been done. The four main components of the project are the GUI, schematic to breadboard, illuminated board, and open/short circuit test.

There are many softwares that allow a user to build a schematic and create a simulation. These include, but are not limited to, Multisim, AutoCard, and LTspice. The project will include aspects similar to these examples because of their easy-to-use interface. These applications have a section where components can be dragged and dropped. Keyboard shortcuts are also added to make schematic drawing faster. Lots of circuits can be created and saved to be accessed later. This requires a memory element to the program that will be considered. When those saved circuits are accessed they have the same output as they did originally so the algorithm is reliable and accurate.

There are not many softwares that will convert a schematic to a breadboard design. However, "Fritzing is an open source software that can allow a user to create a design on a virtual breadboard and convert that into a PCB design or breadboard layout. It allows the user to convert from different views including schematic, breadboard, and PCB layouts". This is an advanced software and provides many capabilities not commonly offered. Fritzing will be useful for guidance through the project on how to visualize the translation process. It gives insight on what the user will prefer to use and what to improve upon. As breadboards do not have communication ports this information from the software will not translate directly onto a physical board. Rather, the user will have to translate this information. This project will differ in that the software will send this information to the board to illuminate the same nodes.

Most LEDs on a breadboard are tutorials of how to illuminate an LED using the breadboard rather than as a feature of the hardware. Instead there are solderless breadboards that offer different options. There is the Thorlab's Temperature-Controlled Breadboard, and the Powered Breadboard which is more common. The powered breadboard offers a way to keep the power supply with the breadboard in one hardware package rather than separately wiring one in. This will be useful in the consideration of the hardware design because of its compactness and portability. The Temperature-Controlled Breadboard is a special consideration because it is not a typical version of the breadboard readily available. Instead, it is made for specific situations. The Advanced Breadboard will consider the unique design of that board since it will be designed differently from the typical breadboard. The Temperature Controlled board includes components such as electrical tape and mounts as a part of its design [12]. These components will be taken into consideration when designing the hardware because the LEDs will need to be placed close to the nodes without interfering with the circuit. As well as considering how to build the board while keeping components snug in the nodes.

For the open/short circuit test there were not a lot of resources where the breadboard itself was able to detect these. However, there are plenty of resources on the method of how to test for both. The test for an open circuit is when there is an infinite resistance between two points. Continuity tests on a multimeter are another way to test for open circuits. For short circuits, a resistance reading close to 0 will be conclusive. There is another method of using thermal cameras to detect short circuits, but given that we will not be testing with a large enough source this may not prove effective.

2.4 Requirements and Specification

2.4.1 Specifications

The goal for our hardware design would be to let the PCB control the LEDs and connect to the GUI using a direct connection. This GUI will be able to provide a user interface for an ELECROW 5 Inch Touchscreen monitor. From there, we will have LED lights to indicate which nodes should be occupied. Finally, a short/open circuit detection method will be used to determine if the power supply has been shorted or opened when the user places their own circuit on the breadboard. We will be demoing Specification 4, 7, and 8. Specification 4 will be presented by having a prototype GUI that connects to the breadboard without any cabling. Specification 7 will show that the open/short circuit functionality is working and warns the user when an open/short circuit has been detected . Specification 8 will showcase a demo program where if the demo-GUI activated LED1 then that corresponding LED will light up.

Specifications	
Weight	**< 10lbs**
Size	**Fit in two hands (Portable)**
Computer Interface	**ELECROW 5 Inch Touchscreen**
Computer Connection	**Direct Connection**
Power Consumption	**5W**
Runtime	**< 30 Seconds**
Open/Short Circuit Detection	**>95% Accuracy**
LED Activation Placement	**>95% Accuracy**
Wireless Connection	**Up to 10 ft**
Cost	**< $200**

2.4.2 Requirements

This section will focus on the requirements that have been setup for this project. These requirements will be used as goals that need to be met when designing the device. Furthermore, this will make the designers understand what the users want and what they need.

General Requirements:

- The device shall be used by one person
- The device shall have a wireless connection with a computer for up to 10 ft
- The device shall detect a short/open circuit is less than 2 seconds
- The device shall be small enough to be held with 2 hands
- The GUI shall have a user friendly interface that requires no training to use
- The device shall have red LEDs for light indication
- The LEDs shall be bright enough to be seen up to 3 feet away
- The device shall have a warning for open/short circuit detection
- The device shall be powered by batteries
- The device shall be affordable for an average person

Possible Constraints:

- Power Supply
- Reliability
- Sustainability
- Cost

- Testing Process
- Time

2.5 House of Quality

The House of Quality shown in Figure 3 is a tool designed to reflect the customer's needs and how it relates with the product specification. Using this tool, we can analyze the qualities of our product to match that of the User's Requirements. In Figure 3, we have used the horizontal row to reflect the Engineering Requirements; and, vertical rows to reflect the User Requirements. These two rows cross with each other to show the correlation between the User Requirements and the Engineering Requirements. The roof represents the interaction between the different Engineering Requirements and how these requirements affect one another.

When analyzing our House of Quality, we have concluded that the most affected factor is the cost. The cost directly affects the quality and functionality of our product. For instance, we cannot increase the size and the number of LEDs without directly affecting the cost; and, by changing the cost we are indirectly changing the quality of the other parts in our product.

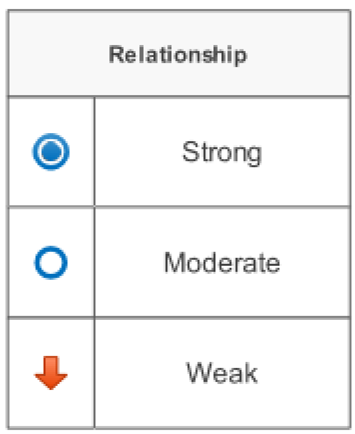

Figure 2: House of Quality Legend

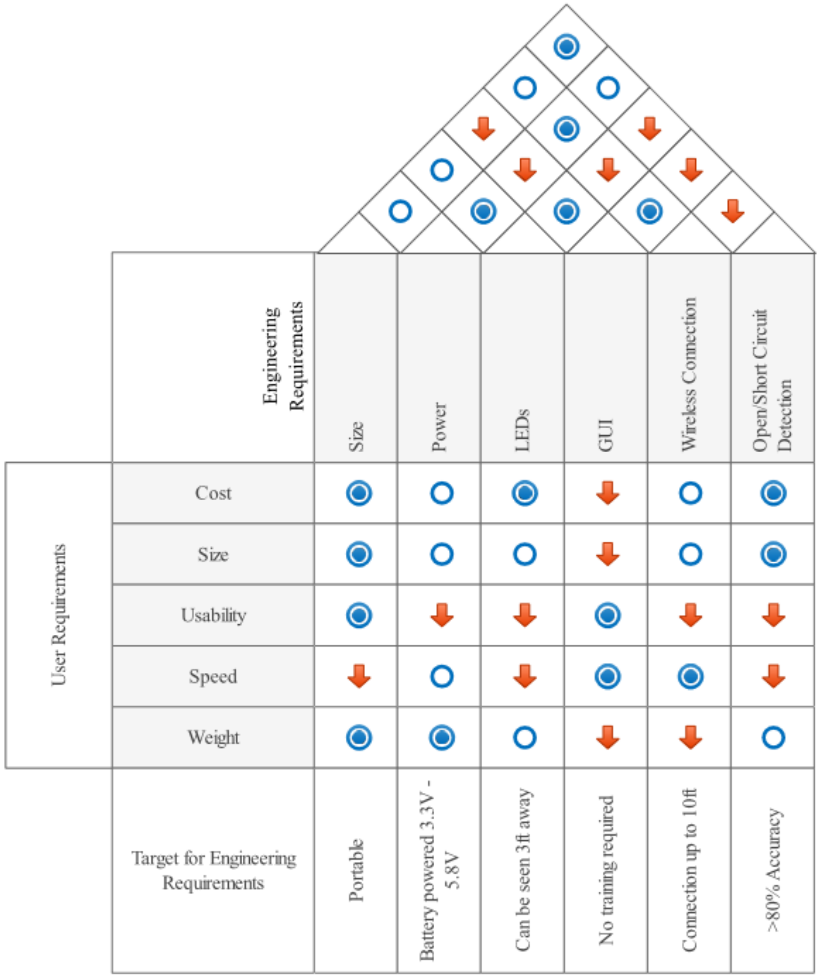

Figure 2: House of Quality

2.6 Diagrams

2.6.1 Hardware Flow

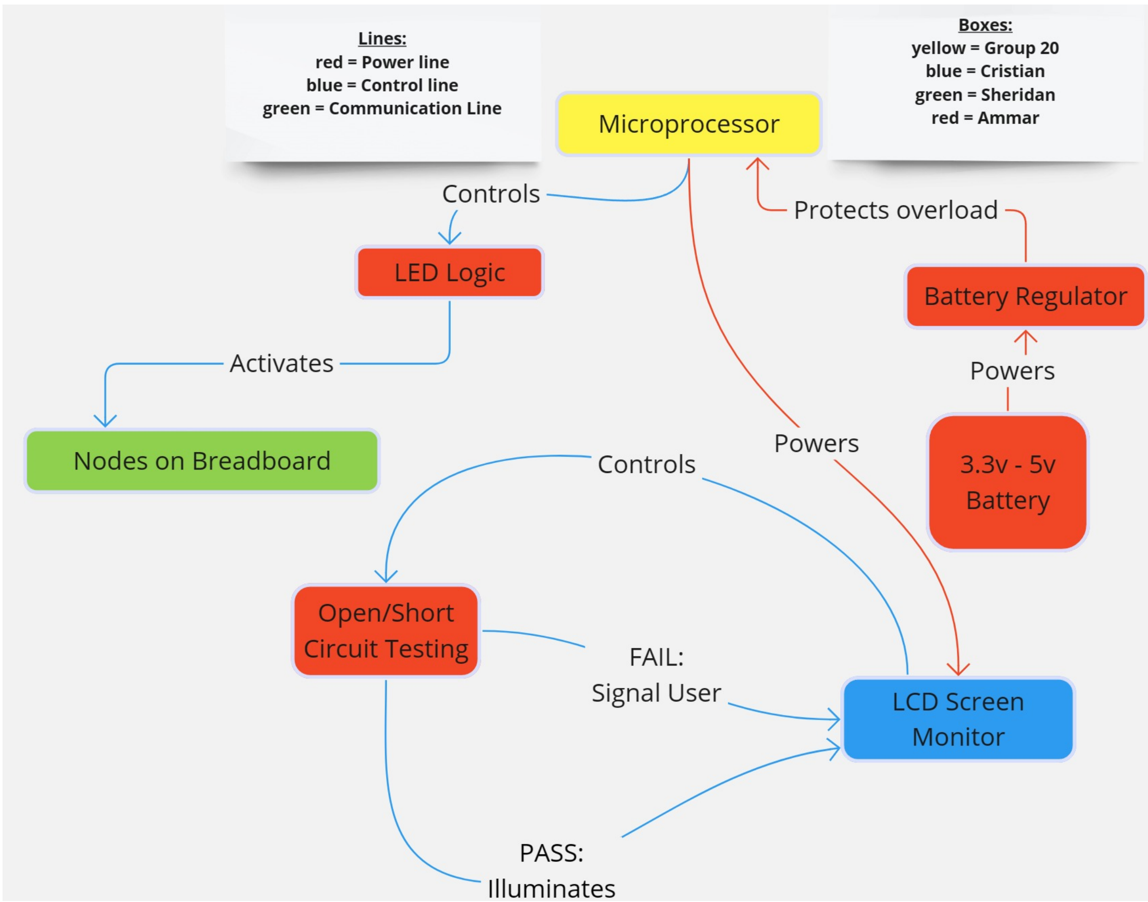

Figure 3: Hardware Flowchart

2.6.2 Software Flow

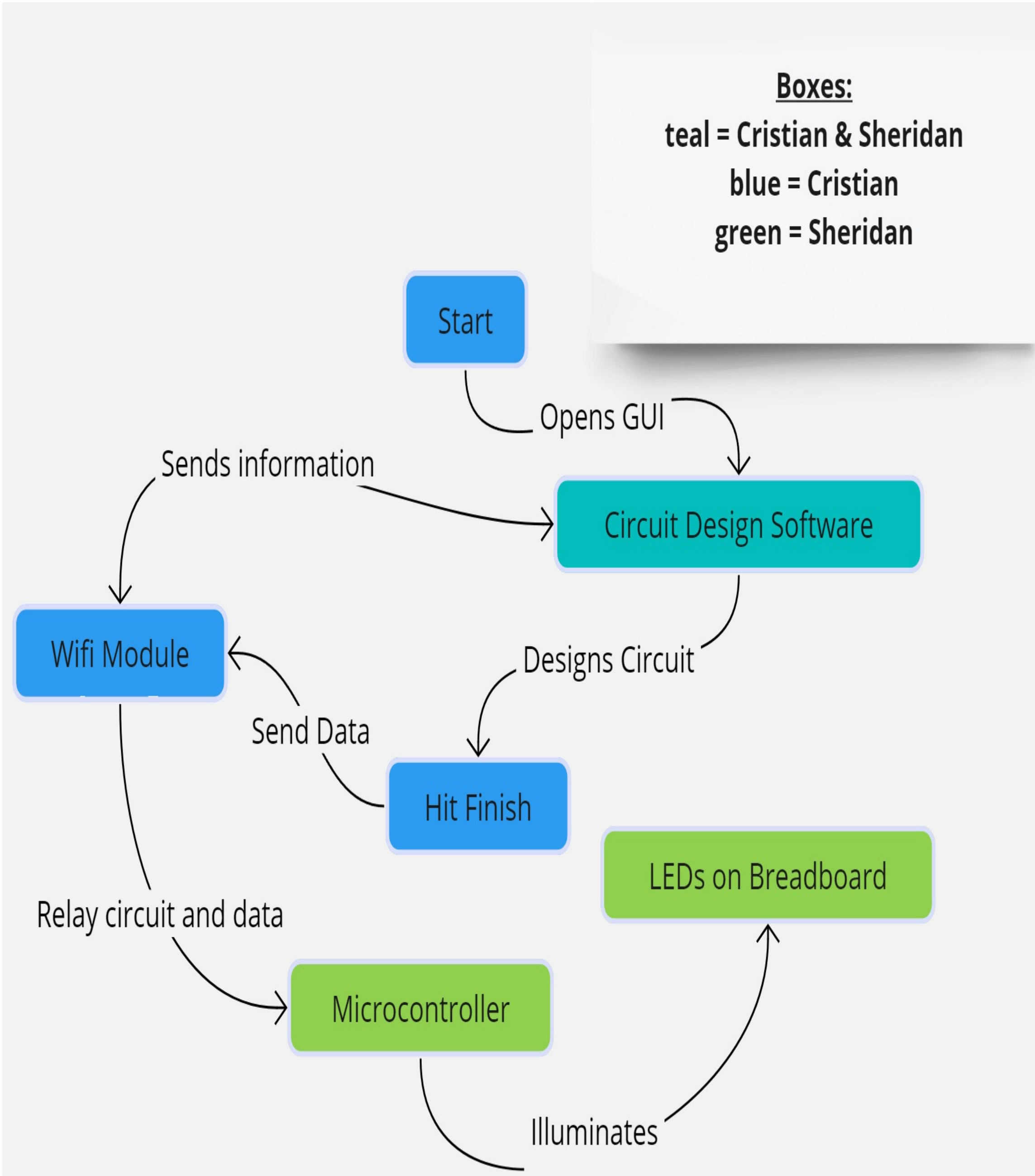

Figure 4: Software Flowchart

3. Research and Part Selection

3.1 Breadboard Design and Development

The breadboard will be designed and built to incorporate all of the customizations for the project. This new design will mimic the look of the typical solderless board, but will be able to house the PCB, Microprocessor,Monitor, and LEDs. The material will be chosen with weight, cost, and size in mind. The number of nodes will be limited to help maintain the smaller size. The nodes themselves will be spaced in order to allow components to stretch to them but not be out of reach. It will also be built to hold the components as a typical board will do to ensure the components share the node on the metal strip. The board will also take into consideration the LEDs and will decide their placement to ensure the user can easily see them and decipher which node it corresponds to. The breadboard size, color, design, and shape will depend on a number of factors.

A typical breadboard cannot be used since there are multiple components that must be incorporated into it to make it more portable. The breadboard design will be separated into layers to organize the different capabilities to be added. It will be important to gain access to the PCB since that is where the power supply will be. The board will have to be made out of a material that can handle these constraints. Breadboards are typically made of ABS Plastic [1] so this will be a strong contender. The breadboard must be made of insulator material to ensure the user's circuit is not affected. Some insulators to be considered are wood, plastic, and glass. The weight, electrical resistivity, accessibility, price, and ability to be manufactured will be the factors in determining which material to build the breadboard out of. Wood does have weight and it is difficult to work with thin pieces of wood because it won't be sturdy enough. It is also not easily manufactured for the shapes and design that are required. For these reasons wood will not be considered. Glass will not be considered because of its manufacturability and cost. It would also incur a lot of weight and will be very fragile for the final design. Plastic, however can be manufactured using easily accessible 3D printers, are cheap, and easy to design with on CAD.

There are different types of plastic that can be 3D printed but the three most popular are Acrylonitrile Butadiene Styrene (ABS), Polylactic Acid (PLA), and Polyethylene Terephthalate Glycol (PETG). These are more commercially accessible so they will be considered. The columns in the table below were chosen to be the most important factors. The Shore measurement is important because the breadboard should not be flexible or soft. The Dielectric Constant must be highly considered because the material needs to avoid messing with the user's circuit. The temperatures were taken into consideration because components may heat up and the environment itself may be warm given the current climate. It is also important to have because the printer will need to be able to handle that type of temperature. Based on these considerations it is determined that ABS is the preferred material because it has a high electrical resistivity and higher processing/melting temperatures. It is also the material that is most typically used for commercial solderless breadboards so it can handle the task.

Plastic Type	Hardness (Shore)	Dielectric Constant	Melt Temperature
ABS	76 [5]	2.19-2.9 [6]	437℉-473℉ [5]
PLA [2]	83	1.7-2.8 [6]	293℉-320℉
PETG	70 [3]	2.6 [4]	410℉-455℉ [3]

Table 1: *Breadboard Plastic Material [2], [3], [4], [5], [6].*

With the board being made out of plastic, it can be designed with different layers and different colors. The layers will include the PCB housing on the bottom, a layer for LED placements, then a top layer for the nodes which can be translucent to allow the light to show through. The bottom part of the layers will be white to stay with the standard color of other solderless breadboards. This makes debugging easier for the user because the white background and the colors of the components will contrast well.

The number of nodes will decide what level of circuits can be built. This breadboard will be primarily a teaching tool and therefore will not be equipped for large, advanced circuits. Rather, this board will only use a handful of nodes to ensure accuracy, speed, and simplicity. Having fewer nodes will allow for higher accuracy since there will be less nodes for the short/open circuit test. The speed will be higher for fewer nodes since the circuit planning algorithm will have less possibilities for the diagrams. The simplicity will be better with fewer nodes because the user will not need to worry about trying to build a complex circuit without having a good understanding of the process. One node will not be considered because a circuit requires a minimum of two nodes. To allow for a variety of circuit designs, three nodes will be implemented.

The next consideration for the nodes will be how to connect the nodes with metal contacts. There are two things that will restrict the placing of the components. How long the components themselves can be stretched and the type of metal strips that will be used to connect a node. The connectors are long pieces of metal that contain multiple clips to hold the components in place and connect them to one node [7]. There are a few options for the metal clips which include scrapping them from regular breadboards or designing something that can be made using regular metal clips.

The first method would be more reliable and require less parts for assembly. The metal contacts in commercial solderless breadboards are mass produced and would have the highest quality of the options. Since most commercial metal contacts contain five holes per node, two of those clips will need to be removed. Removing the clips from the board will require more work as they are not built to be disassembled. Using those metal contacts will also limit the spacing of the nodes on the redesigned breadboard. Some extra spacing between the nodes could increase the accuracy for the user because they won't get confused by the closely placed holes. The second option is the clips can be customized and manufactured. This can be a challenge and will require an advanced knowledge of CAD because of the nature of the clips. The metal clips will need to be designed to hold the component in place and be small. This part would be 3D printed and a metal strip would need to be attached. All of the designing, testing, and machining may take more time than would be necessary. The third option would be to take the metal contacts from miniature boards because that would avoid the issue of removing the two extra contacts like in the first option. However, the contacts in the smaller boards are different than that of larger boards and may be more difficult to integrate into the new design.

Method	**Cost**	**Time**	**Customizable**
Removing metal contacts from solderless breadboard	<$10	24 hours	Fits the design. Must remove two nodes
Designing/Manufacturing	<$10	48 hours	Made to specifications
Removing from smaller breadboards	<$10	12 hours	Correct number of nodes, metal contacts need altering

Table 2: *Breadboard Metal Contact Design Options.*

This project will move forward with sourcing the clips from already manufactured breadboards which are easily accessible. It may take longer than sourcing from the smaller breadboards, but the contacts are made in a way that can be easily integrated into the board. Two of the contacts for a node may need to be removed but that process will not require any advanced skill or tools. A commercial solderless breadboard will have more than enough metal contacts required for the project with enough for testing and prototyping and final submission.

3.3 Microcontroller/Microprocessor

In the context of the Advanced Bread project, microcontrollers and microcomputers play a pivotal role in enhancing the functionality and user experience of the breadboard. The following devices have been selected as options to be an integral part to the project.

Our objective is to select one from these devices to develop a graphical user interface (GUI) that allows users to translate their circuit schematics into physical components on the breadboard. Additionally, the devices will aid in facilitating the LEDs of specific nodes on the breadboard. However, our consideration extends beyond just the physical size of these devices. We must also consider their operating voltages. Also, the output voltage pins of these devices hold significance.

In summary, the microprocessor selected for the Advanced Bread project will serve as the brains behind the system, enabling an intuitive GUI, node illumination, and ensuring the safety and efficiency of the redesigned breadboard for circuit design and integration. Here are the most viable breadboards in question:

3.3.1 Raspberry Pi Zero W

The Raspberry Pi Zero W is a compact yet capable microprocessor board that features a 1 GHz single-core ARM1176JZF-S CPU and 512MB of RAM. It's well-suited for your advanced breadboard project, offering sufficient processing power for tasks like running a graphical user interface (GUI) to assist with circuit design. It includes built-in Wi-Fi and Bluetooth for wireless connectivity, making it convenient for data transfer between the breadboard and a laptop. With 40 GPIO pins, it provides ample options for interfacing with the breadboard's components. However, it's essential to note that it consumes more power compared to the ESP32, which should be considered for portable applications.

3.3.2 Raspberry Pi 4

The Raspberry Pi 4 comes in multiple RAM configurations (2GB, 4GB, or 8GB) and is equipped with a powerful quad-core ARM Cortex-A72 CPU. This microprocessor offers substantial processing power, making it suitable for complex tasks in your advanced breadboard project, including running a sophisticated GUI. It runs Linux distributions and provides a full desktop environment, making it versatile for software development. Dual-band Wi-Fi and Bluetooth connectivity add flexibility for data transfer and remote control. With 40 GPIO pins, it enables seamless integration with the breadboard. However, the Pi 4 consumes more power compared to the ESP32, which may require a reliable power source.

3.3.3 ESP32

The ESP32 microcontroller is known for its power efficiency and portability. It features a dual-core Tensilica LX6 CPU running at up to 240 MHz and 520KB of SRAM. While not as powerful as the Raspberry Pi models, it's suitable for basic tasks in your advanced breadboard project. It can handle a simplified GUI and offers built-in Wi-Fi and Bluetooth for wireless communication and remote control. With its GPIO pins, it facilitates easy interfacing with the breadboard's components. One of its key advantages is low power consumption, making it an excellent choice for portable and battery-powered applications. However, it may struggle with more complex GUI requirements compared to the Raspberry Pi boards.

Microcontroller/Microprocessors	**RAM**	**Pros for Project**	**Cons for Project**
Raspberry Pi Zero W	512MB	Offers ample ram for the project.	Maybe overkill for a simple breadboard project.
Raspberry Pi 4	2GB, 4GB, or 8GB	Provides plenty of RAM for complex tasks.	May be overpowered and more expensive.

ESP32	520KB SRAM	Suitable for basic circuit design tasks.	Limited RAM; may struggle with complex GUI.

Table 4: *Project-Specific Comparison.*

Microcontroller/Microprocessors	**Pros for Project**	**Cons for Project**
Raspberry Pi Zero W	Offers a full Linux environment.	Higher power consumption compared to ESP32
Raspberry Pi 4	Powerful, suitable for a wide range of tasks.	High power consumption may need active cooling.
ESP32	Extremely power-efficient and portable/	Limited computational capabilities compared to Pis

Table 5: *General Aspect Comparison.*

The Raspberry Pi 4 stands out as the ideal choice among the three devices for the advanced breadboard project. Its substantial processing power ensures smooth operation of the graphical user interface and complex algorithms for translating schematics to physical components on the breadboard. With multiple connectivity options, including USB ports, HDMI, Ethernet, and a built-in Wi-Fi (not necessarily guaranteed to be used, but there regardless, displaying further flexibility), it provides the flexibility needed for interfacing with the advanced breadboard and handling software-hardware integration. The Pi 4's capabilities also enhance the GUI's performance to be able to use the monitor to its full potential, offering a better user experience. Additionally, its popularity and reputation is showcased and supported by a large and active community, allowing for customization and access to a wealth of resources. Compatibility with various accessories and sensors, coupled with its longevity and continued support, make the Raspberry Pi 4 the most suitable choice to develop the advanced breadboard project, ensuring efficient development and long-term viability.

3.4 Raspberry Pi 4

3.4.1 Operating System

The raspberry pi is a very common product that a lot of users have experience with and purchased. As such, it has a large community of people who have developed many software and even OSs that are open source. One of the most popular software is the Raspberry Pi OS because of its many capabilities. It is an optimized system designed for the Raspberry Pi to facilitate project building. Its compatibility spectrum, spanning various libraries and tools, ensures rapid software development and a frictionless connection between hardware and software. Additionally, it has a lot of technical documentation in case of the need to dive deeper into the understanding of the operating system. This will be an important technology to be considered for the project because the software side will require housing to interact with.

3.4.2 Application Layer

The application layer can house applications tailored for our project, sculpted in Python. This allows the designers and the users to access the program without hassle. With Python's expansive libraries and Raspberry Pi's intrinsic support, we can ensure optimal control over hardware components. This capability can help with the project's objective of maintaining accuracy and efficiency because there is more control of the device with this service.

3.4.3 Connectivity

The project will leverage devices like the ELECROW 5 Inch Touchscreen. This way, direct connectivity will likely negate the need for Wi-Fi because the user can manipulate the program from the device rather than requiring their own separate device. Setup becomes easier for the user because less hardware will be required. Hence, implementing robust security protocols for data sanctity remains paramount, Wi-Fi-based standards like MQTT may be circumvented due to the direct hardware linkage as provided by the ELECROW 5 Inch package. It will also be important to consider the user when interacting with the touchscreen because it should be accessible and should not require strained effort to use or see.

Another option could be a wired connection between a screen monitor and the Raspberry Pi through HDMI. This type of connection would be reliable and would allow the user to change the type of monitor for their needs since HDMI ports are widely used. It is important for the project to be accessible to users so this adaptability would be a benefit. However, having a wired connection will cause the project to be less portable since the wire would be a limiting factor.

3.4.4 External Devices

One of the pivotal external devices enhancing our project's user experience is the ELECROW 5 Inch Touchscreen. This device offers:

· A 5-inch high-resolution display, boasting 800x480 pixels, ensuring clarity and a vivid representation of our software interface.

· Broad compatibility, including Raspberry Pi 4, 3B+, 3B, and 2B+. This offers flexibility for future adaptations and iterations of our project.

· A resistive touch screen, enhancing the user's interactive experience. The accompanying touch pen ensures precision during operations.

· The provision for manual backlight control, empowering users to manage power consumption based on their requirements.

· While it has been primarily designed for Raspberry Pi integration, its compatibility extends to standard HDMI devices. This positions our project to have a wider application, even beyond the Raspberry Pi ecosystem.

· A comprehensive package that includes not just the screen, but essential accessories like the touch pen, HD adapter, and copper pillars, ensuring hassle-free setup and installation.

3.4.5 GUI (Graphical User Interface)

Envisioning a user interface that encapsulates both simplicity and functionality is one of the most important parts and goals of our software design. Drawing inspiration from the well-established Multisim:

· The GUI will open to an open breadboard layout. This initial setup stage is for the user and it takes them directly into the circuit creation phase.

· Users can drag and drop components onto the breadboard. This interactive method simplifies the learning curve and augments the hands-on feel of circuit design.

· A library of components will be available. Users can easily search, select, and integrate these components into their design.

· To enhance user experience and reduce clutter, unnecessary toolbars and options prevalent in traditional Multisim templates will not be there, offering a clean, concise, and focused design workspace. This is also as a result of the difference in product which naturally requires more simple/less features.

· Incorporating these features ensures our GUI not only resonates with experienced Multisim users but also welcomes newcomers with an intuitive and user-friendly design. This is especially key to users such as students who have had to deal with the original breadboard.

3.4.6 Error Handling

In the realm of software development, especially when interfacing with hardware like the Raspberry Pi 4, error handling is extremely key. A well-structured error handling system not only identifies and captures errors but also provides meaningful feedback to users, ensuring a good experience with the product. Following the IEEE 1044-2009 standard on classification for software anomalies, our approach is to categorize, prioritize, and manage errors effectively. By implementing this standard, we can swiftly find errors/bugs, classify them based on severity, and address them in a structured and organized manner. The primary objectives are to:

· Inform the user gracefully about any issues, ensuring they are not left in the dark.

· Log errors in a manner that aids in swift diagnosis and resolution.

· Ensure that critical functions have fallbacks, so the software can continue operating even when facing minor glitches.

3.4.7 User Experience (UX) & User Interface (UI) Design

The fusion of an intuitive user interface (UI) with a seamless user experience (UX) is the key of any successful software and especially an intuitive or easy one. It's not just about aesthetics though, it's about crafting a user environment where functionalities are easily accessible, and interactions feel natural. The commitment to the ISO 9241-210 standard, which emphasizes human-centered design for interactive systems, is going to our focus on the end-user. By implementing this standard, we ensure:

· A solid understanding of user requirements, tailoring our software to fit their needs.

· Accessibility, making sure that our software can be used effortlessly by everyone.

3.4.8 Testing

Following the guidelines of IEEE 829-2008, our testing won't be haphazard but systematic. This approach allows the Raspberry Pi's software to always deliver reliably when communication to hardware.

3.5 Open/Short Circuit Detection

A crucial component in the Advanced Breadboard project is the ability to detect short circuit and open circuit within the circuits designed by the users. As mentioned in the previous sections of this report, the Advanced Breadboard will be a newly improved version of a regular breadboard that is commonly used in engineering laboratories. A common mistake that occurs when using a breadboard is when components become short circuited or open circuited without the users knowledge. This can be done without intention and is something that could be easily missed by the user; so, the solution we created is the ability to detect when the user's circuit is short circuited or open circuited; and, warn the user when the condition is true.

The main method we have found that can be utilized in the Advanced Breadboard is the use of Voltage Sensors and Current Sensors. The voltage sensors and current sensors would connect to the main power supply and also connect to an A/D Converter to process the data given by the sensors. If the current is equal to zero then the circuit is open, if the voltage is equal to zero then the circuit is shorted.

3.5.1 Voltage and Current Sensor

The outline of this section is to discuss the Voltage and Current Sensor component. This component has the combination of both a Current Sensor and a Voltage Sensor. The voltage and current sensor is the primary component for the open/short circuit detection. This component would connect from the Variable Power Supply, which would be the user's power source for their electrical circuit, and connect to the microprocessor. Since most of these sensors already contain a Digital to Analog converter, and the microprocessor we plan to use also contains an A/D Converter then it is not necessary to include an A/D Converter to the PCB design.

3.5.1.1 INA219AID

The Texas Instrument INA219 Zerø-Drift, Bidirectional Current/Power Monitor With I2C Interface is a unique sensor that measures the voltage, current, and power of various electronic equipment. For the purpose of this project, we will only be examining the functionality and accuracy when measuring both the voltage and current of a power supply unit for the open/short circuit detection functionality implemented in this design. This sensor can measure electrical equipment within 0-26V and 8A with a maximum relative error rate of less than ±0.2%.; and, is typically powered by a separate power supply with a voltage between 3V-5.5V. Applications of this sensor include Battery Chargers, Test Equipment, and Power Supplies which make it the ideal sensor that we need since we may need to use all three of these equipment.

The INA219 utilizes an I2C or SMBUS-compatible interface. However, the I2C interface is mostly used throughout the datasheet while the SMBUS Protocol is used when a difference between two systems is addressed. Which is why for this design we may be utilizing the I2C interface for voltage and current sensing applications.

3.5.1.2 INA260AIPW

This sensor is also manufactured by Texas Instrument and offers a ton of digital-output monitoring. For starters, this sensor can measure current, power, and voltage with an I2C and SMBus compatible interface. The sensor enables high accuracy current and power measurements as well as offering an over-current detection at common-mode voltage varying between 0-36V. Just like the other sensors, it offers an Analog to Digital Converter; and its digital interface allows for programmable threshold alerts, ADC conversion times, as well as averaging.

3.5.1.3 INA233AIDGST

This Texas Instrument sensor measures current, voltage, and power with an I2C, SMBus, and PMBus interface. Independent of the supply voltage, the sensor senses current on common-mode bus voltages that vary between 0-36V. The biggest advantage of this sensor is its .1% Maximum Gain Error which results in a highly accurate sensing. This may be a little too much for the purpose of this project, but it is still something to consider. The compatibility between the three interfaces gives it a huge advantage compared to the others. Another feature this sensor has is power detection. Although we may not need this feature since we are more interested in voltage and current, it is still something we may need to consider if we plan to improve the Advanced Breadboard design.Finally. It has one of the fastest lead times coming in at six weeks.

	INA219AID	**INA260AIPW**	**INA233AIDGST**
Cost	$2.70	$6.38	$4.22
Operating Voltage	3-5.5V	2.7-5.5V	2.7-5.5V
Sensing Voltage	0-26V	0-36V	0-36V
Accuracy	.5% Maximum (over)	.15% Maximum System Gain Error	.1% Gain Error (Max)
Interface	I2C, SMBus	I2C, SMBus	I2C, SMBus, PMBus
ADC	Yes	Yes	Yes
Lead Time	6 Week	8 Weeks	6 weeks

Table 6: *Sensor Comparison.*

Based on the table comparison and the short analysis we made on the different components, we have decided to go with the INA219AID sensor. For the purpose of this project we need two conditions to satisfy the short/open circuit detection. The first, when the current is equal to zero. The second, is when the voltage is equal to zero. Based on those two reasons, accuracy of the sensor becomes negligible after a certain point. Although the INA233AIDGST is the most accurate sensor out of all the choices, it is a bit of an overkill for the purpose of the Advanced Breadboard's open/short circuit detection.

Furthermore, the maximum output voltage by the user's power supply is 15v. So having a sensor that has a higher sensing voltage does not pose any benefits. Having a six week lead time as well as being cost effective are both benefits that the INA219AID has over the other two sensors. For these reasons, we concluded the part comparison for the Voltage and Current Sensors and have decided that the most optimal choice is the Texas Instrument INA219AID sensor.

3.6 Power Supply

Powering the components of our Advanced Breadboard is an important topic that needs to be discussed. The power supply we choose impacts the rest of the design and the components we choose to use throughout the project. We intend to adhere to the environmental, health, and economic constraints discussed in the following sections of the report. Since the Advanced Breadboard utilizes multiple components to fulfill its purpose, we need a power supply adequate enough to power the product and keep it portable. To come up with a proper conclusion we need to figure out the amount of operating voltage needed to power all the components in our product.

After analyzing the various components and Power Supplies for our design, we have found that the best option is to separate the Power Supplies for the PCB and the User's Power Source for their circuit. Firstly, most components used in our design need an operating voltage ranging between 3V-5.5V. If we utilize a Variable Power Supply that can output a voltage between 0V-3V then the Advanced Breadboard's components will not function, but it will still power the user's circuit. Additionally, if the Variable Power Supply outputs a voltage higher than 5V then we can use a voltage regulator to reduce the voltage when powering the components to a voltage between 3V-5.5V. Either way, if we combine the Power Supply to power both the user's electrical circuit and the Advanced Breadboard's PCB the design could be expensive, impractical, large, and time consuming. In conclusion, we have found that separating the Power Supplies will pose the best case scenario.

3.6.1 Variable Power Supply

This section will cover a variable power supply that can adjust the voltage output. This is important because we want the user to have the freedom to choose the voltage input for their circuit. Based on further research we needed to decide whether to use that same variable power supply to power the PCB. This includes all of the components connected to the PCB as well.

The disadvantage with this setup is the voltage range that we need to set. Since one of the environments we are analyzing are university engineering laboratories, we have found that the most common maximum voltage input designed with breadboards is 15V. Another reason to limit the maximum input voltage is due to the voltage and current sensors having a limitation. Most voltage sensors can only measure voltage that is around 4-5x the input voltage. Furthermore, we need a power supply that does not pose a fire hazard when shorting the voltage terminal pins on the breadboard. For this reason, we have decided to use a Variable Power Supply to power the user's electrical circuit. The subsections below will discuss the options we have for a variable power supply while the table below will compare and contrast the power supplies to determine which one is the most suitable part for the Advanced Breadboard.

3.6.1.1 Elenco XP-15K Power Supply Variable Kit

The Elenco XP-15K Power Supply is a very common power supply used by many students and lab instructors in university laboratories. Its affordable price and low voltage output makes it a very valuable tool in an engineering laboratory. According to the manual, the power supply contains a transformer that transforms the voltage from 120V to 18V, an AC to DC converter that converts the 18VAC to 20VDC, and a voltage regulator that changes the voltage between 0V to 15V making it one of the top candidates for the ideal power supply that we need. Although we cannot adjust the output current, the manual specifications state that at 12V the output current is .3A and at 15V the output current is .2A which is something we need to account for. Furthermore, when the power supply is shorted it will turn off and when the short is removed it will recover to full functionality.

3.6.1.2 Korad KD3005D Power Supply

The Korad KD3005D Power Supply is an industrial-grade performance power supply with an affordable price. The power supply offers a system lockout to prevent any unwarranted changes to the voltage and current outputs once they have been set. This power supply offers an output voltage range between 0-30V which is more than double the intended maximum voltage we are searching for. Furthermore, the power supply offers an output current between 0-5A which may be unnecessary considering the scope of the project. The advantage of this power supply is that it offers a full digital control of the voltage and current output and displays using the LED display which allows for easy adjustment to the output voltage and current at the user's discretion.

3.6.1.3 Matrix MPS-3206 Series

The Matrix MPS-3206 Series Power Supply is a high accuracy dc power supply with an output voltage ranging between 0-32V and an output current between 0-6A. Although the price is higher than the Elenco XP-15K, it compensates by having a digital display and adjustable current analog unlike the Elenco XP-15K. The digital display consists of a double four-digit LED display that displays both the voltage and current which can be helpful for the user designing their circuit. Furthermore, the power supply comes equipped with a smart fan to regulate the temperature during long work loads which makes it ideal for laboratory environments. Since we are planning to make the Advanced Breadboard transportable, this power supply is designed to be ultra lightweight weighing in about 1.5kg. Lastly, the power supply offers a short circuit safety measure to prevent any damages to the power supply in the case of a short circuit.

	Elenco XP-15K Power Supply	**Korad KD3005D Power Supply**	**Matrix MPS-3206 Series**

Cost	$34.99	$89.99	$69.99
Output Voltage	0-15VDC	0-30VDC	0-32VDC
Output Current	.3A @ 12V .2A @ 15V	0-5A	0-6A
Short Circuit Safety	Yes	Yes	Yes
Lead Time	1 Week	8 Weeks	5 days
Digital Display	No	Yes	Yes

Table 7: Comparing Power Supplies

After analyzing the different power supplies we have found that the best and most ideal power supply would be the Elenco XP-15K Power Supply. Although there are some downsides to the Elenco compared to the other two power supplies, its benefits far outweigh its downsides and for those specific reasons is why this came out as the ideal power supply for the Advanced Breadboard.

For starters, this power supply will power the user's electrical circuit and for the most case the highest voltage we would need is under 15V. We came to that conclusion by analyzing the current and voltage sensors, most of them specifically state that an input voltage higher than 15V may alter the accuracy of the sensors. So, choosing a maximum voltage output of 30VDC or 32VDC is a bit of an overkill for this project. Secondly, being able to adjust the output current is a benefit; but in the case of simple breadboard circuit designs by the user, that functionality is not a necessity. Thirdly, the fast lead time is another huge benefit. The earlier we get the power supply, the earlier we can start prototyping and designing the Advanced Breadboard. In conclusion, due to the reasons mentioned in this section, we have decided that the most ideal power supply to use for the User's electrical circuit in the Advanced Breadboard is the Elenco XP-15K Power Supply.

3.6.2 Battery Pack

The battery pack we choose will be used to power the Advanced Breadboard's PCB along with the components connected to the PCB. Since the PCB requires 3V-5.5V to power all the components, we figured that a battery pack will be more than enough to supply the power we need. The subsections below will describe the battery selection we have chosen, as well as the benefits and downsides to the battery pack we have selected. Additionally, There is no specification for rechargeable and non-rechargeable batteries. So, we decided to research which battery pack will provide the most benefit to this project.

Since there are many types of batteries, we decided to explore the types and evaluate which battery type will offer the best performance for this project. Alkaline batteries utilize zinc metal and manganese oxide instead of acidic electrolyte to drive the energy. The advantages for this type is a higher shelf life, smaller size, and low leakage. Another common battery type that is mainly used in mobile computing and other applications is the Lithium-Ion. This battery type utilizes Lithium-Ion cells to generate high energy density and low discharge. The last type of battery we analyzed is the Zinc Carbon batteries. This type offers less performance than the alkaline batteries, but can be suitable for devices such as remote controllers, and clocks.

	Alkaline	**Lithium-Ion**	**Zinc-Carbon**
Capacity	850-1200 mAh	1150mAh	1100 mAh
Self-Discharge	2-3% per year	1-2% per month	.32% per month
Shelf-life	5-10 years	10-12 years	1-3 years
Temperature Performance	4-129°F	-4-130°F	23-113°F
Internal Resistance	High	Low	High

Table 9: Battery Type Comparison

Based on the research and the table comparison we have found that the most ideal battery for the purpose of this project is the Alkaline batteries. The availability and popularity of this battery type partially influenced our decision since we are trying to comply with the economic constraints that were placed on this design. Furthermore, the battery capacity of a single AAA Alkaline battery is within range of our design compared to the capacity of the other battery types. The major downside to this battery is the safety concern with a short circuit, due to no short-circuit safety measures the battery could potentially cause harm to the user. This can be avoided due to the safety risk assessment we plan to conduct as well as the risk management plan we have in store. Another benefit that this battery type possesses is the long shelf life and the low self-discharge. This will ensure that the batteries last longer than the other battery types.

3.6.2.1 Duracell AAA Batteries

The Duracell AAA Alkaline battery is a common household item due to its usefulness. Although this battery is non-rechargeable, each battery packs 1.5V and a charge capacity of 1150mAh which is a lot compared to the average rechargeable batteries. The high charge capacity will make it easier to keep the Advanced Breadboard running for a long time, and if the batteries drain, replacing the batteries would not be an issue. Its small size and lightweight is an asset to this project since we intend on making the Advanced Breadboard compact and portable.

3.6.2.2 EN91F3

The EM91F3 battery is a unique Alkaline battery pack manufactured by Energizer. This battery pack utilizes 3 AA battery cells to generate 4.5V which is in the range that we need for the PCB. It weighs at around 64 grams and its volume is around 2 cubic inches which makes it ideal for the Advanced Breadboard size requirements and weight requirement. The only downside is that we need to implement a way to replace the battery pack since it uses a solder tab termination style which can pose a design constraint.

3.6.2.3 Zeus AA

The E92VP is a AA 1.5V Alkaline battery that is manufactured by Zeus Battery Products. This non-chargeable battery offers a capacity of 3000mAh and weighs at approximately 23.8g. A few downsides that this battery has is that it is harder to obtain compared to the other batteries since it is not a very common brand for an alkaline battery. The fact that it is a AA battery means that it can not be used as an alternative battery to the Duracell AAA batteries, for that reason we need to keep in mind the battery we choose since the batteries are non-rechargeable. Since they are not rechargeable we need the user to have an easy and accessible way to replace the battery in case it is depleted.

	Duracell AAA Batteries	**EN91F3**	**ZEUS AA**
Cost	$6.195	$3.22	$6.60
Quantity Needed	3	1	3
Voltage	4.5V Total	4.5V	4.5V

Capacity	3450mAh Total	2779mAh	3000mAh
Rechargeable	No	No	No
Lead Time	1 day	5-7 days	12 Weeks

Table 9: *Battery Pack Comparison.*

Based on the table and short descriptions of the batteries we researched. We have found that the best and most ideal battery pack to use is the Duracell AAA Battery Pack. Although these batteries are non-rechargeable, it surely compensates in other ways compared to the rest of the batteries. Due to this battery being inexpensive and a common household item, we have found that the availability for this battery is endless and replacing these batteries are much simpler than the others. Since we are using three of the Duracell AAA batteries, we would need a combination of three batteries to generate 4.5V thus powering the PCB and all its components. Furthermore, the capacity of all three batteries would total to 3450mAh which would be long enough to keep the PCB powered longer than the other batteries we researched. The total cost of these batteries would total to around $6.195 on average which keeps this whole project within the budget and satisfying the financial requirements that were identified in the beginning of this report.

3.7 Voltage Regulator

A Voltage Regulator is a crucial component in a circuit that maintains a constant output voltage regardless of any changes to the input voltage or load conditions. When it comes to voltage regulators they are commonly used for DC/DC conversion while some are used for AC/DC or AC/AC conversion. For the purpose of the Advanced Breadboard, we will be using a DC/DC conversion voltage regulator to take a DC input from a battery source and convert it to a constant voltage output that will be used to power the PCB.

Of this type there are two types of voltage regulators, the first is known as a linear type while the second is a switching type. The Linear Voltage Regulator, are referred to as step-down converters since the output voltage is always lower than the input voltage. Switching Voltage Regulators are referred to as step-down converters, step-up converters, or a combination of both. The input voltage can vary while keeping the output voltage constant. Since we are using Alkaline AAA batteries we will be using a switching voltage regulator since our input voltage may vary between .8-4.5V due to the discharge of the batteries. The following subsections will analyze the different switching voltage regulators and we will choose which regulator will be the most ideal for the purpose of this project.

3.7.1 TPS82150SILR

The TPS82150SILR is a step-down converter that integrates a step-down converter and an inductor to simplify design and save PCB space. A unique thing about this regulator is that it can automatically enter Power Save Mode to operate at light load currents. Although this regulator may seem like a viable option, the downside to this regulator is that the minimum input voltage is 3V. This may pose an issue considering that we are using batteries that tend to discharge after a period of time. The maximum voltage that will be generated when the batteries are at full capacity is 4.5V and as it discharges the voltage will decrease. Although this regulator has many unique benefits, the minimum input voltage makes it the least ideal of the three choices.

3.7.2 TPS613221ADBVR

The TPS613221ADBVR is a boost converter that provides a power-supply solution for devices powered by alkaline batteries. Thanks to its low input voltage we do not have to worry about the batteries discharging past a certain point. Its small size and high efficiency make it one of the most ideal regulators in the market. Furthermore, its cost allows us to stay within the economic constraint and keeps our Advanced Breadboard within budget. Lastly, the size of the component will help save space on the PCB.

3.7.3 TPS61201DRCT

The TPS61201DRCT is a boost converter that provides power supply solutions for single cell, two cell, or even three cell alkaline batteries. At low load of current the regulator will enter Power Save Mode to maintain a high efficiency, this feature can be disabled making the converter operate at a fixed switching frequency. At 90% efficiency the regulator is about to output a current of 300mA at 3.3V. Its extremely low minimum input voltage and output short circuit protection grants this regulator a high amount of advantages compared to its disadvantages. Lastly, the small size of this component also makes it ideal for a PCB design since the Advanced Breadboard has a size constraint.

	TPS82150SILR	**TPS613221ADBVR**	**TPS61201DRCT**
Cost	$3.92	$0.58	$2.80
Frequency Switching	2MHz	500kHz-2MHz	1.2MHz-1.65MHz
Input Voltage	3V-17V	0.9-5.5V	0.3-5.5V

Output Voltage	.9-6V	1.8-5.5V	1.8V-5.5V
Quiescent Current	20uA	6.5uA	<55uA
Maximum Output Current	1.2A	1.6A	1.2A
Efficiency	No	>90%	>90%
Size	3.0mm x 2.8mm x 1.5mm	2.90mm x 1.30mm	3mm x 3mm
Lead Time	6 Weeks	6 Weeks	6 Weeks

Table 9: *Battery Pack Comparison.*

After analyzing the three choices and comparing them together, we have decided that the best choice is the TPS61201DRCT regulator. Since out Advanced Breadboard component requires a minimum of 3.3V to operate, we needed a regulator that can output the same amount of voltage. Furthermore, we plan to use three AAA Alkaline batteries to power the Advanced Breadboard's PCB as well as the connected components which output a maximum of 4.5V. Unfortunately, the batteries discharge after use reducing the amount of output voltage, the TPS61201DRCT requires a low input voltage which makes it a great solution to this issue. Another advantage is the manufacturer, Texas Instrument, designed a public tool that generates an ideal circuit using their parts when given an input voltage and an output voltage. This tool can be used to help design a regulator circuit that meets our design constraints and keeps us within the given project requirements.

3.7 LEDs

For the Advanced Breadboard we plan on using LEDs to reflect which nodes need to be occupied by the user. The plan is to use the GUI to have the users simulate a linear circuit. From there, the GUI will light up the corresponding node on the Advanced Breadboard. We need to search for an LED light that makes it clearly visible which node is activated, but at the same time we do not want it to be too strong that it overlaps to another node unintentionally. In the subsections below we will look at the different LED lights that we researched and choose based on the comparison table and the description of each LED light.

3.7.1 LTST-C191KRKT

This LED is manufactured by LITEON OPTOELECTRONICS and offers an ultra bright and super thin AlInGaP Chip LED. This particular LED is 2mm by 1.25mm in size making it a great option to light up a node of a 1mm diameter hole in a regular breadboard. However, due to the design of the Advanced Breadboard, for practical and simplicity reasons we may increase the size of the holes of the Advanced Breadboard. The LED offers a water clear lens with the source color being red, which would make it easier indicators for the user to see. The only downside to this LED is that it may pose an issue when designing the prototype of the Advanced Breadboard on a breadboard due to the soldering terminals on the bottom. This means that this LED does not have pins that can be inserted into a breadboard but rather, we would have to solder on a wire in order to connect it to a breadboard.Although, this would be a great choice for a PCB design.

3.7.2 LTST-C171KRKT

This LED is also manufactured by LITEON OPTOELECTRONICS and offers an ultra bright and super thin AlInGaP Chip LED. The difference with this LED is that it is smaller in size compared to the one mentioned in Section 3.6.1. This may help to keep the light contained to one hole and not have it illuminate any adjacent holes causing the user some confusion. This LED also uses a clear water plastic lens and illuminates a red light. Unlike the other LED lights this one generates the least luminous intensity which is something to consider with how bright we want the LEDs to be. This will all depend on how the 3D printed molding will absorb the light. Just like the previous LED light this one also has a soldering terminal.

3.7.3 WP7113SURDK

This LED is different from the rest of the ones we researched. Manufactured by Kingbright, this LED is a Solid State Lamp LED with a Hyper Red source color made with AlGaInP Light Emitting Diode. The LED has a low power consumption and general holespurpose leads which makes it easier to hook onto breadboards for the prototype testing of the Advanced Breadboard. Additionally, the LED is bigger in size measuring at 5mm in diameter which would be helpful if we plan on making the Advanced Breadboard holes bigger than the traditional breadboard. Furthermore, the high luminous intensity may pose an issue with accidentally lighting up the adjacent nodes.

	LTST-C191KRKT	**LTST-C171KRKT**	**WP7113SURDK**
Cost of each	$0.25	$0.27	$0.35
Forward Voltage	2V	2V	1.95V

Viewing Angle	130 deg	130 deg	30 deg
Luminous Intensity	18.0-180.0mcd	18.0-54.0mcd	1300-2300mcd
Size	2.00mm x 1.25mm	1.40mm x 1.25mm	5mm
Lead Time	1 Week	1 Week	6 Weeks

Table 10: *LED Comparison.*

After analyzing the different LEDs and the table comparison of the LEDs, we have decided that for now we will use the WP7113SURDK. The high luminous intensity will provide a benefit to the prototype testing to ensure the Advanced Breadboard works properly. Additionally, the general purpose leads on the LED will make it easier to prototype the Advanced Breadboard. If it is successful we may use the LTST-C191KRKT LEDs for the final PCB design. Both of these LEDs are cost effective, provide enough luminous intensity for the purpose of the project design, and can be adjusted to be bright enough for the node indication on the breadboard. There are many things we have to consider with these LEDs and how they affect the 3D printed molding which will be observed during the prototyping phase. The only issue with the WP7113SURDK is that it has a high lead time and costs more than the other LEDs. In conclusion, for the sake of prototyping we will be using the WP7113SURDK and will be observing its effects with the 3D printed chassis and other components; and, we may be using the LTST-C191KRKT for the PCB design and will also be observing its performance.

3.8 Software Communication

The organization of the software and hardware have not been decided yet, but there will need to be some communication between them. The software will include the GUI and the algorithm for schematic to breadboard. The hardware communication will involve the LEDs being activated and deactivated. The communication will need to relay the GUI information to the LEDs in a timely and efficient manner. The focus on this section will be to determine possible ways to transport this information. The methods below do not represent all of the ways that communication can be accomplished, but for the scope of this project the following will be examined. These were chosen because they are more readily available in terms of price and experience. It has not been decided how the program will be housed, so the communication systems will need to cover options for PCBs and microprocessors.

3.8.1 Wired Communication

High Definition Multimedia Interface, HDMI, is a cable that can transfer data to most applications. This is done with a cable that can connect from the sender to the receiver.

HDMI’s purpose is to transmit audio and visual data using one cable rather than multiple [8]. This feature is not important to the project because there is no audio being included. It is important that the information be translated with high quality, but the application for HDMI doesn’t fit that of the project. It is known for its high resolution ranges between 720p to 4k [8]. The resolution capacity will be important to consider because the GUI will have moving parts and will need to be visually clear for the user. A lack of clarity can cause the user to make mistakes in the circuit design which lowers the accuracy of the project as a whole. HMDIs do not require advanced setup or driver downloads which makes replacing the wire easy for the user incase of damage. There are a wide variety of HDMI cables that can work with many different devices, but it does limit which controllers can be used. Distance is another limitation to this communication style because of the need for wires. Most microprocessors do not use HDMI as they are not equipped for that type of communication but Raspberry Pis are able to handle this. However, there are many options for cables which makes it readily available and affordable.

The Universal Serial Bus, USB, has been a staple to computers communicating with peripherals. The focus will be on USB 3.0 because it is a widely available and newer version. It is capable of two way communication and at many variable cable lengths. USB is widely used and incorporated into many different devices. USBs are convenient because they come in different types that allow for different connections. Acquiring a USB would be very easy since it is very cheap and very accessible.

3.8.2 Wireless Communication

Bluetooth is a type of wireless communication that sends packets of information through radio waves. This two-way connection allows the sender to also be a receiver which in the scope of this project may be necessary during prototyping. The frequency picked up by the antennas is in the range of 2.4 to 2.4835 GHz [9]. It will have to be ensured that the controllers used have a module that can pick up these signals and interact with them. A wireless connection would be ideal because it would make the hardware less complicated and would remove the strict limitations of wires. This would limit our search to microprocessors that contain a bluetooth module or are fit to add a module to it. Many phone apps use Bluetooth to interact with peripheral devices which may be able to be used in this project because it makes it far more portable and shareable. Bluetooth modules can be used to create a bluetooth connection on a microprocessor using some pin designation and programming [10]. This allows more options for wireless connectivity, however, more time will need to be invested to setting up the module and learning about its functionality. Testing will be very important to ensure the data being passed through is accurate.

Wireless Internet would be another wireless connection that is available to most computer devices. Using wireless internet allows for better transferability of data because results can be sent to nearby devices also on the network. However, this may have a security risk which would require extra care and analysis. There are wifi modules that can be added to microprocessors to achieve this communication [11]. This limits our choices to microprocessors that are capable of adding the module if it is not already included.

This increases the difficulty of the setup, but may make the process easier for the user to move the hardware around since it is not wired.

The table below shows a breakdown of what microprocessor options there are for the different communication types. There are other devices like microcomputers and desktop/laptops that can be considered but the majority of those have HDMI, Bluetooth, USB, and Wifi included so they will not be analyzed as there are too many options. The HDMI is not very compatible with microprocessors as none were found to contain modules for that communication. HDMI is for dense data communication which would not be suited for a microprocessor which is set for less complicated actions. Bluetooth can match with a few microprocessors that have the module included while others have the option to have it added. Adding a module can create some difficulty because a setup would be required and would need to be functional. USB is used in many devices including many microprocessors. This makes the process easy because if the microprocessor is required to work with any peripherals it most likely will be able to do so with USB since it is so highly used. The wifi communication will lower the options, but may result in the smoothest process for the user as set up will be very portable. Less options may be better because there will be more resources for that specific device that can handle the wifi communication.

Communication	**microprocessor**
HDMI	Not Compatible
Bluetooth	PIC32CX-BZ2, module to add
USB	Modules to add, many come included
Wifi	“ESP8266”, some options

Table 3: *Communication Options.*

4. Standards and Design Constraints

The following will describe the standards and constraints that are expected to be placed on the specification of the project. The standards included were determined to be the most important for the specific goal of developing a smart-breadboard. Details will be given on how they are expected to affect the project and how this will be considered in the design.

4.1 Standards

The following will describe the standards on the specification of the project. The standards included were determined to be the most important for the specific goal of developing a smart-breadboard. Details will be given on how they are expected to affect the project and how this will be considered in the design. As we are integrating software when using the GUI interface we need to cooperate with the standards related to the software. As well as standards related to the electrical components used. Utilizing these standards will ensure that our product works efficiently, effectively, and within the overall guidelines that are set by these standards. At the heart of our project in the software compartment is the Raspberry Pi 4, an innovative microprocessor that perfectly uses traditional computing with embedded systems. This is especially perfect for a project such as this that relies on a great connection between hardware and software. And while upholding software reliability, efficiency, and adaptability isn't a luxury it is a necessity for the advanced breadboard. Implementing these standards ensures the seamless functioning of our project.

4.1.1 EEE 730-1984 (Quality Assurance)

The IEEE 730-1984 is about the commitment to a high quality project. Set within the realm of Software Quality Assurance (SQA), this standard isn't just about evaluating the end software product. It also offers a more visual approach that highlights the underlying processes, methodologies, and protocols that lead to said final product. The framework provided is complete as it has, encompassing guidelines, requirements, and best practices, all unified towards ensuring that the SQA processes begin, then are planned, controlled, and executed with a degree of professionalism.

IEEE 730 will serve as the quality backbone of our Advanced Breadboard project. We can use the Software Quality Assurance Plan to help us focus on areas such as version control and issue tracking. We'll use Git for code version control, ensuring that any changes made to the GUI or algorithm are logged and reversible (if needed). A Jira board will also be set up for issue tracking and reporting to make sure all software glitches, big or small, are dealt with promptly. Otherwise, this communication can also be tracked via Discord.

A pivotal component within this standard is the Software Quality Assurance Plan (SQAP). The SQAP is a structured document, laying out in definitive terms the methodologies, tools, processes, resources, and responsibilities that will be employed to guarantee software quality. It is typically used as the anchor, ensuring that the entire team has a clear vision of good objectives and the means to achieve them. But on top of having a plan, there is a lot more that this process contains. Periodic quality audits/checks, make sure that the processes and the resulting software remain in alignment with the SQAP. These frequent checks and audits are the checkpoints that make sure that the team remains on the right path towards a finished software product.

Additionally, with the incorporation of quality metrics, the standard pushes towards an approach to quality and also quantity. These metrics that are being measured are things such as code churn rate, or response time, are used as indicators of good or bad software quality. They facilitate the ongoing assessment, pointing out areas of excellence and those needing improvement. Basically, IEEE 730-1984 creates an almost sort of ecosystem of continuous improvement. With structured problem reporting and a way to correct actions in certain situations, issues are not just identified but are resolved, making the software more robust with each iteration.

For a project like ours, where the Raspberry Pi is intertwined with hardware components, this standard's adherence takes on even more significance. Each software module and each functionality, especially those interfacing with hardware, demand rigorous validation and testing. This standard certifies that such consistent checking is not more than it needs to be but rather systematic in nature. Furthermore, it promotes a culture of accountability and continuous enhancement within the group working on the advanced breadboard, ensuring that our Raspberry Pi's software remains agile, robust, and in alignment with our quality aspirations and requirements.

This pivotal standard emphasizes the essence of software quality. Applying quality to our project translates to a lot of software testing and ensuring that our Raspberry Pi's software consistently meets expectations. Every single functionality, especially those that are directly connected or related to hardware.

4.1.2 IEEE 829-2008 (Test Documentation)

When it comes to software, functionality is very important. But, equally important is software with reliability and stability. The IEEE 829-2008 is a standard that speaks to this importance of testing and providing a structured approach to test documentation. This standard doesn't just acknowledge the act of testing but emphasizes the imperative of documenting every single little detail throughout the testing process. At its core, the IEEE 829-2008 presents a structured framework for eight distinct types of test documents. Each document, from the Test Plan to the granular Test Incident Report, serves a unique purpose which makes sure that every aspect of testing is captured, analyzed, and archived. For example, the Test Plan is not just a strategy document. It is the compass, detailing out the scope, resources, schedules, and methodologies that will be used during the testing phase.

Equally as important is the Test Design Specification. This stage describes the reasoning behind specific test conditions, the expected system states, and the criteria that determine the success or failure of a test case. This is further explored and explained in detail in the Test Case Specification, which dives into the specific inputs, the expected outcomes, and the conditions under which the test would be executed. This level and amount of detailing makes sure that the testing process remains clear, replicable, and consistent.

In compliance with IEEE 829-2008, we'll develop a detailed Test Plan with multiple phases. Firstly, in the "Initial Algorithm Analysis" phase we have specific scenarios through the circuit translation to ensure it accurately translates electronic schematics to physical breadboard layouts. Then in the "GUI Operation Verification" phase there will be user acceptance testing, where we verify that the GUI is intuitive and responsive. In this phase, it can be tested amongst the group as well with random people. Finally, "Breadboard Limitation Testing" will check the compatibility limits of our algorithm with different circuit models and sizes.

For a complex project such as ours, based on the Raspberry Pi 4 for the software , such structured test documentation is of utmost importance. Each software module and each line of code, undergoes this regime/process. Detailed test logs, error reports/logs, and summary reports not only ensure that bugs/issues are identified and rectified but also offers users a transparent view of the software's quality and readiness. In essence, the IEEE 829-2008 serves as the guide in the testing process, ensuring that it remains comprehensive, clear, and most importantly effective in validating the software's reliability.

Structured and organized test documentation is crucial to the research and development of this breadboard. By adhering to this standard, we can assertively claim that each aspect of the Raspberry Pi 4's software has been checked for any bugs or errors. In a project that demands precision in operations, meticulous documentation plays a pivotal role in diagnosis and version control.

4.1.3 IEEE 830-1998: Software Requirements Specifications

For our Advanced Breadboard, the IEEE 830-1998 standard will serve to develop a typical Software Requirements Specification (SRS) document. Such as the state of the GUI's functional requirements, like a drag-and-drop feature for electronic components, and the limitations on the number of nodes and connections. On the algorithmic side, performance metrics like speed of schematic translation can be tracked and clearly outlined.

Clear and unambiguous software requirements are a project's bedrock. By following this standard, we will be made fully aware of the precise capabilities and expectations of the Raspberry Pi 4, eliminating any ambiguity. Additionally, this will almost eliminate any need to further buy new parts or technologies.

4.1.4 IEEE 1016-2009: Software Design Descriptions

In the context of the Advanced Breadboard project, we have to follow the IEEE 1016-2009 standard documenting the software design. This standard will guide outlines each GUI component and their functionality, from drag-and-drop functionalities to the typing (in general). It will specify how the GUI and breadboard interact. This standard also helps us detail how the software triggers or activates, like when adding a resistor in the GUI and how it corresponds to physical changes on the breadboard, such as lighting up a specific LED. Additionally, IEEE 1016-2009 informs how we document the system's (possible) scalability and error handling mechanisms, preparing the project for future enhancements and troubleshooting. By adhering to this standard we'll have a well documented project.

A well-defined software design description is the roadmap that guarantees the software's modularity, scalability, and maintainability. As our project takes shape and scales, this blueprint becomes the guiding factor for not just the software but the entirety of the project. A well practiced use of software design descriptions increases its helpfulness down the line of developing the advanced breadboard.

4.1.4 Impact of IEEE Standards on Software Lifecycle

The IEEE 730-1984 standard helps refine how the quality of the code will be. Under its umbrella, our software will not just *do* what it has to but also achieve reliability and efficiency, ensuring the Raspberry Pi 4 will complete its important tasks.

The standards don't just emphasize but mandate software safety. This focus means that the software running on the Raspberry Pi remains secure to its hardware counterparts/components.

Robust documentation, anchored in these standards will act as the project's memory. This detailed record-keeping becomes the touchstone for problem-solving, enhancements, and maybe even future expansions.

The rigorous software implementation standards for the Raspberry Pi 4, steered by the revered IEEE standards, isn't about following a rulebook. It's about a reliable, efficient, and adaptable product.

4.2 Constraints

The following subsections will discuss the constraints that are being encountered with the design of this project. These constraints will surely affect the specifications of this project, but we need to be able to limit these constraints so that ultimately we can design an effective, accurate, efficient, and functioning Advanced Breadboard.

4.2.1 Software Constraints

One big focus for the software of the advanced breadboard is on real-time performance. This is essential to keep the GUI and LED indicators on the breadboard in sync. This is especially important given the limited number of nodes available on the specialized breadboard which sets constraints on the software's efficiency and the types of circuits that can be built on the GUI. Data integrity and memory also seem to be key factors, requiring the software to include error checking and possibly error recovery mechanisms to ensure a seamless and accurate transfer of data between the GUI and the advanced breadboard.

Resource utilization and scalability are other key considerations. The software should be portable enough to run on a variety of hardware specifications without consuming too many resources. Also, one of the goals is that its designed with modularity in mind, allowing for future scalability in terms of additional nodes, features, or components. This would pave the way for easier upgrades, both in terms of hardware and software features in the case of a different/bigger breadboard.

User experience should be front and center, which involves creating an intuitive, user-friendly GUI that minimizes a learning curve as much as possible. The GUI should also have validation checks to guide users in creating feasible projects given the hardware constraints. However, the breadboard is custom and as a result, the validation checks might not be necessary since the breadboard and software are supposed to work in tandem and as such are unique. In a multi-user setting, account management and individual project saves could become necessary, adding another layer of complexity to the software design, although not currently under development.

File format compatibility, especially if schematic importing is to be supported or added as a future feature, this will also be important. This requires the use of parsers for circuit design file formats, adding another layer of complexity. While exporting the file itself may not be a feature, the information from the GUI/schematic will have to be transferred over to the breadboard in some way, so a file transport protocol should be considered. Security is another crucial aspect, with secure protocols being potentially necessary to make sure of the data integrity during the communication between the software and hardware components.

Documentation is essential for a tool designed to be educational and user-friendly. While, the software is intended to be simple to use anyways, user manuals, help features, and possibly even built-in tutorials should be developed to assist those using our product. If the software is to be deployed in educational settings, compliance with relevant educational standards or accessibility laws might also be necessary, which would vary from region to region.

By addressing these software constraints early in the development process, the Advanced Bread project can create a more robust, efficient, and user-friendly product. These constraints, when carefully managed, will contribute to the project's goal of making circuit design more accessible, educational, and simple.

4.2.2 Electrical Constraints

In terms of this project the Electrical Constraints can come in many forms, and our job as engineers is to identify these constraints and minimize the overall effect they have in the project we are working on. The Advanced Breadboard is a unique project that may require a sophisticated PCB design. With all the different components we require and the limited space we have, it may leave room for a lot of mistakes and errors. As you may know, when dealing with a lot of components there will be some form of signal delay. Since we are expecting to use a microprocessor with Wifi communication we want to be able to limit the signal delay between the microprocessor and the LEDs. Furthermore, the voltage and current sensors use an I2C interface and we need to be able to minimize the delay between the sensor and the microprocessor it is connected to.

Another Electrical Constraint we need to focus on is the PCB footprint. Because the Advanced Breadboard has a size requirement we need to be able to save as much space as possible. Good engineering work requires being able to judge the situation and figure out a solution to the problem. This includes properly designing a PCB that does not leave any unnecessary space. On the other hand, our design utilizes many components such as a battery pack and ten LEDs. These alone take up a lot of space on a PCB which leads us to an electrical constraint. Our choice in these components, how we place these components on the PCB, and how we wire them will all be a challenge we need to take into account in order to minimize the electrical constraints.

Furthermore, another Electrical Constraint we need to keep in mind is heat transfer and manufacturing issues. When designing the PCB we have to factor any parts or PCB manufacturing issues as well as how the heat is being transferred throughout the project. Since we are using small components we may not need to worry too much about overheating. This requires more research. As for manufacturing issues, we would need to minimize this issue by ordering a few components of each part that we need as well as ordering a few PCBs to minimize this constraint.

4.2.3 Economic Constraint

The funding of the project is an economic constraint that will affect major portions of the project. There are no outside funders so all expenses will be taken care of by members of the team. Most products offer more benefits, or features, with higher prices. The breadboard could have the option of being sent to a manufacturing company to get machined to perfect specs but the limit of the budget encourages the team to find a more creative alternative. The team will need to determine what parts of the project do not need high accuracy to still perform as intended. The breadboard will be 3D printed which comes with a cheaper cost and will not require shipping. However, the board may not be printed with the most accurate measurements due to cheaper 3D printers not having the capability to print to certain decimal points.

Along with this, microprocessors will have to be chosen based on information gathered in research and personal experience by the team rather than testing all of our options. The team will not be able to purchase multiple microprocessors to test because that can become costly very quickly along with rising shipping costs. A lot of the resources will be sourced on campus as there are many labs and researchers that have access to tools the team may attempt to use during prototyping. This includes resistor components and power supplies.

4.2.4 Environmental Constraint

The environmental constraint on the project comes in two forms: environmental impact and the environment of the user. The environmental impact of this project will be considered during every part of its production. ABS was found to be the preferred plastic for the makeup of the breadboard but a professor of mechanics in malaysia found that “ABS is recyclable”. This finding will encourage the rest of the project to find ways to make it recyclable or reusable. The electronics in the project will be designed to produce as little heat as possible to reduce the waste of energy. This will be done with calculations and simulations to ensure that the design is efficient.

The next consideration will be the constraint imposed on the project based on the environment the user will handle the product. This may include lab rooms which may contain many instruments and tools surrounding the work bench. Because of this, the breadboard will need to be designed to work in smaller environments. Since solderless breadboards are often portable it will be important to maintain that ability so the majority of the hardware should be within the breadboard set up in layers. Choosing the breadboard material out of plastic comes from this constraint because wood or glass would be too heavy. This constraint also influences how a connection from the GUI to the breadboard will look. Using the least amount of hardware and wired connections will help with the adaptability to the environment. Considerations will be made to make wireless connections. The overall design of the breadboard will take into account the ability for recycling materials and for keeping a tight and organized design. These constraints will be made by using a recyclable material for the breadboard and by making it small and portable.

4.2.5 Time Constraint

The time constraint was imposed within the guidelines of Senior Design I. There are hard deadlines for specific aspects of the project. These deadlines create a constraint on the design of the pcb and part selection because of shipping time. This deadline also will affect the use of resources on campus which may be used by others. There are deadlines for the research of the project, the prototyping for proof-of-concept, the final report, and the presentation of the final project result. These deadlines will drive every aspect of the project. The research will need to limit which parts can be analyzed due to lead times and shipping costs. The PCB will also need to be designed with lead time in mind because shipping time has been extremely long as of recent. There are materials and instruments available on campus, but their use will need to be strategic because they may be occupied or inactive which can affect the manufacturing and testing of the breadboard.

The PCB is one of the components of the project that must be sent to be manufactured and may have the longest lead and shipping time. Priority will be on the PCB design and ensuring it is made without mistake. Yedda Yu recommends "some tips to help with delay which includes not having an error in the design including drill hole placement". It will be important to design the PCB with specific goals in mind. These goals will be described further into the report once all parts are chosen and constraints are considered. It is important that the PCB is done correctly the first time because redesigning and manufacturing another will not allow for enough testing time for the final products. The PCB will need to successfully alter the state of the LEDs and assist with the open/short circuit testing. This is a vital part of the project and will need optimal testing to ensure a finished product is presented by the deadline.

The economic constraint on the project led to the decision to resource parts from campus which are available. This will prevent shipping and lead time for some of the parts. However, since campus resources are often available to a large number of students it will be important to plan out their use. There are 3D Printers available that can handle printing the breadboard to its specifications. Printing can often take hours and may need reprinting if not done properly. There is also a process to refill the filament and to ensure the correct type is ordered which can take a few days. Most of the electronics and the hardware will be placed in the breadboard chassis so that will need to be designed once all of the parts are selected and measured. The print should not take longer than 24 hours to print, but may need to be reprinted for accuracy or if changes need to be made. This will be a high priority item to have completed to finish the rest of the project.

The time constraint will drive the design, production, and testing of the project. The research will only consider parts that can be easily acquired in time for the deadlines. Local resources will have priority consideration since they will require little to no shipping time. The PCB design will take special care to ensure that it comes in time. The delay of that part can cause major consequences as time will need to be allotted for testing which leaves little time for shipping since it may be delayed as has been the recent trends. The time constraint has one of the biggest impacts on the scope and part picking since it creates limits, but these limits are useful to help narrow down the vast amount of options available in the market. Creating a project with affordable, and easily accessible parts will allow for it to be easily recreatable which is ideal for product advancement and availability.

4.2.6 Health Constraint

The health constraint will be considered one of the more strict constraints because of its importance. This project will require human interaction and therefore will require safety for its users. The focus on safety will involve the materials being used to create the project, and the electrical hazards that come with it. The rest of the design will take into consideration the health and safety of those building the project and those using it. This will include the proper personal protection equipment, PPE, is acquired and that protections are taken during testing. There are a lot of electrical components that will be tested and will be done safely in the lab.

For the safety of the user, all wired components will need to be insulated to avoid electrical shock. They will also be placed in a way that will avoid getting caught or ripped during transportation or use. The breadboard itself will be designed to avoid injury by ensuring corners are rounded and other aspects will consider safety into its design. The GUI will have the most interaction with the user so its display will have to take health and safety into consideration. It will be important to make sure there is nothing flashing on the screen that can induce a negative response to the user. The font and coloring on the screen will be considered as well to ensure the user can properly see all of the information without any strain.

Printing ABS material has a level of toxicity to it so it will be important to take proper precautions. The printer will need to be encased to direct the fumes away from the public. Other precautions will be taken when 3D printing including checking the temperatures of the bed and nozzle to ensure no skin contact is made to a heated part. This will be considered when removing the part from the bed and replacing the filament in the nozzle.

4.2.7 Social Constraint

A social constraint will be considered because it is important that this project is made to be accessible to everyone. The project will be made accessible by making it portable and adaptable. The users of the project are diverse in ability and skill and therefore will require different specifications. The best way to cater to all will be to ensure effort is placed into the design with this in mind so that equal opportunity is given to all. The LEDs on the breadboard will need to be visible enough so that extra effort is not required to identify them. Multiple colors will not be used to avoid confusion.

Portability will provide a large amount of accessibility because it can adapt to the environment. The breadboard is being designed to be lightweight by decreasing the infill percentage of the print. The electrical design is taking into consideration portability so the wires must be placed in a way that allows them to be easily moved or reconfigured as needed. The majority of the hardware is going to be placed inside the breadboard to facilitate its portability so that less items need to be handled.

5. Comparison of Chat GPT

AI tools, like ChatGPT, are making their way into every industry. For the scope of this project, ChatGPT will serve as a tool that can take an input like a question or idea and expand on it based on what is available on the internet. There are many AI software tools available, but ChatGPT will be the primary tool because it is free, easily accessible, and easy to use. ChatGPT will be used as a starting point rather than a final product. The following sections will describe how ChatGPT will benefit the project and its constraints, followed by examples on its integration.

5.1 Pros

Integration of AI is inevitable, so it is important to take advantage of its use in this project. ChatGPT has the ability to receive an input and provide an output based on data that it accesses on the internet. This is considered a pro because it can help grow an idea. If there is a subject in the project that the team doesn't have a starting point for, ChatGPT can reveal more information about that subject to provide the team with items to search. AI software will help to save time which is one of the largest constraints on the project. It can help with quick information and facilitate research. Sometimes the internet can be difficult to navigate since there is so much information out there that ChatGPT can spend the time sorting through rather than the team spending far more time doing. ChatGPT is also able to take in information and summarize or simplify. This will be an important tool because research includes reading scholarly articles that may be too advanced. Inputting that to ChatGpt will provide a summarized excerpt that will help with understanding and explain how it can be relevant in this project.

ChatGPT offers a tremendous amount of benefits in terms of researching and developing the advanced breadboard. Due to the large database that ChatGPT has from the internet (up until 2019), practically any topic can be verbalized and understood in a matter of seconds. Difficult concepts and ideas could be grasped much quicker as opposed to watching a whole video or reading a textbook/paper on a certain topic. For this project, a lot of electrical engineering concepts and software concepts will be used to develop the breadboard, combining programming with hardware and circuitry. ChatGPT can reduce research time in these topics and help in making templates or skeletons of the project to have somewhere to start in some cases.

Unlike people, ChatGPT is available 24/7, which can expedite research and problem-solving, especially in situations where you need assistance outside of the typical availability hours of group mates or professors. ChatGPT can assist in brainstorming and generating innovative ideas for the advanced breadboard project. It can provide inspiration and suggest alternative approaches to solving complex design problems that otherwise could have unlikely been thought of.

The benefits of using ChatGPT are endless, along with its vast improvements and quick uprising in the world. Rather than viewing ChatGPT as a program that inputs a web of information and outputs answers; instead, it should be seen as a new tool that can be used in many fields including the engineering field. A benefit of using ChatGPT is that it can create circuits to use when being asked. Although the accuracy and function of the circuit can vary, it still has potential to become a very powerful tool in engineers' everyday work.

5.2 Cons

AI tools have their use in research, but they also have constraints as the technology is still improving. ChatGPT is not always accurate and it is not always obvious if it is or not. Anything that ChatGPT produces must be checked to ensure it is correct before using that information for the project. An error in any basic calculation from ChatGPT can disrupt the flow of the project and can cause issues to the software and hardware. Because of this risk, ChatGPT's use will be limited to ensure that the bulk of the research comes from reputable sources rather than quick responses. ChatGPT may provide a correct response but for a different input than the one intended which can cause confusion and errors. It will be important to work all phrases properly so that the tool does not mistake what its output should provide. The safeguard for these is ensuring all outputs are verified through other sources.

Another issue may be that ChatGPT does not cite the source they use in their response which may have been taken from another author. This can create an issue when publishing information about this project that may have come from an unknown source. According to information provided directly from ChatGPT, its knowledge is dependent on when its update was last done so there will be a lack of up to date knowledge (ChatGPT, 2023). This must be considered a con because research should always consider recent discoveries because those may make large impacts on the project.

Developing some aspects of the advanced breadboard can be complex and time-consuming, requiring specialized knowledge and resources. As a result, ChatGPT is unlikely to be effective in EVERY aspect that it can be called during development. The questions we may prompt to ChatGPT can be difficult to put into words and as such, difficult to respond to. For efficient responses from ChatGPT, a relatively new job has recently become popular, prompt engineering. The core concept of using artificial intelligence in general is that what you get from it, is what you put in. Therefore, whenever we might have questions about large scale portions of the project, or maybe a very specific circuit, a large amount of detail will be required to include in the prompt. At some point, the amount of energy/time used towards making a *perfect* prompt is not worth the time it takes to do so. Because we *could* benefit higher from using non artificial intelligence resources in some cases

Relying heavily on AI may reduce the understanding of the underlying principles of the advanced breadboard's design, which can be a drawback in future settings. Whenever ChatGPT is not available, fixing and/or designing the breadboard could be much more difficult. A reliance on ChatGPT deteriorates the learning curve, disallowing a deeper understanding of the product.

Developing electrical equipment is not an easy feat. It requires advanced research, trial and error, finances, and a ton of intuition and creativity. Sadly, some of these things cannot be attained through the use of ChatGPT. For starters, as engineers grow experience in their field they tend to grow an intuition. This intuition affects our decision-making by providing context to the given situation and using our own experience to derive a solution. ChatGPT is capable of providing an answer to a question one asks, but will it consider the context of that situation and make decisions based on that intuition? As engineers, our job is to innovate and create something new or to improve on something old. With ChatGPT the creativity of the human mind does not exist; thus, the lack of new ideas will drive a depression on innovation. That is why ChatGPT can never replace engineers in their craft; rather, it can be used as a tool by engineers to drive innovation by accessing and utilizing the information across the internet.

5.3 Examples

The first example of using ChatGPT as a tool is asking what material would be best to print the breadboard with. The exact prompt given to the tool was "I am working on a senior design project where I am creating a breadboard with advanced features like an open/short circuit test. There will also be LED lights that light up the different in the circuit. I want to 3D print the breadboard, what material should I use to 3D print it". This prompt provided all the information that the team had on-hand so that ChatGPT was working with the same amount of detail. It was important to give context to the question such as it being a Senior Design Project. This detail may inform someone that this project is being made with limited funds, resources, or time. However, when repeating the processes without this detail ChatGPT's response did give any change to reflect the altered input.

The AI tool's response to the prompt included three different sections even though the prompt asked for one answer. The first section includes a list of considerations to take when choosing a material. These considerations were exactly what was considered in the preliminary research: Electrical insulation, durability, thermal resistance, and printability (ChatGpt, 2023). Earlier in the report these constraints were broken down for a set of possible materials. The second section provides a list of four optional materials: PLA, ABS, PETG, and Nylon (ChatGPT, 2023). These materials were also previously considered and narrowed down to PLA, ABS, and PETG as they are more standard. The third section includes more information to consider when building a breadboard. This information does not involve the type of material, but goes into details in other parts of the project. This may be due to the extra information provided in the prompt.

ChatGPT provided more information that prompted it, but this information was found to be useful. Before the question was given to the AI, research was done to answer the question so that a comparison could be made. The response was given in less than 30 seconds, while the research took around 12 hours. The quality of the response was proven when compared to the preliminary research because it matched it very well. However, the response provided less details and more of a simplified explanation. Another prompt was given to test the limits. The AI was asked to choose from the given material list to see if it could make that decision rather than providing another list. ChatGPT then responded with PETG as its choice of material for the given situation (ChatGPT, 2023). The reasoning for this choice was not very detailed, rather, just a sentence with a basic overview as to why it is preferred. The response did not include any data or sources.

For this example, ChatGPT would have provided a strong base for continued research. It provided quality options for the type of materials to consider. Rather than be a source for a final decision, it opened an opportunity for research on more specific ideas. The reasonings and details were lacking because data was not provided to back up its claims, but that is why this tool cannot be used as a source of information. ChatGPT allows a follow up question to reference its previous response which is very convenient because follow-up details can be provided within the same reference frame. This example shows that ChatGPT is quick, can provide a quick overview of the subject, and cannot be used as a direct source because of the lack of details and source citing.

Another example is that, in the early stages of designing the graphical user interface (GUI) for the advanced breadboard project, we would want to ensure that the interface is user-friendly and intuitive. Here, ChatGPT can be used to brainstorm ideas for the GUI layout and user interactions. It can also offer suggestions on how to simplify the user experience, improve accessibility, and make the GUI aesthetically pleasing. All of these are essential aspects to the software portion of the project.

Now consider a scenario during the design of the printed circuit board (PCB) layout that requires specific knowledge and expertise. In this situation, we decided to rely heavily on ChatGPT for guidance. However, despite its vast knowledge, ChatGPT struggles to provide the detailed, nuanced information required for our specific PCB design challenges. Because of that, we spend a lot of time creating the supposed *perfect* prompt to give to ChatGPT about the PCB layout which will become increasingly complex, and ChatGPT's responses, while quick, lack the depth and accuracy needed for making a PCB. This over-reliance on ChatGPT could hinder the team’s ability to design the PCB effectively since we wouldn’t know any details, we would just follow instructions on how to make/fix the PCB. Here we would realize that in such specialized and complex areas, using non-artificial intelligence resources, such as consulting with a professor, watching YouTube video, or conducting in-depth research, would have been more productive and yielded better results. In this case, ChatGPT's limitations in handling highly specialized topics and complex tasks prove detrimental to the research and development of the advanced breadboard.

10. Administrative Content

10.1 Work Distribution

The work for the provided research will be broken down into five different sections: software algorithm, graphical user-interface, microprocessor, breadboard design, power supply, circuit testing, and PCB design. The software algorithm will include the algorithm that converts a circuit drawn as a schematic to its placement on a breadboard. The design and implementation will be completed by the two Computer Engineers on the team with one taking a lead on it. The GUI will require communication to the LEDs on the breadboard and that will have the focus of one of the Computer Engineers. The use of the microprocessor and how it will interact with the GUI will be the responsibility of one of the Computer Engineers. The breadboard design will similarly go to one of the Computer Engineers with input from the Electrical Engineer to ensure all parts are considered for the design. The power supply and circuit testing will be considered by the Electrical Engineer. Finally, the PCB Design will be primarily the work of the Electrical Engineer but in coordination with both Computer Engineers.

All parts will contain a primary and secondary that are overseeing each section. This is to ensure that each section is considered by another engineer that can provide another perspective and can ensure coordination with their respective parts to ensure a cohesive design. Secondaries will be in charge of assisting the primary in research and testing, but will also be involved in checking for mistakes or edge cases. All teammates will be involved in decision making for each section regardless of role but it will be integral that the primary provides the details necessary to making the correct decisions on part selection, methodology, and testing.

Work	Primary	Secondary
Schematic to Breadboard algorithm	Cristian Gutierrez	Sheridan Sloan
GUI to Breadboard Communication	Sheridan Sloan	Cristian Gutierrez
microprocessor	Cristian Gutierrez	Sheridan Sloan
Breadboard Design/Build	Sheridan Sloan	Ammar Mubarez
Power Supply	Ammar Mubarez	Sheridan Sloan
Open/Short Circuit Detection Implementation	Ammar Mubarez	Sheridan Sloan
PCB Design	Ammar Mubarez	Sheridan Sloan & Cristian Gutierrez

10.2 Budget Estimates

The project was designed in a way that allowed the team to financially support it since no sponsors are involved. It is expected to find the majority of the parts fairly cheap as long as lead times remain reasonable. These estimations do not include campus resources and personal resources because inventory has not been taken by the team as of yet. These resources include the Senior Design Lab and the Robotics Club which may have some parts available at cheaper rates. Additionally the team has personal access to 3D printing that can reduce this cost as many parts can be designed and printed. Electronic components like LEDs will depend on the decision of whether or not a microprocessor will be necessary or if it will be incorporated into the pcb. All three members will equally commit to purchasing the following items as needed:

Part	# Units	Estimated Price Per Unit	Total	Estimated Place of Order
PLA Plastic	2 rolls	$20	$40	Amazon
microprocessor w/ Communication Module	1	$20	$20	Amazon
LEDs	10	$.35	$3.50	Amazon
Custom PCB	1	$80	$80	Texas Instruments
Variable Power Supply	1	$34.99	$34.99	Digikey
Duracell AAA Batteries	3	$2.065	$6.195	Walmart
Voltage and Current Sensor	1	$2.70	$2.70	Texas Instrument

10.3 Milestones

This section will outline the milestones we plan to achieve as we are working through this Senior Design project. The Senior Design I milestones represent the report and prototype. These milestones are assigned to the corresponding group member and have an end date to signify the completion of these milestones. On the other hand, the Senior Design II milestone represent the finishing product and our final milestone to completing this project.

10.3.1 Senior Design I Milestones

Number	Milestone Task	Assigned To	Start Date	End Date	Status
1	Initial Team Meeting	Group 20	8/21/2023	8/23/2023	Completed
2	Project Clarification	Group 20	8/24/2023	8/28/2023	Completed
3	10 Page DC Initial	Group 20	9/1/2023	9/15/2023	Completed
4	Short Circuit Detection Research	Ammar	9/11/2023	10/31/2023	Completed
5	LED Integration and Wiring	Ammar & Sheridan	10/1/2023	10/31/2023	Pending

6	Software Design	Cristian	9/11/2023	10/31/2023	Initial Designs In Progress
7	60 Page Draft	Group 20	10/20/2023	11/3/2023	Pending
8	Update Website	Group 20	9/15/2023	1/1/2023	Working on Connection
9	Prototype Testing	Group 20	11/21/2023	11/30/2023	Pending
10	90 Page Report	Group 20	11/25/2023	12/5/2023	Pending

10.3.2 Senior Design 2 Milestones

Number	**Milestone Task**	**Assigned To**	**Start Date**	**End Date**	**Status**
1	Review Senior Design 1 Progress	Group 20	1/8/2024	1/12/2024	Pending
2	Complete Project Design/Testing	Group 20	1/15/2024	3/20/2024	Pending

3	Prepare Presentation	Group 20	3/21/2024	4/1/2024	Pending
5	Final Presentation	Group 20	4/1/2024	TBD	Pending

Appendix

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[DFRobot] Re: UCF Senior Design

Oct 27, 2023, 18:23 GMT+8

Dear Ammar,

Thank you for reaching out to us regarding your senior design project at the University of Central Florida. We're glad to hear that our Gravity: I2C Digital Wattmeter has caught your interest and could be of use in your project.

We are pleased to grant you permission to use and cite the information from our website and datasheet, as well as the images posted therein. However, we kindly request that you ensure that the source is clearly stated as DFRobot.

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Ammar Mubarez
Oct 27, 2023, 13:22 GMT+8

To whom this may concern,

My name is Ammar Mubarez and I am a student at University of Central Florida. My team and I are working on a Senior Desing Project that involves using a particular part. I came across this part during my research and I wish to use and cite the information on your website & datasheet as well as the images posted on the website & datasheet. We are currently writing a Senior Design report and I am asking for your permission to use the content as a reference for our report.

The particular part I am referring to is: Gravity: I2C Digital Wattmeter

Found on the website:https://www.dfrobot.com/product-1827.html?search=SEN0291

I hope to hear from you soon.

.