Engineering Handbook

Tools, Models, and Frameworks

ESC102

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INTRODUCTION

1. INTRODUCTION

1.1. ABOUT THE HANDBOOK

The purpose of this handbook is to serve as a personal reference guide for engineering design. It documents the **tools, models, and frameworks (TMFs)** I have used in my design practice, providing a curated record of their application and value in my work. While the TMFs documented in this handbook have been applied in past design activities, their effectiveness and value in future design contexts remain an unknown. This handbook aims to explore this unknown by reflecting on past experiences and assessing the potential future applications of these TMFs. This handbook is a culmination of my design activities since September 2023, including experiences from Praxis I, other courses, and extracurricular design activities. It is a reflection of my personal philosophy and approach to engineering design, and how this influences my choice of TMFs. Throughout the handbook, I will present each TMF I have used, providing a description, an example of its application, evidence of its use in my design process, and an evaluation of its effectiveness. This setup will allow for a thorough exploration of the unknown, providing insights into the potential future applications of these TMFs in my engineering design practice.

1.2. PERSONAL POSITION

I identify myself as both an **engineering student** and, in many of my projects, an **embedded systems programmer**. As a first-year engineering student, I am constantly learning new things, both in class and outside. Some recent topics I am learning include machine learning algorithms, web integration through personal projects, and circuit analysis. As an embedded systems programmer, I have a keen interest in integrating hardware and software. I have been involved in several projects where I was responsible for Arduino or Raspberry Pi integration, which has allowed me to apply my theoretical knowledge in a practical setting. I approach engineering problems and the design process from these two different perspectives. However, it's also important to recognize the biases that affect this handbook:

- As a student, I am still new to formal engineering design. As a result, I may not have a full understanding of the various tools, models, and frameworks described in this handbook simply because of my limited experience.
- Another bias that affects this handbook is its primary purpose: to fulfill the requirements for my Engineering Design course. While I strive to ensure this doesn't overly influence the content, it's important to note that this is a required part of my coursework.
- In terms of my engineering design work, one of my fundamental principles is adhering to areas and tools with which I have experience. This tendency towards familiarity could potentially limit my exploration and expansion of new TMFs. Recognizing this, I aim to consciously push my boundaries and venture into unfamiliar territories in my future design endeavors.

1.3. VALUES

1.3.1. What Works

Throughout my work, I notice that I have 5 main values that I stick by quite strictly:

1. **Curiosity**: As an engineering student, I have a deep-seated curiosity that drives me to explore beyond the confines of my coursework. This thirst for knowledge propels me to delve into diverse topics and broaden my understanding of the world.
2. **Resilience**: I believe in the power of resilience. Challenges and failures are not setbacks, but opportunities for growth. I embrace difficult tasks and view each failure as a stepping stone towards success.
3. **Responsibility**: I hold myself accountable for my commitments. If I promise to complete a task by a certain date, I ensure it's done. If unforeseen circumstances arise, I communicate proactively. This sense of responsibility extends to my team settings, where I expect mutual accountability.
4. **Well-being**: I value balance in life. While academic and professional achievements are important, they should not come at the expense of mental or physical health. I strive for excellence but not at the cost of my well-being.
5. **Innovation**: I have a strong preference for innovative solutions. Even when faced with complex problems, I'm not afraid to pursue novel and challenging designs. This value is reflected in my approach to brainstorming ideas and problem-solving.

1.3.2. What Doesn't Work

I've been fortunate to work with some truly remarkable teams on most of my projects. We've collaborated effectively to realize our shared vision and achieve our collective goals. However, the ease of this collaboration has varied across teams. It's important for me to share what I've found to be less effective in a team setting, not as a critique, but as an opportunity for growth and understanding.

One aspect that I find challenging is when team members are not actively engaged during discussions. Active participation fosters a sense of shared responsibility and can lead to more innovative solutions. Similarly, it can be difficult when team members do not take the initiative to complete tasks, instead waiting to be assigned work. A proactive approach not only accelerates project progress but also demonstrates commitment and enthusiasm.

Psychological safety is a value I hold in high regard. I believe that for a team to truly thrive, each member must feel comfortable expressing their thoughts and ideas without fear of judgment. I've found that my collaborations are less effective with individuals who do not contribute to a psychologically safe environment. I find that a good way to deal with this is to hold team bonding sessions to build friendships within the team. This isn't to say that they are at fault, but rather that our interaction styles may not be compatible.

In sharing this, my intention is not to criticize but to highlight the importance of **active participation, initiative, and psychological safety** in a team setting. I believe that understanding and addressing these aspects can significantly enhance the effectiveness of any team.

2. ENGINEERING DESIGN PROCESS

2.1. THE PROCEDURE

The engineering design process begins with the '**Framing**' stage, where biases are identified to ensure a clear understanding of the requirements. This leads to the development of a requirements model, which is informed by research to ensure thoroughness. The next step is the '**Diverging**' stage, where brainstorming of ideas takes place to explore various possibilities. In this stage, me and my teams would often use various TMFs to come up with different designs for a solution. Following this, the '**Converging**' stage involves the execution of rigorous tests to validate the design and its functionality. The design phase is characterized by performing iterative design, which involves repeated refinement of the design based on testing. Finally, in the '**Representing**' stage, the results are compiled into a prototype that can be presented to other people for further evaluation and feedback. This systematic approach allows for a thorough and comprehensive engineering design process. It's important to note that while this process serves as a general guide, the actual process is often iterative and non-linear, allowing for flexibility and creativity.

My engineering design process can be broadly categorized using a modified version of the **Framing-Diverging-Converging-Representing (FDCR)** process:

2.1.1. Framing

> This involves identifying the **requirements** and conducting quality **research**. As an embedded systems programmer, I approach this stage by questioning my assumptions, validating their applicability, and justifying them rigorously. Recognizing and addressing my own biases is a critical part of this stage.

2.1.2. Diverging

> In this stage, I brainstorm ideas and explore various possibilities. I often find myself prototyping and iterating over different designs in this stage to be able to just generate as many ideas as possible. My systematic approach to problem-solving, which involves breaking down problems into smaller parts, plays a key role in this stage.

2.1.3. Converging

> This stage involves building more prototypes, testing them, narrowing down the set of ideas, and re-diverging if necessary. As an engineering student, I leverage a variety of tools (which will be mentioned later) to create and compare designs. My preference for using diagrams and visual aids greatly assists me in this stage.

2.1.4. Representing

The final stage involves presenting my ideas to others effectively. Whether I'm explaining the design to a peer, my friends who are not in engineering, or an industry leader, I ensure that my presentation is tailored to the audience's level of understanding.

Example:
After the intense overnight coding session at a recent hackathon (MakeUofT), I wanted to ensure that our team's project was robust and well-articulated. I found myself working while some of my team members were catching up on sleep. This required me to independently progress our project and later explain the developments to my team.
Once our project was complete, I presented our work to two distinct groups: one was my team, where I had to clearly explain the progress made during their absence, and the other was a larger audience that included judges and other participants at the hackathon.
Presenting to my team members ensured that everyone was on the same page and any gaps due to the staggered working hours were bridged. On the other hand, presenting to an audience that included judges and other participants was a different challenge. It forced me to articulate our project in a way that was understandable to people who weren't involved in its creation, ensuring I wasn't overusing technical jargon.
The feedback I received from both these presentations was invaluable. It not only helped in refining our project for the hackathon but also provided insights that I am currently incorporating into my approach towards future hackathons and team projects.

2.2. PROJECTS

Throughout this handbook, I will be referencing the following projects that I embarked on in the 2023-2024 academic year:

- **Design Brief**: My Praxis I team composed a design brief that underscored the opportunity to mitigate thefts of bicycle components such as wheels, handles, and the bike frame. In Praxis II, my new team wrote a new design brief exploring overcrowdedness issues at a local gym.
- **Alpha Release**: We developed a prototype bike lock that secures the frame to the wheels as well as to a post, providing a comprehensive solution to bike theft.
- **Beta Release**: Shifting our focus for the beta release, we created a prototype that automates the watering of mushrooms by misting at low humidity levels.
- **Showcase**: The culmination of Praxis II saw my team developing a tool that automatically sprays water to control the humidity level in a tent growing Lions Mane Mushrooms, enhancing their cultivation process.
- **CIV102 Bridge**: Our team designed a bridge doing vast amounts of calculation and iteration over different designs
- **MakeUofT Hackathon**: At the MakeUofT Hackathon, our team built a prototype of a voice-activated garbage can that can open the appropriate lid (compost, recycling, or garbage) based on what the user is discarding, promoting effective waste management.

TMFS AND FDCR

3. FRAMING

In this part of the Handbook, I will go over the various TMFs that I have used in my teams. I will explain why our team used it, how to use the TMF, and provide an example of one of my teams using it.

3.1. REQUIREMENT STRINGS

Why Did we Use This?
Requirement strings are utilized to establish a clear and comprehensive understanding of the project's needs. They encapsulate the project's objectives, stakeholders' values, specific design choices, and constraints, providing a roadmap for the design process.

How To Use the TMF:
To use requirement strings, begin by identifying the stakeholders and their values. Formulate high-level objectives that capture the overarching goals of the project, and low-level objectives that delve into specific design choices. Establish metrics that can quantify the performance of every design, and set criteria and constraints for each metric.

Example:
I have used requirements in almost all of my projects, but my most formal use of requirement strings have been in my Praxis projects. In my second design brief, our team developed a formal requirement string about overcrowdedness in a local gym:

Objective	Metric	Constraint	Criteria
Should reduce overcrowdedness in the gym	Number of people per 1,000 square feet	Must be less than 27 people [7]	Less is better
Justification	**Metric:** It was noted when interviewing the gym staff [A] that the free weight area and machines become especially congested during the peak hours of 5PM to 8PM. This metric allows for measuring the volume of people to determine the impact of different designs. **Constraints:** As per Standard #15 of the Canadian Fitness Safety Standards [8], patrons must be able to move unrestricted and safely. It is recommended that individuals have around 36 square feet of unoccupied space [7]. 27 people therefore becomes the ideal and maximum number of people that should be in a 1,000 square foot space. **Criteria:** Less people in an area allows for more equipment and machines being available.		

Using requirement strings in the engineering design process has several key takeaways:

1. **Clarity and Focus**: Requirement strings provide a clear and concise description of what the project aims to achieve. This helps keep the design process focused and aligned with the project goals.
2. **Communication**: They serve as an effective communication tool within the team and with stakeholders, ensuring everyone understands the project objectives and expectations.
3. **Guidance for Design Decisions**: Requirement strings guide the design decisions, helping to determine which design options are viable and how they should be evaluated.
4. **Basis for Testing and Validation**: They provide a basis for testing and validation. Once the product is developed, it can be tested against the requirement strings to see if it meets the expected outcomes.
5. **Documentation**: Requirement strings also serve as a valuable piece of documentation that can be referred back to throughout the project, ensuring that the project stays on track.

3.2. RESEARCH

Why Did we Use This?
Research is integral to the engineering design process as it equips us with the necessary knowledge to make informed decisions. The CRAAP test is a valuable tool in this process, helping us evaluate the reliability of our sources.

How To Use the TMF:
To conduct research using the CRAAP test, evaluate your source based on Currency (when the information was published), Relevance (if the source meets your needs), Authority (the credibility of the author), Accuracy (the correctness of the information), and Purpose (the author's intent). This evaluation helps ensure the reliability of the information you gather.

The CRAAP test is not well documented in my work as much of the test is done verbally with my teammates or mentally in my head. With that said, it's important to document the value and takeaways from using the CRAAP test:

1. **Currency**: The CRAAP test helps in assessing the timeliness of the information. It prompts us to check when the information was published and whether there could be significant changes between then and now.
2. **Relevance**: It aids in determining whether the source satisfies our needs. It encourages us to consider if the source is relevant to our research question or topic.
3. **Authority**: The CRAAP test guides us to scrutinize the author's credentials and reputation. It helps us determine if the author is trustworthy and an expert on the topic.
4. **Accuracy**: It assists in verifying the correctness of the information. It encourages us to cross-check the information with other reliable sources.
5. **Purpose**: The CRAAP test helps us understand the purpose or motive behind the information. It prompts us to consider if the author has any bias or hidden agenda.

   In summary, the CRAAP test is a comprehensive tool that helps us critically evaluate sources and use reliable and credible information in our research.

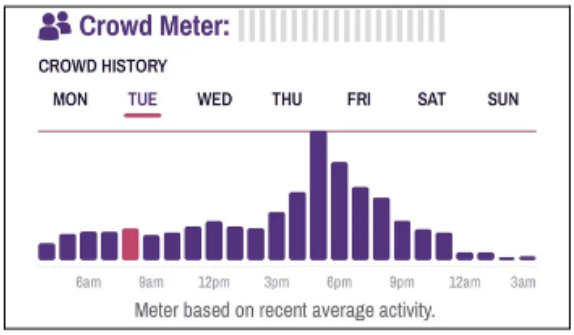
3.3. REFERENCE DESIGNS

Why Did we Use This?
Reference designs are used as a starting point or inspiration for our own designs. They provide a proven template that can be adapted to meet our specific needs, saving time and reducing risk.

How To Use the TMF:
To use reference designs, start by identifying designs that have similar goals or features to your own project. Study these designs to understand their strengths and weaknesses, and how they meet the needs of their users. Then, use these insights to inform your own design.

Example:
In our design brief addressing gym overcrowdedness, we referred to the crowd meter feature launched by the commercial gym franchise Planet Fitness in 2020:

5.1 Planet Fitness Crowd Meter



The commercial gym franchise Planet Fitness launched a crowd meter on their mobile app in 2020 [10]. The occupancy of a location is displayed on a guage comprised of 20 bars, with zero bars meaning the least occupied and a full bar meaning the busiest. You are also able to check the crowd history where the average occupancy of each day of the past week is displayed. The crowd meter works by updating on the basis of how many members check in at their respective gyms at a particular time [11]. When members check into a gym using the key tag or the mobile application, the information is updated on the website and the application automatically. The meter is updated once again when members check out. Using the crowd meter, members are given extra information that will help them schedule their workouts.

Information regarding the capacity of each subsection of the gym is currently unavailable. Gymgoers may arrive at the gym after observing a low crowd meter, only to find that their desired machines are busy. This **fails our requirement regarding reducing wait times**, as patrons may find themselves waiting for equipment despite a low crowd meter. The accuracy of the crowd meter itself has also been disputed in the past [12]. Some members of Planet Fitness have noticed discrepancies between the information displayed on the meter and the actual number of people present at the gym, therefore **failing our requirement of reducing overcrowdedness of the gym** as patrons may show up expecting a relaxed gym only to contribute to an already crowded gym [13].

Using reference designs in the engineering design process has several key takeaways:

1. **Inspiration**: Reference designs can serve as a source of inspiration, sparking new ideas and approaches that we might not have considered otherwise.

2. **Learning from Others**: By studying reference designs, we can learn from the successes and failures of others. This can help us avoid making the same mistakes and build on successful strategies.
3. **Benchmarking**: Reference designs provide a benchmark against which we can compare our own designs. This can help us understand where our design stands in relation to existing solutions.
4. **Understanding User Expectations**: Reference designs can help us understand what users expect from a product or solution in a particular category. This can inform our own design decisions and help us meet or exceed these expectations.
5. **Time and Effort**: Using reference designs can save time and effort by providing a starting point for our own designs. Instead of starting from scratch, we can build on an existing design and focus our efforts on innovating and improving.

3.4. STAKEHOLDER ANALYSIS

Why Did we Use This?
Stakeholder analysis is used to identify and understand the needs and interests of all the people who have a stake in our project. This helps us ensure that our design meets the needs of these stakeholders, and can help us anticipate and address potential challenges or objections.

How To Use the TMF:
To conduct a stakeholder analysis, start by identifying all the people who have a stake in your project. This could include users, clients, team members, and more. Then, for each stakeholder, identify their needs, interests, and any potential objections or challenges they might have. Use this information to inform your design and project planning.

Example:
For the overcrowdedness opportunity at the local gym, we took many different measures to analyze the stakeholders. Our team had an initial site visit to make observations about the members of the gym. We also got an opportunity to speak with the staff twice. This was all in effort of gathering information about our stakeholder to analyze. In the actual request for proposal, we drew conclusions related to our visit and formally analyzed our stakeholders for the project.

3.4 Stakeholders: Opportunity and Needs

3.4.1 Gym Members

One of the key stakeholder groups involved with this opportunity are the gym members that go to higher ground health club. The members of the gym have lived experiences that directly inform the need for addressing this opportunity. To understand the needs of this stakeholder group, we surveyed a gym goer that was leaving the higher ground health club around peak hours, and interviewed them about their experiences with the gym. The gym goer stakeholder's needs can be summarized as a solution that is:

- A solution that is **easy to use** (See Appendix C, Answer 6)
- A solution that is **effective** (See Appendix C, Answer 4-5)

3.4.2 Gym Staff

Another stakeholder group involved is the gym staff. The staff of the gym are directly impacted by this issue of overcrowding and often interact with gym members, who are also important stakeholders, to provide the best service. To better understand the impact of overcrowding on the gym staff and to determine the needs of this stakeholder group, two interviews were conducted with a staff member to determine first the logistics of the issue (i.e., number of members, peak hours, etc.) and then the importance of the issue (i.e., what kind of strain overcrowding puts on the staff). According to these two interviews (Appendix A,C), The needs of the stakeholder group of gym staff can be summarized as:

- A solution that is **easy to implement** (See Appendix C, Answer 3)
- A solution that is **effective** (See Appendix C, Answer 3)

Using stakeholder analysis in the engineering design process has several key takeaways:

1. **Understanding Stakeholder Interests**: Stakeholder analysis helps us understand the interests, needs, and concerns of all stakeholders. This understanding can guide our design decisions and help us create solutions that meet stakeholder needs.
2. **Identifying Potential Challenges**: By understanding stakeholder interests, we can anticipate potential challenges or objections that might arise during the design process. This can help us address these challenges proactively.
3. **Building Support for Our Design**: Stakeholder analysis can help us build support for our design. By understanding and addressing stakeholder interests, we can gain their support and buy-in for our design.
4. **Improving Communication**: Stakeholder analysis can improve communication by helping us understand who our stakeholders are and what information they need. This can guide our communication efforts and ensure that stakeholders are kept informed and engaged throughout the design process.
5. **Enhancing the Quality of Our Design**: By considering the needs and interests of all stakeholders, we can enhance the quality of our design. This can lead to a more successful and effective solution.

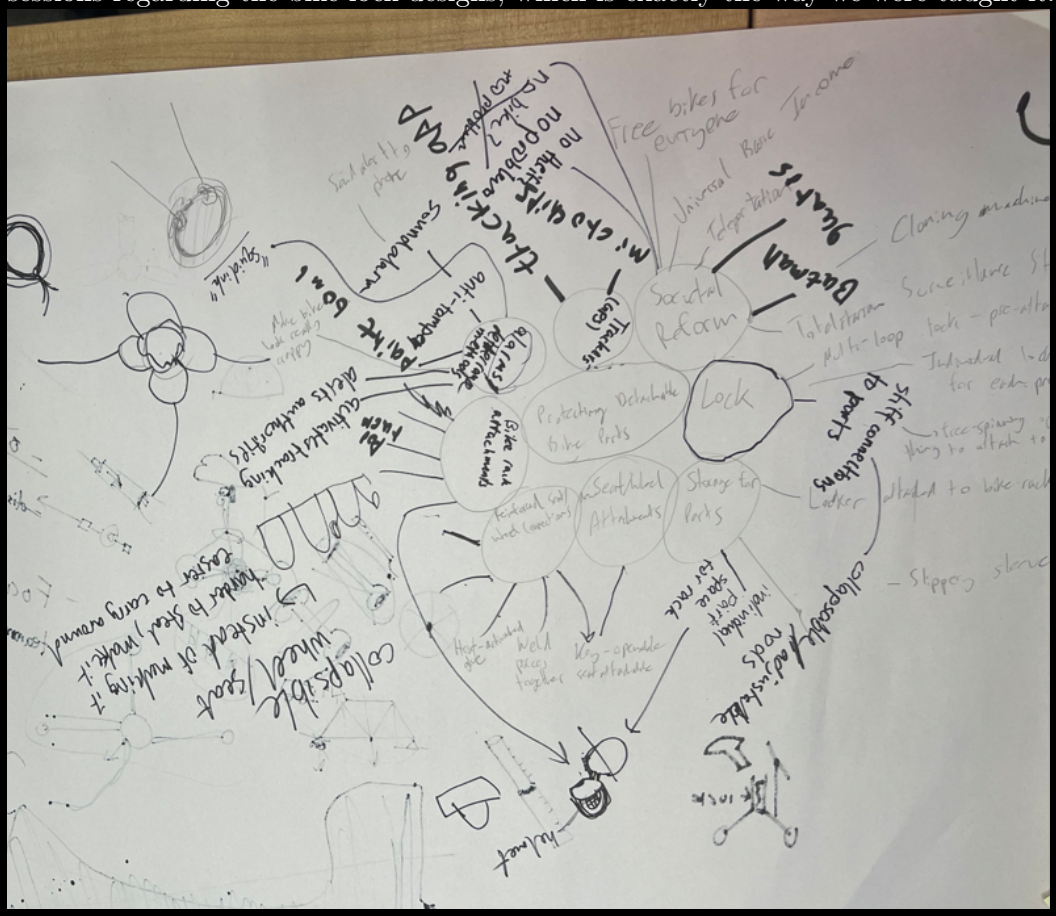
4. DIVERGING

4.1. THE LOTUS BLOSSOM

Why Did we Use This?
The Lotus Blossom technique is a powerful brainstorming tool that helps in exploring all aspects of an issue or problem. It encourages comprehensive thinking and helps in uncovering innovative solutions. The number of petals can vary, and in my experience, I've used both 4-petal and 8-petal variations.

How To Use the TMF:
To use the Lotus Blossom technique, start by identifying the central issue or problem. Then, generate ideas (petals) around this central theme. Each of these ideas can then become the center of its own smaller Lotus Blossom, generating further ideas. This process can be repeated as many times as necessary.

Example:
In Praxis I, our team used an 8-petal lotus blossom for one of our diverging sessions regarding the bike lock designs, which is exactly the way we were taught it.



In this lotus blossom, we had no general direction for our potential design and we just wanted as many ideas as possible. However, when diverging for our mushroom growth opportunity in Praxis II, we settled with a 4-petal lotus blossom for a more focused approach. We did this because this was one of the last diverging tools we used and we already had a general idea of what kind of designs we wanted.

			humidity trays	drip hoses	olla pots			
			watering globles	Capillary Mat	soil			
			hydroponic wicking system	recycled water	watering spikes			
hugelkultur beds	permaculture swales	rain barrels		Capillary Mat		fogging systems	other plants (companion planting)	steamer
mulching	Natural Processes	leaving the mushrooms enclosed outdoors	Natural Processes	Water Delivery System for Mushrooms	Humidifier	damp towel	Humidifier	sauna
compose tea	connection to water spout	evaporation; condensation		Mister		piped in moist air	internal tank	swamp cooler effect
			irrigation systems	drip-tape	supermarket produce waterer			
			revolving bar/on tracks	Mister	fire sprinklers			
			shower head setting	hose head setting	lawn sprinklers			

Through my usage of the Lotus Blossom, I've noticed the following takeaways:

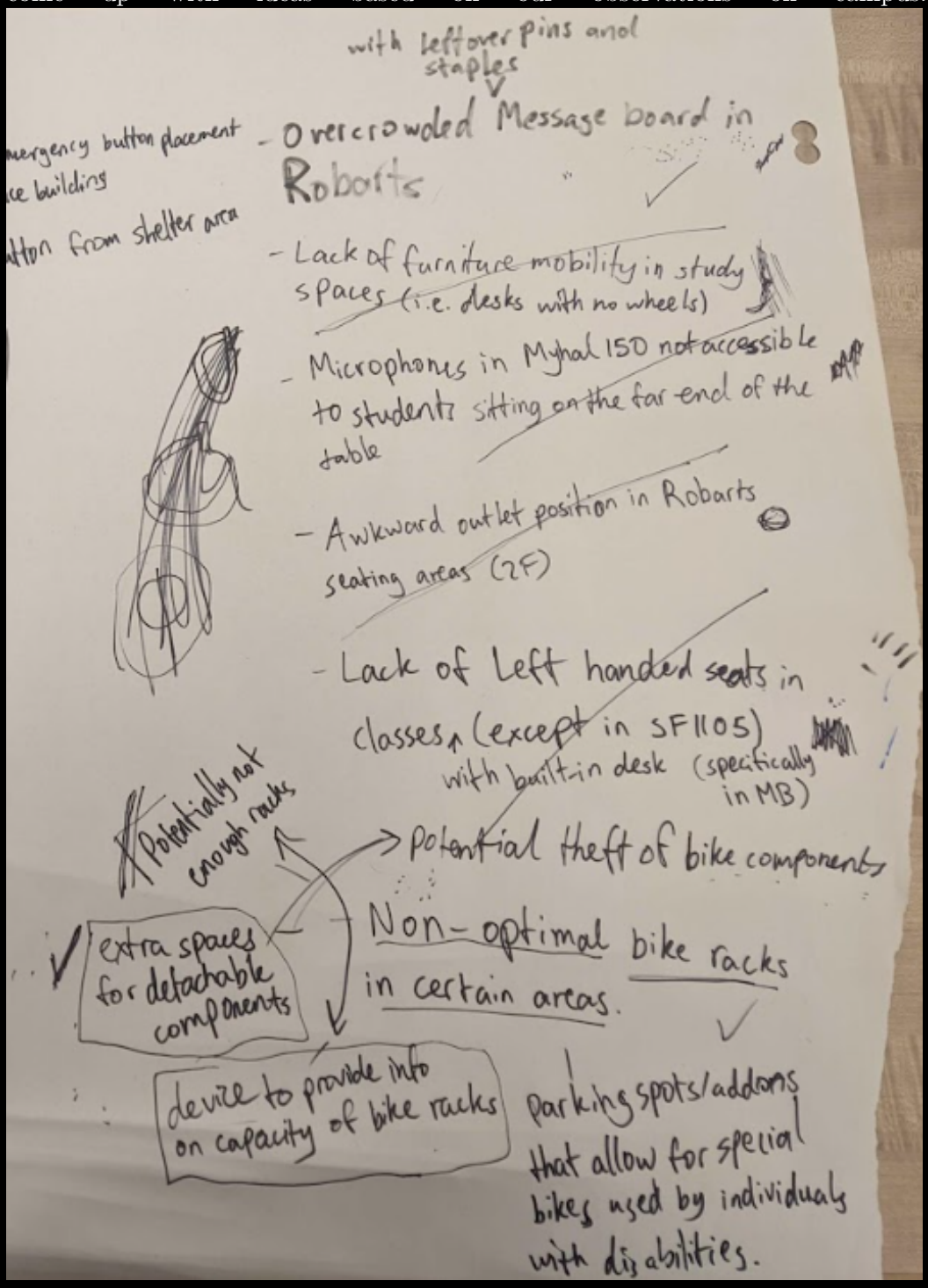
1. **Idea Generation**: Lotus Blossom is a powerful tool for generating a large number of ideas. It encourages divergent thinking and helps to explore all aspects of a problem or issue.
2. **Structure**: The structured format of Lotus Blossom helps to organize thoughts and ideas, making it easier to analyze and evaluate them.
3. **Depth of Exploration**: Lotus Blossom encourages deep exploration of each idea, leading to more innovative and effective solutions.
4. **Collaboration**: Lotus Blossom is a collaborative technique that encourages participation from all team members, leading to a diverse range of ideas.

4.2. CLASSICAL BRAINSTORMING

Why Did we Use This?
Classical brainstorming is a tried-and-true method for generating a large number of ideas in a short amount of time. It encourages free thinking and the sharing of ideas without judgment, which can lead to innovative solutions.

How To Use the TMF:
To use classical brainstorming, gather your team and present the problem or issue you want to address. Encourage everyone to share their ideas freely, without any criticism or judgment. Remember, the goal is to generate as many ideas as possible, not to evaluate them.

Example:
When diverging for potential opportunities or "splartzes" in Praxis I, our team utilized classical brainstorming to come up with ideas based on our observations on campus.



These are my main takeaways from using classical brainstorming:

1. **Idea Generation**: Classical Brainstorming is a tried-and-true method for generating a large number of ideas in a short amount of time.
2. **Free Thinking**: It encourages free thinking and the sharing of ideas without judgment, which can lead to innovative solutions.
3. **Collaboration**: Classical Brainstorming is a collaborative process that encourages participation from all team members, leading to a diverse range of ideas.

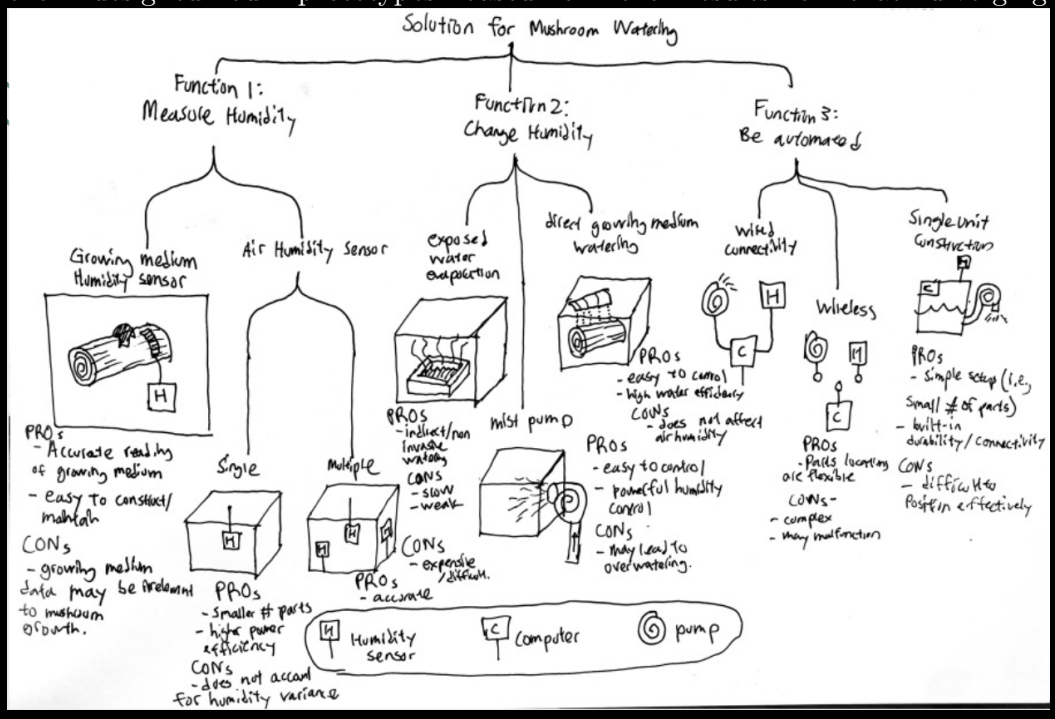
4. **Energy and Engagement**: The dynamic nature of Classical Brainstorming can create energy and engagement in a team, helping to stimulate creative thinking.

4.3. FUNCTIONAL DECOMPOSITION

Why Did we Use This?
Functional decomposition is used to break down complex systems into their constituent functions. This makes the system easier to understand and manage, and allows us to focus on one aspect at a time.

How To Use the TMF:
To use functional decomposition, start by identifying the main function of the system. Then, break this down into its constituent sub-functions. Continue this process until you have a detailed understanding of how the system works.

Example:
When diverging for designs for the mushroom growth opportunity in Praxis II, our group used the functional decomposition diverging tool to break down the opportunity into constituent functions. We then designed our prototypes based on the results of that diverging.



I have had several key takeaways from the functional decomposition diverging tool:

1. **Simplification of Complex Systems**: Functional decomposition breaks down complex systems into simpler, manageable parts. This makes the system easier to understand and manage.
2. **Focus on Individual Functions**: By breaking down a system into its constituent functions, we can focus on each function individually. This allows us to optimize each part of the system independently.
3. **Identification of Dependencies**: Functional decomposition helps us identify depen-

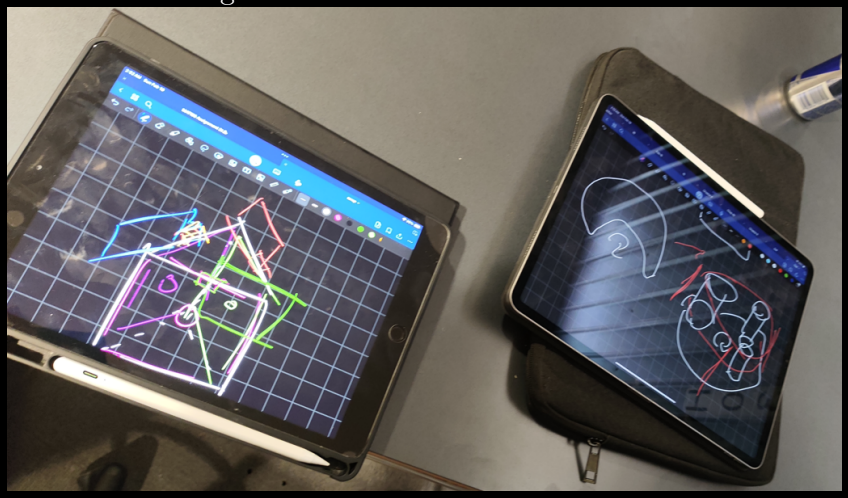
dencies between different parts of the system. This can inform our design decisions and help us anticipate potential challenges.
4. **Facilitates Teamwork**: By decomposing a system into separate functions, different team members can work on different functions simultaneously. This can improve efficiency and facilitate teamwork.

4.4. TEAM DIVERGING SESSIONS

Why Did we Use This?
Team diverging sessions are used to generate a wide range of ideas and perspectives. They encourage collaboration and the sharing of diverse viewpoints, which can lead to more innovative and effective solutions.

How To Use the TMF:
Team diverging sessions can take many forms, including drawing diagrams with live feedback, 3D modeling (in my experience, initially on paint 3D then CAD), and general unstructured conversation about flaws of existing designs leading to designs that address the flaws (but may have more flaws).

Example:
During the MakeUofT Hackathon, our team knew what we wanted to make, but had no idea of how we wanted it to look. Our team started just drawing potential designs, and we judged them live and came up with more designs that addressed the weaknesses of our current designs.



To finish off the diverging section of the handbook, I will talk about the main takeaways from general team diverging sessions:

1. **Generation of Diverse Ideas**: Team diverging sessions encourage the generation of a wide range of ideas, leading to more innovative solutions.
2. **Collaboration and Participation**: These sessions encourage collaboration and active participation from all team members, ensuring that everyone's views are considered.
3. **Freedom of Expression**: In team diverging sessions, all ideas are welcomed and valued. This freedom of expression can lead to unexpected and innovative solutions.
4. **Building on Others' Ideas**: In these sessions, team members can build on each other's ideas, leading to more refined and effective solutions.

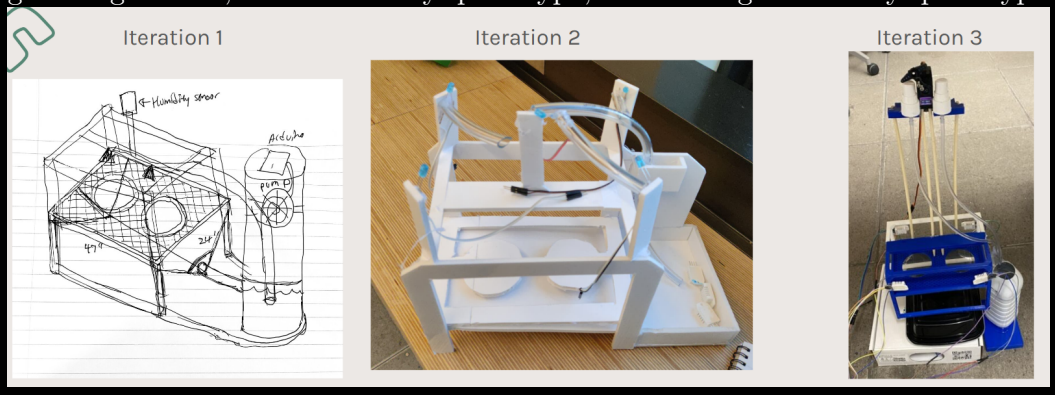
5. CONVERGING

5.1. PROTOTYPING

Why Did we Use This?
Prototyping is a crucial step in the design process as it allows us to visualize and interact with our designs. It helps us identify potential design flaws that may not have been obvious on paper. In my testing, I found that low fidelity prototypes are better for rapidly prototyping different ideas, while high fidelity prototypes are more effective for fleshing out these design flaws.

How To Use the TMF:
To use prototyping, start by creating a low fidelity prototype of your design. This could be a simple sketch or a basic physical model. Use this prototype to test the basic functionality and design of your product. Once you are satisfied with the basic design, create a high fidelity prototype to test the design in more detail and identify any potential design flaws.

Example:
My best example of prototyping so far is the mushroom growth opportunity from Praxis II. We built 2 physical prototypes. One of them was lower fidelity and helped us get a rough shape of what direction we were going to go for Showcase. The second of which was designed for Showcase and it was higher fidelity and demonstrated more than one feature that we wanted on a final design. The image below shows how we iterated through an engineering sketch, a low fidelity prototype, and a higher fidelity prototype.



It is worth noting that prototyping is by far one of my most used TMFs and I have made some use of it in almost all of my engineering projects.

Here are some key takeaways from using prototyping:

1. **Visualization**: Prototyping allows us to visualize our designs and ideas. It provides a tangible representation of our design that can be interacted with and evaluated.
2. **Identifying Design Flaws**: Prototypes can help us identify potential design flaws early in the design process. This allows us to make necessary modifications before the final implementation, saving time and resources.
3. **User Feedback**: Prototypes can be used to gather user feedback. This feedback can provide valuable insights into how the design is used and how it can be improved.

4. **Cost-Effective**: Prototyping can be a cost-effective way to test our design. It can help us avoid the costs associated with failed real-world tests.
5. **Communication**: A prototype can serve as a powerful communication tool. It can help us effectively convey our ideas to stakeholders, clients, and team members.

5.2. CALCULATIONS

Why Did we Use This?
Calculations are used to quantify and evaluate different aspects of our design. They help us make informed decisions about the feasibility and effectiveness of our design.

How To Use the TMF:
To use calculations, start by identifying the key metrics that you need to evaluate your design. This could include things like cost, efficiency, or performance. Then, use mathematical formulas or computational models to calculate these metrics for your design.

Example:
The best example I can present for calculations is my CIV102 bridge. The course was generally very calculation heavy and the culminating project was consequently also calculation heavy. We did calculations by hand, and through a spreadsheet, but primarily processed most of the calculations in a MATLAB program that I contributed. Below is a sample calculation from the project and an extract from my MATLAB program.
The matboard thickness is represented as:

$$t = 1.27\ mm \tag{5.1}$$

Young's Modulus is represented as:

$$E = 4000\ MPa \tag{5.2}$$

Poisson's ratio is represented as:

$$\mu = 0.2 \tag{5.3}$$

The width of the platform is represented as:

$$b = 70\ mm \tag{5.4}$$

The buckling stress of a beam, SigmaBuck4, is calculated as:

$$\sigma_{\text{Buck}} = \left(\frac{4 \cdot \pi^2 \cdot E}{12 \cdot (1 - \mu^2)}\right) \cdot \left(\frac{t}{b}\right)^2 \tag{5.5}$$

Plugging in the numbers, we get $\sigma_{\text{Buck}} = 4.51\ MPa$.

The code from the MATLAB program is:

```
t = 1.27; % Matboard thickness
E = 4000; % Young's Modulus
mu = 0.2; % Poisson's ratio
b = 70; % Width of platform
SigmaBuck4 = ((4 .* (pi .^2) .* E) ./ (12 .* (1 - (mu) .^ 2))) .* (t ./ b) .^2;
```

5.3. PROXY TESTING

Why Did we Use This?
Proxy testing is used to test our design under conditions that simulate the real-world environment in which it will be used. It allows us to evaluate the performance and reliability of our design before it is fully implemented.

How To Use the TMF:
To use proxy testing, start by identifying the key conditions that your design will be exposed to in the real world. Then, create a testing environment that simulates these conditions. Use this environment to test your design and evaluate its performance.

Example:
We ran a proxy test on our higher fidelity prototype for the mushroom growth opportunity in Praxis II. We simulated the humid environment that our community had their mushrooms in, and we ran the test to ensure that the device would maintain the humidity level that it was intended to maintain. We also ran the test twice at 30 hours each time to ensure accurate results and make corrective changes between trials.

Methodology

1. A **high-fidelity prototype** that was scaled down was developed. (Figure 1)
2. A **clear plastic bag** was placed over the prototype with adequate sealing to **mimic** the mycology lab growth tent. (Figure 2)
3. The prototype was **left to run for 30 hours** while measuring and printing humidity levels every 5 minutes.

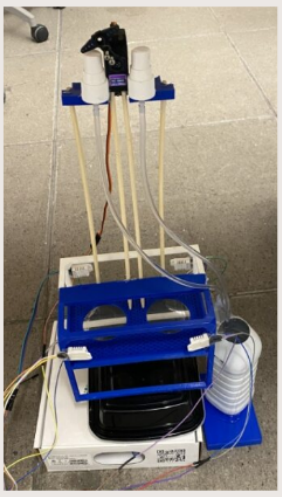


Figure 1

Figure 2

There are some key takeaways that I had after using proxy testing:

1. **Risk Mitigation**: Proxy testing allows us to test our design under conditions that simulate the real-world environment in which it will be used. This can help us identify and address potential issues before the final implementation, thereby reducing risk.
2. **Performance Evaluation**: It provides an opportunity to evaluate the performance and reliability of our design under realistic conditions.

3. **Cost-Effective**: Proxy testing can be a cost-effective way to test our design as it can help us avoid the costs associated with failed real-world tests.

5.4. COMPARISON MATRICES

5.4.1. Pugh Chart

Why Did we Use This?
A Pugh Chart is used to compare multiple design options against a set of criteria. It helps us objectively evaluate each option and make informed decisions about which design to pursue.

How To Use the TMF:
To use a Pugh Chart, start by listing your design options and your evaluation criteria. Then, for each design option, rate its performance against each criterion. Use these ratings to compare the design options and identify the most promising ones.

The takeaways from using Pugh Charts are:

1. **Comparative Analysis**: Pugh charts provide a structured framework for comparing multiple design options against a set of criteria. This can help us objectively evaluate each option.
2. **Decision Making**: They support decision-making by providing a visual representation of the performance of each design option against each criterion.
3. **Consensus Building**: Pugh charts can facilitate discussions among team members and help build consensus on the best design option.

5.4.2. Pairwise Comparison

Why Did we Use This?
Pairwise comparison is used to compare design options two at a time. It simplifies the decision-making process by breaking down a complex problem into simpler, pairwise comparisons.

How To Use the TMF:
To use pairwise comparison, start by listing all of your design options. Then, compare each pair of options and decide which one is better according to your evaluation criteria. Repeat this process until you have compared all pairs of options. The option that wins the most comparisons is the best overall option.

Examples:
We used the Pugh chart and pairwise comparison TMF as our primary convergence method before Beta release. We used the tools to compare our potential designs.

Requirement	Weight	Design 1: Humidifier/Dehumidifier	Design 2: Direct Mushroom Mister	Design 3: Air Mister	Design 4: Time Based Mister	Design 5: Evaporator
Corrosion Resistance	1	0	-1	1	1	-1
Number of Parts	1	0	-1	1	1	1
Automation	1	0	1	1	1	-1
Voltage Used	0.5	0	0	1	1	1
Power supply Cord used	0.5	0	0	0	0	0
Water Use Efficiency	1	0	1	1	1	1
Air Humidity Control	2	0	0	0	-1	-1
	TOTAL	0	0	4.5	2.5	-1.5

	Design 1	Design 2	Design 3	Design 4	Design 5	Sum
Design 1	N/A	0	0	0	1	1
Design 2	1	N/A	0	0	1	2
Design 3	1	1	N/A	1	1	4
Design 4	1	1	0	N/A	1	3
Design 5	0	0	0	0	N/A	0

To finish off the Converging section of the handbook, we can talk about the takeaways of using Pairwise Comparison matrices.

1. **Simplification**: Pairwise comparison simplifies the decision-making process by breaking down a complex problem into simpler, pairwise comparisons.
2. **Focus**: It allows us to focus on two options at a time, making it easier to make decisions.
3. **Comprehensive Evaluation**: By comparing all pairs of options, we can ensure that every option is thoroughly evaluated.

6. REPRESENTING

6.1. PHYSICAL DEMONSTRATIONS

Why Did we Use This?
Physical demonstrations are used to showcase the functionality and effectiveness of our designs. They provide a tangible way to communicate our ideas and allow others to interact with our designs directly.

How To Use the TMF:
To use physical demonstrations, start by creating a working model or prototype of your design. Then, plan a demonstration that showcases the key features and functionality of your design. Be prepared to explain how your design works and answer any questions that may arise during the demonstration.

Example:
During the Praxis II Showcase event, our team ran a demonstration of our design. We had to lower the humidity threshold from 85% humidity to 50% humidity to make the demonstration more smooth. We had our teammates breathe into the humidity sensors to make them more humid and hence cease the water misting. It was a truly comedic part of our presentation and not only set a positive tone for the presentation but also gave the assessors a better understanding of our prototype.

There are some notable lessons that I have learned from using physical demonstrations:

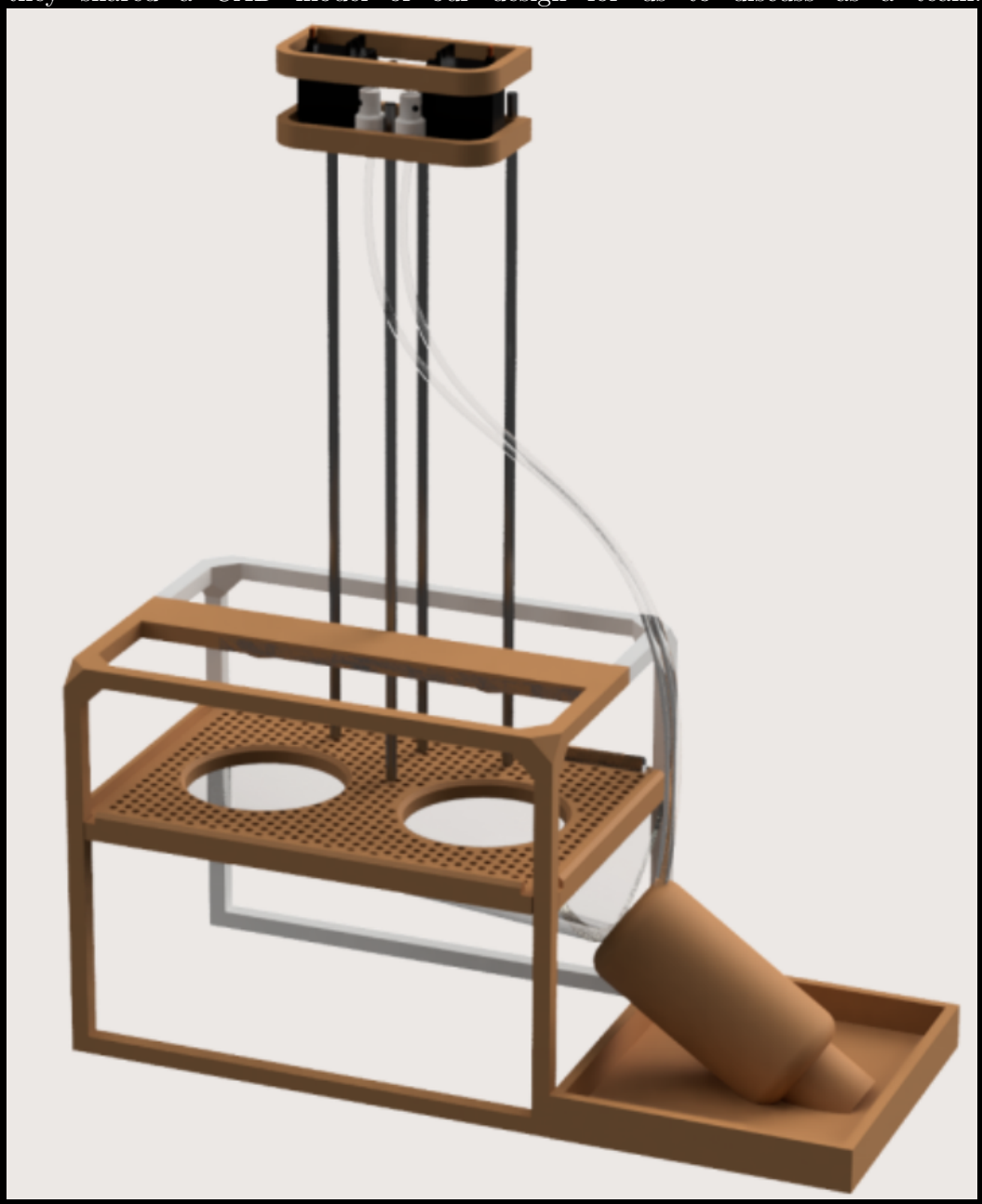
1. **Interactive Learning**: Demonstrations provide an interactive way of learning and understanding concepts. They allow for real-time interaction and feedback.
2. **Engagement**: Demonstrations can engage the audience more effectively than static images or text. They can make complex ideas more tangible and understandable.
3. **Visualization**: Demonstrations provide a visual representation of the concept, making it easier to grasp and remember.
4. **Real-world Applications**: Demonstrations often show how a concept or theory is applied in the real world, enhancing its relevance and practicality.
5. **Immediate Feedback**: Demonstrations allow for immediate feedback and adjustment, making the learning process more dynamic and adaptive.

6.2. MODELLING

Why Did we Use This?
We used CAD and Paint3D modelling as a part of the representing strand TMF because it allows us to create a visual representation of our designs. These tools help us to visualize our ideas, communicate them effectively to others, and identify potential design issues early in the process.

How To Use the TMF:
To use CAD or Paint3D for modelling, start by sketching out your design idea. Then, use the tools provided by the software to create a 3D model of your design. This model can be rotated, zoomed in and out, and viewed from different angles, allowing you to thoroughly inspect your design. You can also make modifications to your design directly in the software, allowing for rapid iteration and improvement.

Example:
One of the members of a team I worked on was proficient in CAD, and they shared a CAD model of our design for us to discuss as a team.



Here are some key takeaways of using CAD models:

1. **Importance of Precision**: Modelling, especially when using tools like CAD, requires a high level of precision. Even small errors can lead to significant problems down the line.
2. **Visualization**: Modelling provides a visual representation of the design, making it easier to identify potential issues and communicate the design to others.

3. **Iterative Process**: Modelling is an iterative process. It's common to go back and forth, making adjustments and refinements to the model based on feedback and testing.
4. **Learning Curve**: Tools used for modelling often have a steep learning curve. It's important to invest time in learning how to use them effectively.

6.3. PROGRAMMING

Why Did we Use This?
Programming is used to automate and control the functionality of our designs. It allows us to create complex, interactive systems and provides a high level of precision and control.

How To Use the TMF:
To use programming, start by identifying the tasks that need to be automated or controlled in your design. Then, write a program that performs these tasks. Test and refine your program to ensure it works as intended.

Example:
In the MakeUofT Hackathon, I served as an embedded systems programmer. I orchestrated communication between a Raspberry Pi and an Arduino Mega. It took hundreds of lines of code to get everything working. I was also in charge of making all of our sensors work properly, and all of the mechanical parts respond correctly to the data. This meant that there was lots of debugging and optimization, but ultimately it was a way that I represented our design to not only my own teammates but also the judges of the hackathon. Below are extracts of the code used.

Python Code on Raspberry Pi:

```python
# Open a serial connection to the Arduino
ser = serial.Serial('/dev/ttyACM0', 9600)
# ...
# Recognize speech using Google Speech Recognition
text = r.recognize_google(audio)
print("You said:", text)

# Send the recognized text to the Arduino
print("Sending word:", text)

bin = machine_learning.guessbin(text).lower()
print(bin)
# fancy arduino integration
ser.write((bin + '\n').encode())
```

C++ code on Arduino:

```cpp
void loop() {
  if (Serial.available()) {
    command = Serial.readStringUntil('\n');
    if (command == "garbage") {
      rotateServo(myservo1, 1);
    } else if (command == "recycling") {
      rotateServo(myservo2, 1);
    } else if (command == "compost") {
      rotateServo(myservo3, 1);
```

```
    }
  }
}

void rotateServo(Servo myservo, int times) {
  for (int i = 0; i < times; i++) {
    myservo.write(180);
    delay(10000);
    myservo.write(0);
  }
}
```

To finish off the representing section of the handbook, we can talk about the lessons I learned while using programming as a TMF, since this mostly makes up the part of my position as a embedded systems programmer.

1. **Problem Solving**: Programming is essentially problem-solving. It involves breaking down complex problems into smaller, manageable parts.
2. **Attention to Detail**: Programming requires a high level of attention to detail. Even a small mistake can cause the program to not work as expected.
3. **Debugging Skills**: Debugging is a crucial part of programming. Learning how to effectively debug code is key to becoming a proficient programmer.
4. **Continuous Learning**: The field of programming is always evolving, with new languages, tools, and best practices emerging regularly. Continuous learning is a must.

7. CLOSING STATEMENTS

7.1. CONCLUSION

In conclusion, this handbook serves as a testament to my journey in engineering design since September 2023. It encapsulates the various tools, models, and frameworks (TMFs) that have been instrumental in shaping my design practice. Each TMF has been presented with a detailed description, an example of its application, evidence of its use in my design process, and an evaluation of its effectiveness. This rigorous approach has allowed for a comprehensive exploration of the unknown, shedding light on the potential future applications of these TMFs.

Reflecting on my experiences from Praxis I, other courses, and extracurricular design activities, it is evident that my personal philosophy and approach to engineering design have significantly influenced my choice of TMFs. This influence is not static but evolves with each new experience, each new project, and each new challenge.

As I look forward to future design contexts, the value and effectiveness of these TMFs remain an exciting unknown. However, armed with this handbook, I am better equipped to navigate this unknown. It will serve as a guide, reminding me of the lessons learned, the successes achieved, and the challenges overcome.

This handbook is not just a record of past design activities, but also a roadmap for future endeavors. It is a living document, open to revisions and additions as I continue to grow and evolve in my engineering design practice. As I embark on this ongoing journey, I am excited about the new TMFs I will encounter, the new experiences I will gain, and the new insights I will uncover.

In essence, this handbook is a reflection of my past, a guide for my present, and a beacon for my future in engineering design.

7.2. CREDITS

In accordance with the University of Toronto Code of Academic Behaviour and the Professional Engineers Ontario Code of Ethics, it is essential to acknowledge and give credit for the design work performed by my teammates. Their contributions have been invaluable in shaping the outcomes of our projects and have greatly enriched the content of this handbook. Each tool, model, and framework (TMF) applied in our design activities is a testament to our collective effort and collaboration. I express my deepest gratitude to my teammates for their dedication, creativity, and expertise. Their work has been instrumental in our shared journey of engineering design.

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