Engineering Design Handbook

Praxis II

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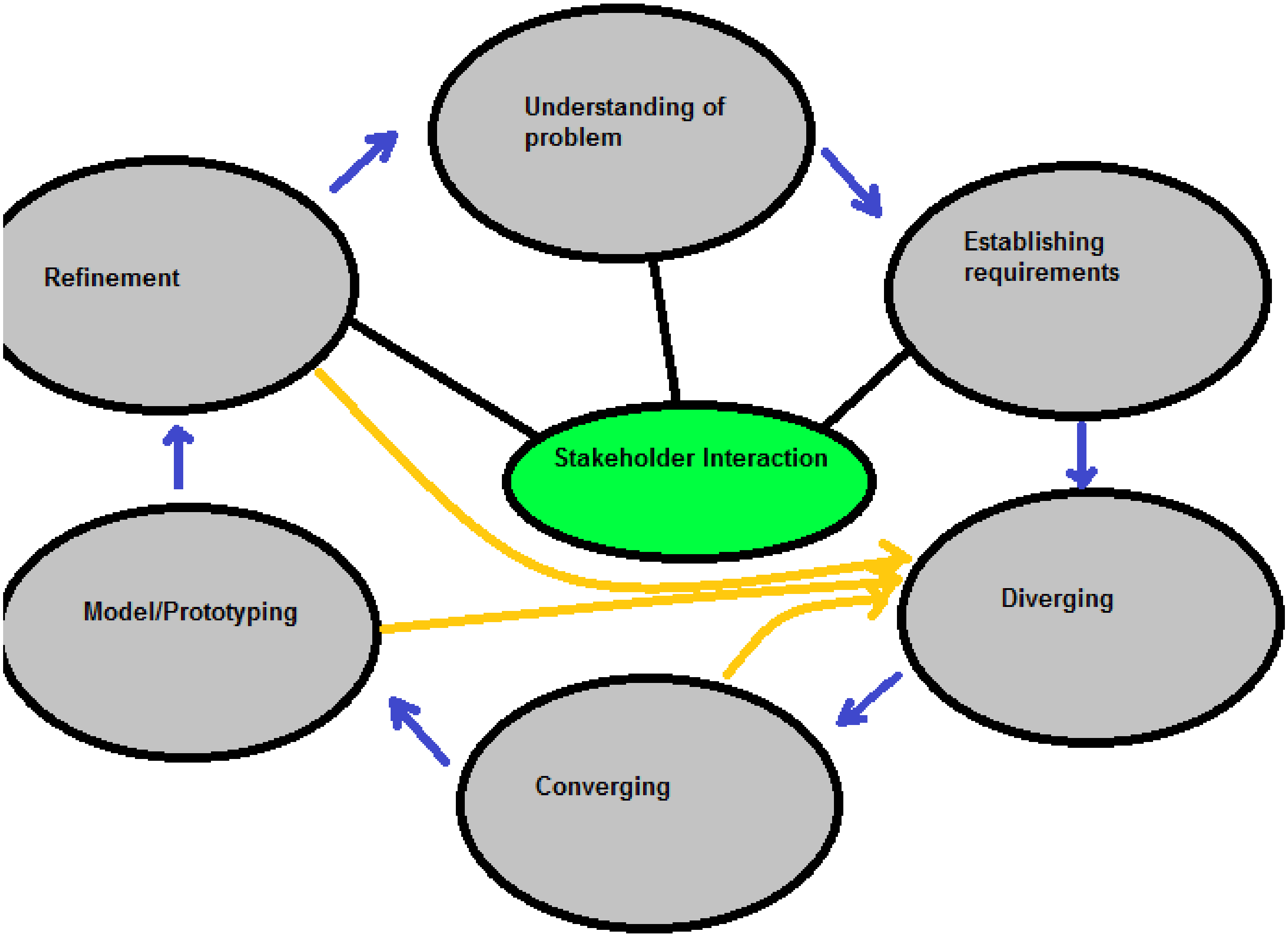
Personal Engineering Design Process

Overview

This handbook will cover my personal engineering design process, and includes guidelines, tips and examples. My design process can be cyclical: in the case that the final outcome isn't satisfactory, it is to be re-iterated until there is nothing more to be desired. The design process is depicted below:



Understanding the problem: Designer does necessary research to understand the problem. Should include stakeholder interaction if possible.

Establishing Requirements: Designer frames the problem by imposing engineering design requirements to the design problem. May include stakeholder interaction to help set requirements.

Diverging: Designer thinks of various approaches to solving the problem. The designer May be aided by the use of ideation tools.

Converging: Designer narrows down plethora of various approaches established earlier by using decision making tools.

Prototyping: Designer creates higher fidelidy prototypes to further communicate the design and make it less conceptual and more tangible.

Refinement: Final stages of the design. Design is assessed by stakeholders to ensure satisfactory, and designer makes any necessary changes. Designer performs a critical assessment of design to make sure it fully meets requirements.

Understanding the Problem

This stage of the design process is about doing any necessary research to fully understand the problem in question, using available research and literature relating to the given problem. It also involves a feasibility assessment. This feasibility assessment is to ensure that a 'gap' actually exists that needs to be filled. The following guidelines may help with this stage:

Guideline #1: When given a problem, it is often useful to understand all dimensions of what may be causing the problem. This will allow you to choose between multiple approaches later on.

Example: Given a problem such as “Design a more durable laptop”, you could go for a direct appraoch by using more expensive, but stronger materials, or you could make the laptop more ergonomical so that more people carry it the correct, convenient way, thus making it less likely to be dropped and break.

Guideline #2: Consider the following when performing the feasibility assessment: Does the problem actually exist? Does the problem already have good solutions? Is the solution to this problem within the scope of my abilities? Look for research that suggests the problem is large enough, and that those it affects would benefit greatly from a solution.

Guideline #3: Doing sufficient research is crucial to properly understanding the problem, especially if the problem is outside of ones experience. Understanding the problem is crucial due being successful in later phases as the decisions made early on will affect later decisions. Do your due diligence!

Stakeholder Interaction (if applicable): Contact with the primary stakeholder is vital as they will be the ones whom the solution effects most, and therefore they need to be satisfied with the solution. This means that their feedback has a direct effect on the requirements in the next section. Additionally, stakeholder interaction can lead to further insight regarding the problem.

Tips for dealing with stakeholders

- Plan out all the questions beforehand and make sure they cover as much information as you need. Ensure that the questions are going to direct the stakeholder to give you the information you need, as to avoid them going on about less useful information.
- Be concise. Don't ramble on, be clear to get your question/point across. Both of you will save time.
- Be politically correct and have good manners. The worst thing you want to do is to offend one of your stakeholders.
- Provide incentive for helping you. This incentive will usually be in the form of a promise that your design, once completed, will have a positive impact on their life. Don't make any commitments that you will not be able to meet, however.

Establishing Requirements

First and foremost, the designer should make his/her high level and detailed objectives clear based on the problem and stakeholder interaction. The designer may also impose objectives that he feels is important, however all decisions made should be justifiable. Then, using previous stakeholder interaction and research, or conducting more research and interactino if necessary, constraints should be imposed for every objcetive, each with corresponding metrics and criteria. The constraints should be either based on stakeholder information or Dfx guidelines. Additional research and stakeholder interaction may be required to complete this phase.

Guideline #1: It will be helpful to rank objectives based off importance, as some requirements may be more important than others. The relative importance should be based off stakeholder interaction. If this is not possible, then all decisions made should be justifiable.

Example: If the problem in question is to improve roadway safety, the safety requirement may be weighted higher than the cost requirement because the safety requirement is more relevant to the high level objectives.

Guideline #2: This phase will most directly effect the following stage, diverging, as the divergent solutions must harmonize with the constraints imposed in this phase.

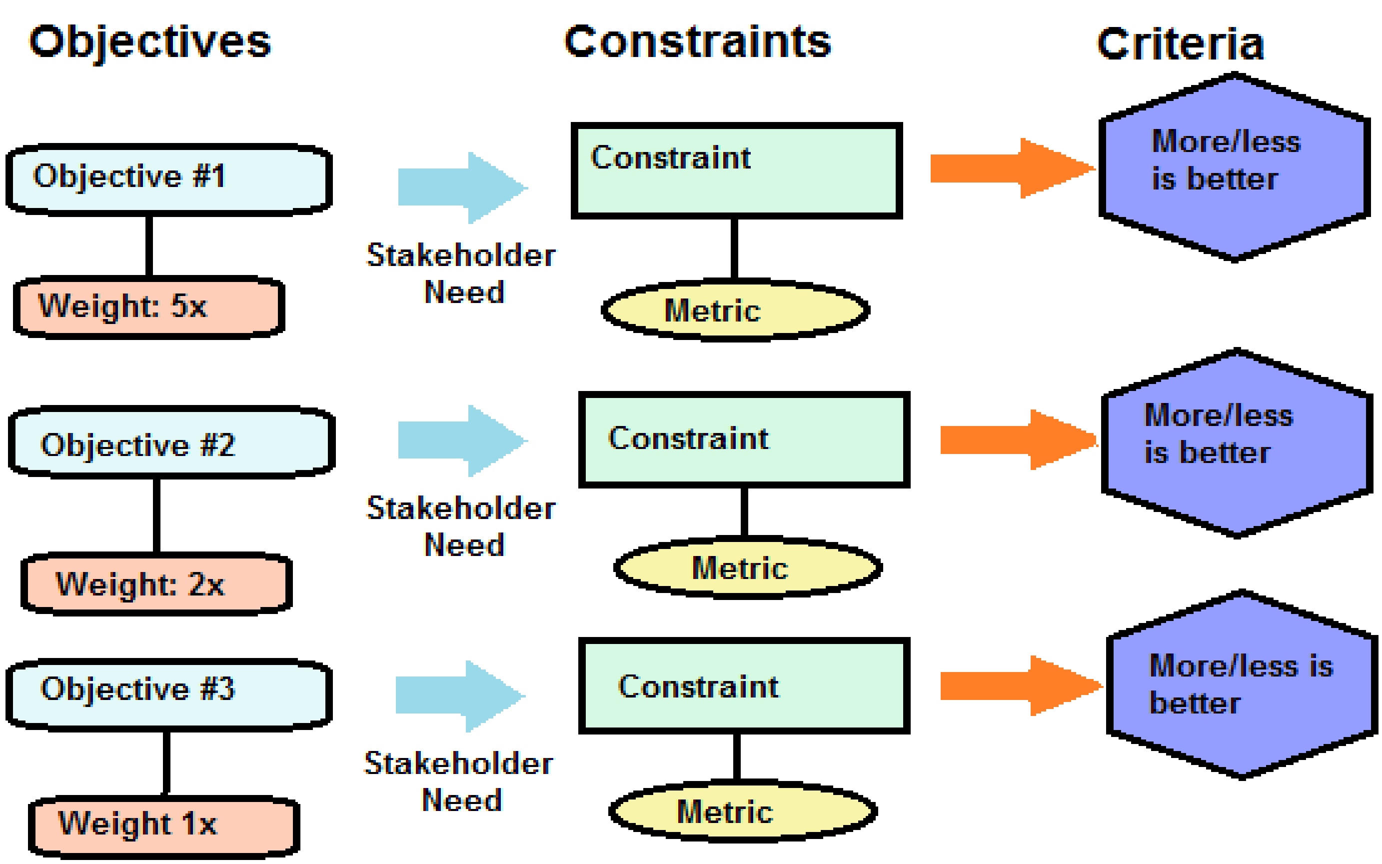
Guideline #3: Find a balance between being too specific and too general to avoid the solution space being too broad or too narrow.

Guideline #4: If stakeholder interaction is possible, allow the stakeholder to critique the requirements that you propose until they are satisfied. This will allow you to determine whether or not you are on the right track, and ensures that the requirements accurately encapsulate the problem at hand.

Guideline #5: Dfx, abbreviating for design for X, includes a large set of guidelines when trying to include that design factor x in the design. These guidelines can help with the formulation and justification of requirements.

Example: When designing for manufacturability, some guidelines may include the use of multifunctional parts as this leads to less manufacturing required, or using parts with symmetry as this eliminates orientation problems in assembly and incorrect installment of parts.

Guideline #6: If given a set of requirements that you did not set earlier, you may deem it necessary to reframe/rescope the problem into one that is easier to work with and is more sensical to the designer. All reframing/rescoping decisions should be justifiable.



Diverge

This phase involves the designer 'diverging', that is, creating various solutions that each head in a different direction by approaching the problem differently. Despite the different approach, all proposed solutions must still lie within the defined constraints. The designer might find that using diverging techniques will help with this phase. Some of the familiar divergent techniques are described below.

After using one of the techniques to think of a solution, the designer should draw out sketches of this idea to serve as a low fidelity prototype.

Guideline #1: Use of the divergence tools may not be necessary – they are only meant to help. If you can come up with a good solution without them, that is equally as good as coming up with a good solution with them.

Guidelines#2: Using the divergence tools can especially help if you run dry of thoughts – the fact that most of them are done in groups can help you think from a different point of view.

Brainwriting 6-3-5

About:

-Used in a group setting for open problems regarding both products and services

-Similar to brainstorming, but ideas are sketched instead of verbally discussed

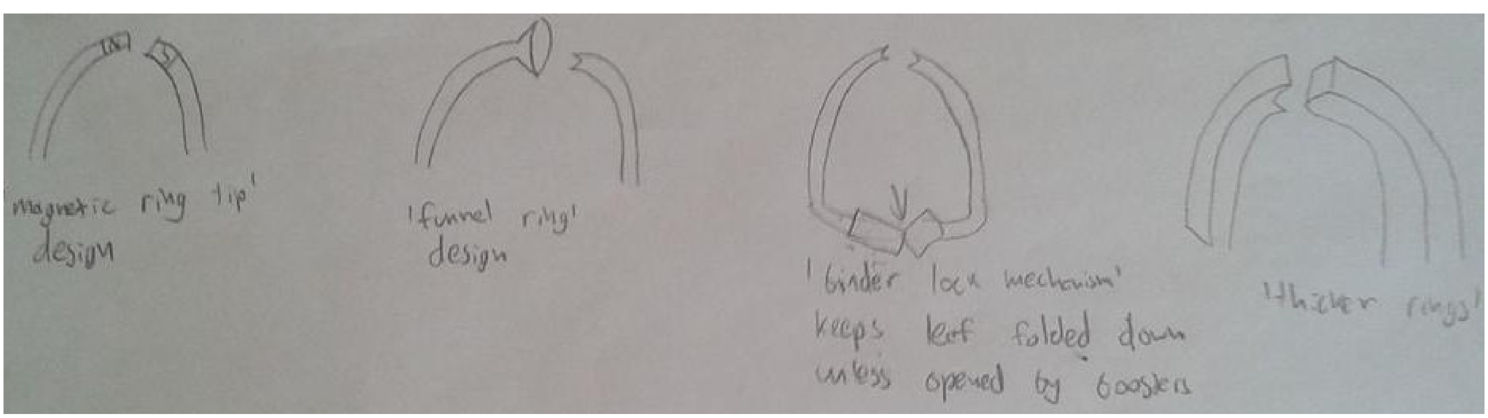
-As ideas are sketched, nobody is discouraged from contributing [1][2]

Process:

1. Write goal/problem statement
2. All participants generate at least 3 ideas on their sheet of paper in about 5 minutes
3. Each member passes his paper to his right, who then modifies and augments the ideas currently proposed
4. #3 is repeated until every sheet is modified by every member
5. The team then discusses what has been written in a traditional brainstorming manner [1][2]

Worked example:

Shows a worked example of stage 2 of brainwriting. This page would then be passed on to the rest of the group, who would improve these 4 designs in some way.



Redefinition

About:

-Can be used both individually or in a group for closed problems regarding both products and services

-Redefines the problem by narrowing or broadening the problem, allowing the designer to select a problem that he is more comfortable solving [1]

Process:

1.Write out the original problem

2. To broaden the problem, the answer to the question: “Why do I want to solve this problem? Why else”?

3. To narrow the problem, answer the question: “What's stopping me from solving this problem? What else?”

4. Repeat this until the problem is redefined as fit [1]

Reverse Brainstorming

About:

-Used in a group setting for open problems regarding both products and services

-Focuses on preventing ways of causing the problem [1]

Process:

1. Think about various ways to cause the problem
2. Think about various ways of preventing the problem caused
3. Do this for each of the causes and it will solve the original problem [1]

Example:

Problem: Binder rings misalign over time.

1. Opening the binder incorrectly can cause this problem
2. Making the binder easier to open the correct way can provent this problem

Wishing

About:

-Used in a group setting for open problems regarding both products and services

-Uses out of the box thinking to imagine a wishful, although perhaps impractical and over the top, solution. [1]

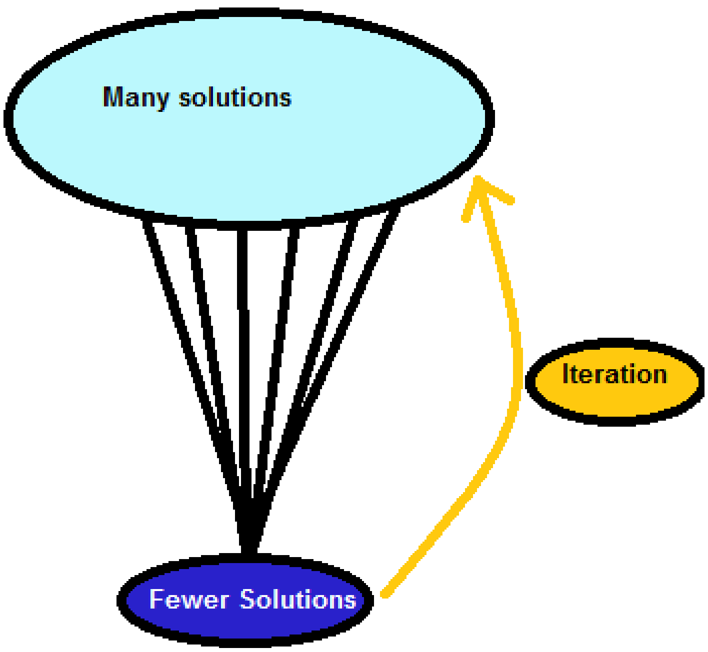
Process:

1. Begin your idea with “I wish” or “Wouldn't it be nice if”, then state your idea.
2. Repeat until an idea stands out as feasible, or can be worked down to one that is feasible. [1]

Example:Wouldn't it be nice if I could remove gum off this table just by waving my hand over it? -> Leads to the idea of a spray-can for removing gum by the application of a disintegrating chemical.

Converging

After diverging, many ideas will be generated- converging is about bringing those many ideas to few ideas (or possibly one idea if at the final stage of iteration). A variety of tools may be employed to help make decisions and eliminate unsatisfactory designs. Often, these tools will narrow the solutions down to those that most adequately meet the requirements established previously. This section provides detailed examples on how to use some of the more common decision making tools. Below shows a model for converging: The designer decisively goes from many solutions to few: This is repeated recursively with iteration. Divergence, as discussed earlier, can be seen as simply the inverse of the below diagram: going from fewer solutions to many.



Guideline #1: These are tools for guiding you towards a decision, not making the final call. Remember to exercise good judgement when analyzing the results of these tools.

The Pugh Chart

About: The pugh chart compares a reference design with other proposed designs based on a set of criteria. This set of criteria is often the requirements established previously. The relative scoring between other designs can provide the designer insight as to whether or not a design should be continted, revised, discontinued or possibly even combined with other designs. [3][4]

Process:

1. Create a table with the designs as the header to the column and the requirements as a header to the rows.
2. For every design, compare it with the reference design using the requirements. If it meets the requirement moreso than the reference, it scores 1, if it fails to meet it at the same level it scores a -1. If it is not better nor worse, it scores a 0. The relative comparisons for the reference design itself should be 0.
3. Create 3 more rows below the table to sum the +'s, -'s and 0's. For each design, determine these values and fill them into the table.
4. Using the above 3 rows, find the net score. Then, using the net score, rank the designs relative to one another.
5. With the help of the rankings, decide where you wish to go with the design.

Example: (below) Worked example that illustrates the various aspects of the pugh chart.

Reference Design

Candidate designs

Requirements/dfx's

Selection Criteria	Reference Design: Vending machine	Design #1: Removable box	Design #2: Dispenser	Design #3: Rotating table	Design #4: Teabag stack
Space Efficiency	0	1	0	-1	0
Compatibility	0	1	1	-1	-1
Accessibility	0	0	1	1	1
Cost	0	1	1	0	1
Cleanability	0	0	0	-1	0
Σ +'s	0	3	3	1	2
Σ 0's	5	2	2	1	2
Σ -'s	0	0	0	3	1
Net score	0	3	3	-2	1
Rank	4	2	1	5	3
Continue?	No	Yes	Yes	No	Combine with dispenser

Results

Rating against other concepts

Tips for working with pugh charts:

1. To aid in comparing the design with the reference design, it may help to draw out a small sketch of each design at the top of its respective column
2. If two designs score the same, rank them depending on which has the more heavily weighted requirements/dfx's
3. Choose the reference design to be an existing, unsatisfactory design. If this is not available,choose what appears to be the most average design.

Borda Counting

About: Bording counting allows each member of the design group to rank designs by perference. The result then shows which designs are, on average, preferred by most members and which are not. [4]

Process:

1. Create a scoring interval. If you have n designs to compare, this is a set of n numbers which are monotonically decreasing by a constant value.
2. Each member will rank the designs with a list, with the most preferred designs at the left of the list and the least preferred at the right. If a person ranks a design at position p, then the score that design gets from that person is the number at position p in the scoring interval.
3. For every design, sum the score that each participant gave it.
4. To find a weighting for each design, divide its score by the total number of available points
5. Use the scores and weightings to aid your decision of where you will take each design. [4]

Example:

Designs: Removable box, Dispenser, Teabag stack, Rotating table

Scoring interval: {3,2,1,0}

Person #1: {Removable box,Teabag stack, Dispenser, Rotating table}

Person #2: {Dispenser, Teabag stack, Removable box, Rotating table}

Person #3: {Dispenser, Removable box, Teabag stack, Rotating table}

Person #4: {Dispenser, Removable box, Rotating table, Teabag stack}

Scores:	Weightings
Removable box = 3+1+2+2 = 8	Removable Box = 8/24 = 0.3333
Dispenser = 1+3+3+3 = 10 (winner)	Dispenser = 0.4167
Teabag stack = 2+2+1+0 = 5	Teabag stack = 0.2083
Rotating table = 0+0+0+1=1	Rotating table = 0.04167

From this, we can see that the removable box and dispenser are most favoured, while the teabag stack and rotating table are much less favoured. A possible continuation would be to continue working on the removable box and dispenser and scrap the teabag stack and rotating table.

Pairwise Comparison Matrix

About: The pairwise comparison matrix provides a way to analyze the preferences of one design compared to another. It is a matrix with its dimensions being equal to the # of designs. The designs are put along the both row and column headers. For each element, if the design in the row is preferred to the column, the entry is 1, if not, the entry is 0. [4]

Process:

1. If there are n designs, create an nxn matrix with the designs labelling the row and column headers
2. For each element, if the design for the row is preferred to the column, enter a 1 for that element. If not, enter a 0.
3. For each row, sum the number of 1's. To obtain the weight for this row, divide by the total # of available score. [4]

	Design #1: Removable box	Design #2: Dispenser	Design #3: Teabag stack	Design #4: Rotating table
Design #1: Removable box	-	0 (Dispenser preferred to removable box)	1 (Removable box preferred to teabag)	1 (Removable box preferred to table)
Design #2: Dispenser	-	-	1 (Dispenser preferred to teabag)	1 (Dispenser preferred to table)
Design #3: Teabag stack	-	-	-	1 (Teabag stack preferred to ta ble)
Design #4: Rotating table	-	-	-	-

Score: Weightings:

Removable box: 2 Removable box: 2/6 = 0.33

Dispenser: 3 Dispenser: 3/6 = 0.5

Teabag stack: 1 Teabag stack: 1/6 = 0.1667

Rotating table: 0 Rotating table: 0/6 = 0

Tips for working with pairwise comparison matricies:

1. As the designs need not be compared with themselves, the diagonal of this matrix can be left empty
2. As this matrix is symmetric, the bottom half/top half of the triangle does not need to be filled in as it can be easily determined just by looking at one half of the matrix. [4]

Prototyping

This stages involves the creation medium-high fidelity prototypes of the single solution that has been converged to in the previous stages. Before this can begin, this phase involves making detailed design decisions as the design is still likely to be mostly conceptual. The detailed design decision process should be very similar to steps 1-4 of the design process so far, and is outlined below:

Detailed design process:

1. Identify what decision needs to be made. Perform research/stakeholder interaction if neccessary.
2. Identify the requirements of this decision. This may be based off the requirements of the overall design itself, however new requirements may also be imposed based off of newfound research.
3. “Diverge” by formulating various possible decisions that can be made by using available research
4. “Converge” by using decision making tools and requirements established in step 2.

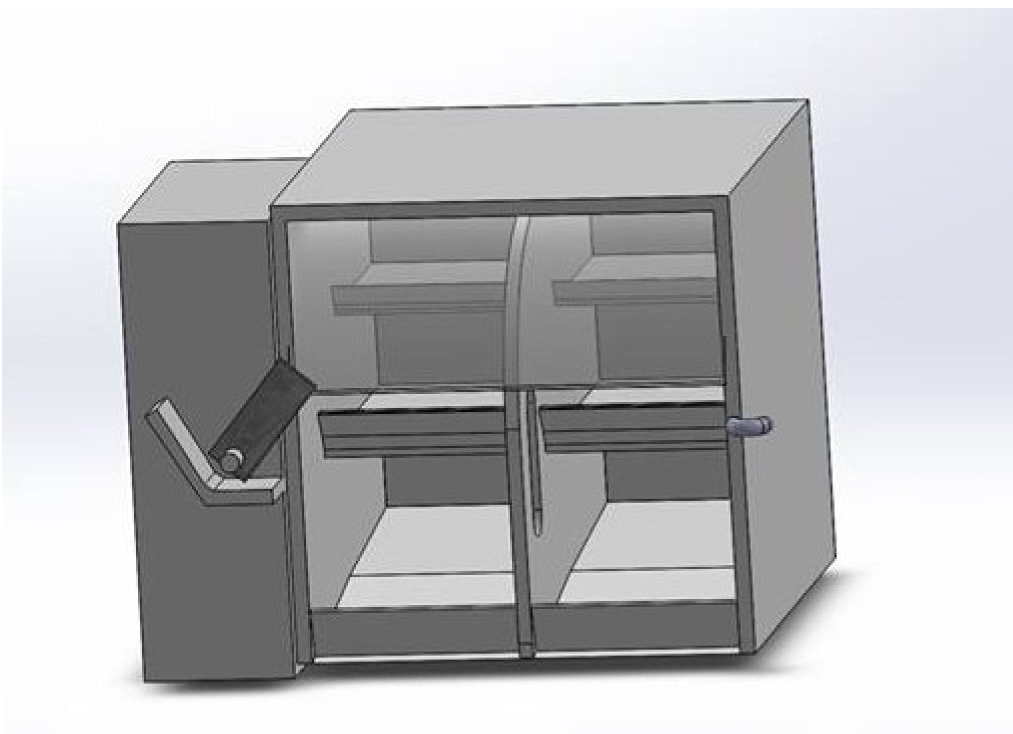
If the design is in the form of a product:

Once the detailed design is complete, the prototype can begin to take form using these decisions. First, model the design using a much more detailed sketch of the design, or a 3-D CAD model. This may reveal oversights that should be addressed before continuing. Then, using these models to aid you, begin constructing a physical, tangible prototype with functionality. This may reveal even more oversights throughout the process of constructing the prototype – if these cannot be overcome then you may deem it necessary to step back and redo some of the previous steps.

Worked Example:

This is the finalized prototype in the form of a CAD model. This is fully to scale, as the detailed phase has been completed before the prototype was actually made. This is a removable storage box, meant to replace the storage system within an ambulance. A sample of a cycle through the detailed phase is shown below:

1. The material for the box must be determined. Research is done to determine the forces the box must endure when rounding a turn.
2. Various requirements are imposed, most of which have already been established, such as affordable, durable and safe. Some requirements are made more specific, such as 'must not break when rounding a 30km/h turn'.
3. Various candidate materials are proposed by conducting research on commonly used plastics. Woods of various types are also considered
4. With the use of a pugh chart, the decision of which material was narrowed down to polypropylene, a cheap, but strong plastic that adequately fit the requirements.



Refinement

This stage involves critical assessment of the design to ensure it meets the initially imposed requirements. A large component of this stage involves a strong communication of the design, in which the designer is presenting the design to the set of primary stakeholders. This presentation will allow the stakeholders to reveal any problems, oversights and room for improvement in the existing design. In addition, the designer should do a critical assessment of the design, in which the design itself is questioned, along with its ability to meet the requirements.

Based on the stakeholder interaction and critical assessment, the designer should decide whether or not the design is suitable for production or if he/she needs to continue to iterate. If the designer so chooses to iterate, then the designer should go to the divergence stage, to create various ways of improvement that make the design more viable.

Guideline #1: For the critical assessment of the design, ask yourself questions like: Does this design really meet all the requirements at an acceptable level? Would I feel comfortable using this design if I were a stakeholder? Could this design be improved at all? Is there an easier way to fufill the requirements?

Guideline #2: If necessary (and possible), the critical assessment should also involve testing the design to help evaluate it and ensure that it meets the requirement that it is being tested for.

As this phase usually involves a presentation to stakeholders, some tips on giving presentations are given below:

- Know your design inside and out. Avoid memorizing a presentation – instead remember rough structure of how the presentation should go and fill in based on what you know about the design. This will make the presentation appear much more natural
- Avoid the use of jargon, instead use simple, everyday words to get your point across
- Acquire and maintain their interest from the beginning. This can be done by quickly summarizing your design – you can bore them with the details once they've decide that they like your design.
- Use any sort of available information given to you during the presentation to help you – blueprints, research, sketches, diagrams, and prototypes can all help you convey what you have to say and also strengthen your argument.

Iteration

Iteration is a cyclic process that involves the Diverging, Converging, Prototyping and Refinement stages of the design process. Based on the results of each stage, the designer might find that they must move to an earlier stage in the design process. This cycle is repeated until the final product is satisfactory – after all, the purpose of iteration is meant to improve the quality of the design.

Example: After completing the prototype for a design and showing it to stakeholders, it is found that there are usability issues and other subtle design flaws existing within the design. The designers then head back to the diverging stage to brainstorm new, but similar solutions that alleviate the existing problems. They then converge to one of these solutions then prototype. This process is repeated until the issues have been mitigated and the design is at an acceptable level.

Although this example involves going to the diverging stage straight from the refinement stage, iteration can occur earlier if the problems with the design are noticed sooner.

Definitions

The meanings of some words within this handbook are not explained and assume the designer is already comfortable with such vocabulary. Here are some quick definitions for reference, if needed:

Metric: Way to measure a certain aspect of the design quantitatively

Constraints: Provide upper/lower bound limitations for parameters regarding the design. These restrictions must not be violated.

Criteria: A rule in which the design can be evaluated (i.e. more is better is a rule which means that something that has more of that given metric would evaluate better)

Reframing: Conciously/subconciously imposing an assumed structure on a situation by the selection of relevant features and deciding what is important/less important.

Rescoping: Choosing what is important/unimportant to the design

Stakeholders: Those (usually referring to people) who the engineering design will have an effect on, both directly and indirectly. The fact that they are effected by the design implies they have some sort of "stake" in the outcome of the design.

References

[1] Foster J, Irish R, "ESC101 Engineering Science Praxis I 27 creativity & innovation techniques explained" Retrieved April 2014

[2] "Creativity Techniques – Brainwriting -Rapid Idea Generation" [Online] Retrieved April 2014. Available: http://creativeagni.com/ezine/2011/07/creativity-techniques-brainwriting-635-idea-generation-sheets-cards-advantages-8-step-process/

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[4] Foster J, Irish R, "ESC101 Engineering Science Praxis I Decision Making Tools". Retrieved April 2014