The Principles and Practices of Praxis

A handbook detailing 10 useful TMFs
for the engineering design process.

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Introduction

This handbooks explores the different tools I've used in engineering design, primarily in the Praxis II context. I include my key takeaways from applying these TMFs in my projects and explore how my own interpretations of these tools have helped me grow as an engineer, designer, and team member.

I've realized that I am a visual learner who benefits from being able to physically or digitally see how concepts are applied. Thus, many of the TMFs in this handbook encourage sketches, flow charts, and free creative thinking. For example, biomimicry, classical brainstorming, and researching reference designs.

This handbook also addresses TMFs that have helped me improve in areas that I find myself struggling with. These areas include feeling open with sharing my ideas with others and communicating concisely, both orally and through text. I found that Toulmin's has helped me become a better presenter and writer, especially with time and word count constraints. Classical brainstorming as a group has been extremely helpful for encouraging me to articulate my ideas in larger groups and to receive and give feedback.

I hope that this handbook serves as a handy reference for future course projects, research roles and career experiences. It also serves as a time capsule that captures my first experiences with engineering design! So, hello future me, hope you are able to see this and reconcile about the good old days of Praxis and the beginning of your engineering journey.

Formatting

The handbook is divided into 4 sections, Framing, Diverging, Converging, and Representation. However, most of the tools can be used in one or more of these areas. The format of each page is catered to my own learning style. It starts off with a short introduction on how the TMF can be used, followed by the Procedure, which include suggestions, not rules, of how to use the tool. I find it easier to digest suggestions and advice when they are linked with examples, so the Examples section is integrated with my takeaways and suggestions, which are written in green text.

Developing Requirements

Stakeholder needs, wants, and values are translated to and interpreted in an engineering design context through the development of requirement strands which ultimately shape the design process and final product.

Procedure

Conducting primary research (interviews and site visits) and secondary research (existing designs and journal articles) is crucial to the development of effective requirement strands. Interacting with stakeholders allows us to learn about their values and needs, which help us determine and rank the importance of high level objectives. Interviews and site visits may also help with the realization of previously unknown or overlooked constraints such as size, energy, time, cost, etc.

A requirement usually consists of the following elements:

Objective | Metric | Criteria | Constraint

Objective

- Describes an intention of the design
- Should be relevant to the interpretation of stakeholder needs/wants/values
- Can be high level or low level, determined by the specificity of the objective
- May address one of the DfXs

You should be able to use Toulmin's Model (F3) to justify why this is an significant objective that should be considered

Use words such as must, must not, should, should not, required, recommended

Metrics

- Quantitative measurement unit used for evaluating the design

Criteria

- Description of what metrics would make the design better
- Utility curves can be used to represent non linear criteria

Constraint

- Description of what metrics the design must meet to make it viable
- May be set by the stakeholder(s) or by the designer

Look into relevant codes and standards that may serve as constraints

Example

Developing requirements for an automated mushroom growing chamber

We interviewed the stakeholder, an employee of the Black Creek Community Farm, and attended a site visit. We were able to learn more about the values of the stakeholders, which was education, automation, and humidity/circulation which led to our reinterpretation of the RFP.

  - Requirements are volatile and will need to be reframed if you decide to reframe the opportunity

We learned about the size of their tent (F1-1) and their bucket mushroom growing setup (F1-2), which our group eventually decided to use in our final design.

F1-1. A labelled image of their current setup, sent by Black Creek Community Farm [1]

F1-2. Photo of bucket growing system from site visit. Photo: Eila.

We conducted further research to learn more about mushrooms. This allowed us to come up with the fungal infections requirement.

  - Extensive research outside of stakeholder interactions is required to formulate objectives, especially when the topic is new for most members.
  - It's important to justify objectives, constraints, and criteria, but metrics must also be justifiable and may need to be adapted to better fit the opportunity (L/day and number of parts to dissemble)

- We ranked our requirements using pairwise comparison (F1-3). It helped us make decisions in the converging stage. For example, running water has a high chance of splashing, and since fungal infection is high on the list, it was a contributing factor to why we did not choose that design.
  - Ranking gives a weighting to each requirement which may be useful in the diverging stage
- We sorted and displayed our requirements into a table (F1-4)
  - Presenting requirements in tables is very effective and makes it easy to interpret at a glance. They can be grouped by high level objectives.

F1-3. Pairwise comparison matrix used to rank requirements. Photo: Eila.

High Level	Detailed	Metric	Criteria	Constraint
Sustainability	Should reduce water usage	L/day	Less the better	N/A
	Mushrooms produced should be safe to eat	Material standard from ISO • Food safe • Non-corrosive • Impermeable	N/A	Complies with ISO/TS 22002-5
Maintenance	Should be easy to clean	# of part which need tools to disassemble	Less is better	N/A
Mushroom Growth	Should avoid water induced fungal infection	Amount of time the cap remains wet	Less the better	< 240 minutes
	Should dispel CO_2 through air exchange	CO_2 levels (ppm)	Between 500-800 ppm	< 1000 ppm
	Should maintain ideal humidity level	Difference in humidity level (RH%)	Smaller is better.	Within 2.5% of ideal humidity level.
Automation	Should be partially automated	Time of no human input	Higher is better	72 hours (justified by stakeholder)
Growing different mushrooms	Should be able to adjust ideal humidity to different levels	The range of humidity that can be maintained (highest maintainable humidity level - lowest maintainable humidity level)	Higher is better	N/A

F1-4. Organized requirements table that was used in beta and showcase presentations.

F
2

Reference Designs

Researching existing designs is a tool often associated with diverging. However, it can also play a big role in the framing process. Identifying reference designs can help with setting the design space or scope, establishing requirements, and is overall a great way to be introduced to the design space of an opportunity.

Procedure

Research an existing design that is related to the opportunity.

Here are some useful things to take note of:

- Size, colour, material, location of parts, types of connections
  - Why were these design decisions made?
- System Design
  - What are the steps taken to successfully use the design?
  - Why or why not is this ideal?
- Standards and Codes
  - Does the design reference any standards/codes? Why is it important that it meets these standards/codes?
- Reviews
  - Why do consumers prefer/not prefer this product over others?

Use insights gained from researching to develop requirements, develop a design space, and for proxy testing design in the future.

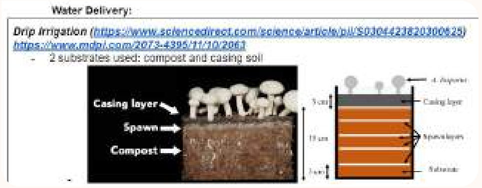
Example

Initial research into mushroom cultivation

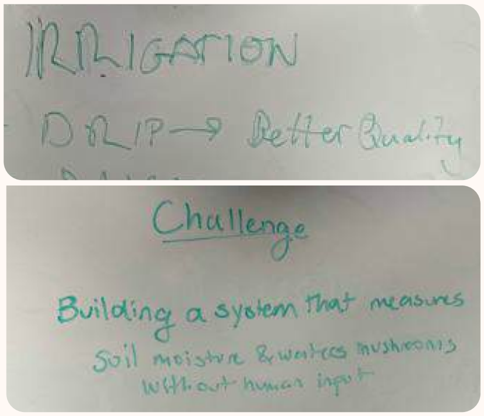
In the early stages of framing the RFP we had chosen, we looked into commercial mushroom cultivation. It helped us establish a general understanding of how mushrooms are cultivated autonomously in a large scale setting (F2-1).

- Researching reference designs is a good way to understand an opportunity better. It supplemented our initial research on the science behind how mushrooms grows and allowed created the initial large design space of "mushroom cultivation."

In commercial mushroom farms, the mushrooms are watered through drip irrigation. Additionally, we assumed mushrooms to be similar to plants, which require regular watering. We initially scoped our opportunity around creating a watering system and developed a bias to including watering mushroom substrate as one of our main focuses (F2-1, F2-2).



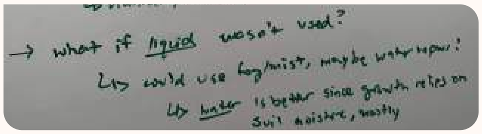
F2-1. My initial research on how mushrooms grow and how drop irrigation is used to water them in commercial agriculture.



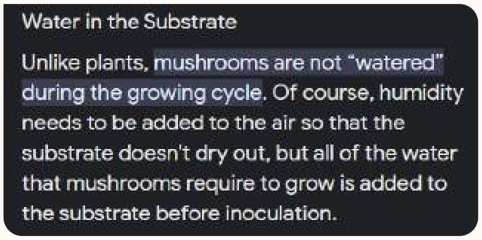
F2-1. Lots of our earlier diverging revolved around the idea that the mushroom substrate must be watered. Photos: Eila

We overcame this bias upon using the “challenging assumptions tool” (F2-2) and further research on mushroom cultivation, particularly smaller scale operations, such as at-home growing rooms and tents. Rather than watering the mushrooms, a high humidity is maintained (F2-3). We ultimately decided to narrow to this design space to a humidity and ventilation system after comparison to stakeholder and team values.

- It is important to explore a wide range of reference designs to prevent anchoring and confirmation bias.
- It also may be helpful to explore designs that aren’t conventionally related to the RFP (such as not being used with the same materials), which also helps to kickstarts the diverging process.



F2-2. Challenging our assumption that the system needs to water the substrate, leading to some ideas of using water vapour. Photo: Eila


Water in the Substrate

Unlike plants, mushrooms are not “watered” during the growing cycle. Of course, humidity needs to be added to the air so that the substrate doesn't dry out, but all of the water that mushrooms require to grow is added to the substrate before inoculation.

F2-3. Although mushrooms are often watered when commercially grown, it may not be necessary to water the substrate in a smaller scale operation if a high humidity is maintained. [1]

Toulmin's

Toulmin's is a great tool for all of FDCR, but was particularly valuable in developing a concise list of requirements. It's easy to get carried away and develop a lengthy list with unnecessary requirements. Using the structure and presenting possible counterclaims ensured that our claim, that the design should meet a certain requirement, was backed by strong justification and evidence.

Procedure

Toulmin's can be used as a "checklist" and consists of 5 main parts:

Claim	The argument that is being made
Ground	The claim is based on the ground
Qualifier	The space in which that the claim holds
Justification	Why the claim should be accepted
Evidence	Example of when the claim holds

When using it to determine if a requirement is effective and concise, you can try to evaluate it according the following claims that it should hold:

- The requirement is within the specified scope
- The requirement reflects stakeholder and team values
- The requirement is measurable to a reasonable accuracy and the metrics are relevant to the opportunity
- The requirement does not overlap with others
- The requirement allows for converging and does not narrow the design space

Example

Requirement development for an automated mushroom growing chamber

We freely wrote down requirements that we had brainstormed as a team while discussing each of their justifications (F3-1).

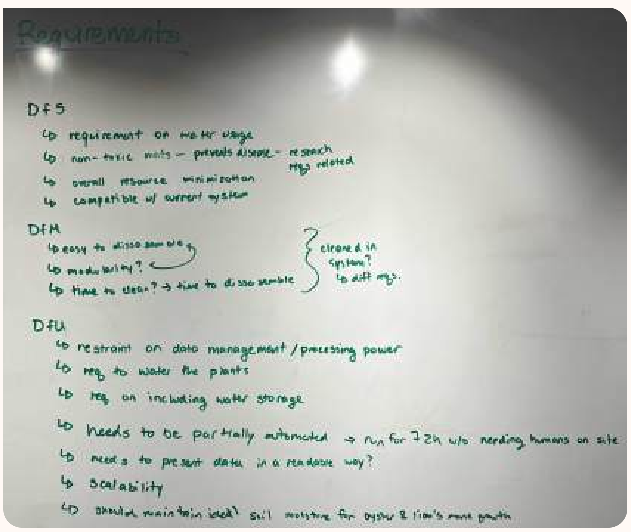
- Toulmin's can loosely be used for idea generation as more focused "classical brainstorming"

Eventually, we evaluated each requirement, going through Toulmin's structure. Some requirements were removed as they were out of out of the scope or were restatements of other requirements (F3-2).

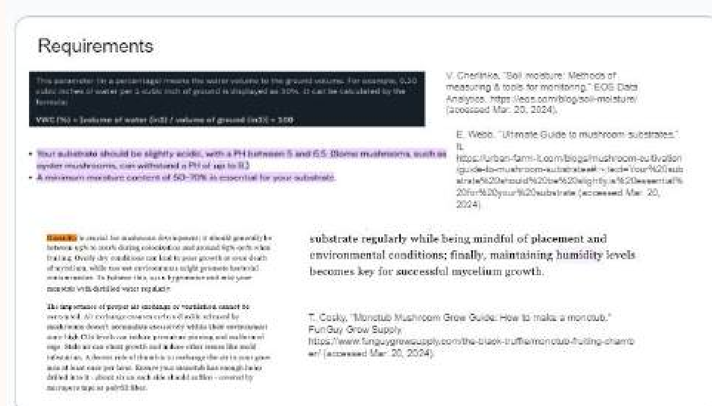
- The justification needs to describe why the requirement is relevant to the opportunity and how it addresses stakeholder and/or team values.

We were ready to present our requirements using Toulmin's Structure and prepared a document with the justification for each requirement (F3-3).

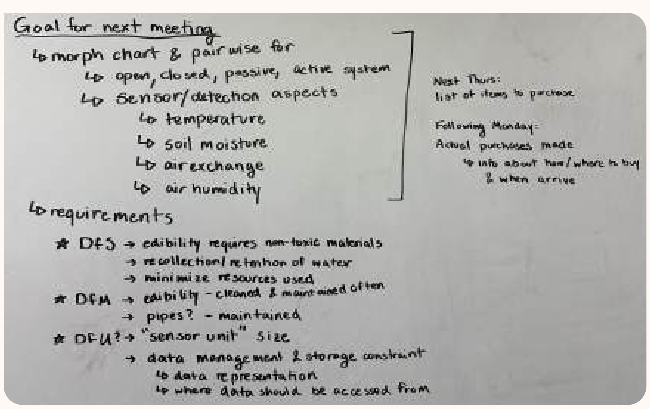
- Toulmin's Structure can easily be restructured into sentence form, such as *justification* so *qualifier* *claim*. For example, *evidence*.



F3-1. The first list we developed of the reframed requirements. Photo: Eila



F3-3. Example of a slide that contains source extracts justifying the requirements. Slides were printed out to be referred to during Beta.



High Level	Detailed	Metric	Criteria	Constraint
Sustainability	Should reduce water usage	L/day	Less the better	N/A
	Mushrooms produced should be safe to eat	Material standard from ISO/TS 22002-5 ☐ Food safe ☐ Non-corrosive ☐ Impermeable	N/A	Complies with Material standard of ISO/TS 22002-5
Maintenance	Should be easy to clean	# of components	Less the better	N/A
Mushroom Growth	Should avoid water induced fungal infection	Amount of time the cap remains wet	Less the better	< 240 minutes
	Should not interfere with lighting	Light level at mushroom	200-300 lux	N/A
	Should dispel CO_2 through air exchange	CO_2 levels (ppm)	Between 500-800 ppm	<1000 ppm
	Should maintain ideal humidity level	Difference in humidity level (ΔRH%)	Smaller is better.	Within ±2.5% of ideal humidity level.
Automation	Should be partially automated	Time of no human input	Higher is better	>72 hours
Growing Different Mushrooms	8. Should be able to adjust ideal humidity to different levels	The range of humidity that can be maintained (highest humidity level - lowest humidity level)	Larger range is better	Range must include 80%-90% RH

F3-2. Second draft (left) and scoped requirements list (right). Photo: Eila

Classical Brainstorming

Classical brainstorming allows ideas to flow, making it a great first step in the ideation stage, especially as it is easy to get caught up in fulfilling requirements and/or to ignore ideas that may seem unviable and suboptimal at first glance.

Procedure

Make sure that you and all group members have a good understanding of the opportunity and goals for the brainstorming session.

Classical brainstorming can be done in a variety of ways: in person, online, on paper, on a whiteboard, in a Google Doc, drawings, jot notes, etc. It can be carried out in a group or be modified to allow for independent brainstorming. Pick your desired medium for documenting the session and decide on the desired brainstorming method.

Group
- Designate one or more people to be scribes
- Group members take turns expressing their ideas randomly or by going around in a circle
- Group members may bring up a new idea or add on to an existing idea

Individually
- Take some time to do some independent brainstorming. The group decides if there is a time constraint (a few minutes) or to bring the ideas to the next meeting.
- Reconvene with team members and share/discuss your ideas with others.

Note that ideas do not have to completely thought out and developed. Often times they may be along the lines of:
- What if it was like this?
- I'm not sure if this would work, what do you guys think?
- This information feels relevant to our opportunity. How can we apply this to our design?

Example

Diverging for an automated mushroom growing chamber

We used classical brainstorming to diverge around possible designs for the automated mushroom system, keeping in mind that the ideas should relate to one or more of automation and environment control.

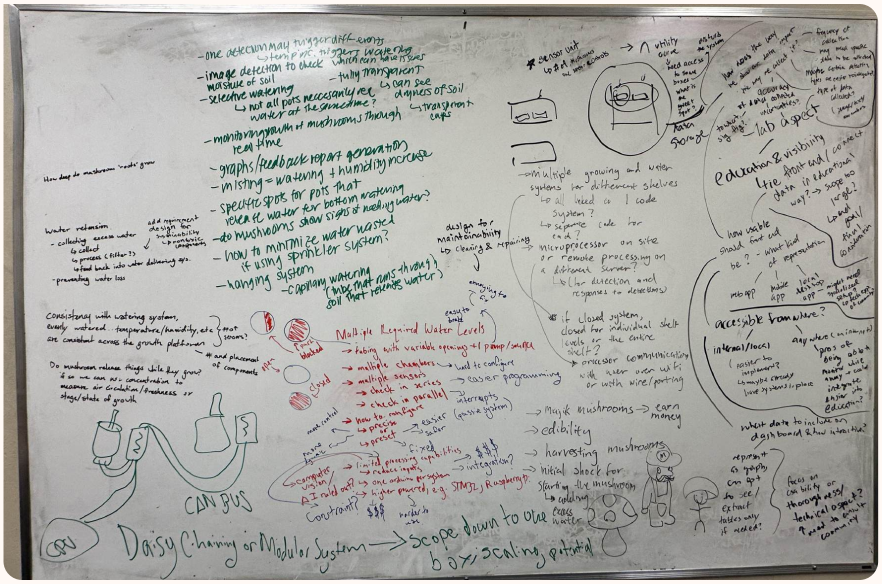
- Setting some boundaries may or may not be helpful during a brainstorming session. Boundaries narrow the design space, which can help keep brainstorming more focused and can act as a basis for ideas to branch off of. However, limitations may cause you to shy away from “wilder” ideas.

We were each given a space on a whiteboard to ideate on (D1-1). We wrote jot notes, made small sketches, and drew lots of arrows to link information together (D1-2).

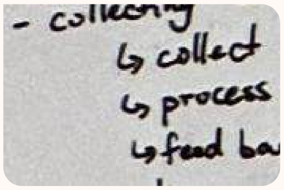
- Whiteboards and chart paper are ideal in classical brainstorming. It is easier to draw arrows to add on information or small sketches.
- We preferred individual brainstorming, especially as we were a larger group of 5. This prevented us from expanding too much on a single idea or losing ideas from talking over each other or waiting for a scribe to finish writing.

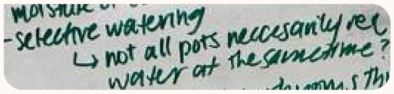
We took turns presenting our ideas to the rest of the group, acknowledging doubts and biases we had towards ideas (D1-3) and worked as a group to try and overcome these biases. We were able to pinpoint aspects we found interesting to incorporate into our final design (D1-4).

- Discussions when sharing designs allowed everyone to input their own unique perspectives which is based on our past experiences and unique skill sets. This helped us refine some of the rougher ideas from individual brainstorming.

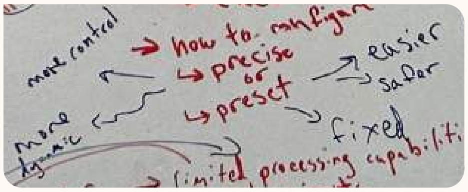


D1-1. Whiteboard after being used for classical brainstorming. Each section was filled by a different person.

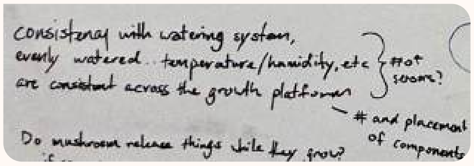




D1-2. Using arrows to link related information



D1-3. Examples of biases that need to be discussed as a group



D1-4. Consistency, sensor placement, and component placement were concepts that we considered later on for facilitating humidity distribution and air circulation.

Morph Chart

Morph charts are especially useful in the diverging process when the opportunity can be broken down into functions. It may be easier to diverge around a certain function, then create combinations from the morph chart.

Procedure

- Determine functions that the design may or must fulfill. Refer to the requirements and stakeholder/team values to develop these functions. Each function serves as a design subspace.
- Create a chart with each function and ideate within each function. You may use other diverging tools such as classical brainstorming to ideate.
- Determine combinations between ideas of each feature. Combinations should be compatible and relatively feasible. They should not contradict each other.

Example

Diverging for an automated mushroom growing chamber

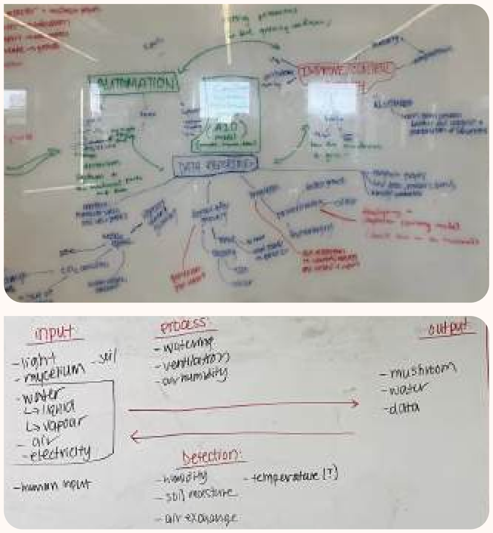
Since we were designing a system with parts that are interconnected but can be ideated upon independently, a morph chart was a good way to start our diverging process.

- Connections between the features need to be noted, as it might affect the types of combinations that are viable. For example, humidity and ventilation are related since increasing ventilation decreases the humidity of an area.

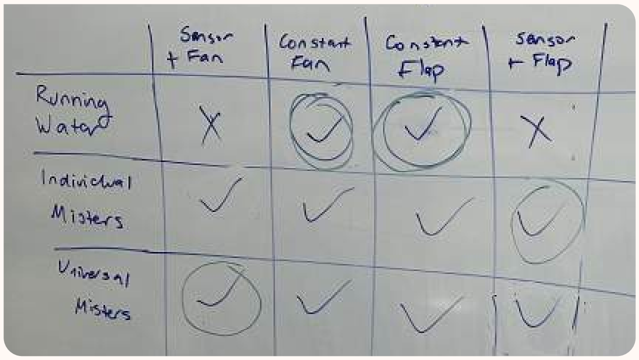
The 4 areas that we focused on were automation, humidity control, CO2 control, and air circulation. Within these areas, we were able to identify subareas that need to be addressed: humidity and air circulation. We were able to identify that systems can be passive (always on or open) or active (responsive to sensors).

  - Morph charts should be paired with other tools (D2-1), as biases may arise when developing the functions, which can limit the design space.

We settled on 4 different combinations of humidity and circulation after looking at the compatibility of the systems (D2-2). A passive humidity system, such as running water, works best with passive circulation systems, such as a constant fan or flap, as running water evaporates naturally as drier air is circulated in.



D2-1. Brainstorming (top) and FSD (bottom) to determine the functions necessary for our design



D2-2. Chart containing ideas for air circulation along the top axis and humidifying on the side axis. Circled combinations are the potential designs that were presented at Beta.

Biomimicry

Biomimicry takes inspiration from nature to diverge on designs that address an opportunity. Nature acts as a library of designs that have been iterated on and improved through adaptation and natural evolution. Biomimicry is a fun way to kickstart the diverging process, as it is easier to understand concepts when you have encountered them before when they have been applied to nature.

Procedure

Biomimicry can be described as a "themed" version of classical brainstorming, with the theme being that the idea must be inspired from a concept in nature. Therefore, the two tools follow similar steps, and you may refer back to the Classical Brainstorming section for the detailed steps.

An important thing to consider generally when diverging, and especially when using biomimicry, is to keep an open mind and to not automatically close the door on ideas that feel too out there, as it can sometimes feel overwhelming to find a way to connect a natural concept into a manufactured and human context.

Example

Diverging for an automated mushroom growing chamber

My team used biomimicry as one of our first diverging tools to design the automated mushroom system. We used it to diverge both before and after reframing (D3-1). One idea that I came up with was to imitate the way elephants take in and sprinkle water (D3-2). Additionally, my group members raised the idea of running water source similar to a river (D3-3).

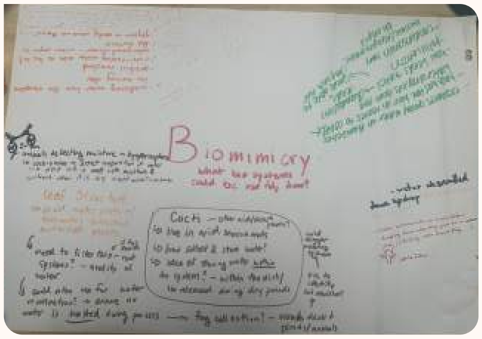
- It may be useful to identify functions that your design might have and find how that same function is performed in nature. For example, these ideas are inspired by ways water is spread in nature.

In another one of my ideas, I considered the way that dandelion seeds travel in air (D3-4) and wondered if that could be applied to our project, as it relates to ventilation and spread of a material. In the context of our opportunity, this material is water vapour.

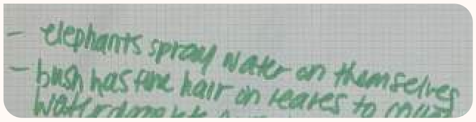
- Sometimes, it may be useful to scope out from the identified functions and to think more broadly. Rather than looking for ways to move water in water, I simply looked into how transportation occurs in nature.

Our brainstorming work wasn't always the neatest. It often had arrows leading to other bullet points many question marks.

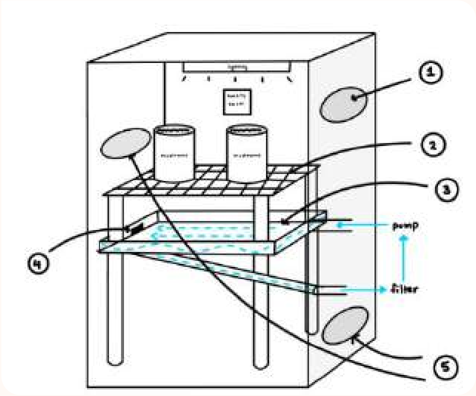
- Write down questions or doubts that you may have about a design. When presenting your ideas to the group, group members might provide a different perspective on the design.



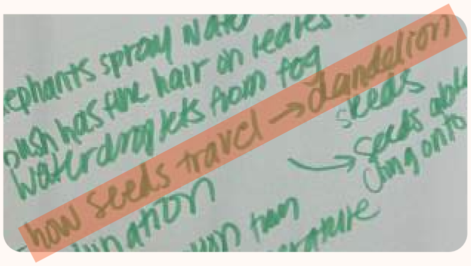
D3-1. We used biomimicry as our first few diverging tools.



D3-2. Example idea inspired by elephants.



D3-3. Potential design that has a "river" flowing through the tent.



D3-4. Drawing inspiration from the way dandelion seeds travel

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Scale Prototype

Creating a scale prototype is an easier way to evaluate the effectiveness of design decisions, especially those relating to orientation, location, and interactions between parts. Scale prototypes are particularly useful if the original scale is too large to be built, as there may be constraints imposed by availability/cost of materials, available time, and size of storage. Additionally, data collected when scale models are used for proxy testing more accurately reflect the results that may be seen on the real-sized model.

Procedure

Choose which requirements you intend to test and the metrics and data associated with that requirement.

- The prototype might need to address many different requirements or will just be tested for one requirement. This will depend on the stage of the design process. Multiple prototypes may be created to individually test different parts of a system, as well as a one that models how they interact with one another.
- Gather the materials needed to measure for that specified metric, such as sensors, laptops, phone for filming, etc.
- Determine and gather the materials that you will use for building the prototype. They may not be the ones that you intend on using in your final design, but make note of how the difference in materials might affect the outcomes of your testing.
- Build the prototype and take notes of challenges encountered during the building process.
- Observe how the prototype functions. Take note of and analyze fails, successes, and surprises that occurred during the testing process.
- If used in the diverging stage, compare and converge onto a design. Take into consideration the building process and ease of operation, as that may affect how viable a design is.

Example

Creating a scale prototype for an automated mushroom growing chamber

We created a half sized functional model of the automated mushroom growing tent. It was unreasonable for us to build a full scale model because of material costs, time constraints, and issues with finding a large enough storage space. We needed to drill holes into the mist distribution PVC pipe where the mist would enter the tent. However, we weren't sure what size to drill the holes, as we initially did not consider this as a design choice and could not find any existing information online.

- We encountered a design decision that we probably would not have been aware of if we did not build the prototype. Since we had no information to go off of, "guess and test" was the most effective way to converge to a hole size.

We started with a smaller hole size, and after turning the mister on for the first time, we were able to see mist blowing into the tent (C1-1). However, after a few cycles of the humidifier being turned on and off, water condensed in the pipes and covered the holes because of its surface tension (C1-2). The holes were redrilled to be larger (C1-3) and the prototype was retested.

- Creating the scale prototype allowed us to converge to a cutout size that can be scaled up with the PVC pipe diameter and humidifier to create a full size design that works.

C1-1. Mist can be seen leaving through the holes on the PVC pipe.

C1-2. Initial smaller hole (bottom) and larger hole (top) after redrilling.

Time (minute)	Humidity
24	72
25	74
26	77
27	80
28	83
29	84
30	79
31	74
32	72

C1-2. Humidity begins to drop drastically after 30 mins due to clogged pipes.

Comparison Matrix

A comparison matrix evaluates potential designs on how well they meet a set of requirements. They can be adapted to be used in different scenarios depending on the goal for using this tool, specificity of the potential designs, and testing data.

Procedure

- Create a table with requirements along one axis and potential designs along the other axis.
- Compare holistically and score each design on how effectively it meets each requirement.
- Keep track of holistic comments, as they may help you realize that certain requirements need to be prioritized over others.
- Comparison matrices are helpful for use in SCAMPER, as they can be interpreted to find aspects of each design that may be combined for a better design.

Example

Converging to potential designs for the automated mushroom growing chamber

We created a table on the whiteboard with our possible designs along one axis and requirements along the the other axis. We decided on a ranking scale of -2 to +2. Negative values indicate that the design poorly/does not meet the requirements and positive values indicate that the design meets or surpasses the requirements. A rating of 0 means that it is similar to the reference design.

  - You may determine the “points” system used for scoring each design according to the end goal or nature of the opportunity. In this instance, we chose to reference it to one design. Additionally, many of our requirements have linear utility curves, so we chose to use numbers between +/-2 to represent that in our table.
- We started with the first requirement and moved down the list of designs. We discussed and compared them holistically using Toulmin’s before scoring (C2-1).
  - Picking a requirement then comparing going down the list of designs rather than vice versa allows for direct comparison between the potential designs. We sometimes found ourselves changing around scores as we continued to discuss and justify our scoring.
  - Holistic comments are valuable as some requirements may be more significant than others. Keep that in mind when interpreting the total “scores” for each design.

C2-1. Comparison matrix to determine which ideas should be developed in more detail

Figma

Figma is an app and browser based collaboration tool that can be used for brainstorming and making visual representations. In an engineering design context, it is useful for brainstorming and designing poster and page layouts.

Figma has far too many capabilities to be summarized into a few sentences. Instead, it is easier to explore useful features in Figma by seeing how they can be integrated into an engineering design work flow.

Example

Creating graphics for showcase

Our poster, one pager, and supplementary showcase handouts were created in Figma on one canvas. The file was shared with all team members. None of them had used Figma in the past, but they were able to become familiar with the interface relatively quickly.

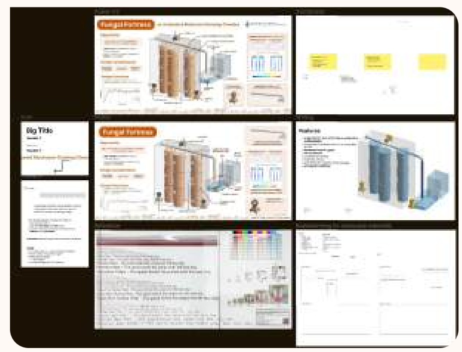
- Figma has an intuitive and simple layout and therefore has a shallow learning curve.

The main frame for the poster was created. Smaller frames around the poster frame were used to ideate what we wanted to put on the poster and held notes/reminders (R1-1). To experiment with a different colour or layout, we tested these changes on a duplicated frame (R1-2).

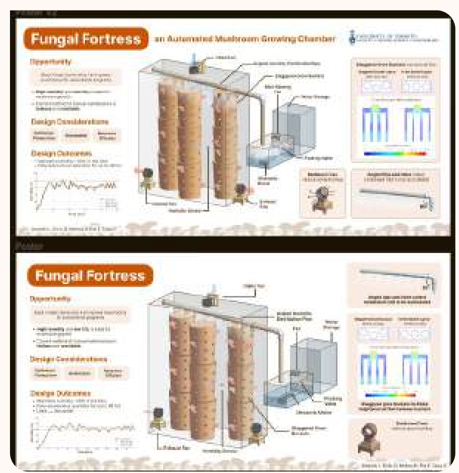
- The ability to create different pages on one canvas made it easy for us to visually compare changes that we were made and decide which version is better.

We created the one pagers and supporting documents on the same canvas (R1-3).

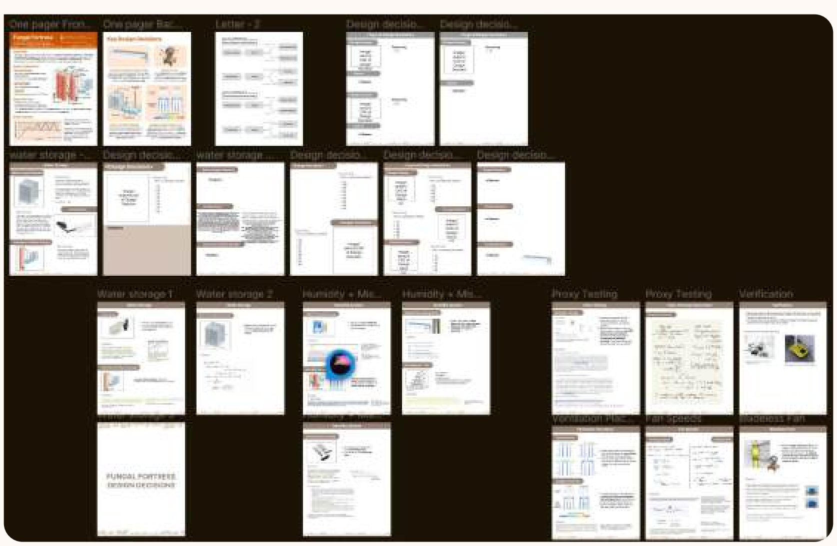
- This streamlined our work process and made our graphics more consistent as we were able to quickly pull elements directly from the poster without having to switch tabs.

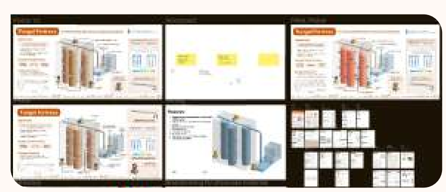


R1-1. Non poster frames contained references, to do lists, and jot notes of information to include in the poster.



R1-2. Experimenting with different layouts





R1-3. One pager (top left of left image) and supporting documents on the same canvas of the poster (shown in right image)

CAD Models

CAD models can be used for the digital representation of the final design, 3D printing, and for visualizing how different parts can interact with each other.

Procedure

Think about the goal of the CAD model. Is it to communicate ideas to an audience? For 3D printing? To test angles and make measurements which can be seen to scale?

- Open up your CAD modelling software of choice (Solidworks, Onshape).
  - Onshape may be better for collaborative projects where more than one person will be working on the CAD.
- Check to see if there are any available resources or background information you must be aware of before you start to model.
  - It may be easier and faster to modify existing CAD models found online through websites such as Thingiverse and GrabCAD.
- For 3D printing, be aware of necessary tolerances (+0.5mm diameter for a snug fit, +1mm diameter if the part needs to slide). Additionally, consider the intended use of the part when deciding infill, as higher infill means longer print time.
- If necessary, break the design down into individual components that can be assembled together
- Create the model.
- Measure twice so that you only have to print/export once.

Example

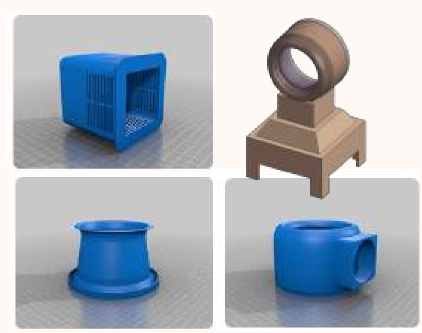
Representing our mushroom growing chamber using CAD models

Our CAD model was created using Onshape, mostly by my group member Melissa. I designed the bladeless fan parts in Solidworks by adapting the parts from a existing bladeless fan design. The fan ring was sized down to meet our fan requirement. The base of the fan was remodeled to fit the fans we used in the prototype.

- Solidworks files can be imported into Onshape. STL files do not work as well and display mesh lines that we ended up keeping in our poster because it was hard to get rid of them without sacrificing the legibility of other parts of the assembly.

The rendered and exported CAD model was used in our poster, one pager, and presentation. Individual parts of the were rendered and exported to showcase the individual parts of the system (R2-2).

- The CAD model was an essential part of how we communicated our final design, especially since it may be hard to understand our whole system, which has many moving parts, in words or a 2D image.
- Exported renders of different parts of the assembly gave us higher quality examples of design choices that were made, such as the bladeless fan and angled pipe.



R2-1. Models of a bladeless fan from Dylman3000 on Thingiverse [2] (left, bottom) and my adaptation to fit the pc fans (top right)

R2-2. CAD models of parts used in the poster

References

[1] T. Shields, “Understanding mushroom substrates,” FreshCap Mushrooms, https://learn.freshcap.com/growing/understanding-mushrooms-substrates/#:~:text=Water%20in%20the%20Substrate,-Mushroom%20fruiting%20bodies&text=Unlike%20plants%2C%20mushrooms%20are%20not,to%20the%20substrate%20before%20inoculation. (accessed Apr. 17, 2024).

[2] dylman3000, “Bladeless desk fan,” Thingiverse, https://www.thingiverse.com/thing:2685544 (accessed Apr. 17, 2024).