Engineering Strategies & Practice

University of Toronto
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APS111 & APS113
Conceptual Design Specifications (CDS)

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Please check off which components you are submitting for your assignment.
_√_ CDS submitted as a PDF to Quercus with the following components:

_√_ Cover Page
_√_ Executive Summary
_√_ Introduction
_√_ Problem Statement
_√_ Service Environment
_√_ Stakeholders
_√_ Detailed Requirements (FOCs)
_√_ Alternative Designs
_√_ Proposed Conceptual Design
_√_ Measures of Success
_√_ Conclusion
_√_ Reference list
_√_ Appendices

Attribution table with ALL team members' signatures must be submitted in the status meeting of the assignment debrief. An incomplete or missing attribution table will result in zero on the assignment for the team.

Executive Summary

Our team has set to work on designing an innovative household product for Vandelay Industries, as a part of their hiring process. This design must lay the foundation of a tangible and realistic product that the company may produce, market and sell. Therefore, the proper engineering process has been completed, and it is detailed below as to how the team ended up deciding on their final proposal.

Our team has chosen to pursue the optimization of available storage space in the average American (United States of America) home. In addition to an increased level of accessibility for elders, children, and physically handicapped individuals.

This decision was based on the collection of data for American home renovations in 2020, in which nearly 27% of which involved remodeling the kitchen space []. From the research conducted by our team, we have deduced that kitchen cabinets comprise the primary location for kitchen ware and food item storage. However, in the modern kitchen environment, there is a large caveat for those who are vertically disadvantaged, as cabinet storage is primarily located above counter level, and is thus inaccessible or unsafe to access for a large portion of the population. Leading our team to access how to make the storage not only safer to access, but more efficient as well.

A component of consideration for the design revolves around the environment of the kitchen. Due to the large number of living organisms that exist within this space, there must be special consideration for health and safety. Additionally, there exists exposure to extreme temperatures, as well as potentially damaging forces which the design must be durable to withstand repetitive use.

The critical stakeholders in our design include Vandelay Industries, and the homeowner. Our design must be safe, efficient, and effective, and not compromise the health of the consumer. However, the design should maintain a fair market price, and be relatively simple to install and use, without the need for a large re-modeling or re-shaping of the kitchen space.

Our team has decided to recommend an inter-island storage solution, that is fairly priced below $600 per unit, can be prototyped simply within a month, and can be tailored to a customer's kitchen island dimensions and material specifications. This design capitalizes on the wasted space between island cabinets and provides a deeper, recessed pullout cabinet with shelved storage. This pullout features a secondary top which may be raised or lowered to be used as an extension to the pre-existing countertop. This design greatly increases the utilization of wasted space in the kitchen, and in tandem reduces the dependency on upper cabinet storage. Leading to a more functional, modular kitchen environment that is safer and more efficient for the homeowner to use and operate.

This design is an infant iteration that may be fine turned over the coming weeks with the assistance of Vandelay Industries resources, to fully optimize the design as a marketable product.

1. Introduction

For our household product, research has been conducted in the kitchen to set the constraints of the household appliance. The client for this document is Vandelay Industries.

To effectively utilize kitchen space, adequate storage is required. Thus, smaller kitchens are utilizing vertical space, making cabinet placement higher to accommodate for the other functions of the kitchen[1]. However, this poses a problem for vertically disadvantaged people who are shorter than ~170 cm such as those in wheelchairs and other disabilities[2, 3].

Through research, the ideas generated were documented into three categories. Subsequently, these ideas were filtered using multi-voting, graphical decision chart, and the Pugh method, resulting in three alternative designs. A proposed conceptual design was reached based on how accurately it met the objectives.

2. Problem Statement

In the household, the kitchen is the most common room to be remodeled, with 27% of renovating homeowners upgrading their kitchens in 2020[4]. 63% of homeowners in a 2018 survey upgrade their kitchen to store and find things easily[5]. 81% of kitchen renovators remodel their cabinet systems and incorporate built in storage, specifying that they want to “make better use of space”(79%) and “make it easier to find items”(56%)[6]. Other reasons for built in storage such as “utilize unreachable space”(44%) and “reduce bending”(13%), articulate the inaccessibility of kitchen storage[6].

Figure 2.1. Statistics displaying the top reasons of kitchen renovators in the U.S. for upgraded storage units and incorporated built-in storage [6].

The gap that we are addressing is the inaccessibility of storage in American residential kitchens. As homes become more compact, U.S. homeowners indicate a demand for more effective and accessible storage. Hence, our scope will focus on the storage aspect of residential kitchens in the U.S., and we will design a product that maximizes storage accessibility while maintaining space efficiency and usage in the kitchen.

3. Service Environment

The service environment describes the physical and living elements of an area that the design will operate within.

The targeted environment is residential kitchens across the US. This design is aimed to target the median US home kitchen, based upon its size and purpose. Room temperatures in the kitchen range from 21°C to 25°C[7]. The average humidity levels of the environment are 60%[8]. The average area of a US kitchen is between 9.57m^2, to 16.2m^2[9]. Within this environment there is exposure to extreme heat at a maximum of 1950°C[10] and extreme cold at a maximum of -18°C[11] due to appliances. Waste gases such as carbon dioxide are produced due to the combustion of natural gas and propane, used in appliances. The living aspect of the environment contains four categories, human, pets, pests, and bacteria. The human aspect is composed of children, adults, and the elderly. The pets and pests consist of Felines, Canines, Aves, and Rodentia most commonly. Due to the surplus of organic material in the kitchen, there exists a risk of disease and bacterial growth.

4. Stakeholders

To identify the potential impact of the kitchen renovation project, it is necessary to understand the stakeholders that are involved. Stakeholders include people and organizations that will be impacted by the design.

Table 4.1: The table below describes the possible stakeholders involved in the project and their interest of the design.

Stakeholders	Interest
Homeowners, guest, and tenants	Social and Human factor: Interest in staying connected with individuals that utilizes the kitchen space and having the most convenient experience utilizing the design.

U.S. Department of Health and Human Services	Economic: Interest in providing states with block grant to design and operate programs to meet temporary assistance for needy family goals.[13]
U.S. Consumer Product Safety Commission	Ethical: Interest in reducing the risk of injuries and deaths from the kitchen design product by developing mandatory safety standards.[14]
Kitchen Service Technician	Economic: Interest in having the job in which they are responsible of communicating with other food industry professionals and making sure food appliance work properly.[15]
Realtors	Economic: Interest in assisting with the home inspection and negotiating repairing fees.[16]

5. Detailed Requirements

There are three sections in the detailed requirements: Functions, objectives and constraints.

5.1 Functions

The design functions determine what exactly the design will do. We are designing a product that maximizes accessibility and efficiently utilizes available space in the kitchen.

Table 5.1: The table below outlines the primary and secondary functions of our design.

Primary Function	**Secondary Functions**
The product accesses all available kitchen storage and makes use of unreachable spaces.	The product maintains the accessibility and usage of the surface area in the kitchen.
	The product makes efficient use of space available and provides storage organization.
	The product removes the need to bend, reach, or extend to access storage.

5.2 Objectives

The design objectives are determined with consideration to stakeholders, and through extensive research and benchmarking.

Table 5.2: The table below outlines the objectives of the design in order of significance.

	Objectives	Metrics	Objective Goals
1	Minimizes work needed to access kitchen storage.	The amount of mass the user must handle.	< 15 kg
		How far the user must reach.	< 0.5m
2	Efficiently utilizes available space.	The volume ratio of the available space to the total space.	> 80%
3	Mechanism of the design is easily understood.	Number of uses required to understand mechanism.	< 5
4	Supports similar loads as regular cabinets.	Kilograms.	> 272 kg[17]
5	Provides levels of organization for items.	Number of different types of objects that can be stored.	4-8
		Number of sub-storage compartments.	2-4
6	Inexpensive.	American Dollars.	< $400 USD[18]

5.3 Constraints

The design constraints address regulations and safety codes, stakeholders' considerations, patents and other limitations that the design must not violate under any circumstances.

Table 5.3 The table below outlines the constraints.

Constraints	Codes, Considerations, limitations
Design	• Shall not exceed 0.6m in width[19]. • Must not require user to reach farther than 0.8m. • Must accommodate for the full usage of the space surrounding the storage system[19]. • Must provide accessibility for the height range of 0.4m-1.8m for average homeowners[19]. • Must provide access of storage elements above 1.2 m to individuals who are disabled or use wheelchairs[19]. • Shall not have sharp corners or edges[20].
Materials	Must not contain or be constructed from the following substances[21]: • Lead • Cadmium

	• Leather dust or Acetamide
Property	Nonconductive of heat or electricity[20]
Price	Must not exceed cost of $600[18, 22]
Infringing patent	Must not infringe on any of the following patents: • US7770986B1 Overhead pull-out swing-down drawer[23]. • US9055813B2 Pull-down shelf for furniture[24]. • US8424693B1 Rollout drop down shelves[25]

6.0 Alternative Design Generation, Selection and Description

The team used various idea generation methods to generate 50 ideas and through idea selection the team selected three ideas to be modified into three alternative designs.

6.1 Idea Generation Process and Tools

For the idea generation process, the team used three main methods. The mind map technique produced initial ideas and the team iterated to further develop them into potential solutions. The black box method was used to analyze the inputs and outputs of the design, and form ideas that addressed this gap. Then the team used visual methods such as sketching and modelling to develop and communicate complex ideas.

6.1.1 Mind Map

The ideas were generated in direct consideration of the gap and the design functions. If an idea connected to another idea, it was visually branched from the other idea, creating a clear hierarchy. The team created categories to organize similar and connected ideas.

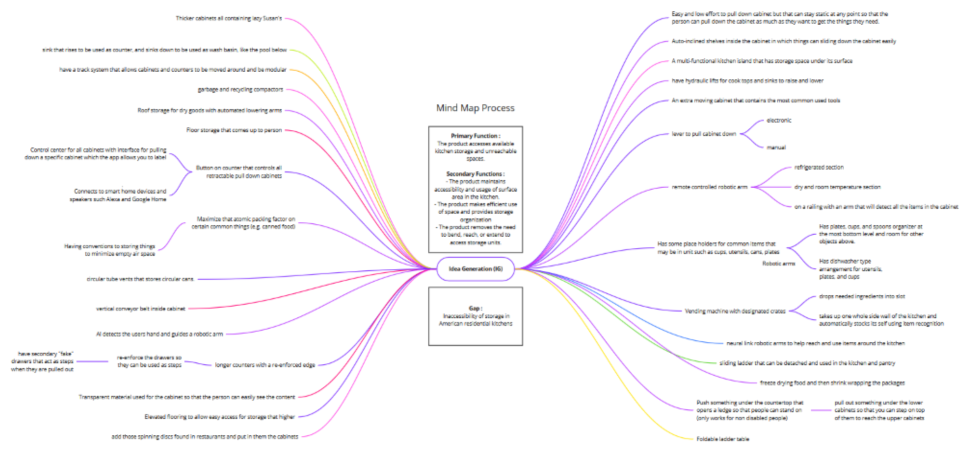


Figure 6.1.1. Ideas that were connected were represented as extensions or branches of other ideas. The collaborative web app Miro was used for the Mind Map process[26].

6.1.2 Black Box

The Black Box method considers the design inputs and outputs, generating ideas that will bridge the gap and create a functional design. This method readdressed problems we had set to solve. This method was effective; however, it was less productive than the Mind Map as it limited the size of the idea generation space.

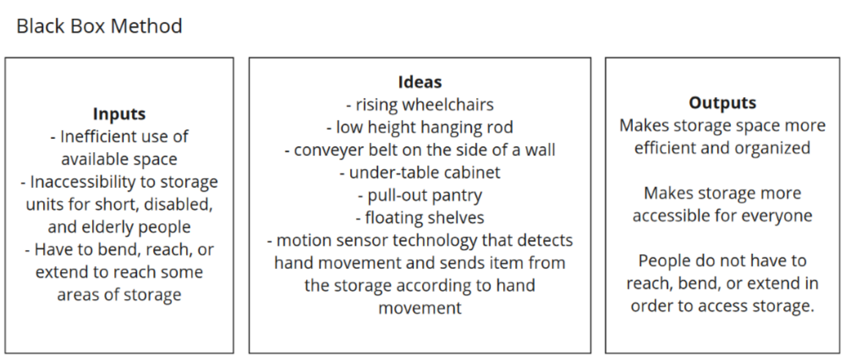


Figure 6.1.2. Black Box Method Chart outlining the inputs and outputs in consideration for the design and some ideas generated through the process in web app Miro[26].

6.1.3 Sketching, Visualizing, and Modelling

Visual methods were used to generate more ideas. The team used visualization and sketches to propose their ideas and communicate them effectively.

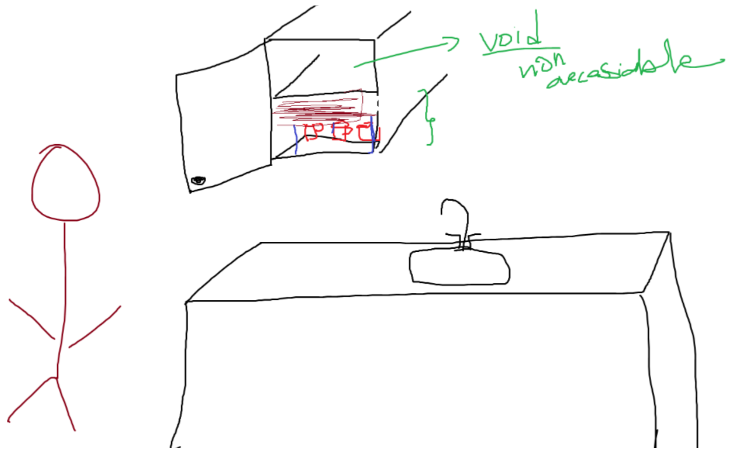


Figure 6.1.3.1. A rough sketch on MS Paint illustrating how certain items in a cabinet do not occupy all available space.

The 3D modelling software Blender was used for modelling complex ideas[27].

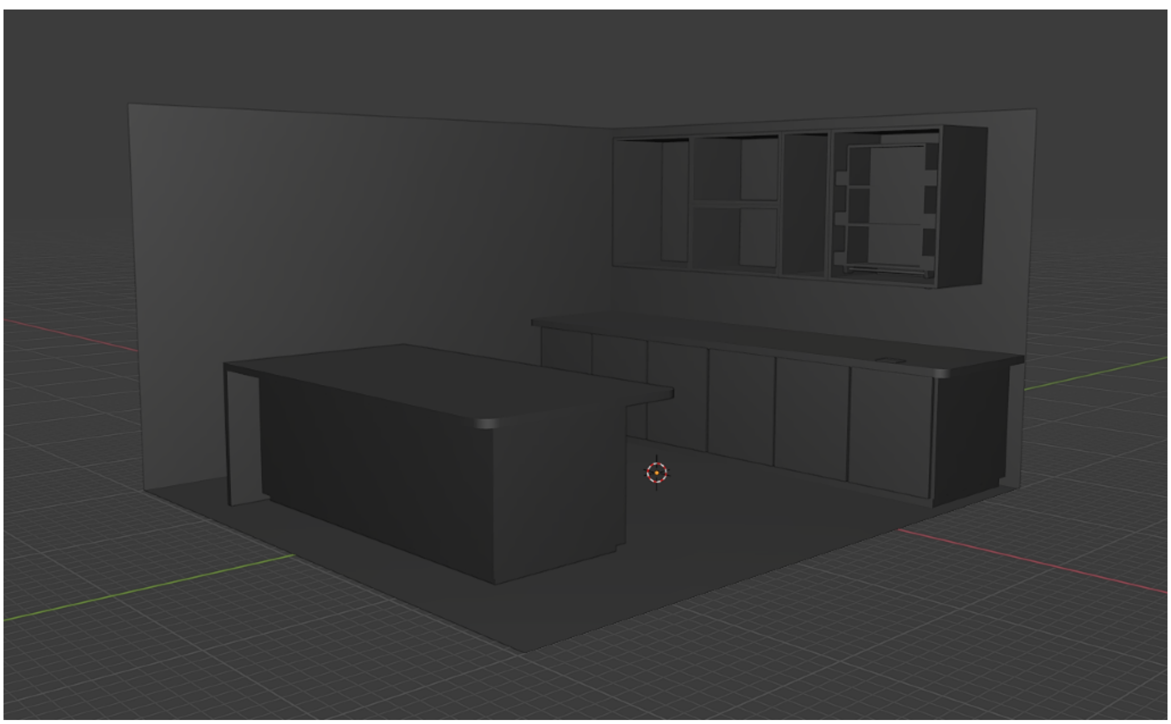


Figure 6.1.3.2. Model of a standard kitchen design.

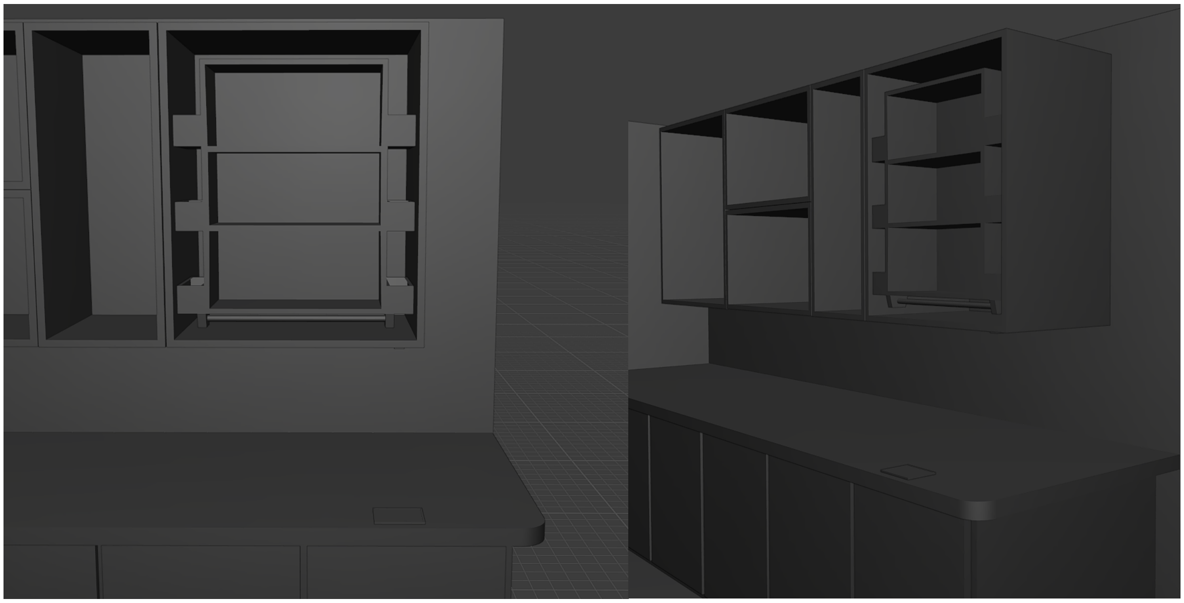


Figure 6.1.3.3. Model displaying a combination of ideas such as the manual or electronic pull-down cabinet, organizational features such as side holders for cans and spices, and countertop control center for cabinets system.

6.2 Alternative Design Selection Process

The team used a five-step process to select the alternative and recommended designs.

First, the team consolidated the list of all ideas. Then the team performed a feasibility check and used the Multi-Voting method to reduce the number of ideas. The team used the graphical decision chart to select three alternative designs and the Pugh method to select the recommended design.

6.2.1 Idea List, Feasibility Check, and Multi-Voting

In the idea generation process, the team generated a long list of ideas. To begin the idea selection process, the team consolidated this list of ideas and organized them into categories. Then the team performed a feasibility check on selected ideas for the Multi-Voting method, ensuring that the idea met the design functions and constraints. Each team member selected 8-10 ideas, with consideration of the design objectives. Ideas with less than two votes were eliminated.

	A	B	C	D	E	F	G
1	**Master List**	**Andy**	**Torre**	**Yug**	**Edison**	**Larry**	**Total**
2	Sink that rises to be used as counter, and sinks down to be used as wash basin, like the pool below. (Figure 7.1.1)	1					1
3	Have a track system that allows cabinets and counters to be moved around and be modular.	1	1	1	1		4
4	Roof storage for dry goods with automated lowering arms.		1				1
5	Floor storages that come up to person.			1			1
6	Button on counter that controls all retractable pull-down cabinets (Figure 7.1.2):			1	1		2
7	Easy and low effort to pull down cabinet but that can stay static at any point.		1	1		1	3
8	Auto-inclined shelves inside the cabinet in which things can sliding down the cabinet easily.			1	1	1	3
9	An extra moving cabinet that contains the most common used tools.					1	1
10	Lever to pull the cabinet down.			1	1	1	3
11	Remote controlled robotic arm (Figure 7.1.4):						0
12	Neural link robotic arms to help reach and use items around the kitchen.						0
13	AI detects the user's hand and guides a robotic arm						0
14	Re-enforce the drawers so they can be used as steps	1			1		2
15	Having hydraulic lifts for cook tops and sinks to raise and lower						0
16	Sliding ladder that can be detached and used in the kitchen and pantry	1	1			1	3
17	Foldable ladder table		1			1	2
18	Push something under the countertop that opens a ledge so that people can stand on (only works for non-disabled people)						0
19	Pull out something under the lower cabinets so that you can step on top of them to reach the upper cabinets	1	1				2
20	Elevated floor with floor storage underneath, providing underneath storage and easier access to top cabinets.			1			1
21	Thicker Cabinets containing lazy Susan's turntables(Figure 7.3.1).				1		1
22	Maximize the atomic packing factor on certain common things (canned food) -having conventions to storing things to minimize empty air space.	1	1				2
23	Circular tube vents that store circular cans.				1		1
24	Vertical conveyor belt inside cabinet.	1		1	1	1	4
25	Longer counters with a re-enforced edge.		1				1
26	Transparent material used for the cabinet so that the person can easily see the content.						0
27	A multi-functional kitchen island that has storage space under its surface.		1			1	2
28	Has some place holders for common items that may be in unit such as cups, utensils, cans, plates			1		1	2
29	- Has plates, cups, and spoons organizer at the most bottom level and room for other objects above.						0
30	- Has dishwasher type arrangement for utensils, plates, and cups						0
31	Vending machine with designated crates	1			1		2
32	- drops needed ingredients into slot						0
33	- takes up one whole side wall of the kitchen and automatically stocks it self-using item recognition						0
34	Freeze drying food and then shrink wrapping the packages						0
35	Add those spinning discs found in restaurants and put in them the cabinets.	1			1	1	3

Figure 6.2.1. The number of votes for each idea was summed on MS Excel and the ideas with less than two votes were shaded gray and eliminated.

6.2.2 Graphical Decision Chart

To select the alternative designs, the Graphical Decision Chart was used with the remaining list of ideas. Each idea was assessed on how well it met the top two design objectives, from a scale of 0-4. The top objectives were determined by the gap and the design functions. These objectives had associated constraints which represented the score 0 on the Graphical Decision Chart.

Table 6.2.2 The top two objectives, their goals, metrics, associated constraints, and evidence justifying the significance of these objectives.

	Objective	**Metrics**	**Goals**	**Associated Constraints**	**Justification**
1	Minimizes work needed to access kitchen storage.	The amount of mass the user must handle.	< 15 kg	Must not require user to reach farther than 0.7m.	This objective associates with the design's primary function. • 63% of homeowners in a 2018 survey upgrade their kitchen to store and find things easily[5]. • 44% of renovators incorporate built-in storage to utilize unreachable spaces and 13% to reduce bending[6].
		How far the user must reach.	< 0.5m		

2	Efficiently utilizes available space.	The volume ratio of the available space to the total space.	> 80%	Must accommodate for the full usage of the space surrounding the storage system[19].	This objective addresses the secondary function: maintaining the amount of available space. • 76% of kitchen renovators incorporating new storage state that they "want to make better use of the space"[6].

The team collectively discussed each idea, plotting all points onto the Graphical Decision chart, then the ideas in the fourth quadrant which best met the top two objectives were selected for the Pugh method.

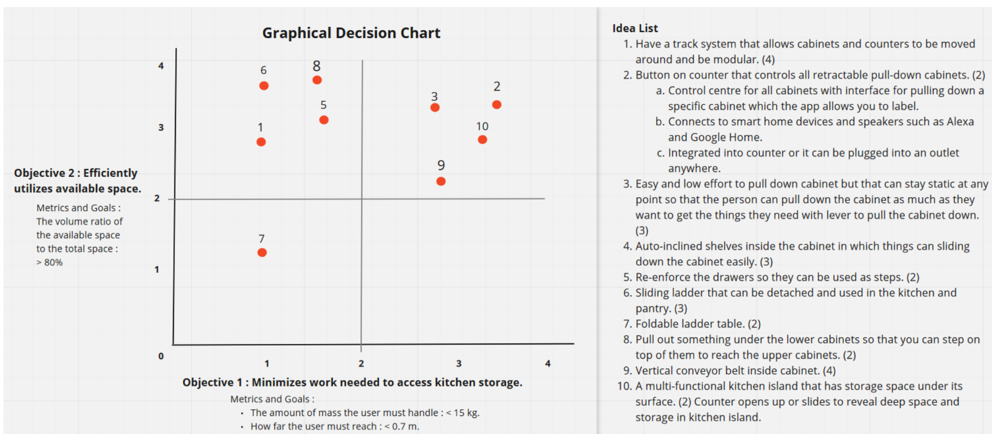


Figure 6.2.2. The Graphical Decision chart with the list of remaining ideas at this stage of the Idea Selection Process. The first objective represents the x-axis, and the second objective represents the y-axis. The web app Miro was used for the Graphical Decision Chart method.

6.2.3 The Pugh Method

The Pugh method was used to compare the four potential design solutions. All objectives were considered during the comparison against the standard kitchen cabinet. A design was given a "1" if it better meets the objective than the datum solution; a "0" if it was about the same; a "-1" if it performs worse than the datum. The team went through each objective and the sum result that we have for the four designs are 1, 1, 0, and 2 respectively.

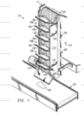
					
Solution Objectives	Standard (Typicall Kitchen cabinet)	[2] Retractable pull-down cabinet w/remote	[3] Static pull down cabinet	[10] conveyor belt	[11] multi-functional kitchen island
Minimize work needed to access kitchen storage	S	1	1	1	1
Mechanism of the design is easily understood	S	0	0	-1	1
Efficiently utilizes avaliable space	S	0	0	-1	1
Supports similar loads as regular cabinets	S	0	0	1	1
Provides levels of organizations for items	S	1	1	1	-1
Inexpensive	S	-1	-1	-1	-1
Sum	0	1	1	0	2
	INSTRUCTIONS:	In the blue boxes, give a value of -1, 0, 1 (-1 being worse than the STANDARD, 1 being better than the STANDARD).			

Figure 6.2.3. A table on MS Excel is created for the Pugh Method to be implemented, and the recommended design solution has the highest sum.

6.3 Alternative Designs

Through the idea selection process, the team selected three alternative design solutions which are the retractable static cabinet, the vertical conveyer belt cabinet, and the multi-functional kitchen island storage system.

6.3.1 Retractable Static Cabinet

The Retractable Static Cabinet is an extension for the upper cabinets that can lower down to any point, allowing the user to access items in any selected shelf. The unit can be pulled down using a wide handle along the bottom of the unit, and the mechanism requires low effort and allows the unit to stay stationary at any incline. There are two extension arms along the side that attach to the cabinet, and a wide extension arm at the back of the unit. The design has three shelves along the middle and two small storage compartments situated along both sides towards the bottom of the Retractable cabinet.

Design Size and Materials (Appendix A):

- Dimensions (Height×Width×Depth):
    - Relative to cabinet occupied.
    - (-0.14×-0.3×-0.25) m
- The main structural material:
    - Wooden structure and selves.

- Metal handle with rubber grip.
- Titanium extension arms.

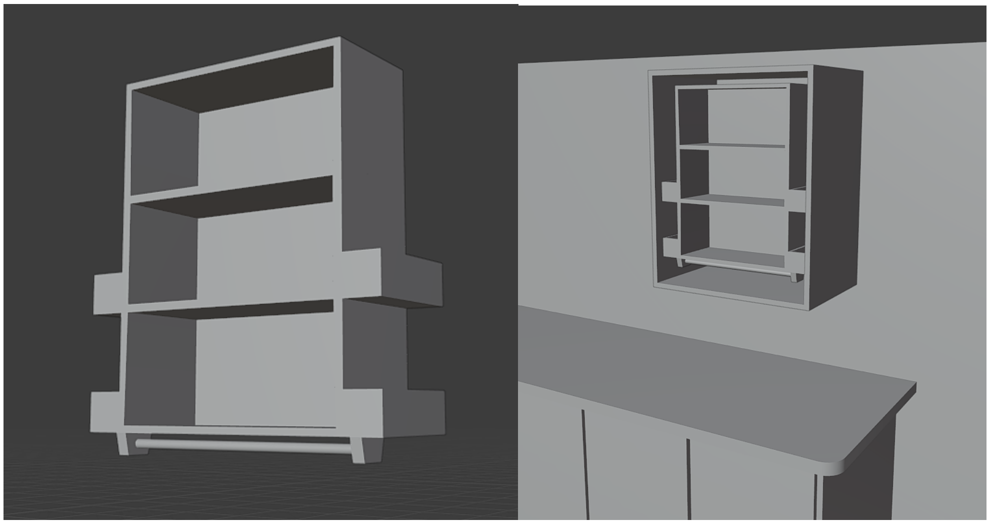


Figure 6.3.1.1. The retractable static cabinet is shown here, as 3D modelled in Blender [27]. The handle situated at the bottom provides easy accessibility and there are many storage compartments for organization.

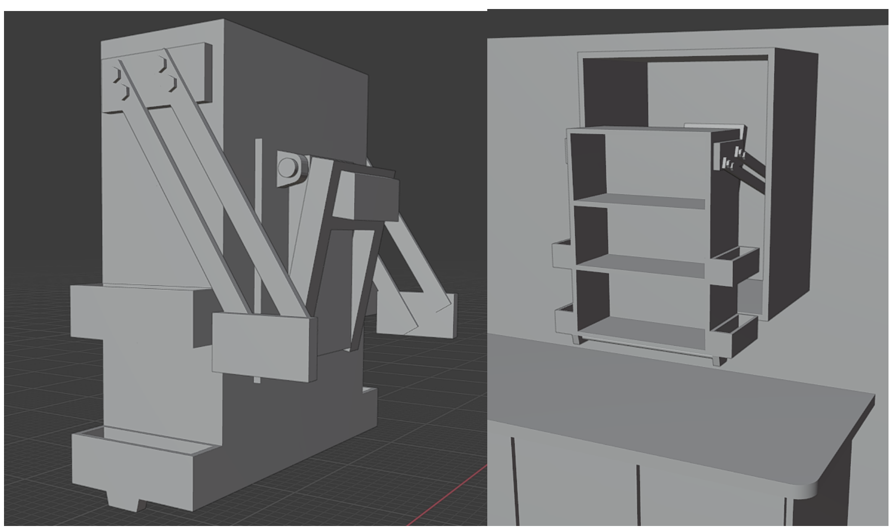


Figure 6.3.1.2. The pull-down mechanism of the design is depicted in these images.

Table 6.3.1. Performance of the Retractable Static Cabinet regarding the design objectives

Objectives	How this design meets the metrics
Minimizes work needed	• The user is only required to reach the height of ~1.4 m [19]. • User needs to reach 0.3m - 0.6m to access the handle, depending on the height of the user.

	• Brings entire shelf down 0.3m and pulling it out ~0.3m from the cabinet [28].
Efficiently utilizes space	• Utilizes around 70% of the original cabinet space (Appendix A).
Mechanism easily understood	• One single retractable motion (up and down) • User may need 3-5 tries to understand the design.
Load support	• ~ 35kg [29].
Organization	• 7 levels of organization. • User can store a variety of items.
Inexpensive	• ~550 USD [29] (Appendix A)

6.3.2 Vertical Conveyor Belt System

The vertical conveyor belt enables the position of items to be moved, making it accessible at low positions. The platforms on the conveyor belt are protruding out and the system is mounted against the wall. The system will be positioned vertically so that the items will be rotated along a path like a rectangle and containers will have VELCRO® underneath to attach onto the platform. The design is situated 0.45m[29] above the countertop. Providing easy accessibility to most users. Compared to the standard cabinet, the design can attain this space, allowing the entire vertical space to be utilized.

Design Size and Materials:

- Dimensions (Height×Width×Depth):
  - (1.2×0.8×0.2) m
- The main structural material:
  - Plastic containers
  - Stainless Steel alloys for the frame
  - Motors and electronics

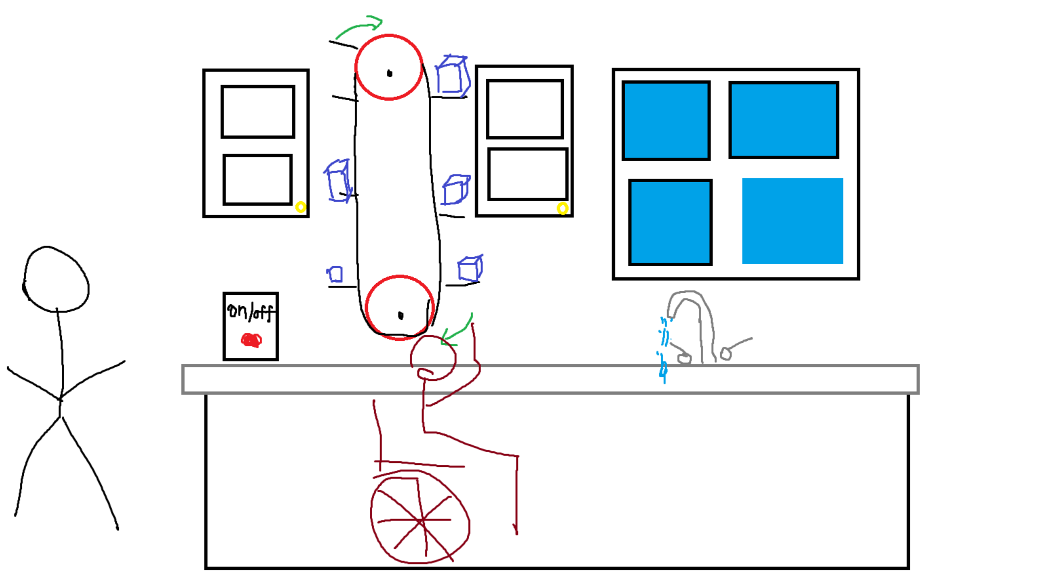


Figure 6.3.2.1 A rough sketch on MS Paint illustrating the vertical conveyer belt system in the kitchen space

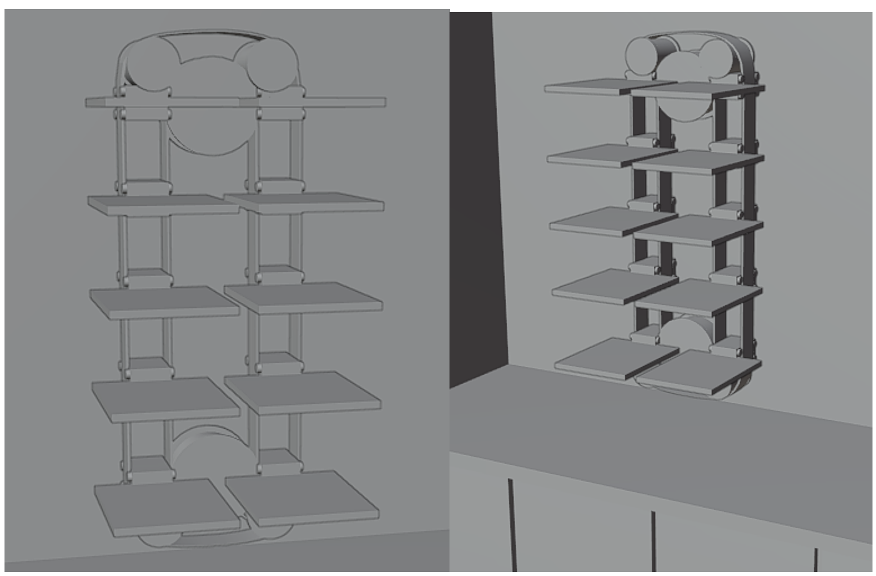


Figure 6.3.2.2 Models of the Vertical Conveyor Belt system.

Table 6.3.2. Performance of the Vertical Conveyor Belt System regarding the design objectives.

Objectives	How this design meets the metrics
Minimizes work needed	• Transfer object from an upper space to a lower space simply by pressing a button on a 0.9 m kitchen countertop [31]
Efficiently utilizes space	• Gains height of 0.35m of accessible vertical space. • Space o each platform is limited. • 50% of the typical cabinet space is utilized.

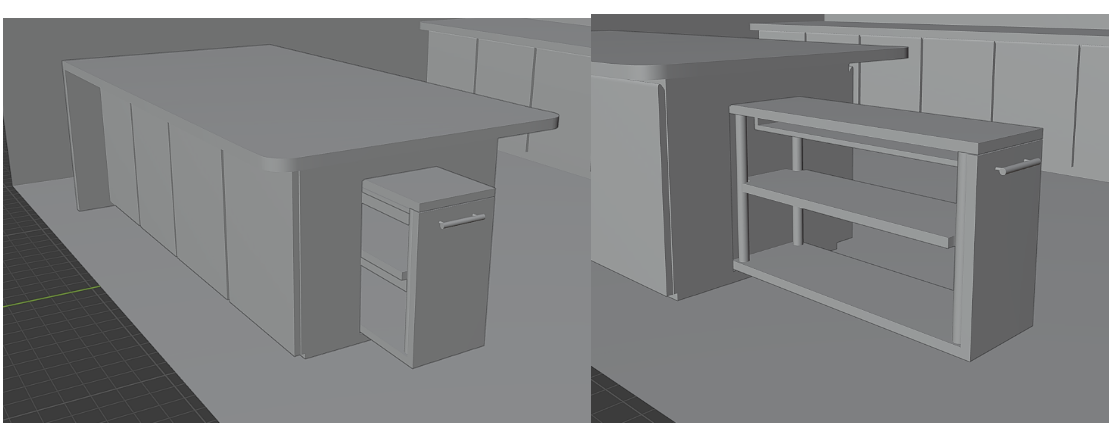
Mechanism easily understood	• Transport items via a horizontal platform that can be gravity actuated or powered. [32] • Motors or electronics.
Load support	• 454 kg [33] (Appendix B)
Organization	• Multiple levels of platform allow objects are arranged in an organized way.
Inexpensive	• > 400 USD

6.3.3 Multi-Functional Kitchen Island Storage System

The multi-functional kitchen island storage system is an extension for the kitchen island. This system allows the lower spaces of the kitchen to be used efficiently and enables the users to have extra countertop space. The kitchen island is an underutilized entity, as there is an abundance of empty space and a multitude of gaps. This design introduces a sliding storage space that fills this void. It is a shelved unit with a cover on top made from the same material as the island countertop. This top can then be raised into position, through four piston pillars residing on the corners of the unit, to sit flush with the primary countertop.

Design Size and Materials:

- Dimensions (Height×Width×Length);
    - (0.5×0.3×0.5) m
- The main structural material:
    - Steel alloy for the frame
    - Wooden or plastic surface
    - Piston pillars
    - Other materials vary



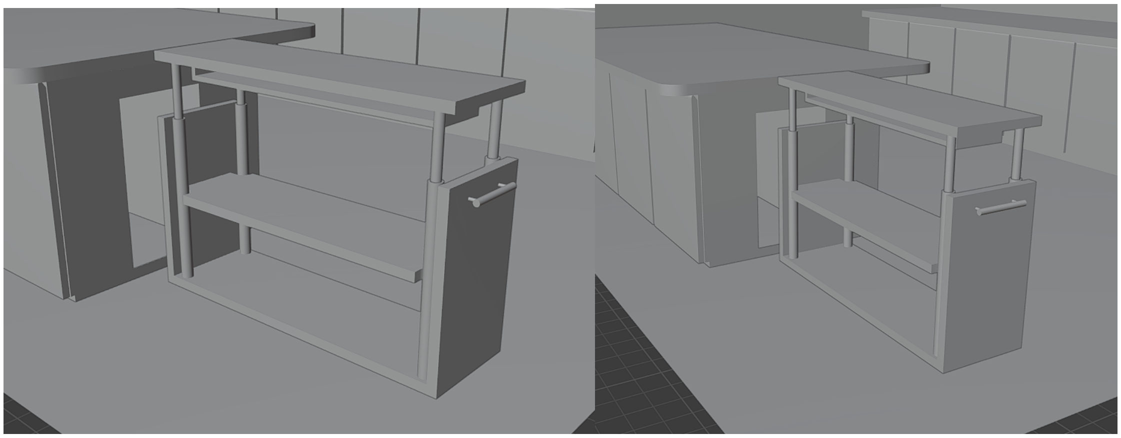


Figure 6.3.3. Models of the Multi-Functional Kitchen Island Storage System

Table 6.3.3. Performance of the Multi-Functional Kitchen Island Storage System regarding the design objectives.

Objectives	How this design meets the metrics
Minimizes work needed	• Moves primary storage beneath the 0.91m[31] countertop. • Accessible from both sides of the pull out
Efficiently utilizes space	• Adding on average $0.0675m^3$[34] of usable storage • Allows for selective use of the space, so the pull-out drawer and cabinet may be inserted back into the island to increase floor space
Mechanism easily understood	• Similar to typical kitchen drawer system • Slides in and out of the space on a sliding rail system • May be manually operated, or mechanically operated
Load support	• ~270 kg[33]
Organization	• Multi-level shelving unit that allows for categorized storage
Inexpensive	• > 400 USD

7.0 Proposed Conceptual Design

By analyzing the result obtained from the Graphical Decision chart and the Pugh method, the team decided to use the multi-functional kitchen island storage system as our proposed conceptual design.

This design highly utilizes the empty space inside the kitchen island and makes the kitchen island nearly 100% space efficient. Not only that, the raised surface space extends the countertop, and may be used for food preparation, serving, or as an extended eating area. The shelved unit below can be used to store kitchen wares or food products. Moreover, this product resolves the issues of accessibility to kitchen storage by providing ground level storages that reduces the need for vertical cabinets. Additionally, ground level storage may support greater loads, and thus withstand storing a greater amount of kitchen wares or food items, than a conventional cupboard. Hence, to have the accessibility of all kitchen storage and utilize the unreachable space, the design solution multi-functional kitchen island will be our recommendation.

8.0 Measures of success

The measures of success are tests that the team will conduct to measure how well the design meet its objectives.

To test each objective, the team will design a model to simulate the design. The storage extension is modelled by a hollow wooden rectangular box with 6 50kg dumbbells piled inside to represent the storage under maximum loading. Wheels are placed underneath the box for pulling. Four metal rods are wielded to each of the four corners of the box to represent the extended pistons and they hold on top of a wooden surface that represents the raised countertop. The model will not have the full functionality to raise or lower the wooden surface. The test results from table 8.0 will then be compared to each objective goal to understand the performance of the design.

Table 8.0: Tests that the team will conduct on the model to understand how the design meets each objective.

Objectives	Test for each objective
Minimizes work:	The force that the user must apply to use the design: • Calculation: Fa*cos(theta) = Ff (friction force) + Fn (normal force of the box). • Experiment: the team use a force gauge[35] to measure the applied force.
Utilizing space	Net volume that the design occupies: Calculation: • Volume of the wooden box) - 4*(Volume of the cylindrical rod) = net volume. • Net volume/volume of the box = available volume

Easy to operate	The team will let 25 – 50 people perform the following actions and ask how many tries it took them to understand using the model: • Pushing, pulling • Adding and removing weights from the box
Load support	The team will impact the model to test its durability: • Impact all angles to simulate accidents and bumps that could occur in the kitchen space. • Impact the wooden surface with a hammer to test the design's structure.

9. Conclusion

Through extensive filtration and reasoning and multiple idea selection methods, we have concluded that the Multi-Functional Kitchen Island Storage System to be the optimal solution.

What makes the kitchen island solution effective is its utilization of untapped space. Furthermore, the storage space remains closest to the ground compared to the other alternative designs, making it accessible to all heights. However, the numerous moving parts in this design can be prone to damage which is noted in the measures of success.

Nevertheless, we believe the Multi-Functional Kitchen Island Storage System to be the finest design as it best solves the gap of storage inaccessibility in American residential kitchens.

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Appendices

Appendix A: More on the Retractable Static Cabinet (RSC)

The dimensions of the Retractable Static Cabinet (RSC) is estimated with the standard upper cabinet size. The regular size of an upper kitchen cabinet is 76.2cm wide x 30.48cm deep x 91.44cm tall [1] and since our design will be pulled out of a regular cabinet, the dimensions of the RSC will be slightly smaller than a regular cabinet and we will use a dimension difference of 5cm. The RSC is supported by titanium extension arms that are

Width: 76.2 (regular width of a cabinet) - 4 (2 2cm thick extension arm on each side) - 5 (width difference) = **67.2** cm (our estimated design width)

Depth: 30.48 (regular depth) - 5 (depth difference) = **25.48**cm (estimated design depth)

Height: 91.44cm (regular height) - 5(height difference) = **86.44**cm (estimated design height)

The space that the RSC utilizes can be found by calculating the
Volume of RSC / Volume of a regular cabinet: (67.2 x 25.48 x 86.44) / (76.2 x 30.98 x 91.44)
Which equals 0.696. The RSC can utilize around **70%** of an upper cabinet storage space.

The cost of making the RSC will be expensive regarding our objectives and constraints. Through research, a metal shelf of similar design [2] costs around 400 USD (~510 CAD). It is made out of metal, so the price is more expensive than our design, but we are also using titanium and titanium is very expensive we estimated our design to be more expensive than the metal shelf. Therefore, the estimated price to build the RSC will be around 550 USD.

Appendix B: Calculations for the load support of the vertical conveyor belt system

Since the vertical conveyor belt system has about 2 times the height than the cabinet, we assume that is can support a load that is twice the load support for a standard cabinet.

2*(500 lbs)/(2.2lb/kg) = **454 kg**

Appendix C: The thought process of coming up with the functions of the design

We used the Blackbox method to help generate a list of ideas that will help us identify the functions for the design:

Input	Output
1 People that are vertically challenged cannot access upper kitchen storage	All users can access kitchen storage
2 People have difficulty using vertical upper kitchen cabinets.[36]	Vertical upper cabinet and storage spaces are easily accessed
3 Kitchen space outside of vertical cabinets are not utilized as much. [37] [38]	All available kitchen space is utilized.

Here is another list of black box method we used:

Inputs

- Storage is inaccessible in some areas
- Available space is not utilized for storage as it is inaccessible
- Storage requires bending to access
- Storage requires a long span to access
- People who are short, physically disabled, and old cannot easily access storage

Outputs

- Storage is easily accessed
- Available space is utilized for storage and is accessible
- Storage can be accessed without bending or reaching
- Storage does not require a long span to access
- Storage can be accessed by short, disabled and elderly people
-
- Of 2707 of U.S. renovating homeowners, 81% upgrade their cabinets and incorporate built in storage.
- Top reasons for install new built in storage:
    - 76%: Make better use of space
    - 56%: Make is easier to find items
    - 49%: Reducing clutter and organization
    - 44%: Utilize unreachable spaces
    - 14%: Make cooking and baking easier
    - 13%: Reducing the need to bend over

We used a picture to try help us understand what to look for in objectives:

Figure 1: This picture shows an example of a kitchen Appliance that meets our optimization goal: this storage space can be easily accessed by the vertically challenged and can provide the most storage area in a confined space [39].