

I'm Blinded by the Lights [BBTL]

Presents

03.007: Design Thinking and Innovation



A project by SC11 Group 10

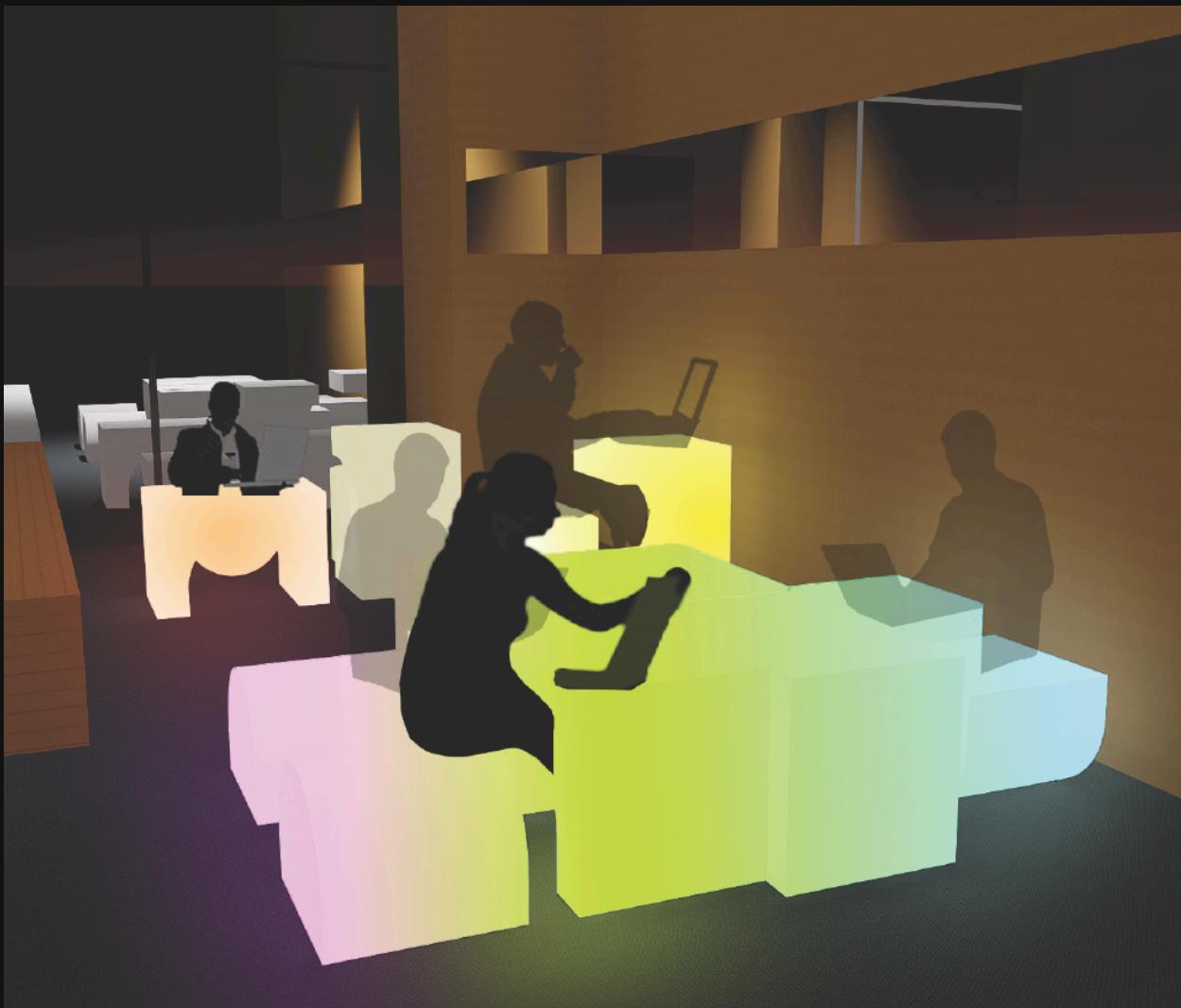
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Background Information

BBTL presents to you a way to make workspaces more interesting. We have created a modular box that can take on many forms and adapt to any kind of workspaces that you need.

Our design, named REM, stands out due to its innovative integration of lighting and modularity, which enhances adaptability and interaction between people within the workspace. Notably, being able to change the modes of our product provides customisable functions, catering to the diverse needs of our target audience. This design embodies a thoughtful convergence of form and function, making it not only a visually captivating piece but also a breakthrough in the industry.



Inspirations

Our initiative was sparked by a scarcity of preferred study spaces within the hostel. We uncovered that students were gravitating towards certain types of workspaces. It became apparent that their activities fluctuated between deep-focused study sessions and group study sessions. This revelation was the cornerstone for our project and to resolve this we aimed at developing an adaptable workspace solution tailored to the fluctuating rhythms of student life. The main inspiration was taken from an exhibition at the Art Science Museum where they utilised lights to promote interactions and convey emotions between people. We also drew inspiration from Bauhaus-style modular furniture that creates a minimalistic and clean look to homes.



Interactive Lights at The Art Science Museum



Modular Bed



A student studying with a table lamp



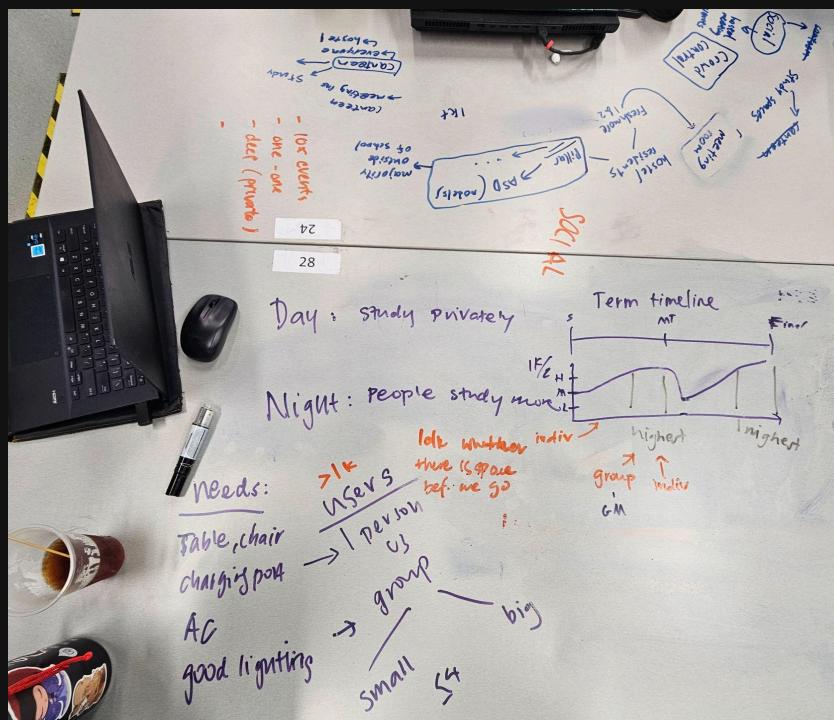
Setup with Philips Hue Lights

Image of static prototype



Our Journey

Ideation Process: We began with an in-depth refinement of our problem statement, achieved through internal interviews and a thorough site analysis that helped crystallize the objectives of our project. Collaboratively, we had multiple brainstorming sessions, utilizing mind mapping techniques to expand upon our ideas. These concepts were then organised and evaluated for viability. Through a collective decision-making process, we merged several concepts and ultimately distilled our vision into one singular, focused idea poised for development.

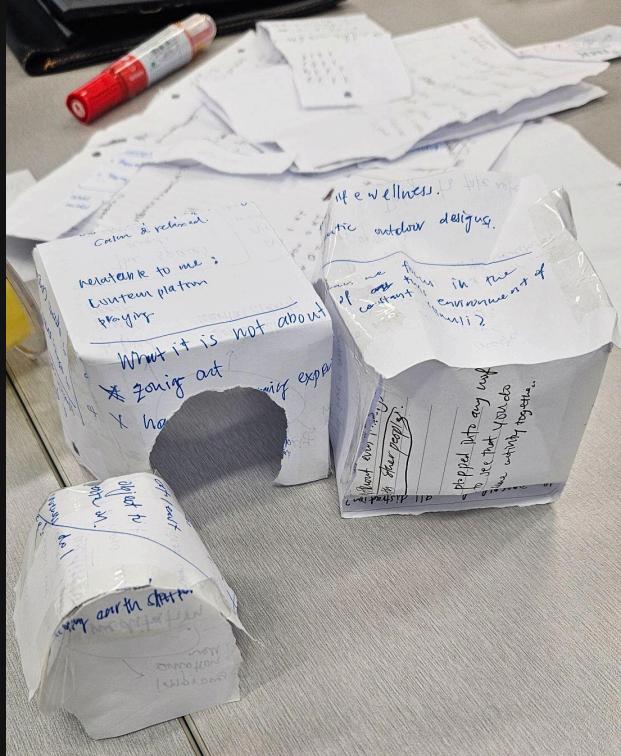


Defining problem statement and finding pain points

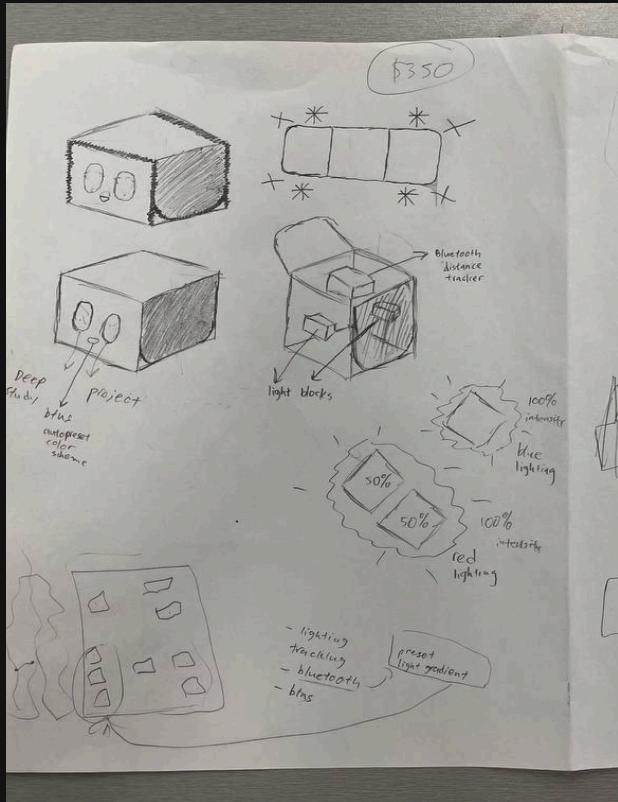
Prototyping Process: The development of our prototype involved a dynamic, iterative process, beginning with rudimentary paper models to conceptualise the physical form. Significant effort was invested in perfecting our design, particularly in programming the LED lights to achieve the desired functionality. Through persistent testing and refinement, we ensured our prototype not only met but surpassed our initial expectations in terms of aesthetics and functionality.

Our process was Planning -> Developing -> Executing. We wrote down our ideas and planned out the next steps before we actually ordered and started developing our product.. Execution came to play when we tested our products and went through rounds of optimisation and refining.

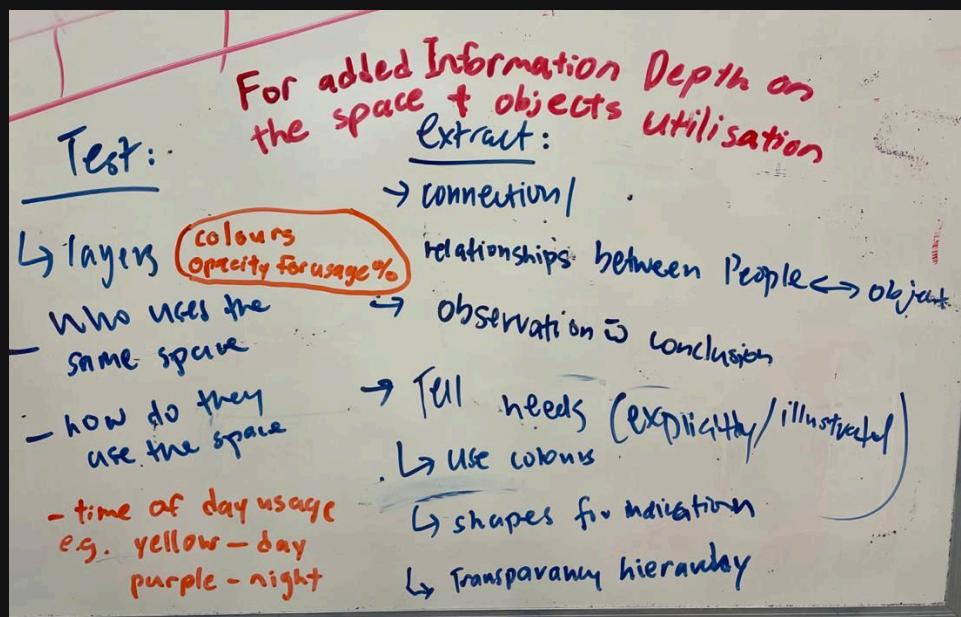
PLANNING



Mock-up with paper

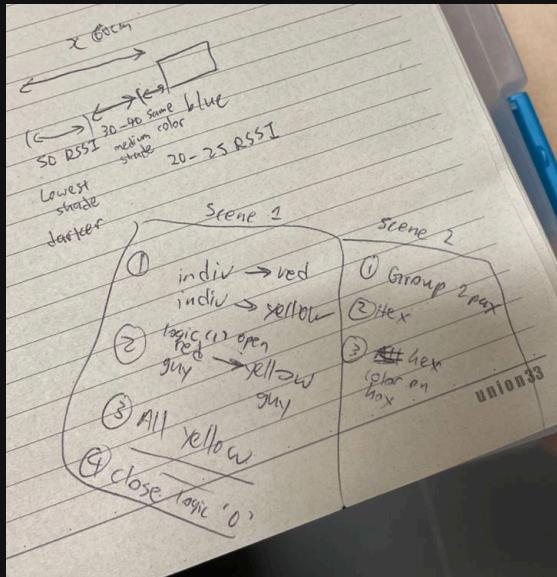


Rough sketch of product

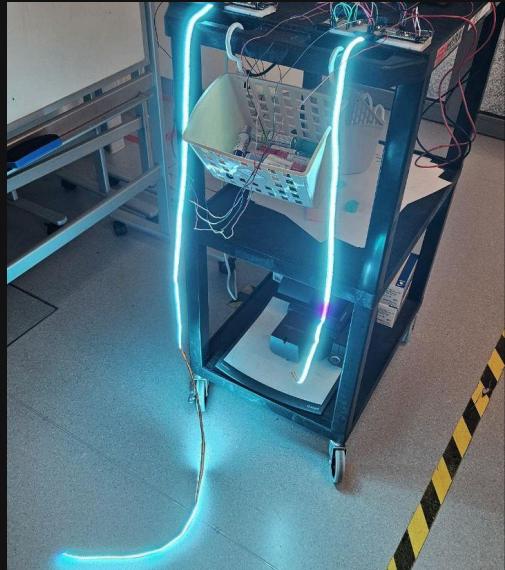


AEIOU planning

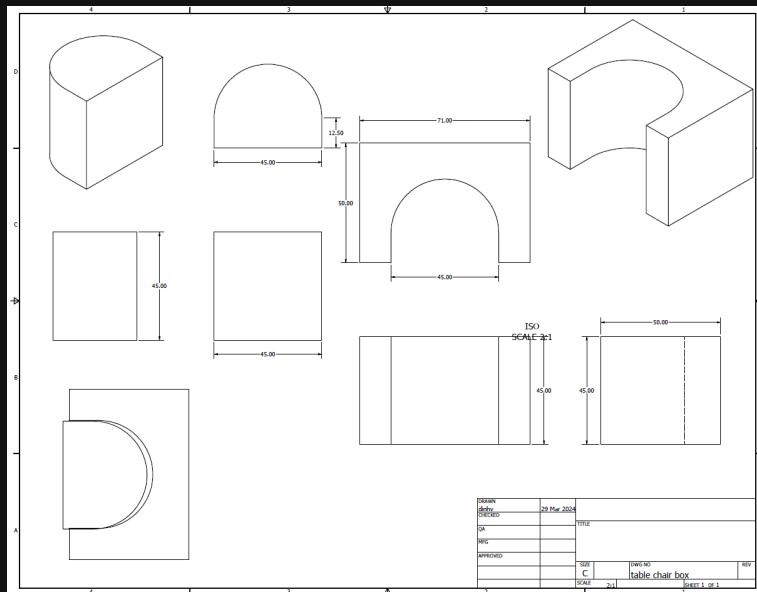
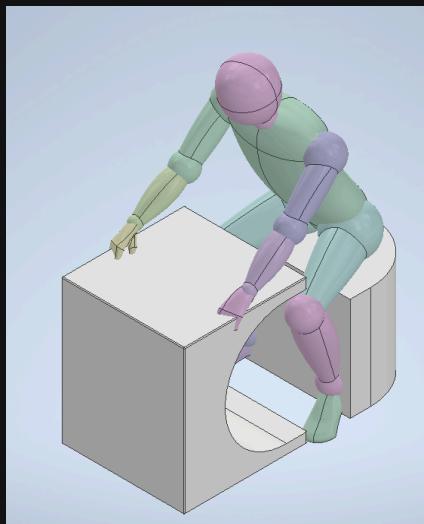
DEVELOPING



Rough programming logic of the prototype



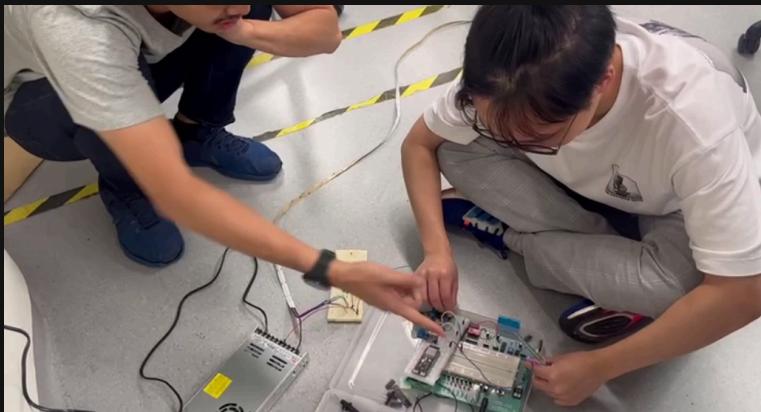
Testing LED-strip



Actual product's 3D CAD and dimension (scaled down for prototype)

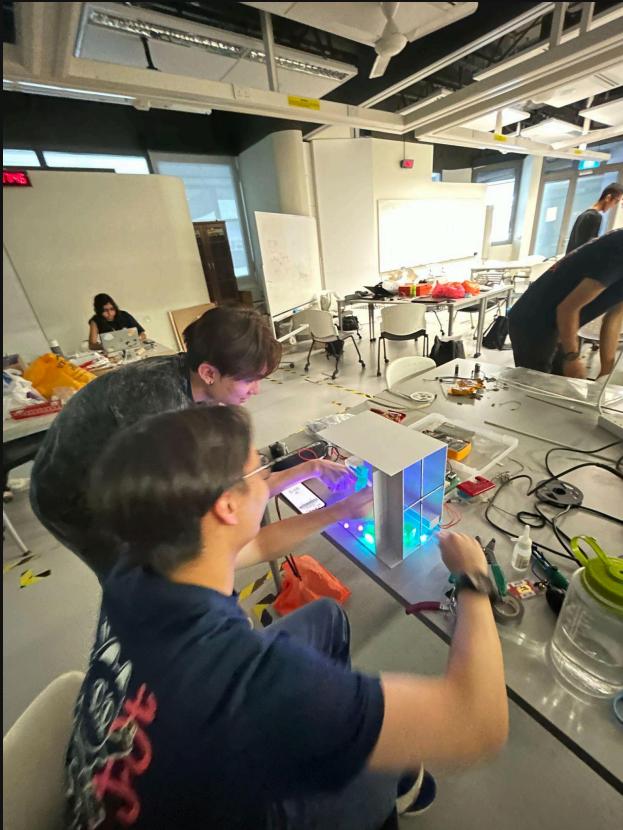
After the ordering what is needed for the project, our team started to try to figure out how to actually set up our led strips. Our first attempt failed with the testing led strip were blown from connecting with more volt than its rated volt . Subsequence failure attempts were also about electrical circuits, with short circuit, loose wire, or simply careless mistake.

Reflecting on our setbacks, our team has implemented stringent safety measures to mitigate risks. We now ensure that two team members independently verify the circuitry before activating any power source. As our projects become more intricate, we've also embraced electrical engineering safety protocols, including meticulous cable management, the incorporation of circuit breakers (fuses in our case), and the diligent taping off of exposed wires. Recognizing the potential hazards inherent in our work, we prioritize safety for ourselves and those in our vicinity.



Dylan and Kovan double checking the circuit

CAPTURING THE MOMENT



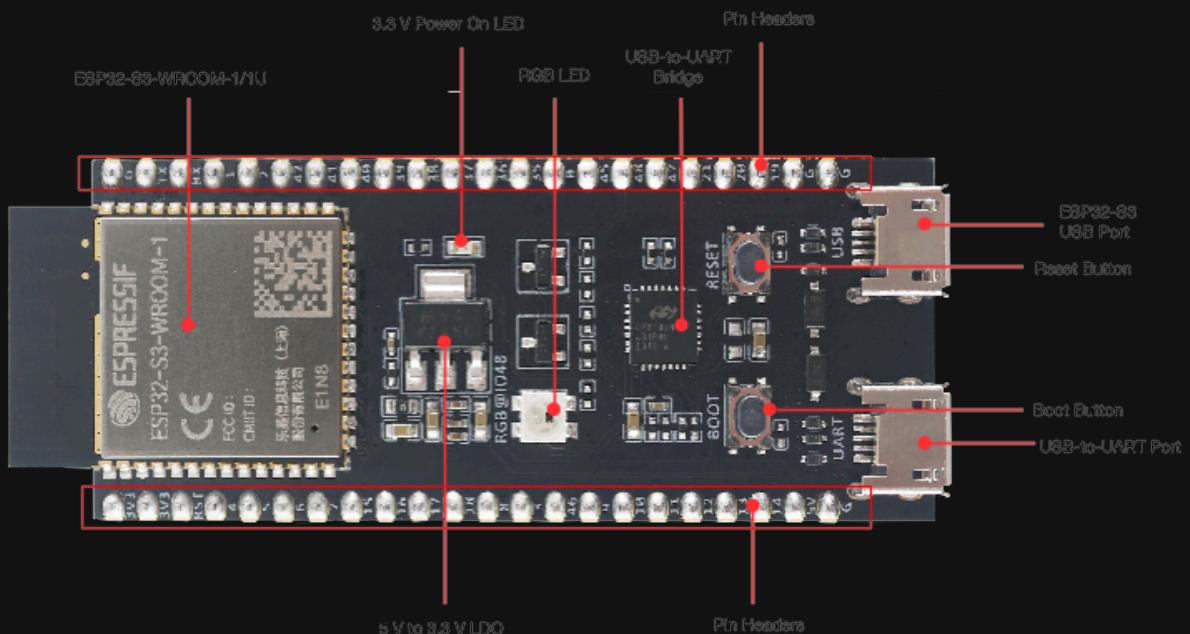
Documentation:

Specifications and dimensions



Dimensions (table): 71cm (length) x 45cm (breadth) x 50cm (height)

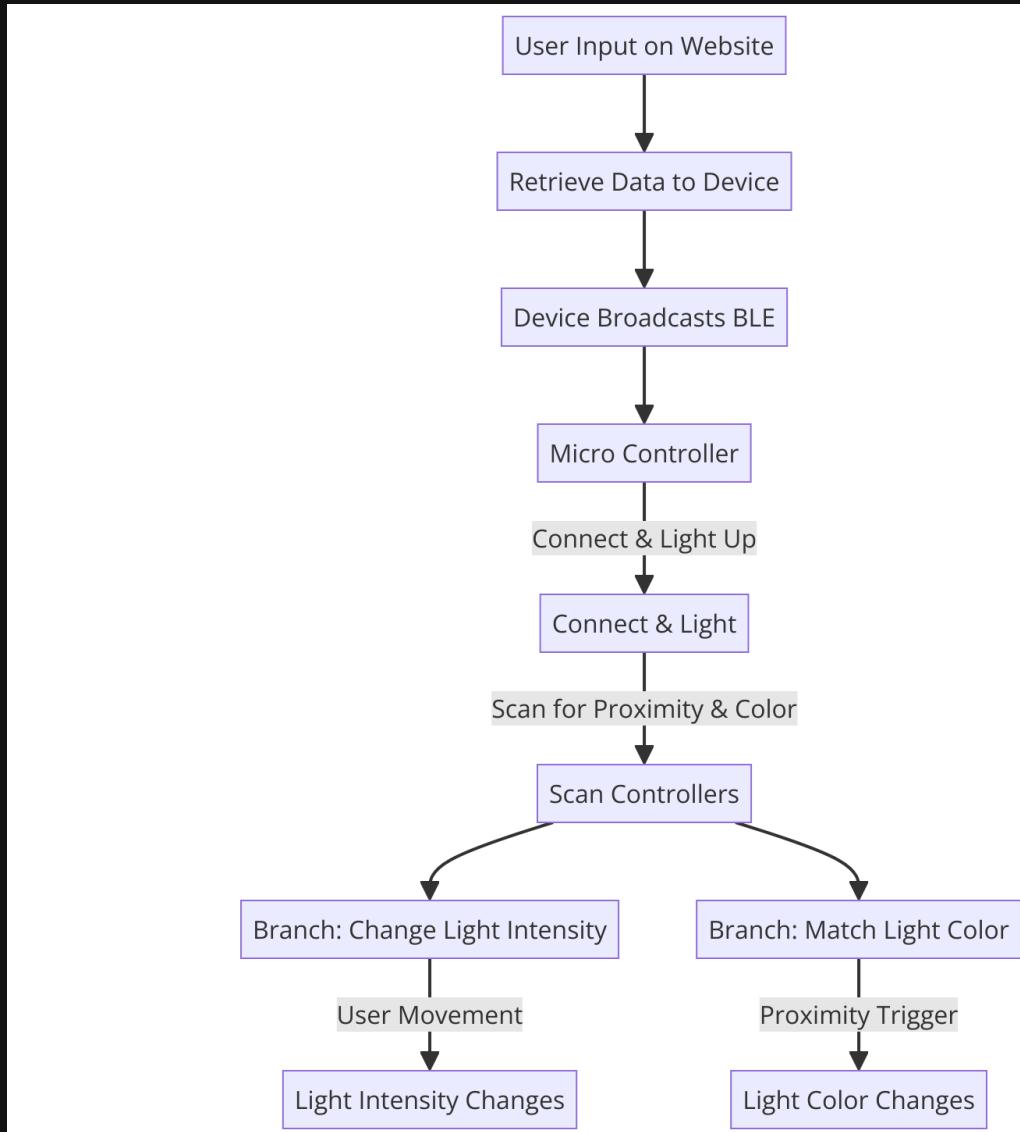
Dimensions (chair): 45cm (width) x 50cm (height)



ESP32 Module
Dimensions: 62.74mm (length) x 25.40mm (breadth)

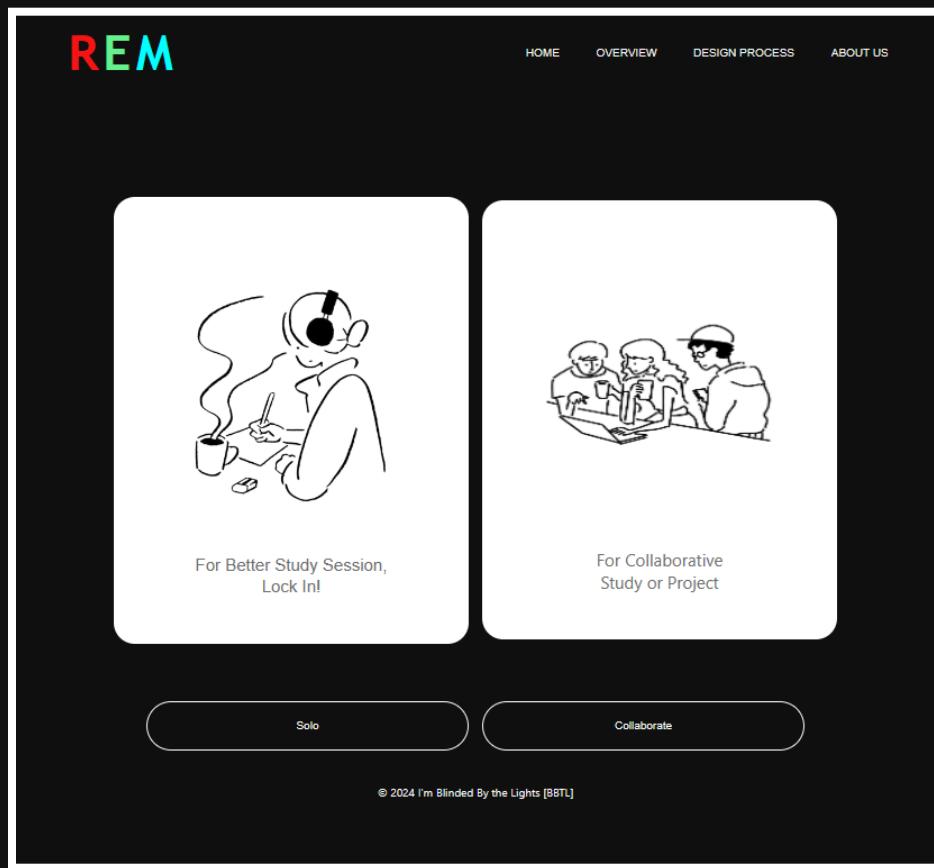
Software

- Logic Flowchart



- **Code Snippets**

- Front-End Web:



```
59      <div class="mode-selection">
60          <a href="individual.html" class="solo-mode-button-wrapper">
61              <button class="solo-mode-button">Solo</button>
62          </a>
63          <a href="group-pax.html" class="collab-mode-button-wrapper">
64              <button class="collab-mode-button">Collaborate</button>
65          </a>
66      </div>
```

The code above allows the user to select the choice of number of pax using the room, between individual or group options.

LOCK IN!

Select your level of Individual Study Intensity



Low

High



submit

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Intensity Indicator Guide:

▪ Low Intensity:

- Casual browsing of materials.
- Limited focus and occasional distractions.
- Relaxed pace with breaks taken frequently.

▪ Medium Intensity:

- Engaged reading and note-taking.
- Moderate focus with occasional minor distractions.
- Consistent pace with scheduled breaks for refreshment.

▪ High Intensity:

- Deep focus and active learning.
- Minimal distractions and full immersion.
- Intense concentration for extended periods with strategic breaks for optimization.

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The code above allows the user to hover over the '?' icon to view the colour indicator guide and allows the user to slide their choice of colour before using the submit button.



How many of you are there?

e.g. 2

submit

reset

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Color Your World with REM: Suit Your Group's Mood!

1. Hover your cursor to the choice of color.
2. Left-click to select the color before submission.



submit

```

8     @app.route('/receive_data', methods=['POST', 'OPTIONS'])
9     def receive_data():
10         if request.method == 'OPTIONS':
11             # Handle OPTIONS request
12             response = jsonify({'message': 'CORS preflight request received'})
13             response.headers.add('Access-Control-Allow-Origin', '*')
14             response.headers.add('Access-Control-Allow-Headers', 'Content-Type')
15             response.headers.add('Access-Control-Allow-Methods', 'POST')
16             return response
17
18         if request.method == 'POST':
19             data = request.json
20             hexVal_dCount = data.get('hexVal_dCount')
21             output_string = f"{hexVal_dCount}"
22
23             print(output_string) # This will print "Hex value Number of passengers"
24
25             # Write output_string to a JSON file
26             with open('output.json', 'w') as f:
27                 json.dump({'output_string': output_string}, f)
28
29             return jsonify({'message': 'Data received successfully'})
30         else:
31             return jsonify({'message': 'Method not allowed'}), 405

```

app.py code file

Request method OPTIONS returns a response and allows POST requests.

Request method POST retrieves JSON data of hexVal_dCount (hex value sent to product + number of products 'ESP32-S3' required for use) from the website.

```

if request.method == 'POST':
    data = request.json
    hexVal_dCount = data.get('hexVal_dCount')
    output_string = f"{hexVal_dCount}"

    print(output_string) # This will print "Hex value Number of passengers"

    # Write output_string to a JSON file
    with open('output.json', 'w') as f:
        json.dump({'output_string': output_string}, f)

    return jsonify({'message': 'Data received successfully'})
else:
    return jsonify({'message': 'Method not allowed'}), 405

```

A Flask app sets up a route '/receive_data' that accepts POST requests containing JSON data, extracts a specific value from the JSON, prints it, and then writes it to an 'output.json' file. CORS is enabled to allow cross-origin requests

```

output_string = data.get('output_string')

my_service_uuid = "A07498CA-AD5B-474E-940D-16F1FBE7E8CD"
if output_string is not None:
    # my_service_uuid = my_service_uuid[:-8] + "00ff0002"
    my_service_uuid = my_service_uuid[:-8] + output_string[1:]
    logger.debug(f"New UUID: {my_service_uuid}")

```

ble_data_transmitter.py reads data from an 'output.json' file, modifies a UUID based on the data, and then creates a BLE server with a service and characteristic. It periodically updates the value of the characteristic based on the data from the JSON file and runs indefinitely.

```

}
else { // switch back later 1
// if (true){
if (advertisedDevice.getName().find("esp1") != std::string::npos ) { // only check with esp3 table set 2
| Serial.println(advertisedDevice.getName().c_str());
int rssi = advertisedDevice.getRSSI(); // Retrieve RSSI value
Serial.println(rssi); // Print RSSI

// Extract RGB components from original color hex string
uint8_t originalRed = strtol(hexValue_S.substring(1, 3).c_str(), NULL, 16);
uint8_t originalGreen = strtol(hexValue_S.substring(3, 5).c_str(), NULL, 16);
uint8_t originalBlue = strtol(hexValue_S.substring(5, 7).c_str(), NULL, 16);
// Smooth the RSSI value using EMA
smoothedRSSI = alpha * rssi + (1 - alpha) * smoothedRSSI;
int darkness_level = map(rsssmoothedRSSI, -60, -30, 10, 1); // Map smoothed RSSI to darkness level (1 to 10)

// Calculate darker shades
// Calculate darker shades with boundaries
int darkerRed = constrain(originalRed * (10 - darkness_level) / 10, 0, 255);
int darkerGreen = constrain(originalGreen * (10 - darkness_level) / 10, 0, 255);
int darkerBlue = constrain(originalBlue * (10 - darkness_level) / 10, 0, 255);

// Set LED color
// if (counter >= 2) {

    // Serial.print("Counter reached:");
    // Serial.println(counter);
    setRGBColor(darkerRed, darkerGreen, darkerBlue);
    Serial.println(darkerRed );
    Serial.println(darkerGreen );
    Serial.println(darkerBlue );
}
}

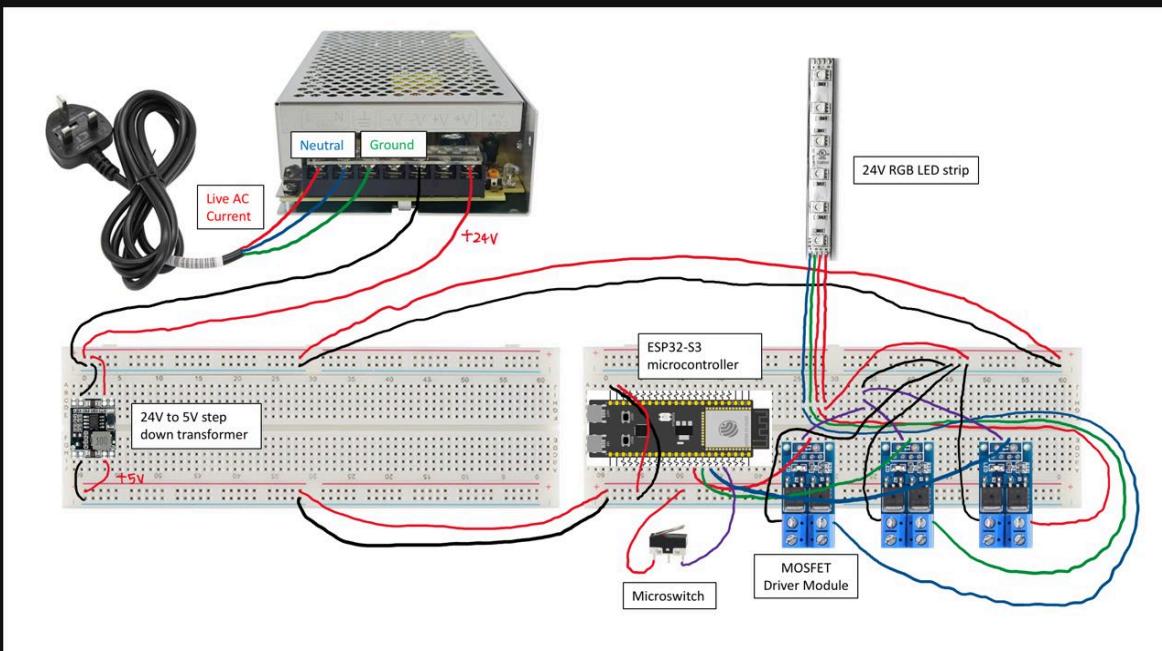
```

Lastly, Arduino code sets up each ESP32 device to function as both a BLE advertiser and scanner simultaneously. It initializes BLE advertising with a custom beacon and sets up a BLE server with a characteristic for reading, writing, and notifying. Additionally, it scans for nearby BLE devices (other REM or user's devices), extracts specific information from their advertisements, and adjusts an RGB LED's color based on the received data. The code leverages the ESP32's capabilities to manage BLE communication and LED control effectively, facilitating bidirectional interaction with other BLE devices.

Furthermore, the code incorporates a signal smoothing mechanism to mitigate fluctuations in Bluetooth signal strength, which commonly occur in wireless communication environments, ensuring more stable and reliable performance.

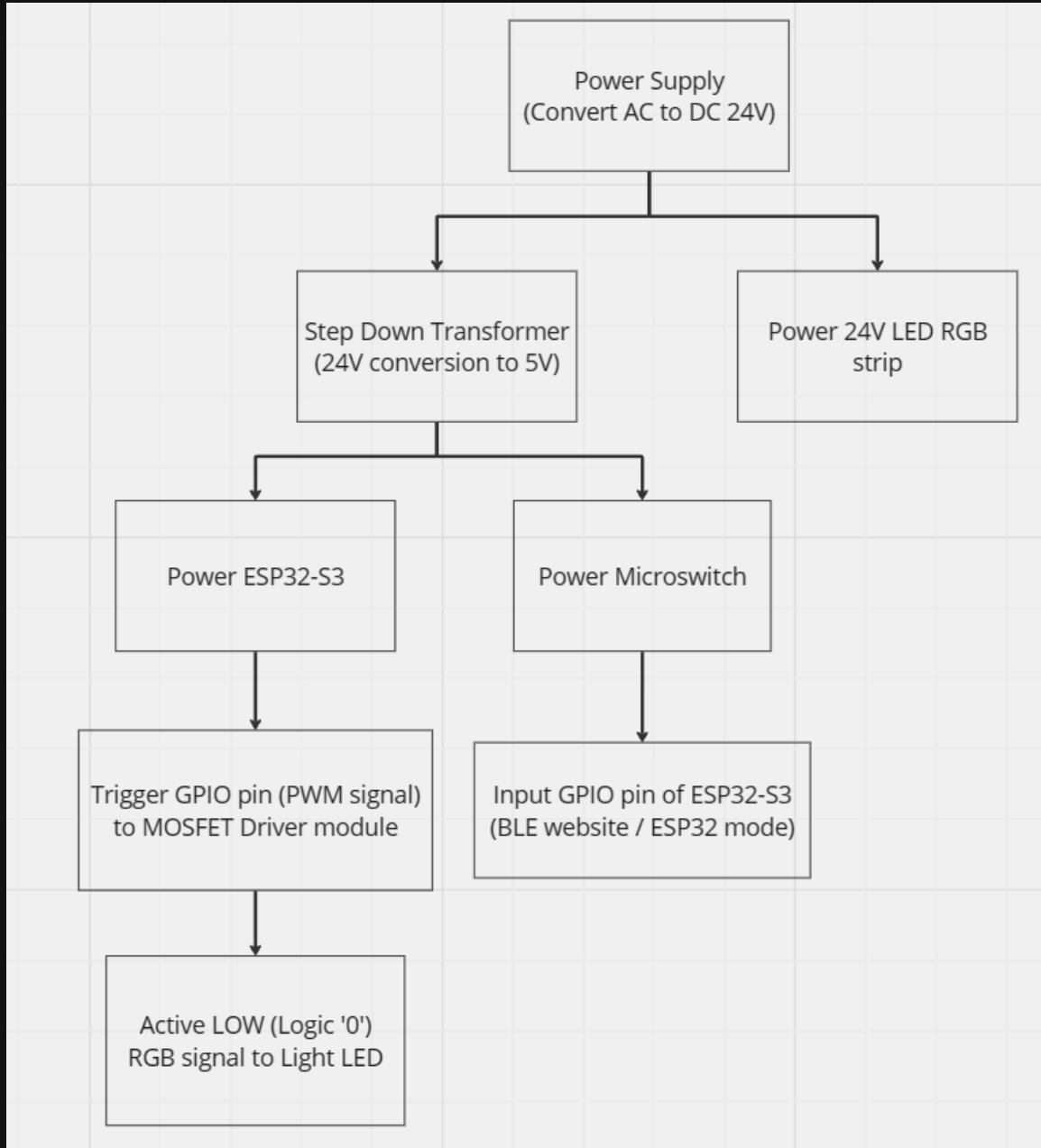
Electrical

- Schematic Diagram



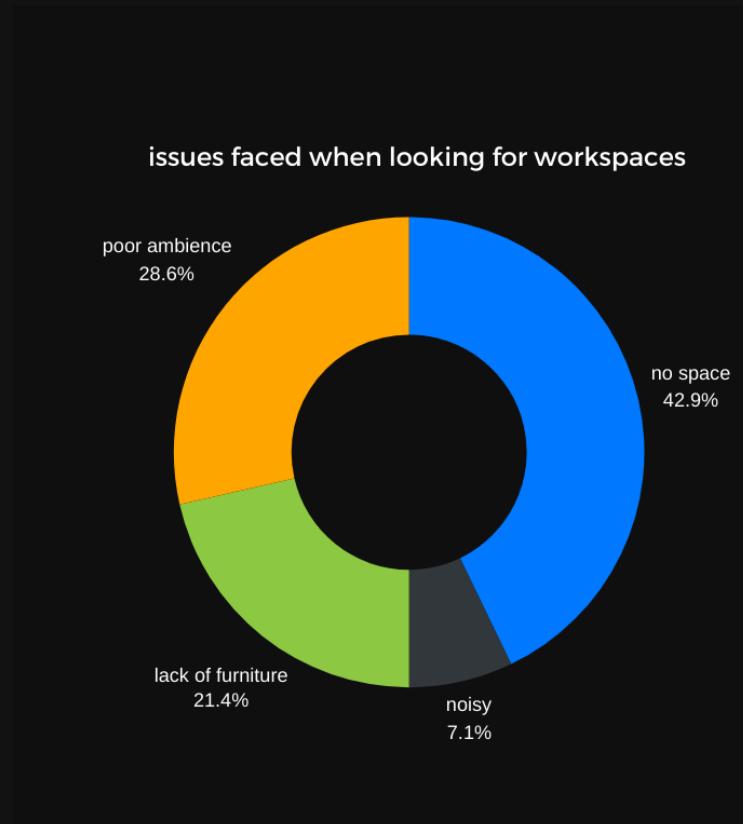
Schematic diagram of 1 product component

- **Circuit Flowchart**



Data & Feedback

We conducted BOTH qualitative surveys and verbal interviews

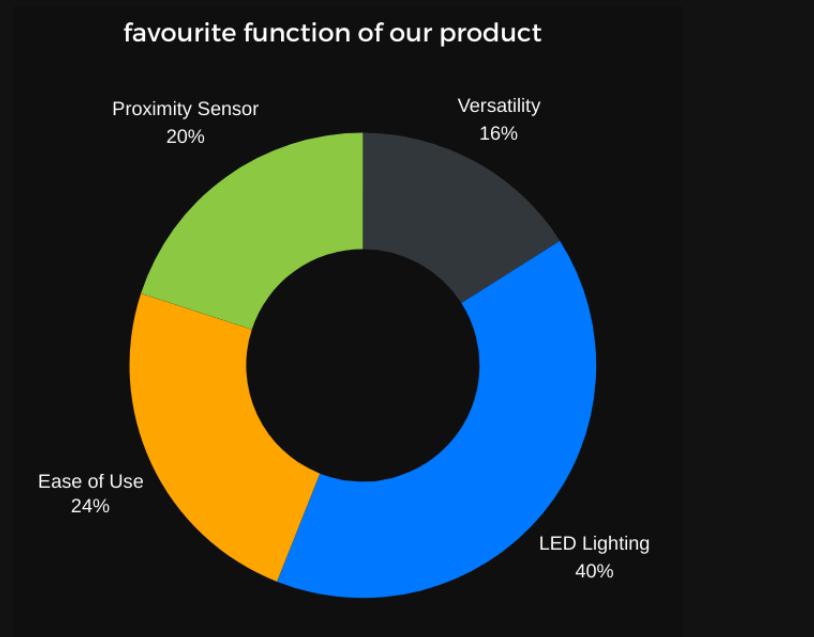


We identified **key issues** that were faced by students that support our problem statement to ensure we were on the right track.

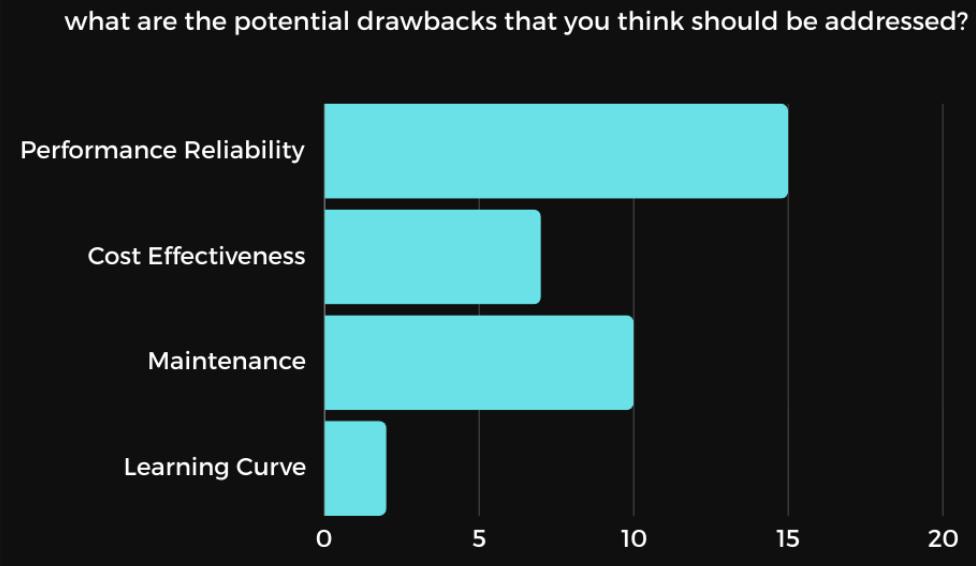


8 in 10 people were willing to test our product

An astonishing 80% of people were willing to give our product a shot.



We conducted a survey to find out what people love most about our design.



Verbal interview for potential improvements that we should look at.

Video



https://youtu.be/_FS3sQ58yWw

Additional Communication Details

Keywords & Tags

ADAPTABILITY, SOCIAL INTERACTIONS, ESP32, MODULARITY, LED STRIPS

Interaction / Flow / Operation

When users use our website, they are able to select between Solo or Group studying, from there they can also choose their colours from a wide variety of options. If they move closer to one another, the colours become interactive as well, allowing them to switch between study modes seamlessly.

Location

School Workspaces

Project Abstract

The inception of REM was driven by a need to address workspace usage. Our investigative approach involved user behaviour studies, aiming to deeply understand how people use respective workspaces. The objective was to create a solution that not only meets but exceeds the expectations and needs of students.

Utilising qualitative interviews, quantitative data analysis and design thinking processes, we crafted a series of prototypes, each refined through iterations based on feedback and performance metrics.

The results were transformative, leading to a product that reduces waste, enhances user engagement and overall looks cool. Insights gained from this project highlight the potential impact of REM in a public setting, expanding the scope of the impact to a larger audience. This project not only meets the contemporary demands of the market but also sets a new benchmark for future developments in light and social interactions.

Creative Challenge

The hardest part of the design activity was striking a balance between creative aspiration and the practical constraints of technology and production. We wanted to push for functionality while making our product as aesthetically pleasing as possible. Externally, we contended with regulatory standards and the availability of technology, which dictated our approach to materials and processes. Internally, the team had to align diverse perspectives and expertise to forge a path forward. Overcoming these hurdles was a testament to our adaptability and collaborative spirit.

2D Posters

REM

HOW MIGHT WE design adaptive workspaces that dynamically transition between promoting social interactions and supporting deep study sessions, accomodating to different phases of the term?

1. Copper



Very durable: Copper is corrosion-resistant, making it long-lasting. Copper demonstrates excellent corrosion resistance in a multitude of different environments.

High conductivity: Pure copper has the highest electrical conductivity of any commercial metal. This property makes it the preferred material for power cables, circuit board conductors and a variety of other electrical applications.

Environmental Impact:
Sea pollution: excess copper in the water has adverse effects on aquatic life, with damage to freshwater organisms such as fish. Copper damages the kidneys, nervous systems, and livers of most water creatures.

Habitat destruction: Copper mining has a significant environmental impact, destroying habitats. Conservationists suggest that forest has been severely affected by mining caused deforestation that began decades ago.

End-of-Life Analysis:
Recycling: Copper is highly recyclable and can be recycled indefinitely without losing its properties. Recycling copper uses much less energy than producing new copper from ore. By recycling copper, we reduce CO₂ emissions and save about 85% of the energy required for primary production. Moreover, the European Circular Economy Stakeholder Platform notes that using copper scrap can lower CO₂ emissions by 65% compared to using virgin materials.

Incineration: Not applicable, as copper does not burn. However, copper can contaminate the fly ash if other materials are incinerated with it.

Landfill: Copper in landfills does not degrade, but it can potentially leach into the soil and groundwater, which can be toxic to wildlife and plants.

How we made it sustainable:
By using recycled copper, we can save costs and lower our environmental footprint. Recycled copper reduces the need for mining, lowering the associated land and water use, and it consumes up to 85-90% less energy than normal copper production.

3. Polyvinyl Chloride (PVC)



Durability: PVC is resistant to weathering, chemical roofing, corrosion, shock, and abrasion. It is the preferred choice for many long-life outdoor products. About 60% of PVC manufactured has a service life of between 15-100 years.

Anti-microbial properties:
PVC (polyvinyl) is less tough while having high impact strength and is easy to extrude or mould. It has lower temperature resistance and usually lower tensile strength that allows for easy manipulation.

Environmental Impact:
Production releases organic pollutants: dioxins, furans, polychlorinated biphenyls (PCBs), hexachlorobutadiene (HCB). Vinyl chloride is identified as a carcinogen with links to liver, lung, brain cancers, lymphoma, and leukemia. Any exposure carries risk, with high levels potentially causing severe symptoms or death. PVC production can lead to harmful substances like phthalates and vinyl chloride leaching into top water, posing health risks.

End-of-Life Analysis:
Recycling: PVC can be recycled, and there are two main types – mechanical recycling where the material is melted and remolded, and feedstock recycling where it is broken down into its chemical components. However, recycling rates for PVC are relatively low compared to other plastics.

Incineration: When incinerated, PVC can release toxic chemicals, including dioxins, which are harmful to human health and the environment. This makes energy recovery from PVC less desirable.

Landfill: PVC is non-biodegradable, and when placed in landfills, it can take a very long time to break down. The presence of additives can also lead to potential leaching issues.

How we made it sustainable:
Design for Disassembly: Our PVC-based products that can be swiftly and easily taken apart. This facilitates efficient recycling processes, ensuring that each component can be properly sorted and reused, thus reducing the environmental impact and promoting a circular economy.

Overall Analysis:

Life Cycle Assessment (LCA):

Silicon and Copper are highlighted as energy-intensive, while Acrylic and Plywood significantly affect water resources, marking these as critical areas for efficiency improvements. During end-of-life processing, recycling is vital for materials like PVC, Acrylic, and Plywood, significantly lowering their environmental impact. Combustion reveals that PVC and Acrylic release considerable emissions, emphasizing the need for prioritizing recycling to reduce environmental harm. CO₂-equivalent emissions analysis identifies PVC and Copper as major contributors due to their energy-intensive production, targeting them for urgent emission reductions.

Technology Improvements:

Focusing on efficiency metrics, significant technological innovations in the production of Silicon, Aluminium, and Plywood have led to reductions in energy usage by up to 10% and water usage by 30%. Enhancements in recycling technologies for PVC and Acrylic have also notably increased recycling efficiency. These improvements are not only pivotal for achieving environmental objectives but also for driving cost efficiencies.

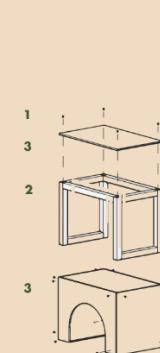
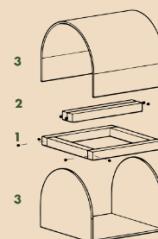
Benchmarking:

Comparative benchmarking across companies illuminates variances in energy and water use, waste management, and CO₂ emissions, allowing for the identification of industry leaders in sustainable practices. This benchmarking is instrumental in pinpointing companies that excel in environmental stewardship and those that need substantial improvement, providing a clear roadmap for industry-wide enhancement.

Recycle or Sell Reusable Parts:

Donating or selling reusable parts helps prevent waste and supports community resources. Functional components such as sensors or switches can be invaluable to educational institutions and DIY enthusiasts, we can use the money we get back to buy parts for another project, promoting economic and environmental sustainability.

2. Plywood



Easy to Handle: Plywood's lightweight quality simplifies transport and handling. Its ease of shaping often leads to better craftsmanship and more aesthetic designs.

Cost Effective: Plywood production allows for wood to be sourced from a single tree compared to solid wood, enhancing efficiency and conservation of resources. The increased availability of plywood makes it a cost-effective option for both residential and commercial use.

Dimensional Stability: plywood has amazing dimensional stability, allowing it to maintain its shape and size even when exposed to moisture, heat, or cold which is highly relevant since our product can be exposed to the elements.

Environmental Impact:

Plywood has a relatively low carbon footprint due to carbon sequestration in the wood. The adhesives used in plywood often contain formaldehyde, which can off-gas volatile organic compounds (VOCs) into the environment, posing health risks and contributing to indoor air pollution.

End-of-Life Analysis:

Recycling: Plywood can be recycled into wood chips or fibers for other products, though the presence of adhesives can complicate the process.

Incineration: Plywood can be utilized for energy recovery through incineration. This process not only reduces the volume of waste but also harnesses the energy contained within the wood to generate electricity. However, the efficiency and environmental impact of this method can vary based on the technology used and the composition of the plywood, such as the type of wood and any treatments it may have undergone.

Landfill: Plywood is biodegradable, especially if it is not treated with preservatives. However, degradation can release methane, a potent greenhouse gas, and chemicals from adhesives can leach into the environment.

How we made it sustainable:

Our design incorporates a combination of plywood and other reclaimed wood materials for the frame construction. While plywood remains the predominant material—reflected in our LCA analysis—integrating other wood types allows us to minimize waste and make use of existing resources.

4. Acrylic



Property: Highly transparent, transmitting up to 92% of visible light, more than glass, while being malleable and sturdy and not brittle.

Low Maintenance: It maintains its optical clarity and doesn't yellow with age, making it a great choice since our product can be used for prolonged periods without needing much maintenance, saving costs over time as well.

Environmental Impact:

Dangerous and harmful to humans and wildlife: production of acrylic fabric involves volatile processes and the use of toxic substances, posing explosion risks at manufacturing plants and potential ecological harm if mishandled. Legislation mandates that the harmful gases from acrylonitrile production be filtered in a controlled environment to prevent environmental and health hazards.

End-of-Life Analysis:

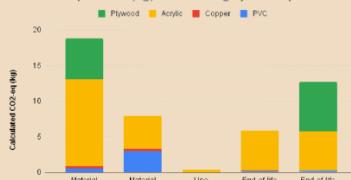
Recycling: Acrylic can be recycled, but the process is not as straightforward as with other plastics. It often requires chemical recycling to break it down into its monomers.

Incineration: When burned, acrylic can release toxic fumes including carbon monoxide and formaldehyde.

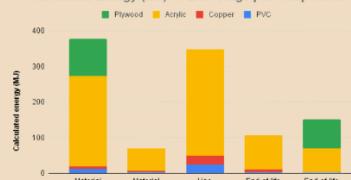
Landfill: Acrylic is non-biodegradable and can last for many years in a landfill. It does not leach toxic substances but does contribute to the volume of waste. Acrylics contribute to landfill volume due to their non-biodegradable nature. In 2018 U.S. landfills received 27 million tons of plastics, which accounted for 18.5% of all municipal solid waste landfilled that year.

How we made it sustainable:
We used bio-based acrylic that transitions away from conventional petroleum-derived acrylic, actively reducing our reliance on finite non-renewable resources. Bio-based materials can reduce carbon emissions by up to 75% compared to their petroleum-based counterparts. Additionally, the biodegradable nature of bio-based acrylic could potentially decrease plastic waste in landfills by a substantial margin.

Calculated CO₂-eq emitted (kg) vs LCA Stage per component



Calculated Energy (MJ) vs LCA Stage per component



Calculated Water-eq (l) vs Material Production



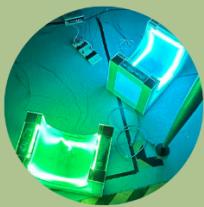
LCA / References / Assumptions

1008116 Dinh Van Ky
1007924 Darren Goh-Xin Yang
1008239 Beatrix Acosta Ong
1007519 Tan Tian Kieran
1005088 Khoo Li Cheng Dylan



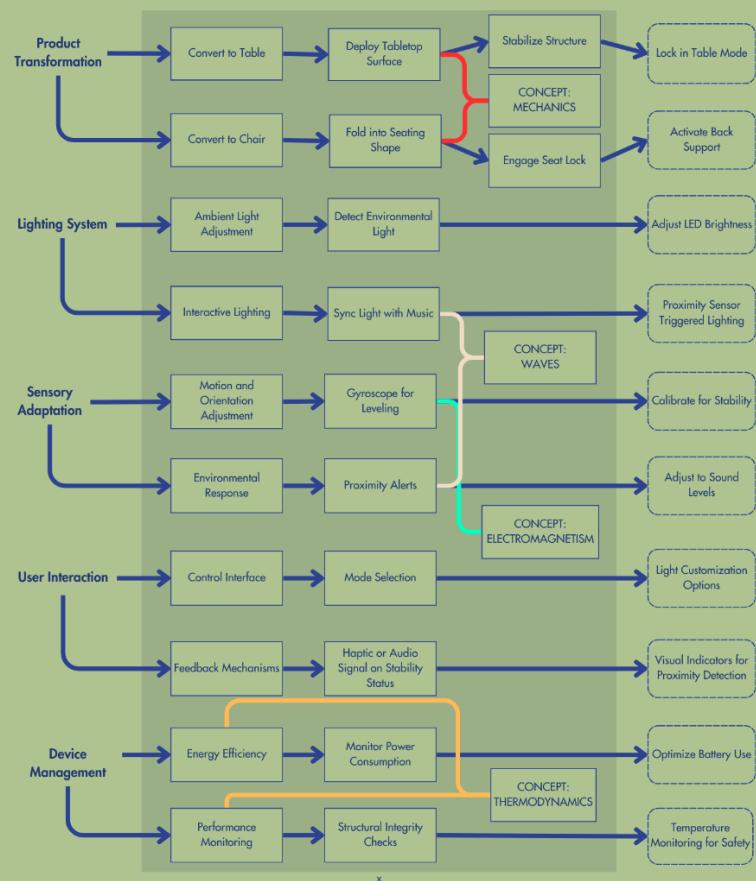
REM

EXPERIMENT DATA

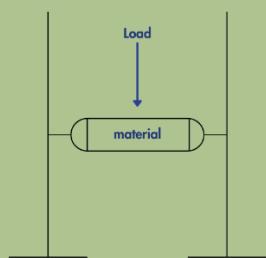


HOW MIGHT WE DESIGN ADAPTIVE WORKSPACES THAT DYNAMICALLY TRANSITION BETWEEN PROMOTING SOCIAL INTERACTIONS AND SUPPORTING DEEP STUDY SESSIONS, ACCOMODATING TO DIFFERENT PHASES OF THE TERM?

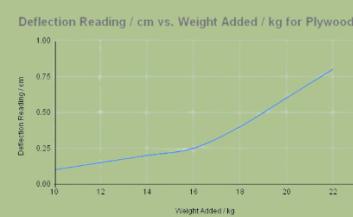
FUNCTIONAL DIAGRAM



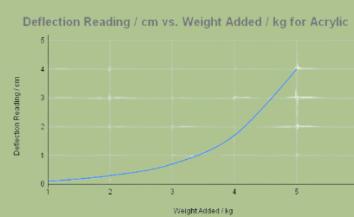
EXPERIMENT 2



Experiment 2: Determining the maximum load the product can handle.



To conduct this load experiment on both Acrylic and Plywood which are the materials for the main frame of the product and where they will be in contact with most. By incrementally applying weights to each material, we simulate the stress they would encounter in everyday use. This systematic approach allows us to determine the load-bearing threshold where the materials begin to warp or sustain damage. Deflection is measured from an unloaded state to maximum load, noting any point of permanent bend or fracture. By understanding the limits of Acrylic and Plywood, we can make informed decisions about the product design, ensuring that it can withstand the typical forces exerted by users without compromising on form or function.



Experiment 2: Plywood can withstand weight up to 22 kg while acrylic, which matches with our frame being made out of mepoxy plywood. However, beyond the weight threshold at which failure occurs, we've implemented targeted reinforcements. This has not only increased the product's load-bearing capacity but also its longevity. Now, even under varied weight distributions that come with different user interactions—whether it's being used as a table or a chair—our product maintains its integrity. This ensures that our product is reliable, safe, and user-friendly without compromising on the elegant design our customers value.

IMPROVEMENTS



Incorporate safety features that deactivate electrical components if structural integrity is compromised, such as breakaway connectors or circuit breakers sensitive to physical deformation. Equipped with detachable connectors and sensitive circuit breakers, these systems preemptively avoid electrical risks, enhancing user safety and product reliability.

Protective coatings and laminates will be applied to the surfaces to improve resistance to scratches, impacts, and weathering. These enhancements will maintain the product's appearance and structural strength over extended use.

Conduct extensive load testing for all possible configurations to identify weak points and confirm the maximum safe load. Protective coatings and laminates will be applied to the furniture surfaces to improve resistance to scratches, impacts, and weathering. These enhancements will maintain the product's appearance and structural strength over extended use.

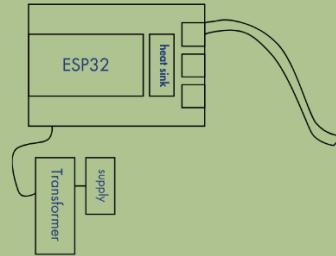
LIMITATIONS



Material durability, the materials used (e.g., plywood, acrylic) might be prone to scratches, impacts, or weathering, which could limit its longevity or aesthetic appeal. Furthermore, when the materials become more worn out, it could be dangerous to use as there are a lot of electrical wiring insides in the event the product collapses.

There might be limitations on how much weight the box can support in various configurations, affecting its functionality as a piece of furniture. A table will have less support when the 2nd component of the box is removed from below.

EXPERIMENT 1



Experiment 1: Finding out how temperature of circuitry components affect resistance, power loss and hence cost of running our product. Relation between temperature and resistance is given:

$$R = R_{\text{ref}} [1 + \alpha(1 - T_{\text{ref}})]$$

Where,
 R = Conductor resistance at temperature "T"
 R_{ref} = Conductor resistance at reference temperature
 $T_{\text{ref}} = 20^{\circ}\text{C}$, usually 20°C but sometimes 0°C.
 α = Temperature coefficient of resistance for conductor material.
 T = Conductor temperature in degrees Celsius.
 T_{ref} = Reference temperature that is specified at for the conductor material.

How it works:

To calculate power loss and hence cost, we will set up a similar circuit to the one we are using for our product. Voltage is kept at a constant 24V through the transformer, initial resistance was gauged using a multimeter. Then we conducted two trials, one with and without a heat sink. We then proceeded with temperature recording over specific intervals, with one trial including a heat sink and another without, to measure the impact on resistance. Power Loss = $V^2/2R$, where V is the constant voltage and R is the calculated resistance, was monitored under both conditions. The outcomes of the experiment will guide optimizations in circuit design to help us enhance energy efficiency and thermal management.



Experiment Results:
 Experiment 1: The incorporation of a heat sink substantially reduced the temperature within the circuitry, leading to a decrease in power loss. This suggests that the heat sink is highly effective in managing thermal stress, which is a crucial factor for product's life span and safety. However, only a small amount of power is needed to power the product so the difference in power loss did not make a huge difference in the costs. In scenarios where multiple units operate continuously, the cumulative effect on power consumption and thus costs will then become significant.

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