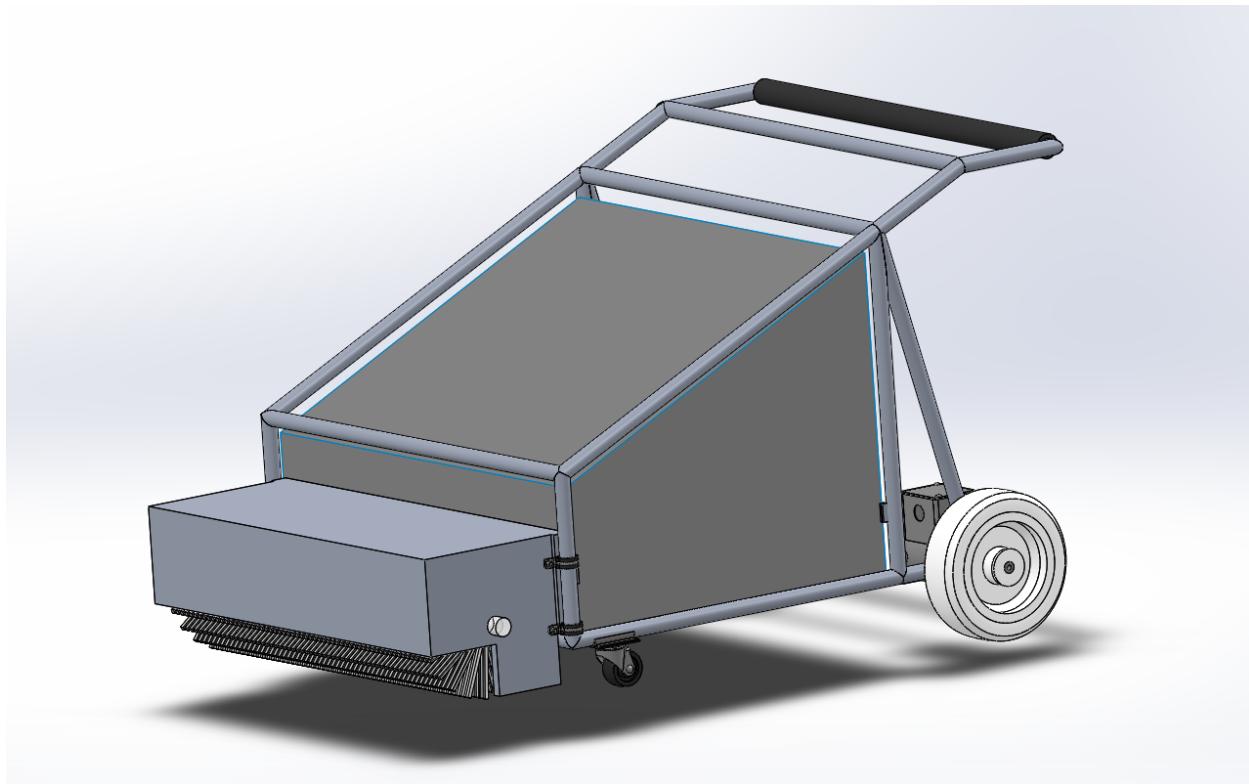


**FALL 2019**  
**MEC325: INTRODUCTION TO ENGINEERING DESIGN**  
**FINAL DESIGN PROJECT REPORT**



**DOMESTIC LEAF MANAGEMENT  
SYSTEM**  
**TEAM 0205**

# team declaration

We, the undersigned members of Team 0205 in MEC325, agree that:

- all team members have abided by all Ryerson Policies and course rules, and
- one of our members has shared a properly completed Workload Distribution Form with our Teaching Assistant and our instructor.

We furthermore accept that any violation of Ryerson Policy or course rules will lead to a grade penalty or charges of academic misconduct.

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# executive summary

Leaf management is a crucial system that is implemented in areas such as the GTA during Autumn.. Every year, thousands of leaves pile up in yards, only for homeowners to find ways to dispose of these leaves. Our team has designed a motorized leaf sweeper to provide users with a new and improved leaf management system. After viewing various leaf management systems via popular home improvement retailers such as Lowes and The Home Depot, the most efficient design for its price was the leaf sweeper. However, with many design flaws and lack of human factor consideration, our team saw an opportunity to innovate and design a superior product.

After thorough background research, it was found that pricing and ease of use were the most crucial factors for consumers. In addition, the size and storage capabilities were also influential factors when deciding on a leaf management system. Because of this, a lightweight and assistive design became the top priorities during the design process. By using higher caliber materials with a more efficient design, our team was able to minimize excess parts and keep the price within a consumer friendly range. In addition, keeping the product reasonable in size and collapsible for storage also became key factors in the design, as this allows for a greater audience for consideration as the design is able to accommodate diverse different lifestyles.

For the final design, the motorized leaf sweeper will feature a 12.6V battery that will power the spinning brushes and assist in movement. When the sweeper is in motion, battery assist will provide support in the mentioned areas to reduce the physical capabilities required by the users. A 26.5 inch brush is the optimal size to collect leaves in an efficient matter; any size bigger would result in excess weight which would slow the user down and any smaller size would result in more work needed. The device will be powered by a single switch along a bar between the handles. A hopper will be used for storage, featuring a removable bag for ease of usage. The device is intended for use of people aged 12 and up.

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# Introduction

## design brief

Domestic Leaf Management System

Overview

Every fall in the GTA, thousands of people collect leaves that have fallen from trees onto their properties, and “dispose” of them in some way. Some people “bag” the leaves for collection by the city; others compost the leaves; still others find other uses for them. However, many other people cannot do this activity (which can be enjoyable, meditative, and a healthy activity). **Design a way for one to manage the leaves on one’s property.**

### Background and Details

This effort is part of a larger coordinated project by a NGO to improve the general physical, mental, environmental, social, and economic well-being of individuals in urban and suburban areas, as well as creating more “livable” communities. Specific goals include to:

1. Cover all stages of leaf management from storage and maintenance of physical elements of the intervention (if any) through to ultimate disposal/treatment of the leaves
2. Encourage light-to-moderate physical and cognitive activity in those who would benefit from such exercise
3. Decrease the amount of “waste” collected by municipal waste management services, as well as other environmental damage / encourage sustainable living throughout the intervention’s life-cycle
4. Facilitate property maintenance for the sake of creating a healthy community
5. Accommodate different users that will invest different amounts of time and effort managing the leaves on their property
6. Remain both functional and usable for different climatic circumstances (e.g., soggy/wet leaves versus dry leaves)

The NGO recognizes that there are many existing solutions, but most of them assume

the users are already motivated to manage the leaves on their properties. The NGO is interested in new interventions that provide a more complete solution covering all aspects of leaf management.

New interventions may incorporate existing products in new and interesting ways to achieve the goals indicated above. Scalability is also important to accommodate different property sizes and number of people who may contribute to leaf management on a given property (i.e., a single person, versus a family of four).

Interventions that involve multiple physical elements must address the systemic and operational aspects of leaf management. For instance, simply directing a user to buy a rake and some (decomposable) plastic bags is unacceptable because it does not address how the user should best collect and dispose of the leaves; it limits who can use it and how long leaf management will minimally take; and it can easily result in repetitive strain and other types of injuries.

#### Other Notes

- The goals of lowering waste and environmental damage, combined with seeking to create healthier communities implies considering *all* relevant sources of waste, including noises, smells, etc.
- Storage and maintenance issues need to be addressed with respect to the targeted users as well as their types of homes and properties.
- Project scoping must include specifying the level of perceptual, cognitive, and physical ability required to use the intervention.
- Preference is given to solutions that can manage leaves on any ground surface typically found on urban/suburban properties.

# current situation

## initial research

### Goals

- Design a complete leaf management system including the collection, storage, and disposal of leaves, as well as any required maintenance of physical elements involved
- Make the device easy to store in both personal and business use
- Ensure the device can be accessible by the largest possible user group
- Decrease the amount of waste collected by waste management services
- Remain reliable and functional through different weather conditions
- The product should at least partially help improve physical, social, mental, environmental, and economic well-being of users
- Reduce the amount of waste collected by waste management
- Encourage sustainable living and design an environmentally friendly product

### Exclusions

- any aspect related to manufacturing and retail of product
- limitations on the size of property
- The method of disposal of leaves

### Users

- The sales and marketing team will be in charge of developing marketing opportunities and strategies

- User characteristics can vary, and may include landowners, maintenance workers, who are in varying degrees of health but are still mobile and have reasonable use of hands.
- Users can also have different backgrounds, with varying degrees of socioeconomic status. This includes newcomers to Canada, as they may not come from a climate with deciduous trees and therefore are unfamiliar with this aspect of lawn care.
- User's abilities can include full-to-moderate function of hands and arms, full range of motion in their back, use of their legs and have a relative degree of strength.
- User's disabilities can include various physical disabilities, including disabilities that limit the body's movements as well as heart conditions, as the activity is not necessarily strenuous on the body. Users with some mental disabilities would be able to complete the task.
- Users can be in different states of emotional and psychological being, as the activity requires the user to be relatively calm, may even be annoyed that they have to complete the task.
- Agents that may be positively affected by this task include the environment, as the user minimizes the waste made, as well as the economy in terms of creating manufacturing and maintenance jobs.
- Agents that may be negatively affected can also include the environment.

## Circumstance

- The design brief overview states that this product will be used with the Greater Toronto Area

- GTA consists of four regions: Halton, Durham, York, and Peel, as well as the City of Toronto
- Toronto is a large city with a dense population and lots of infrastructure [6]
- Humid continental climate (Koppen Climate classification)
- Many thriving forests, woodlands, temperate grasslands, temperate deciduous, temperate evergreen forests,<sup>[9]</sup> and coniferous forests. Within wetter areas, maple, spruce, pine, fir, and oak can be found
- Toronto has approximately 10 million trees (including trees located on sidewalks and government owned land, as well as parks, public places, and private property)
- First-world economy, thriving and growing
- Businesses/industries in the area: restaurants, malls, stores, factories, small farms
- Other notable geographic areas include: conservation areas, forests, reserves, parks
- For users in residential areas, noise is a concern
- One-person households: 520,000 vs. Couples with children: 824,000
- Average income: \$46,000 vs. Average household income: \$100,000
- 215,000 businesses Statistics for the GTA (Toronto Region) - all found on the City of Toronto website
- \*Note: numbers have been rounded

## Competition

### Rake

Figure 1. Amazon root assassin [10]

A rake is the most common and simple leaf management solution available. It consists of sharp prongs attached to a long handle, and functions similar to a broom.

#### Key features

- Least expensive solution
- Easy to store and transport
- Carbon-neutral to use (does not require a power source)



#### Users

- Able-bodied users
- Extensive motion in arms, legs, and wrist is required
- Due to low price-point, users will put up with using a rake even if it is not the most suitable option for them

The root assassin [3] is a current product that is being sold on amazon for \$45.

- Notable Points
  - Lifetime warranty
  - Lightweight (weighs 1.75 pounds)
  - Easy to transport and store

### Lawn Bag/Compost Bin for Storage

Compost bags and bins are used by people who place leaves on their curb to be picked up by waste management teams. In the GTA, in order for leaves to be picked up by the

city's waste management workers they must be placed in specific compost bins provided by the government or paper compost bags.

- Features
  - Large, therefore difficult to store and transport
    - However, the large size ensures greater capacity for storing leaves
  - Biodegradable, therefore sustainable
  - Lightweight
  - Easy to store when folded

Users who do not own a bin may use green compost bags, however, these bags must be purchased repeatedly



Figure 2. lowes brown paper lawn bag [5]

This paper bag from lowes priced at \$1.5 each has a capacity of 30 gallons, and holds sticks, twigs, clippings, leaves, and plant matter.

### Leaf Blower

Leaf blowers work by using a current of air to direct leaves in a particular direction. These require a power source to propel air, and are characterized by a nozzle where the air comes out of, as well as a handle to hold the tool.

- Users
  - Easy to use while on a wheelchair, depending on the size/shape of the model
  - Suitable for those with back problems
  - Does not require extensive motion in wrist, arms, or shoulders
  - Not suitable for those with weak muscles
  - Users must be able to lift a heavy product for prolonged periods of time
- Specifics
  - Noisy, therefore users may avoid using them early in the morning or in residential areas
  - More expensive than a rake
  - Useful for large areas because it requires very little physical exertion
  - More difficult to store than a rake



Figure 3. Black & decker electric leaf blower [8]

An electric leaf blower priced at 110\$ with shipping

#### Notable Features:

- Grinds 16 small bags of leaves down to one bag
- 3-in-1 blower, vacuum, mulcher

- Insight from Reviews:

- A 70-year-old woman says that it gets too heavy for her (10 lb weight)

- Tube falls off sometimes and blows leaves everywhere
- Major design flaw: plastic piece that attaches bag to device doesn't release when required - requires lots of fidgeting to get bag off

### Tow-Behind Lawn Sweeper

The tow-behind lawn sweeper is a larger version of the basic lawn sweeper, specifically made to hook on to the back of a lawn tractor for bigger yards. Driving the lawn tractor around the yard with the leaf sweeper attached will automatically collect the leaves as the person drives along.

- Features
  - Able to cover the largest area out of all the leaf management devices
  - Efficient and faster than other leaf management devices (driving is faster than walking with a manual sweeper or leaf blower)
  - Contains a large collection bin because the device is designed for larger areas
- Users
  - Users are limited by age - only users old enough to drive can use this device
  - Users are limited by ability - being able to drive is essential, and this is affected by eyesight, license, and financial status
  - Range of motion in arms and legs is not a necessity
  - Least physical exertion required (out of all the leaf management options)

Figure 4.Figure 5.Figure 4. Brinly-Hardy 42-inch Tow Behind Lawn Sweeper [9]

The Brinly-Hardy lawn sweeper can be hooked onto the back of a lawn tractor as shown in Figure 5. for a faster leaf sweeping solution. This product is sold at home depot for \$398.00.

Figure 5. Tow Behind Lawn Sweeper Hooked to the Back of a Lawn Tractor

This picture shows how a tow-behind lawn sweeper would be connected to a lawn tractor.

### Waste Management Comes Every Week to Collect Leaves

This is a key component of most people's leaf management routine in the GTA. The management process for most families ends when they put the collected leaves on the curb for the city to collect. A limitation of this is that the leaves are only collected on certain days/times. People lose the option of flexibility when relying on waste management collectors.

According to the city of Toronto [website](#), organic waste collected by waste management services is turned into compost (therefore it is environmentally friendly).

### Wheelbarrow

Wheelbarrows are used to transport leaves from one location to another. It is typically a large cart with a wheel at the front for mobility, and handles on the opposite side for driving.

- Specifications
  - Helpful for transporting large or heavy loads
  - Can be heavy if made of metal
  - Easy to drive on smooth terrain but impossible to use on pebbles or sand
  - Very strenuous to drive if transporting something heavy, specifically uphill
  - Typically large (therefore difficult to store)
- Users
  - Require full range of motion in legs
  - Usual design requires the use of two arms and hands
  - Strength capability is required
  - Not ideal for users with back or shoulder pain
  - Requires range of motion in wrist

### Shovel

Shovels are used to scoop leaves into bags. The design consists of a scoop attached to a handle, and they can be made of plastic, metal, or composite materials. Most Canadian homeowners own shovels as they are used in the winter to clear the driveway. Shovels come in a variety of shapes and sizes, and are sold for a wide range of prices. The design for the Aurora Tools Square Point Shovel is analyzed below.

- Specifications of the Aurora Tools shovel
  - 32.5 inch fibreglass handle
  - Tempered steel blade
  - Weighs 1.47 kg
  - Size of blade : 11.5 inches x 8.5 inches

- Users
  - Requires range of motion in arms and wrist
  - Requires bending of back
  - Requires a firm grip and dexterity



Figure 6. Aurora Tools Point Shovel

Figure 6. shows the Aurora Tools shovel which retails for \$31.50 CDN on amazon.ca.

#### Additional Products/hybrids

- Worx Tri-Vac: A leaf blower, vacuum, and mulcher combined
- Leaf Lugger: A large tarp that lies flat while users rake leaves onto it
  - Reduces the number of bags used
- Shredders - to cut leaves into small pieces

## Environment

- Climate environment of the GTA
  - Leaves drop from mid-september to mid-December
  - In 2019, the first snowfall occurred during the first week of November, covering any leaves that were not removed from properties
  - The sun sets at approximately 6 pm during the start of Fall (September)
  - Daylight savings time causes the sun to set at approximately 5 pm during (November and December)
  - Temperatures range from 7 °C to 9 °C, with some rainy days throughout the season

- During the first week of November 2019, wind speeds in Toronto ranged from 12 km/h to 33 km/h
- Physical environment
  - Urban areas with infrastructure, small lawns, crowded housing
  - Suburban areas with larger lawns including sidewalk patches
  - Public spaces with lots of trees that the city needs to maintain
- Design constraints derived from the GTA's Environment
  - Product must effectively collect wet leaves
  - Product should function in low lighting to maximize the number of hours in a day that it can be used
  - Users should be able to use the product comfortably while wearing thick gloves, jackets, and scarves
  - Product should be well balanced in windy conditions
- Environmental Issues
  - Air pollution
    - Air quality in large urban areas such as the GTA is a concern
    - 80% of people living in large cities are exposed to inadequate air quality according to the World Health Organization
  - Noise pollution
    - A concern in busy urban areas like Toronto
- \*Environmental issues will be discussed in greater detail in the product strategy section

# reference design

The reference design chosen for this project is a lawn sweeper, a lawnmower-shaped tool that uses rotating brushes to sweep leaves into a reusable plastic bag. The product is sold by *Coopers of Stortford*, a home and garden store in the United Kingdom.

- Specifications
  - Rotating nylon brushes
  - Adjustable brush height to control the amount of pressure applied
  - Rot-proof bag
  - Large Front wheels to drive over uneven terrain, twigs, and stones
  - Reusable plastic bag for leaf collection
  - 66-inch brush width
- How it works
  - Users position themselves behind the device, grasp the handle, and push
  - Rotating brushes collect leaves as sweeper is driven over them
  - Leaves are collected in the open bag attached to the device
  - The bag is detachable, allowing users to empty and reuse it
- What makes it better than other designs
  - More efficient than a rake (much faster and less effort)
  - Very lightweight - according to multiple customer reviews from amazon (actual product weight not available on Coopers website)
  - Works in damp conditions
  - Picks up acorns and twigs (according to 1 reviewer) which is not possible for leaf blower or vacuum
  - Does not require as much back-bending or arm exertion as a rake - more accessible
- Who can use the design
  - Users with back pain, weak arm muscles (bending and arm motion are not required)

- Users with limited mobility in wrist ( hands are stationary on handle during use)
- Users with some cognitive limitations - design is intuitive and easy to understand (no buttons, power supply, or extra parts)
- Who cannot use the design



Figure 7. [Victor Tools Lawn Sweeper \[4\]](#) - Depiction of the lawn sweeper used for the reference design

- User's with limited/no mobility in legs (pushing it while walking is required, and the handle is not adjustable so it is too low to use while on a wheelchair)
- User's with limited dexterity ( having a firm grasp on handle is essential)

# situated use cases and usage scenarios

Table 1.

SUC 1	Young girl cleans neighbor's lawns for money
Owner	Zaira
	On a Tuesday evening in October after returning home from school, 12-year-old Katie borrows her father's sweeper to clean the lawns of 2 elderly couples in her neighborhood to earn some money.

This SUC is included because the ability, strength, motor skills, height, and physical capabilities of a 12-year old user differ significantly from the average adult user. This scenario takes place after school in October, which means the user has very few hours of daylight to clean both lawns. This brings the efficiency of the product into focus, as well as the speed with which it allows the user to finish their task.

Figure 8. Usage Scenario 1

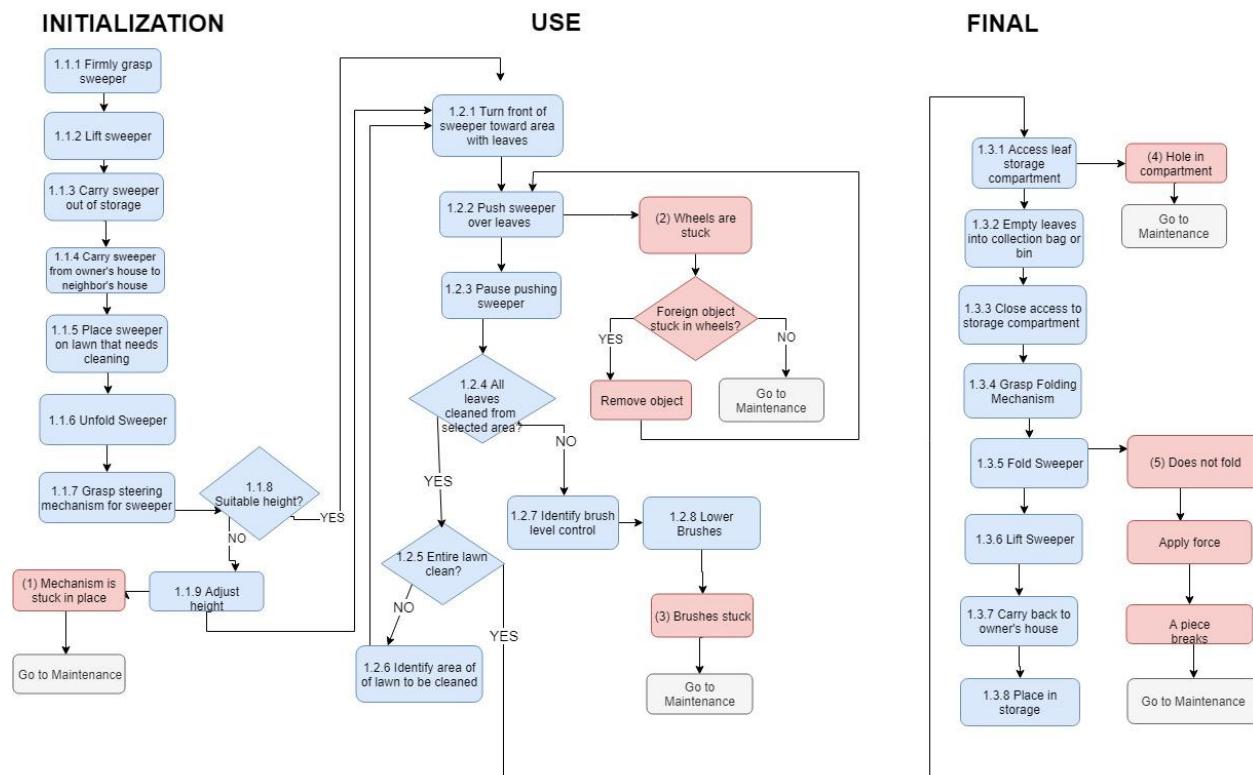


Table 2.

SUC 2	An old man is replacing a part on the leaf sweeper
Owner	Jesvin
	The user is replacing the wheel for the device and uses the provided owner's manual to understand how to do this. He's working in his poorly illuminated garage.

It's important for users to understand how their product works, and how it goes together, so that they can easily troubleshoot any issues that they might have with the product. This enables the user to be able to fix their own product, with little assistance from any third-party company to fix it for them, thus saving money on repairs/maintenance. A service manual can help the user work understand the assembly and disassembly of their product, as well as assist in diagnosing how to work it out. In addition, this SUC is dependent on the users strength, motor skills, precision, reasoning, and increased attention for vision because of the environment.

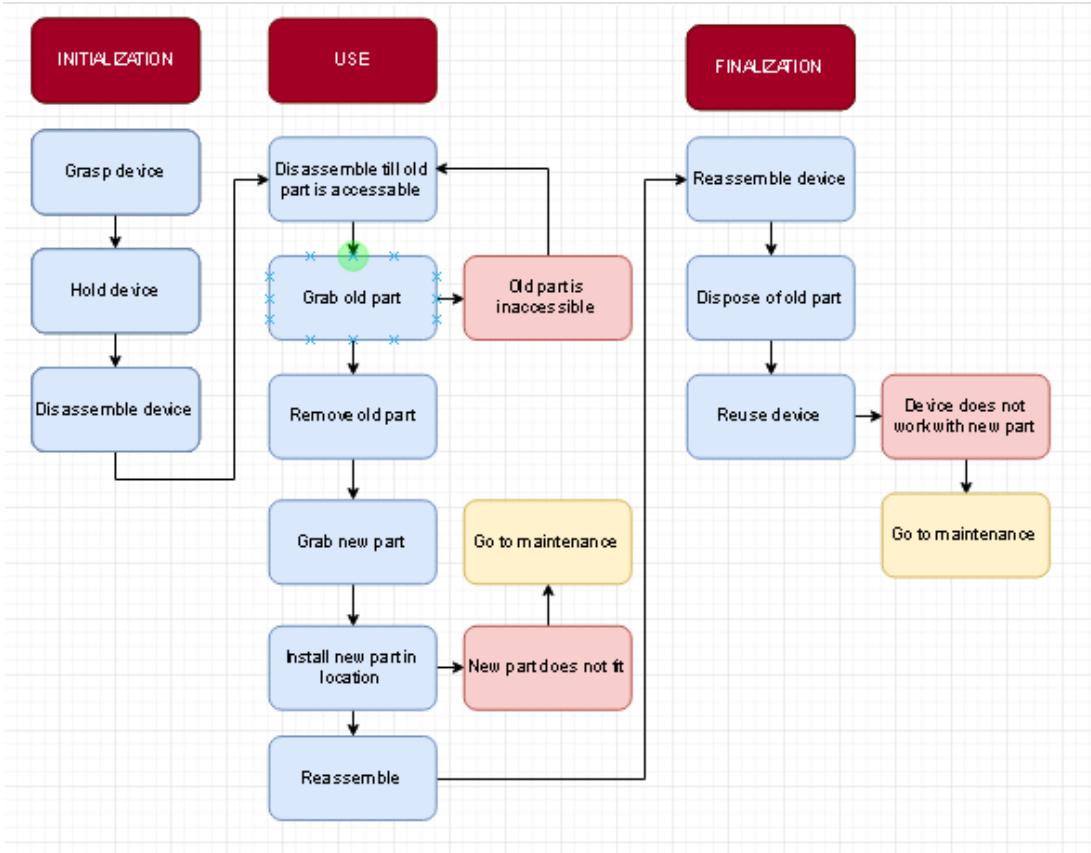
Figure 9. Usage Scenario 2

Table 3.

SUC 3	Collecting leaves across a very large area
Owner	Arpen
	A company cleaner is using an tow-behind leaf sweeper to collect the leaves of their large property.

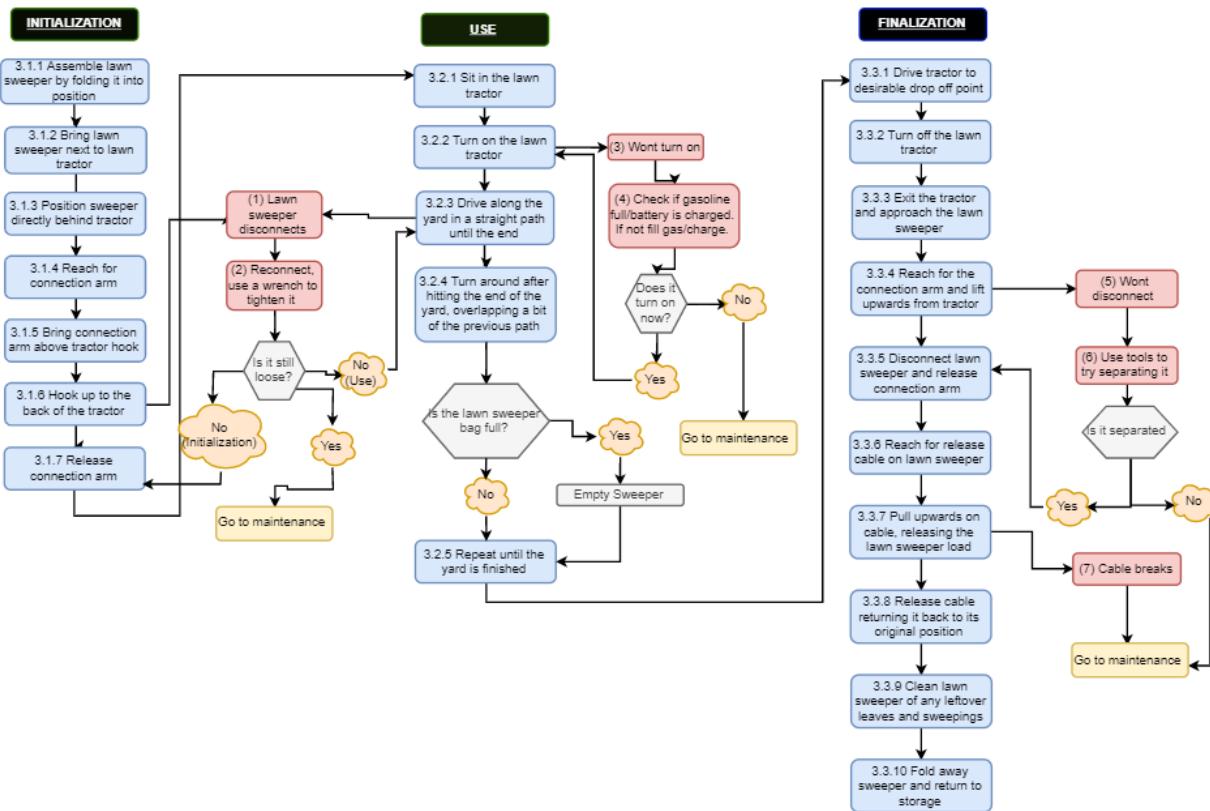


Figure 10. Usage Scenario 3

It's crucial for large lawn owners to be able to keep their properties clean using a fast effective method. A tow-behind lawn sweeper can attach to the back of a tractor and collect leaves as the tractor moves around. This SUC was included because the task can only be completed successfully depending on multiple human factors such as vision, strength, physical capabilities and high levels of body mobility and dexterity.

Table 4.

SUC 4	Person using the device after a rainstorm
Owner	Maggie
	A mother of young children is using the device on their lawn, which is host to a few large maple trees, and is trying to clean up his lawn after a light rainstorm that lasted a full day.

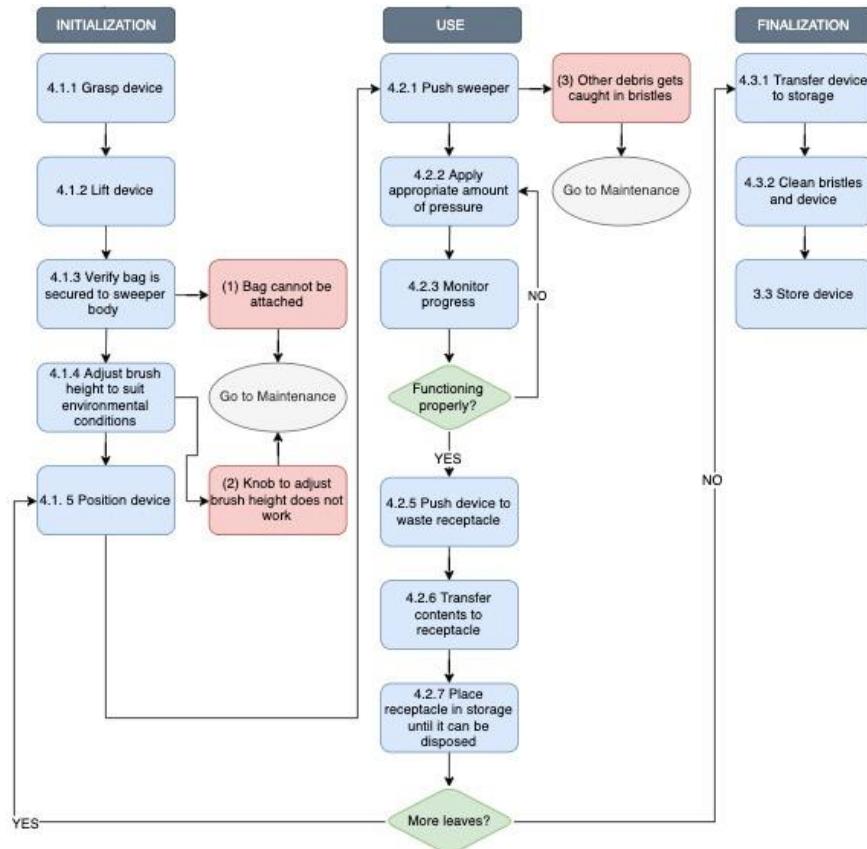


Figure 11: Usage Scenario for SUC 4

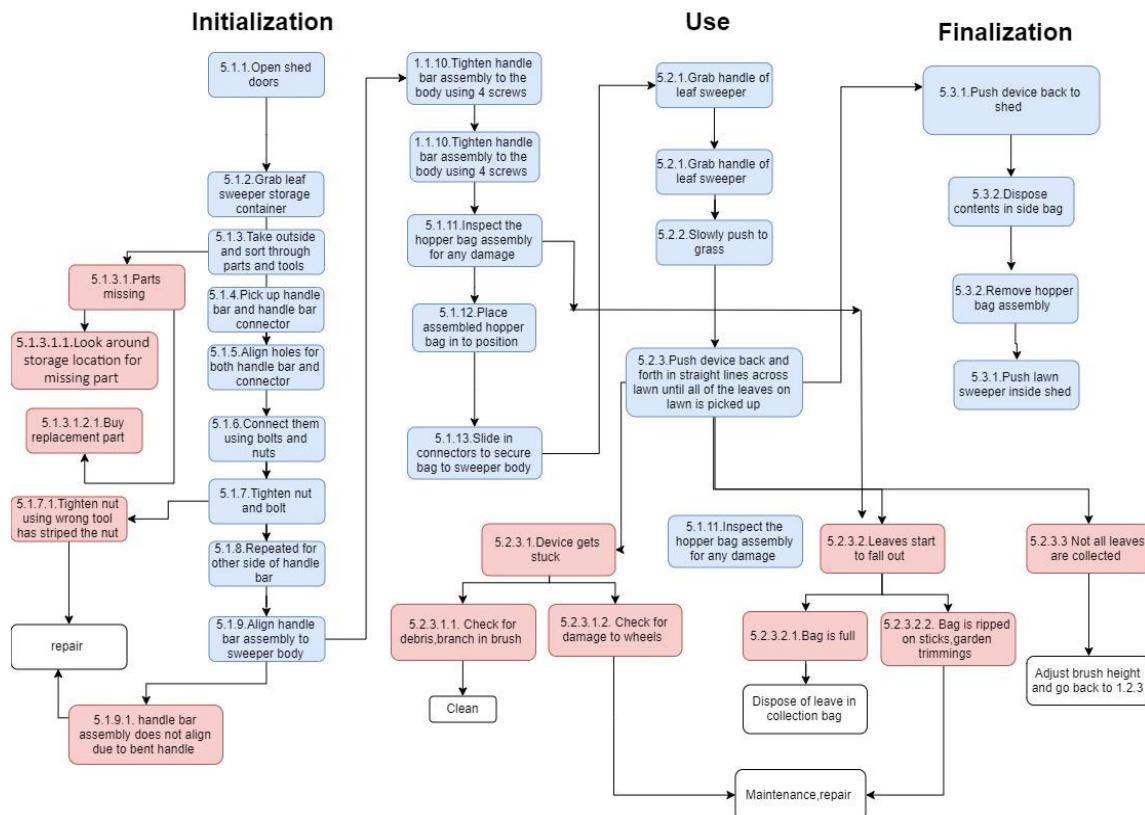
This use case was included as it draws on specific details that pertain to the user and the environment where the device is being used. The user's age and ability, as well as the age of the co-users, are factored into how the user would use the device. The mother is 35, and has fully functioning arms and legs, and her children are 5, 4 and 8 months. The device may or may not be able to pick up wet leaves, which can create the possibility for error. Prolonged use and the possible heavy weight of the leaves may impact the user's wrist. Her children may cause her to become distracted, which would make the task more difficult than if the user was completely focused.

Table 5.

SUC 5	Taking device out of storage for the first time and running a quick test
Owner	Janakan
	On a very cold November evening the user is walking home from the gym and notices leaves start to change colour. They decide to retrieve the sweeper from his small shed in the backyard for a quick test.

This suc is included as it brings up important factors such as the cold weather and the location he's walking from. Since he's walking from the gym, there's a good chance his bodies already exhausted and his physical performance will be decreased because of the workout. In addition, because of the very cold weather, the user is most likely dressed accordingly, wearing a jacket and gloves which could hinder the performance. As the device has been stored in the shed, it's probably at the very back in a hard to reach spot, with objects piled up on top it will be difficult to move. Furthermore, because of the long period it was kept in storage, problems might occur

Figure 12: Usage Scenario for SUC 5



# product strategy

Affordable and efficient leaf management solution that is usable for the largest group of people. Usability in this case refers to multiple aspects that make a product suitable for specific users, including cost, efficiency, storage space, varying levels of physical/cognitive abilities, and environmental impact. This product will improve the quality of life of the population of the GTA by saving them time, making their properties visually appealing, and turning leaf management into an enjoyable outdoor activity.

## Usability and user Breadth

- Maximize user breadth and usability
- Property owners and government employees managing the upkeep of public spaces
- A major barrier for users managing their properties is physical disabilities
  - Includes temporary or permanent injuries to back, legs, arms, wrists, fingers
  - Depending on the size of the property, tasks can become physically demanding over an extended period of time
- Our solution should not create any cognitive disabilities in users - it should be easy to understand
- Leaf management, when treated as a family activity can be more enjoyable
  - Users will be more motivated to manage leaves on their property if the process is enjoyable
  - For a family activity, the majority of family members should be able to utilize our solution
    - Includes children and elderly users
- Our product should be more affordable than its competition to ensure it is accessible for a large population of people
  - Should be as affordable as the average lawn mower, which is a very

common lawn maintenance tool found in many homes

### Market Segment

- Targeting users who are old enough to be concerned about property maintenance, and are looking for an **ongoing, permanent** solution
  - Children/teenagers do not fit the market segment
  - Not marketed to someone who occasionally cleans their lawn
- Homeowners, owners of large properties,
- Users who are not satisfied with a simple rake
  - Elderly people - rakes require physical exertion
  - Busy people - rakes require a time commitment
    - Young working adults
- Middle-class
  - Users that are very rich would likely pay a third-party to clean their lawns, therefore would not be concerned with the time or effort it takes
  - User's that struggling financially would likely invest in the least expensive solution regardless of the time and effort they have to input
- Product should be efficient and reduce the time spent on leaf management for busy, working families
- Product should be easy and comfortable to use for individuals with varying degrees of strength, physical abilities, and cognitive abilities

### Degree of Innovation

- A low-to-moderate degree of innovation will be required for the leaf management system.
  - Various leaf management solutions exist that are used by many, and effective at completing the task
  - Goal is to make minor improvements which make the process of leaf management easier, faster, and more enjoyable

- Users may become overwhelmed with a completely unfamiliar leaf management system, and choose the product they are used to
  - A system which functions similarly to existing product, but improves on them will be appealing to users
- More innovative products are typically less affordable due to the advanced technology they use
  - To keep our product affordable, the technology utilized will be common and inexpensive

### Functional Complexity

- System will be intuitive, simple, and easy to use
  - Increasing complexity will deter users who are looking for a quick and efficient solution
- Complex solution goes against our product strategy
- High degree of complexity will decrease our market segment size and user breadth because less people are able to use a complex system
- Higher degree of functional complexity will be less affordable (goes against product strategy)
- An overly complex product will not be as efficient and quick as a simple one
  - Efficiency is an important aspect of our product strategy
- To simplify our system
  - Clean interface
  - Only the most necessary choices or settings will be presented to the user
  - Minimal number of steps to completely manage leaves: collection, storage, disposal
  - Minimal maneuvering of product will be required

### Time to Market

- Product should be on the market by Summer 2021

- Users will use the system by Autumn, and therefore should be able to choose and purchase it a few months prior
- As the degree of innovation is low, only technology that is presently available will be utilized
  - Product will be marketed as fast as possible
- To minimize errors, a time span of 1 year is given to refine the design process
  - An additional year is given to outsource materials, test prototypes, and finalize the product

### Production

- Lawn mowers will be used to help predict the product demand
  - Lawn mowers are used by households for property management
  - The leaf management system targets a similar demographic (middle-class homeowners who are looking to maintain their properties)
- 86% of households in Ontario use a lawnmower (statistics canada, 2007)
  - Approximately 3.5 million households in Ontario (excluding apartments)
  - Therefore approximately 3 million potential users
- The system will need time to gain popularity, therefore we do not predict that all potential users will buy the product
  - Approximately 300,000 units will be produced
    - This figure will be negotiated and changed depending on the minimum production quota received from the manufacturing company

### Environmental Concerns and Maintainability

- Grass and soil quality should be maintained after use of the product
- Air pollution (from initial research)
  - Air pollution from carbon emissions, factories, and use of non-renewable resources causes smog

- Our product must minimize use of non-renewable resources in its production and as a power source
- Failure to do so will result in our product directly contributing to lung diseases, breathing problems, visibility problems, and decreased vitamin D in the GTA population
- This goes against our product strategy as we aim to improve the quality of life of the GTA population
- Water pollution
  - Levels of ocean acidity are increasing due to CO<sub>2</sub> emissions - will increase by 150% by 2100
  - Chemicals used on land are washed away into oceans and water bodies
    - Directly affects drinking water and the freshwater lakes on Ontario
    - Bioaccumulation and biomagnification in sea life negatively affects biodiversity, as well as the humans that ingest these organisms
- Biodiversity
  - Deforestation is increasing
  - Property owners who are frustrated with unmanageable leaves can contribute to the problem by cutting down trees on their property
- Fossil fuels and non-renewable resources
  - Using fossil fuels and non-renewable resources leads to air pollution, resource depletion, and ozone depletion
    - These should be avoided in the production of our product and in the power source
  - Non-biodegradable plastic used in our product will require oil for its production (non-renewable resource) and directly contribute to the problems stated above
- Carbon footprint
  - Carbon emissions are at an all-time high, and a contributor to climate change

- The production of regular plastic releases greenhouse gases into the atmosphere
- The burning of plastic at the end of a product's life cycle releases carbon
- Waste
  - Waste that ends up in landfills contributes to global warming
  - Like carbon emissions, burning of landfill waste releases carbon and methane
  - This can be avoided if materials are composted
  - Our product can make an impact by using biodegradable materials in its production, and collecting leaves that are composted as a final step in the system
- Noise pollution
  - Disrupts peace and disturbs nearby people/neighbors
  - Harmful effects on human hearing
  - Inhibits animal communication and hearing and disrupts ecosystem
- Design constraints derived from current environmental issues
  - Chemicals should not be deposited on soil or grass as a component of the solution ( ie. no chemicals to speed up the decomposition of leaves)
  - Air quality should not be compromised by greenhouse gas emissions from our system
  - Trees should not be damaged as part of our system
  - The solution should make leaf management an easy process to encourage property owners to plant/retain trees
  - Fossil fuels/non-renewable resources should not be used as a power source for our product, if applicable
  - Waste during production should be minimized
  - Components should be made of biodegradable or recyclable materials to minimize landfill contribution

- Replacement parts should be available to extend the life cycle of the product
- Consider: bioplastics such as algae plastic or polylactic acid (corn plastic)
- Using biodegradable material that is composted at the end of its life cycle reduces methane production, and can create useful substances like compost and renewable energy (Environment and Climate Change Canada, 2017)
  - Noise-pollution should be minimized during the use of our product
  - End of product life cycle (disposal) should minimize landfill contribution
    - Using bioplastics will ensure that minimal material ends up in landfills
  - Harmful chemicals and materials for which the extraction and use contributes to the issues listed above should be avoided in the manufacturing of the product

### Profitability

- 90% of smaller manufacturing companies operate with 10%-15% profit margins (study)
- Keystone pricing requires doubling the cost of a product to determine selling price
- To keep the product affordable, the final cost for the consumer should be less than \$150

### Risk

- Assessed on a scale of 1-3, with 1 being the least severe and 3 being the most severe
- Failure to market correctly
  - Likelihood: 2, severity: 3

- Successful marketing takes time and can be a trial-and-error process
- The market reaction can be unpredictable, however, market research and variety in marketing tactics can increase chances of successful marketing
- Consequences of failure: lose investment money, waste of resources, unable to sell the required number of units
- Manufacturing an unsafe product
  - Likelihood: 1, severity: 3
    - This is unlikely due to the heavy emphasis and amount of time spent on the design and planning stages
    - Product will be tested in several runs, and at various stages to test safety
    - Consequences: lawsuits and bankruptcy

### Cost

- Proportional to product features
- Existing leaf management solutions range from \$10 - \$300
  - Our direct competition, based on the reference design chosen falls around the \$100-\$200 range
- Cost of production per product will decrease as the number of units produced increases

### Customization

- Very few customizations to ensure that product remains usable for the largest group
- Customizations should increase usability and help specific users be more comfortable while using the product
- Adjustable features will be considered

# problem analysis

## preferred situation / expectations

### relevant human factors & personas

#### HUMAN FACTOR CAPABILITIES

##### Vision

HF Demand: The reference design was analyzed with regards to Table 1: Vision Categorization. There are no tasks associated with reading text while using the reference design, therefore the task of visually processing leaves on the ground was deemed the most visually demanding. The breakdown of the task demands can be found in the Vision Table in appendix. The Cambridge exclusion calculator was used to obtain the percent of population excluded from using the reference design. 3.5% of the population is excluded from using the reference design.

HF Capability: The team decided that there will be no change to the number of excluded users for our design. Using an online vision simulator, it was determined that a user with 20/160 vision would be able to distinguish a blurry shape and colour on the ground and identify it as a leaf to sweep. There are no steps associated with using the reference design that require reading of small fonts or very detailed vision. As the reference design only excludes the most severe case of complete vision loss, the team considers this a realistic goal for our design as well.

## Hearing

HF Demand: The values from Hearing analysis of reference design were used as inputs for the Cambridge exclusion calculator. An output of 2.2% for the value of population excluded was obtained. See Hearing table in appendix for justifications and reasoning.

HF Capability: Although 2.2% is a small exclusion percentage, our team feels we can reduce this number easily by making feedback sounds such as clicks louder than the estimated 20 dB sound of the reference design. According to the Wyoming EHDI, 16-25 dB is minimal hearing loss, and 25-40 dB is mild hearing loss. 4.74% of the Canadian population is deaf or hard of hearing (Canada Census 2006). A large portion of this percentage may not experience complete hearing loss. A 20 dB sound can be heard by anyone with minimal hearing loss, while a 40 dB sound can be heard by users with mild hearing loss. With a hearing aid, the number of users may further increase. As 40 dB is similar to the noise level of bird calls (Industrial noise control, n.d.), the team feels this is a respectful and non-invasive sound level for the click.

## Touch and Balance

HF Demand: The reference design requires that users be able to feel the handle, as well as any adjustment knobs for proper use of the device. Being unable to feel the device will cause problems while driving and steering. Peripheral nerve damage (PND) causes damage to the nervous system and causes numbness in the hands, which can decrease one's sense of touch and balance (National Comprehensive Cancer Network, 2019). Conditions associated with PND include diabetes, cancer, and autoimmune diseases, spinal cord injuries, and vitamin B deficiency.

- Statistics for Canadians
  - 7% diagnosed with diabetes in 2017 (Statistics Canada)
  - 50% expected to develop cancer (Government of Canada, 2017)
  - 19% live with arthritis and autoimmune diseases (Government of Canada, 2017)

- 3-5% have insufficient levels of Vitamin B (Statistics Canada, 2011)

Averaging the numbers above shows that approximately 19% of people are predicted to be affected by one of the conditions. Not every user affected by a condition will develop PND, therefore it is predicted that approximately 15% of people may experience PND and experience difficulties with touch while using the reference design. The number of excluded users for balance is much lower, as the handle of the reference design functions as a stabilizing hand-rail throughout its use.

**HF Capability:** The team aims to reduce the excluded number of users for the new design. The reference device does not contain any features to help increase the sense of touch and to improve grip. Adding such features will help include users with mild-moderate PND, and exclude only severe cases, as opposed to excluding any user with any form of PND. Thus the new target population exclusion is no more than 10% for touch, while the balance exclusion rate will stay the same at 0.1% (most severe cases).

### Cognitive (Memory and Reasoning)

**HF Demand:** The Cambridge exclusion calculator was used to estimate the level of memory and reasoning required to use the reference design. The task was deemed most similar to filling a bath, as both tasks require users to monitor progress (is the bathtub full vs. is the leaf storage compartment full) and make a decision to stop (the tub is full enough vs. the lawn is clean). The calculated value of exclusion was 1.6%.

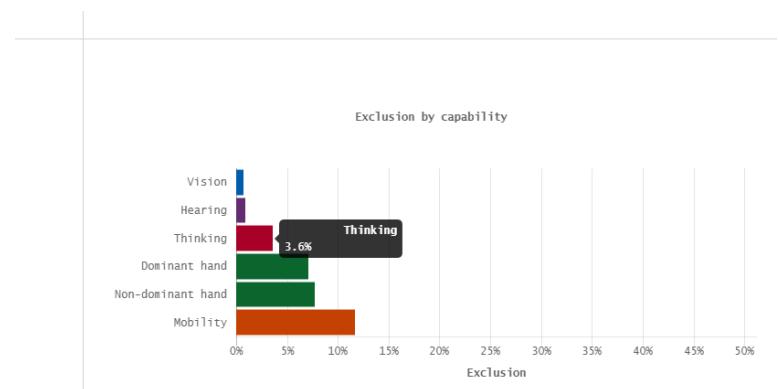


Figure 13.

HF Capability: The reference design does not require any complicated steps, and the back and forth motion of using the design is easy to remember. However, the team aims to make minor improvements, such as the addition of large labels and feedback indicators on the design that can help reduce the excluded numbers marginally. Thus the target exclusion rate is no more than 1%.

### **Strength**

HF Demand: The liberty manual material analysis tool was used to estimate the HF demands of using the Reference design. See Strength table in appendix for details and justification. The estimated exclusion is 10% of males, 16% of females.

HF Capability: The team considers it realistic to decrease this exclusion rate by 5% for both genders. Regardless of the final design, lighter materials can be used to decrease the weight of the weight of the product and the strength required to carry or drive it. In all cases, several aspects of the product can be redesigned to be lighter and easier to move. However, the task of cleaning leaves is physically demanding, and some endurance will be required. Therefore, a new realistic target exclusion rate of 5% of males and 10% of females is set.

### **Mobility:**

HF Demand: The Cambridge Exclusion Calculator was used to estimate the number of excluded users for mobility. The reference design requires continuous walking at a moderate pace to facilitate the rotation of sweeper brushes. A calculated 11% of the population is excluded from using the design. The calculator only takes mobility in terms of walking into account, and does not consider mobility in the arms, shoulders, and back. The team feels that these types of mobility are equally important for using the reference design. Therefore the team has decided to increase the percentage of excluded users to 15% to account for users who may have any mobility issues, not just walking.

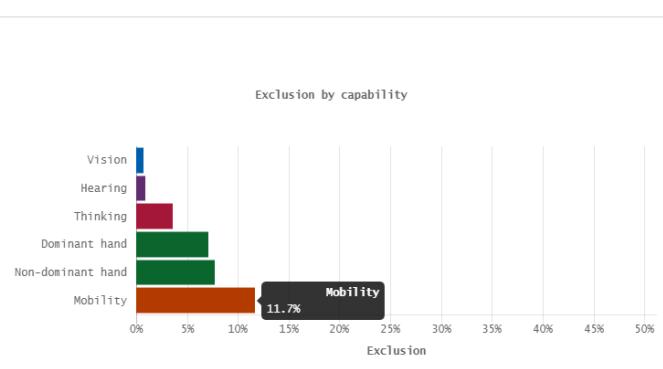


Figure 14. Exclusion by capability; mobility

**HF Capability:** The number of excluded users for this HF demand is significantly higher than the others. The team aims to keep the percentage of excluded users under 10% where possible. The task of clearing leaves off one's property requires movement, as leaves are scattered, therefore it is unrealistic to assume that every user with mobility issues should be able to use our design. The team has decided that a 10% reduction in excluded users is realistic, leaving no more than 5% of the population excluded from using the reference. This number is closer to the exclusion percentages for the other HF capabilities, and ensures that a significant portion of the population is not excluded.

### Dexterity

**HF Demand:** Usage of the reference design requires dexterity in both hands. In multiple steps of the team's usage scenarios, dexterity is required to grip the handle of the device, to use controls for brush adjustment, and to hold empty the leaf storage bag. Based on these tasks, the cambridge exclusion calculator was used to estimate an exclusion percentage of 7.1% for use of dominant and non-dominant hands. This percentage includes dexterity, reach, and lifting strength.

**HF Capability:** The team aims to reduce the number of excluded users to be below 5% so that the new exclusion rate matches the other HF demands.

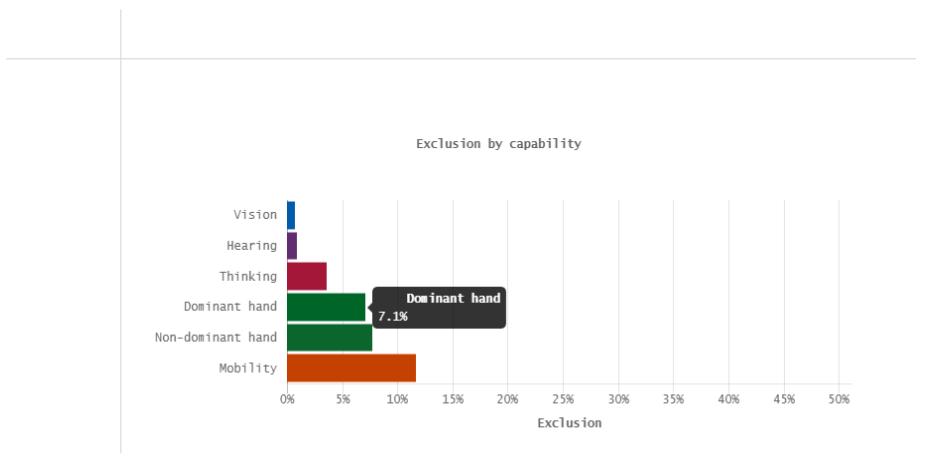


Figure 15. Exclusion by Capability: dominant and non-dominant hand

## PERSONAS

### Persona 1: Leila, Owner: Zaira

Leila is a twelve year old girl who was diagnosed with mild myotonic muscular dystrophy at the age of 3. She is very independent and active, and loves helping her family and friends with any tasks they need to get done. She is very intelligent, with good perception and cognitive abilities, however she is living with some physical disabilities due to her condition.

### Leila's disability: Myotonic Muscular Dystrophy

- Her symptoms are mild and non-life threatening
- Her muscular system is weakened, and she tires easily
  - Once she contracts her muscles, she can have trouble relaxing them
  - Her muscles can spasm, and are weak

- Her condition worsens in cold temperatures
- She has mobility in her arms/legs
- Mild vision impairment which is corrected with prescription glasses (-2.25 prescription)

### Personal Information & Characteristics

- Female, age 11
- She is 4"10, and weighs 89 pounds
  - Her slight build means she has trouble lifting very heavy or big objects, as well as seeing over tall objects
- She loves being physically active, although she gets frustrated when she gets tired or slows down
  - She often ignores how tired she is and must be reminded to take breaks
- Lives in a bungalow in Mississauga, Ontario

### Education

- She is in grade 6, a year behind her peers due to taking time off school for regular physical therapy sessions
  - She was upset about being a year behind her peers, as she is very smart and always does well in school
  - As a result, she is very determined to perform tasks independently to prove her intelligence and capability
- Attends a public school in her neighborhood

### Family Life

- Has a supportive, loving family
  - Her mother and father both work, and they are a middle-class family with no apparent financial struggles
  - She has a sister who is 2 years older, and a 5-year-old brother
    - They are close friends who love playing outside together
    - Her siblings ensure that Leila takes frequent rest breaks when playing games requiring moderate physical activity
  - Her family lives in a bungalow in Mississauga and she spends a lot of time playing in her front and backyard

### **Persona 2: Owner: Jesvin**

James is a 28 year old auto mechanic. He works long hours, even during weekends to make ends meet. He is recently married, with a child on the way. He has excellent mobility, and is very strong. However he has issues with feeling in his right hand, resulting from a burn that he sustained many years ago in a welding accident.

### **Personal Information & Characteristics**

- Male, age 28
- Married, expecting first child soon
- High levels of strength
- Lives in a semi-detached home in North York
- Height 5'11", Weight 225 lbs
- Active, exercises regularly
- Severe burns in right hand from welding accident

Education:

- High school diploma
- Auto Mechanic apprentice at Mohawk college

Family:

- Recently married (1 year)
- Has his first child on the way

**Persona 3: Owner: Arpen**

Auston is a 34 year old father who is currently a construction worker. He typically works long hours and intense shifts due to the nature of his job. He lives with his wife and 2 young children in Caledon. He is very strong and has excellent dexterity and mobility, however he has poor memory and hearing due to an accident a couple years ago.

Personal Information & Characteristics

- Male, age 34
- Married, 2 children
- 6'3 and weighs 226 pounds
- Lives in a townhouse in Caledon, Ontario
- Ethnicity: Mexican
- Strong build due to high levels of activity, well conditioned

Education

- High School Diploma
- College Diploma from Humber College - Carpentry and Renovation Technician

### Family Life

- Has a loving and supportive family
  - He has 2 young daughters aged 6 and 2 years old
- Currently, the family is mostly debt free with minimal financial struggles due to Auston and his wife's putting in long hours at work

### Auston's Weaknesses

- Weak hearing, 10 to 40dB loss
- Poor memory, can recall information that occurred during the day but has difficulty remembering specific details from the previous day

### Persona 4: Owner: Maggie

Erin is a thirty-five year old Caucasian high-school teacher who is the mother to three young children under the age of five. She recently gave birth in February via C-section and currently suffers from postpartum depression, for which she sees a therapist weekly. She is very empathetic, good with children and intelligent, but finds herself tired very frequently because of the work and effort needed to take care of her children. Erin and her husband have a very good marriage, and he helps out with the children when he is home from his job as a high-school teacher. She runs weekly, and is in moderate physical condition. She is very familiar with yard work and her husband recently purchased the lawn sweeper this past summer. Her goal is to complete yard work as quickly as possible during her baby's naps.

### Physical Characteristics

- She is 5'4" and weighs 170 lbs, has full range of motion in her arms, legs, back and neck, with a slightly stiff left wrist from a bad break when she was 19
- 20/60 vision, wears contacts during the day to help her see
- Moderate physical activity
  - Runs weekly
- Moderate physical condition
- Ethnicity: Caucasian
- Prone to migraines, can make simple tasks difficult and especially difficult with a new baby.
- Left wrist can become stiff when used in hard physical labour as it was improperly healed after it was broken when she was 19

### Behaviour Characteristics

- Good with children
- Empathetic, Intelligent
- Suffering from postpartum depression
  - Sees a therapist weekly
- Very tired most days because she has to look after her kids
- Wants to get yard work done as quickly as possible

### Education

- University bachelor's degree in Child Studies from Ryerson University

- Teachers College diploma

### Family Life

- Happily married to her husband of seven years
- Lives in a detached home in Vaughn, Ontario
- Husband is also a high-school teacher
- Has three children under the age of 5
  - They are 5, 4, and 8 months old.
- Recently gave birth in February of this year through a C-section
- Currently on maternity leave

### Persona 5: Owner: Janakan

Billy is a caucasian 25 year old single male. He works in a factory as a labourer handling chemicals used to create bath products. He is currently living in a townhouse basement with his parents. He is mentally deficient, with low reasoning and IQ. He loves to paint pictures of nature even though he has seasonal allergies, and he is aiming to become a future artist. Some things that he gets frustrated about is aesthetics, since he's a painter he always wants everything to look nice.

### Physical Characteristics

- Single male, age 25
- Height 5'7, weight 160lb
- Lives in a townhouse basement in Scarborough, Ontario
- Active, exercises regularly
- Mentally deficient, poor reasoning and low IQ

Education

- High School Diploma
- Iq of 75

Weakness

- Poor reasoning capabilities due to mental deficiency
- Very Low IQ
- Seasonal allergies

**interaction errors**

Table 7. Interaction Error Number 1

<b>IE</b>	<i>Placement (3.1.5.4)</i>		
<b>Context</b>	<i>Auston tries hooking up the sweeper to the tractor but the connection is loose and won't stay on.</i>		
<b>Impact</b>	<p>Impact = 2 + 2 + 3</p> <p>Likelihood: A loose connection will likely happen a few times over the product life cycle.</p> <p>Exclusion: Significant users will experience this due to physical capabilities required and accuracy.</p> <p>Severity: Failure to secure connection will not allow product to operate.</p> <p>Impact = 7</p>		
<b>SII 1</b>	Dexterity and Precision	6/10  User must move connection arm to a specific point to lock.	5/10  New design should have easier and faster locking mechanism. (Thus, lower target value)

Table 8. Interaction Error Number 2

<b>IE</b>	Assembly (3.1.1.2)		
<b>Context</b>	Auston is having difficulty folding up the sweeper due to its complexity.		
<b>Impact</b>	<p>Impact = 3 + 3 + 1</p> <p>Likelihood: At first, almost all users will experience a setback from folding up the product. This will almost continue periodically for some users throughout its lifecycle.</p> <p>Exclusion: Almost all users will be affected by this at least once.</p> <p>Severity: Minor inconvenience, will not affect performance only storage.</p> <p>Impact = 7</p>		
<b>SII 1</b>	Reasoning	8/10	5/10
		Must be able to visualize the final assembly to set up.	New design should be a simple and intuitive pull out design. (Less reasoning required)

Table 9. Interaction Error Number 3

<b>IE</b>	Assembly (3.1.7.7)		
<b>Context</b>	After trying to connect the connection arm to the tractor hook, too much force was applied and Auston ended up breaking a piece		
<b>Impact</b>	<p>Impact = 1 + 1 + 3</p> <p>Likelihood: Fairly unlikely, user must be very strong for this to happen.</p> <p>Exclusion: Small but visible group of people will be excluded.</p> <p>Severity: Breakage of any connection piece results in total product failure, must be fixed or replaced.</p> <p>Impact = 5</p>		
<b>SII 1</b>	Strength	5/10	10/10
		Over use of force caused breakage.	New design should be less stiff and easier to move around.

Table 10. Interaction Error Number 4

<b>IE</b>	Placement (3.1.3.6)		
<b>Context</b>	Auston is having trouble connecting the sweeper to the tractor because both sides move away during connection.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p>Likelihood: This is a common issue that users will experience if they are</p>		

	<p>assembling alone.</p> <p><b>Exclusion:</b> Most users will be excluded due to increased difficulty when multitasking.</p> <p><b>Severity:</b> Will cause product not to perform task, however no failure because it hasn't been damaged or degraded.</p> <p><b>Impact = 6</b></p>		
<b>SII 1</b>	Sturdiness	6/10	8/10
		Wheels and unequal weight distribution affect sturdiness.	New design should have better balanced and weighted design.

Table 11. Interaction Error Number 5

<b>IE</b>	Usage (3.2.4.1)
<b>Context</b>	Auston is having difficulty emptying out the lawn sweeper bag when its full.
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p>Likelihood: Likely to occur a couple of times throughout lifecycle for most users.</p> <p>Exclusion: Significant amount of people will be excluded, despite the</p>

	<p>strength of some users its a lot of load to bear one the users back.</p> <p>Severity: Will affect overall performance because product cannot perform when bag is full.</p> <p>Impact = 6</p>		
<b>SII 1</b>	Accessibility	4/10	6/10
		Old design has poorly designed system to empty bag	New design should be simple and assist with motion.

Table 12. Interaction Error Number 6

<b>IE</b>	Usage (3.2.2.8)		
<b>Context</b>	Auston is driving around the yard but the sweeper is not collecting all the leaves. Upon checking the product, he realizes that the bristles and product are worn out.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p>Likelihood: Will occur several times while user is trying to collect leaves but the product fails.</p> <p>Exclusion: Improper maintenance is common and will affect most users.</p> <p>Severity: Failure to maintain product will slowly degrade performance over time.</p> <p>Impact = 6</p>		
<b>SII 1</b>	Ease of Maintenance	5/10	10/10
		Due to poor maintenance the sweeper has been worn out and is not as effective as a result	New design should have easy maintenance protocols to ensure product will work when needed

Table 13. Interaction Error Number 7

<b>IE</b>	Disassembly (3.3.4.3)		
<b>Context</b>	After using the sweeper, Auston is having a tough time disconnecting it.		
<b>Impact</b>	<p>Impact = 2 + 2 + 1</p> <p>Likelihood: Common issue, most users will face this throughout product cycle.</p> <p>Exclusion: Significant users will face this due to physical and cognitive capabilities required.</p> <p>Severity: Minor inconvenience, since task is done it will only affect disassembly.</p> <p>Impact = 5</p>		
<b>SII 1</b>	Disconnection after usage	6/10	10/10
		Old design has poor locking mechanism	New design should have simpler but secure locking mechanism

Table 14. Interaction Error Number 8

<b>IE</b>	Breakage (3.3.7.5)		
<b>Context</b>	After pulling on the release cable, there was too much tension and the upwards force caused it to snap and break.		
<b>Impact</b>	<p>Impact = 1 + 1 + 3</p> <p>Likelihood: Uncommon, user must posses high strength.</p> <p>Exclusion: Only a few users will be excluded from this situation due to high levels of strength.</p> <p>Severity: Major issue, total product failure.</p> <p>Impact = 5</p>		
<b>SII 1</b>	Strength	5/10	10/10
		Over-strength caused cable to snap	New design should feature much stronger materials and cables

Table 15. Interaction Error Number 9

<b>IE</b>	Breakage (3.3.9.9 )		
<b>Context</b>	During the cleaning phase, Auston applied too much force to a delicate section and cracked one of the components.		
<b>Impact</b>	<p>Impact = 1 + 1 + 2</p> <p>Likelihood: Only a few users will experience this problem due to excessive force.</p> <p>Exclusion: Fairly low amount of users will damage and crack a component through force.</p> <p>Severity: Substantial damage, will degrade performance depending on the type and location of damage.</p> <p>Impact = 4</p>		
<b>SII 1</b>	Strength	6/10 Poor materials caused easy breakage	10/10 New product should feature much stronger materials

Table 16. Interaction Error Number 10

<b>IE</b>	1.1.3.1		
<b>Context</b>	Leila finds the sweeper handle uncomfortably high, but doesn't adjust it because there is no indicator on the device that the handle is adjustable. She continues to use the device to get her yard work done. She tires quickly from holding her arms at an uncomfortable height and has to stop mid-task.		
<b>Impact</b>	<p>Likelihood: 2; The device is designed for the average user, so many users will not need to adjust handle height. However, there still are a significant number of users who would benefit from minor adjustments.</p> <p>Exclusion: 2; If there is no indicator on the device, it is impossible for users to know that the handle is adjustable regardless of any human factor indicators. Everyone who needs an adjustment can be affected.</p> <p>Severity: 3; A device that is uncomfortable to use will not sell, and cause users pain and possibly injury.</p> <p>Impact = 2 +2+3 = 7</p>		
<b>SII 1</b>	Time	>15 seconds	<5 seconds
		A hidden or non-existent indicator will take more than 15 seconds to search for, after which they will likely give up searching.	A clear indicator should be very easy and quick to find

Table 17. Interaction Error Number 11

<b>IE</b>	1.1.6.2		
<b>Context</b>	Leila attempts to carry the sweeper out of her lawn but she cannot find a good place to grip it. Halfway through carrying it, she drops it on her foot and injures herself.		
<b>Impact</b>	<p>Likelihood: 3; Without a handle users will hold the device from anywhere and chances of dropping it are very high.</p> <p>Exclusion: 3; Gripping things without a clear carry handle is very difficult for everyone, and this can affect every user of the device, as they will likely have to carry it at some point.</p> <p>Severity: 3; Dropping the device is a serious cause for injury. An unsafe product is inadequate and this is seen as product failure.</p>		
<b>SII 1</b>	Size	0	3
		A carrying handle or similar part to make carrying easier is not present on the device or is too small to be seen.	The handle should be significantly large (enough to be clearly identified).
<b>SII 2</b>			

Table 18. Interaction Error Number 12

<b>IE</b>	1.1.9.3		
<b>Context</b>	Leila attempts to adjust the height of the steering control, but as she attempts to hold the mechanism she is unable to get a grip because her fingers are spasming.		
<b>Impact</b>	<p>Impact = 1+1+2</p> <p>Likelihood: Issue will rarely occur and is dependent on prior conditions and environment.</p> <p>Exclusion: Small but noticeable amount of users will be excluded</p> <p>Severity: Causes temporary product failure due to inability to handle it, however once spasm is over product becomes usable</p> <p>Impact = 4</p>		
<b>SII 1</b>	Size	1 in	2
		1 inch is a standard size for buttons and knobs, but can be hard to grip	Doubling the size will provide a greater surface area to get a grip on
<b>SII 2</b>	<p>as above</p> <p><i>optional - there can be many SII's for each IE</i></p>		

Table 19 Interaction Error Number 13

<b>IE</b>	1.2.4.4		
<b>Context</b>	Leila stores the product away with mud and dirt still on the brushes, because she was unable to distinguish dirt from the bristles as the colours are too similar.		
<b>Impact</b>	<p>Impact = Likelihood + Exclusion + Severity</p> <p>Impact = 2+2+2 (When there is little light, even those with great eyesight cannot see, they may sustain injury and it is not possible to use the product without seeing the leaves on the ground)</p> <p>Likelihood: Common issue most users will face throughout cycle</p> <p>Exclusion: Only a few users will be able to distinguish between the dirt and bristles</p> <p>Severity: Will cause substantial performance degradation</p> <p>Impact = 6</p>		
<b>SII 1</b>	Brightness	0	300 lumens
		<i>There is no light source in the reference design</i>	Average flashlight brightness
<b>SII 2</b>			

Table 20. Interaction Error Number 14

<b>IE</b>	1.2.8.5		
<b>Context</b>	Leila continues using the device after the storage bag has reached capacity because she cannot see inside the bag as it is opaque. The leaves it picks up fall out of the device as there is no room for them.		
<b>Impact</b>	<p>Likelihood: 3. Not only is it troublesome for users to stop and check the storage bag mid-use, it is also easy to forget to do so. In addition, users are likely to push the boundary and assume they can get away with over-stuffing the bag a little more to avoid having to empty it.</p> <p>Exclusion: 3. All users can experience this, regardless of their capabilities. Thus a large number of users will be affected. No users will be able to see through an opaque bag, and users of all abilities can forget to check whether it is full as that is common human error.</p> <p>Severity: 2. While the safety of users will not be affected, being unable to keep stored leaves in the storage compartment and renders the product useless.</p>		
<b>SII 1</b>	<i>Opacity</i>	90%  <i>The storage bag is almost completely opaque</i>	30%  <i>Some opacity is ok, as users do not need to see exactly what is inside, however they should be able to see the level to which the storage is filled.</i>
<b>SII 2</b>	<p><i>Capacity: a storage compartment that is too small is likely to cause this issue more often.</i></p> <p><i>Value: 25% (needs to be emptied 4 times to clean the average lawn)</i></p>		50%: Doubling the capacity is realistic, as making the storage too large would make it heavy.

Table 21. Interaction Error Number 15

<b>IE</b>	1.3.2.6		
<b>Context</b>	Leila attempts to place leaves into the bin but has a muscle spasm and the leaves fall on as she is lifting them into the bin		
<b>Impact</b>	<p>Impact = Likelihood + Exclusion + Severity</p> <p>Impact = 1+1+2</p> <p>Likelihood: Will only occur to small group of people that frequently experience muscle spasms</p> <p>Exclusion: Only a small group of people will face this issue throughout cycle.</p> <p>Severity: Will cause a major setback and the user now has to manually dispose of leaves.</p> <p>Impact = 4</p>		
<b>SII 1</b>	<i>Distance</i>	21 in	15 in
		<i>There is no connecting piece between compartment and bin, therefore leaves must be carried at least the width of the sweeper</i>	<i>Reducing the distance the leaves have to travel decreases the chance of them falling</i>
<b>SII 2</b>	<i>as above</i> <i>optional - there can be many SII's for each IE</i>		

Table 22. Interaction Error Number 16

<b>IE</b>	1.3.5.7		
<b>Context</b>	<i>Leila attempts to fold the sweeper but after the physical activity of using the sweeper, she cannot strain her muscles to fold it. She cannot figure out if she is pushing too hard or not hard enough, and to avoid breaking it, she gives up.</i>		
<b>Impact</b>	<p>Impact = 2+2+1</p> <p>Likelihood: Due to the energy required for using the sweeper, most users will be tired by the time they're done.</p> <p>Exclusion: Only a small group of people will be able to bypass this issue due to conditioning.</p> <p>Severity: Will not cause product failure since task is already done, only storage issues.</p> <p>Impact = 5</p>		
<b>SII 1</b>	Resistance	8/10  <i>If the sweeper is difficult to fold, it is likely higher up on the resistance scale.</i>	3/10  <i>We aim for our design to have low resistance.</i>
<b>SII 2</b>	<p>as above</p> <p>optional - there can be many SII's for each IE</p>		

Table 23. Interaction Error Number 17

<b>IE</b>	1.3.8.8		
<b>Context</b>	<i>Leila attempts to place the sweeper into storage, but she is unable to maneuver it into the tight space while keeping her balance</i>		
<b>Impact</b>	<p>Impact = Likelihood + Exclusion + Severity (Anyone can lose their balance in a small space while lifting something large and heavy, regardless of ability), but it may not cause injury or product failure</p> <p>Impact = 3+3+2</p> <p>Likelihood: In tight situation such as this, most users no matter their physical capabilities will face this</p> <p>Exclusion: Almost all users will be affected by this issue</p> <p>Severity: Causes storage problems, however nothing related to product since task is done.</p> <p>Impact = 6</p>		
<b>SII 1</b>	<i>Size while folded</i>	<i>21 inches wide</i>	<i>15 inches</i>
		<i>The reference design does not fold in such a way that decreases its width or length</i>	<i>Reducing the width/length of the design means less maneuvering</i>

Table 23. Interaction Error Number 18

<b>IE</b>	1.2		
<b>Context</b>	Leila is unable to tell if the storage bag is full		
<b>Impact</b>	Impact = 2+2+2		
<b>SII 1</b>	Height	10 in	5 in
		A higher storage bag cant be seen	A lower storage bag will be visible.

Table 24 Interaction Error Number 19

<b>IE</b>	4.1.2.1		
<b>Context</b>	As <i>Erin lifts the device out of storage, the handle becomes detached.</i>		
<b>Impact</b>	<p><i>Impact = 1 + 1 + 2</i></p> <p><i>Likelihood: Likely to occur a couple times throughout lifecycle</i></p> <p><i>Exclusion: Small but noticeable amount of users will be excluded</i></p> <p><i>Severity: Causes a high degree of product failure as it makes it much harder to use, however can be fixed when handles reattached.</i></p> <p><i>Impact = 4</i></p> <p><i>This impact has a value of 5 because it would only exclude a small number of users in becoming detached and is only a minor inconvenience to the user.</i></p>		
<b>SII</b>	Durability	8/10  <i>The handle can become detached which makes the device less durable.</i>	10/10  <i>The handle should not be easily detached from the base.</i>

Table 25. Interaction Error Number 20

<b>IE</b>	4.1.3.2		
<b>Context</b>	As <i>Erin goes to attach the bag to the base, the bag keeps popping off due to faulty hook design.</i>		
<b>Impact</b>	<p><i>Impact = 2 + 2 + 2</i></p> <p><i>Likelihood: Likely to occur several times over cycle because of faulty design.</i></p> <p><i>Exclusion: Excludes most users due to design.</i></p> <p><i>Severity: Not total product failure, however temporarily makes product useless.</i></p> <p><i>Impact = 6</i></p> <p><i>This impact has a value of 6 as it would exclude more users if the bag kept falling off during use, causing more strain on the user. This is a larger inconvenience.</i></p>		
<b>SII</b>	Functionality	6/10  <i>The latch for the bag is not currently very functional.</i>	8/10  <i>The hook should be more secure to the base.</i>

Table 27. Interaction Error Number 21

<b>IE</b>	4.1.4.3		
<b>Context</b>	<p>As <i>Erin tries to adjust the brush height, she does not feel any movement in the knob and is unsure that the mechanism is working. She then must turn the device upside down to verify the brushes have been adjusted.</i></p>		
<b>Impact</b>	<p><i>Impact = 1 + 3 + 2</i></p> <p><i>Likelihood: Only when user is very alert will they notice this.</i></p> <p><i>Exclusion: Most people will be affected if the design doesn't give feedback.</i></p> <p><i>Severity: Results in user manually checking if brushes adjusted.</i></p> <p><i>Impact = 6</i></p> <p><i>This impact has a value of 6 as it would be incredibly exclusive if the user had to have the strength to turn the device over to verify the knob works. This is also a larger inconvenience.</i></p>		
<b>SII</b>	Functionality	6/10	9/10
		<i>The knob is currently not very functional.</i>	<i>The mechanism should be more functional.</i>

Table 28. Interaction Error Number 22

<b>IE</b>	4.2.1.4		
<b>Context</b>	<i>As Erin pushes the device, the brushes get stuck and the device stops moving.</i>		
<b>Impact</b>	<p><i>Impact = 2 + 2 + 2</i></p> <p><i>Likelihood: Due to high volume of collected waste, this is likely.</i></p> <p><i>Exclusion: Most users will be affected due to faulty design.</i></p> <p><i>Severity: Temporarily disables product until brushes are fixed.</i></p> <p><i>Impact = 6</i></p> <p><i>This impact has a value of 6 because it excludes users who are unable to push the device any harder. This is also a large inconvenience and is likely to happen.</i></p>		
<b>SII</b>	Ease of use	7/10  <i>The device currently can be difficult to use.</i>	10/10  <i>The device should be able to be used by everyone and the brushes should not get stuck.</i>

Table 29. Interaction Error Number 23

<b>IE</b>	4.2.6.5		
<b>Context</b>	<i>As Erin is transferring the leaves to the waste receptacle, the device tips over and the leaves spill on the lawn.</i>		
<b>Impact</b>	<p><i>Impact = 1 + 2 + 3</i></p> <p><i>Likelihood: Will only happen depending on user actions that would make it tip; which are uncommon</i></p> <p><i>Exclusion: Most users would be affected due to weight of product and size.</i></p> <p><i>Severity: Undesired outcome, results in the user having to lift machine into place.</i></p> <p><i>Impact = 6</i></p> <p><i>This impact has a value of 6 because this would be a severe consequence of the action. This would be incredibly frustrating for the user after she had cleaned her entire lawn. This is less likely and excludes people who would be too tired to redo the action.</i></p>		
<b>SII</b>	Sturdiness	7/10  <i>The device may not be weighted enough on the base so it cannot be tipped.</i>	9/10  <i>The device should be sturdy enough that the device will not tip.</i>

Table 23. Interaction Error Number 24

<b>IE</b>	4.2.3.6		
<b>Context</b>	Erin cannot tell if sweeper is making progress due to obstructed view.		
<b>Impact</b>	<p>Impact = 1 + 1 + 2</p> <p><i>Likelihood: Only users heights close to handle will experience this.</i></p> <p><i>Exclusion: Only a certain height range will experience this problem.</i></p> <p><i>Severity: Product still functions, however cannot monitor progress</i></p> <p><i>Impact = 6</i></p>		
<b>SII 1</b>	Obstruction of view	9/10	3/10
		Old design blocks the view for certain users.	New design must have very minimal obstructed views.

Table 23. Interaction Error Number 25

<b>IE</b>	4.3.2.7		
<b>Context</b>	Erin cannot collect leaves because the bristles have become jammed after cleaning them.		
<b>Impact</b>	<p>Impact = 1 + 1 + 3</p> <p><i>Likelihood: Unlikely unless excessive force applied when cleaning</i></p> <p><i>Exclusion: Only certain users under certain conditions will be affected</i></p> <p><i>Severity: Prevents machine from functioning completely.</i></p> <p><i>Impact = 5</i></p>		
<b>SII 1</b>	Ease of Maintenance	5/10  Maintenance is difficult and discourages users from doing it.	10/10  Maintenance is very simple and worthwhile.

Table 23. Interaction Error Number 26

<b>IE</b>	4.3.2.8		
<b>Context</b>	Erin cannot lift the product over a box in the garage due to lack of grip and space to hold on to.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p><i>Likelihood: Will occur frequently to people storing the device in congested areas.</i></p> <p><i>Exclusion: Most users will be affected unless they have superior grip and arm length.</i></p> <p><i>Severity: Doesn't affect product function, only storage.</i></p> <p><i>Impact = 6</i></p>		
<b>SII 1</b>	Grip	6/10	9/10
		Poor grip which most users will struggle with.	Grip should be strong enough for 90% of users.

Table 23. Interaction Error Number 27

<b>IE</b>	4.3.3.9		
<b>Context</b>	Erin cannot store the device because she cannot figure out how to hold the locking mechanism.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p><i>Likelihood: Common due to faulty design.</i></p> <p><i>Exclusion: Most users be struggling when they first try locking it.</i></p> <p><i>Severity: Affects the storage process of the device.</i></p> <p><i>Impact = 6</i></p>		
<b>SII 1</b>	Reasoning	8/10  High complexity makes it more difficult for users.	5/10  New design should be intuitive.

Table 32. Interaction Error Number 28

<b>IE</b>	5.1.3.1		
<b>Context</b>	<i>Some parts have gotten damaged/misplaced during storage/handling.</i>		
<b>Impact</b>	<p>Impact = 1+1+2</p> <p><i>Likelihood: Will only occur to careless mistakes from user.</i></p> <p><i>Exclusion: Only affects users with weak cognitive factors.</i></p> <p><i>Severity: Requires addition of new parts to replace missing ones.</i></p> <p>Impact = 4</p>		
<b>SII 1</b>	Memory	4/10	8/10
		Poor part design resulted in losing and having difficulty finding piece.	Better designs make it more memorable.

Table 33. Interaction Error Number 29

<b>IE</b>	5.2.3.2		
<b>Context</b>	<i>Not all leaves are collected due to brush not being at the right height</i>		
<b>Impact</b>	<p>Impact = 2+2+1</p> <p><i>Likelihood:</i> Common for users with lots of trees.</p> <p><i>Exclusion:</i> Prevents most users of continuing their task due to obstacle.</p> <p><i>Severity:</i> Can easily be bypassed with removal of brush.</p> <p>Impact = 5</p>		
<b>SII 1</b>	%of leaves left on the ground	<i>20% of leaves left on ground</i>	100%
		<i>Taken from reviews online</i>	<i>Should be able to pick up all the leaves</i>

Table 34. Interaction Error Number 30

<b>IE</b>	5.2.3.3		
<b>Context</b>	<i>Leaf sweeper gets stuck due to user leaning to much on device</i>		
<b>Impact</b>	<p>Impact = 1+2+3</p> <p><i>Likelihood:</i> Only occurs when excessive force it applied.</p> <p><i>Exclusion:</i> Excludes uses who will use too much force on handle.</p> <p><i>Severity:</i> Causes total product failure until resolved.</p> <p>Impact = 6.</p>		
<b>SII 1</b>	<i>Percenta ge of body weight</i>	<i>Have more than 40% of the person's body weight supported by leaf sweeper</i>	100%
	<i>On device</i>	<i>Value taken from product reviews</i>	<i>Should be able to support user full weight</i>

Table 35. Interaction Error Number 31

<b>IE</b>	5.2.3.4		
<b>Context</b>	<i>User tries to push leaf sweeper over stick and it rips the bag and leaves start to fall out</i>		
<b>Impact</b>	<p>Impact = 2+1+3</p> <p><i>Likelihood: Likely to occur due to different types of debris across yard.</i></p> <p><i>Exclusion: Only users with poor visual capabilities would be excluded.</i></p> <p><i>Severity: Would result in total product failure.</i></p> <p>Impact = 6</p>		
<b>SII 1</b>	Durability	6/10	10/10
		Weak design causes obstacles such as sticks to rip bag.	Strong design to withstand almost all obstacles.

Table 36. Interaction Error Number 32

<b>IE</b>	5.2.3.5		
<b>Context</b>	<i>Person is going along and collecting leaves and leaves start falling out due to bag being full</i>		
<b>Impact</b>	<p>Impact = 3+1+1</p> <p><i>Likelihood:</i> This is an issue that almost all users will experience at one point in their cycle.</p> <p><i>Exclusion:</i> Very small user groups are excluded.</p> <p><i>Severity:</i> Minor inconvenience, can easily be fixed.</p> <p>Impact = 4.</p>		
<b>SII 1</b>	Capacity	<i>Half a bag</i>	<i>2 full bags</i>
		<i>That is the maximum capacity</i>	<i>Average number of bags needed to complete entire lawn</i>

Table 23. Interaction Error Number 33

<b>IE</b>	5.2.2.6		
<b>Context</b>	Billy cannot properly control the direction of the sweeper due to the grass being wet.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p><i>Likelihood: After rainfall, most users will face this unless superior strength allows for control.</i></p> <p><i>Exclusion: Significant number of users will be excluded due to physical capabilities.</i></p> <p><i>Severity: Degrades product performance, cannot perform the task properly.</i></p> <p><i>Impact = 6</i></p>		
<b>SII 1</b>	Traction Control	5/10 Weak tire grip prevents traction control.	8/10 Weighted design, improved grip.

Table 23. Interaction Error Number 34

<b>IE</b>	5.3.1.7		
<b>Context</b>	Cannot push around corners on the way to the shed due to fatigue.		
<b>Impact</b>	<p>Impact = 2 + 2 + 1</p> <p><i>Likelihood:</i> Most users will experience fatigue at least once during product cycle.</p> <p><i>Exclusion:</i> Significant number of users will face this due to lack of physical capabilities.</p> <p><i>Severity:</i> Does not degrade performance, only storage capabilities.</p> <p><i>Impact = 5</i></p>		
<b>SII 1</b>	Ease of Movement	5/10  Design prevents ease of movements around control.	8/10  Improved features such as caster wheels can help maneuver around corners.

Table 23. Interaction Error Number 35

<b>IE</b>	5.3.3.8		
<b>Context</b>	Cannot remove hopper bag due to the weight of leaves.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p><i>Likelihood: Most users will face this problem due to significant number of leaves collected by the end.</i></p> <p><i>Exclusion: Because of physical capabilities, most users will experience this.</i></p> <p><i>Severity: Prevents user from proceeding to put the sweeper in storage.</i></p> <p>Impact = 6</p>		
<b>SII 1</b>	Lack of assistance	5/10	9/10
		Lack of assistance, relies on user strength capabilities	Assistive movement takes load off user

Table 23. Interaction Error Number 36

<b>IE</b>	5.3.2.9		
<b>Context</b>	During the usage process, the sweeper collected a piece of plastic which has tangled up the bristles and jammed the collection system.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p><i>Likelihood: Most users will experience this due to the large number of objects the sweeper can collect.</i></p> <p><i>Exclusion: Visual capabilities will exclude a significant amount of users.</i></p> <p><i>Severity: A jammed sweeper will degrade performance, however when fixed there is minimal damage.</i></p> <p>Impact = 6</p>		
<b>SII 1</b>	Collection Strength	4/10  Weak collection when small debris can jam it.	10/10  Very strong collection system, can retrieve most debris off yard.

Table 23. Interaction Error Number 37

<b>IE</b>	2.1.2.1		
<b>Context</b>	Cannot hold device due to weight.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p><i>Likelihood: Likely to occur because maintenance will be necessary throughout product cycle.</i></p> <p><i>Exclusion: Significant number of users excluded due to high levels of physical capabilities required.</i></p> <p><i>Severity: Substantial performance degradation due to inability to replace product.</i></p> <p>Impact = 6</p>		
<b>SII 1</b>	Weight	8/10	5/10
		Poor design and material choice lead to unnecessary weight.	Smarter choices can result in lighter weight.

Table 23. Interaction Error Number 38

<b>IE</b>	2.1.3.2		
<b>Context</b>	Unable to disassemble device due to stiffness.		
<b>Impact</b>	<p>Impact = <math>2 + 2 + 3</math></p> <p><i>Likelihood:</i> Likely to occur because over time, parts become harder to move due to weather and other conditions.</p> <p><i>Exclusion:</i> Most users will be excluded due to physical capabilities required to overcome this.</p> <p><i>Severity:</i> Prevents maintenance process to starting.</p> <p>Impact = 7</p>		
<b>SII 1</b>	Material Selection	5/10 Cheap Fasteners	10/10 High Quality Fasteners

Table 23. Interaction Error Number 39

<b>IE</b>	2.1.3.3		
<b>Context</b>	After disassembling device, a fastener will no longer fit due to damaged thread.		
<b>Impact</b>	<p>Impact = 1 + 1 + 2</p> <p><i>Likelihood: The longer the product is active, the higher the chances of this happening.</i></p> <p><i>Exclusion: Small but noticeable amount of users will be excluded</i></p> <p><i>Severity: Can cause major product failure, however the right fastener can replace old ones.</i></p> <p>Impact = 4</p>		
<b>SII 1</b>	Material Selection	5/10	10/10
		Cheap Fasteners	High Quality Fasteners

Table 23. Interaction Error Number 40

<b>IE</b>	2.2.1.4		
<b>Context</b>	Cannot find the part that needs to be fixed.		
<b>Impact</b>	<p>Impact = <math>2 + 2 + 2</math></p> <p><i>Likelihood: Common for users who are not used to maintenance work.</i></p> <p><i>Exclusion: Most users will face this due to cognitive abilities.</i></p> <p><i>Severity: Can result in replacement not happening, however once location is found the problem can easily be fixed.</i></p> <p>Impact = 6</p>		
<b>SII 1</b>	Design	6/10	9/10
		Poor design leads to misplacement of parts.	Improved design makes parts more memorable.

Table 23. Interaction Error Number 41

<b>IE</b>	5.2.2.5		
<b>Context</b>	Cannot remove the part that needs to be replaced.		
<b>Impact</b>	<p>Impact = 2 + 2 + 3</p> <p><i>Likelihood: Likely to happen since parts become harder to remove over time due to stiffness and rust.</i></p> <p><i>Exclusion: Many users will be excluded due to lack of physical capabilities.</i></p> <p><i>Severity: Prevents part from being replaced, product cannot function.</i></p> <p>Impact = 7</p>		
<b>SII 1</b>	Design	3/10	9/10
		Poor design did not consider maintenance factors.	New design should consider all steps.

Table 23. Interaction Error Number 42

<b>IE</b>	5.2.5.6		
<b>Context</b>	New part will not install correctly (does not fit or device will not work after replacement).		
<b>Impact</b>	<p>Impact = 2 + 1 + 2</p> <p><i>Likelihood: This issue will most likely happen at least once throughout cycle due to difficulty level.</i></p> <p><i>Exclusion: Only users who lack cognitive abilities will be excluded.</i></p> <p><i>Severity: Temporarily prevents usage, however can be easily fixed.</i></p> <p>Impact = 5</p>		
<b>SII 1</b>	Assistance	4/10 Failed to assist user through support and manuals.	10/10 Able to fully guide users through installation and support.

Table 23. Interaction Error Number 43

<b>IE</b>	2.3.1.7		
<b>Context</b>	User does not know how to reassemble device.		
<b>Impact</b>	<p>Impact = 2 + 2 + 2</p> <p><i>Likelihood: Likely to happen due to overwhelming amount of parts.</i></p> <p><i>Exclusion: Significant users will be excluded from this.</i></p> <p><i>Severity: Temporarily prevents usage until properly installed.</i></p> <p>Impact = 6</p>		
<b>SII 1</b>	Design	3/10	9/10
		Poor design did not consider reassembly.	New design should consider all steps.

Table 23. Interaction Error Number 44

<b>IE</b>	2.3.1.8		
<b>Context</b>	During the reassembly process, the user puts the wrong fastener into a thread and it becomes stuck.		
<b>Impact</b>	<p>Impact = 1 + 1 + 3</p> <p><i>Likelihood: Unlikely to happen in most scenarios, dependent on user.</i></p> <p><i>Exclusion: Small but noticeable users will be excluded.</i></p> <p><i>Severity: Can result in complete product failure if the jammed fastener cannot be removed.</i></p> <p>Impact = 5</p>		
<b>SII 1</b>	Design	3/10	9/10
		Poor design lead to user confusion.	New design should consider all steps.

Table 23. Interaction Error Number 45

<b>IE</b>	2.3.3.9		
<b>Context</b>	Upon usage, a fastener was not secured properly and has fallen out, causing the issue to resurface.		
<b>Impact</b>	<p>Impact = 1 + 1 + 2</p> <p><i>Likelihood: Unlikely to happen, dependent on user awareness level.</i></p> <p><i>Exclusion: Small group of users will be excluded.</i></p> <p><i>Severity: Causes performance degradation, however can be fixed once part is put back.</i></p> <p>Impact =</p>		
<b>SII 1</b>	Quality of Materials	5/10  Quality is below average and causes frequent product failure.	10/10  New design should use high quality and durable material.

## revised usage scenarios

We are constantly reviewing our usage scenarios in order to perfect them. For example, Usage Scenario was reviewed to make sure that the proper tools are used to tighten the screws on the device to avoid unnecessary wear.

## requirements

1. The product must be lightweight
  - a. The product must weigh 10 lbs or less
    - i. The reference design weighs 12 lbs, and has an exclusion of 10% of males and 16% of females. According to the Liberty Mutual Tables, decreasing the weight to 10lbs decreases the exclusion to <10% of females and males.
2. The product must be storable
  - a. The product must be no larger than 2 ft. x 2 ft. when stored
    - i. In order to be wide enough to be efficient ( see requirement 9 also), while remaining storable, the product can only be 1-2 ft. wide
3. The product must be mobile over large distances
  - a. See requirement 1 for weight constraints.
  - b. Coefficient of static friction of bottom of product should be <0.2 for easy dragging
4. The product must be comfortable for various users
  - a. The product must accommodate weaker dexterity
    - i. Grip strength required should be no more than 20 lbs
      1. According to the Journal of the American Geriatric Society, 44 lbs is an average grip strength for females, and we aim to accommodate lower than average.
5. The product must be affordable

- a. The product must cost \$150 or less
  - i. The reference designs and other similar designs cost anywhere between \$100-\$300. We aim to create an affordable, good quality product, therefore a mid-price range is chosen.
- 6. The product must be environmentally friendly
  - a. The product must contribute minimally to environmental damage during use
    - i. 0 greenhouse gas emissions must be released during use of product
  - b. The product must be environmentally-friendly in its disposal stage
    - i. 60% of the product components must be recyclable
      - 1. The design brief states that the product must minimize waste collected by the city, and parts of the product that end up in landfills contribute to waste. A significant portion of the product must be kept out of landfills if we are to rightfully classify it as “environmentally friendly”, therefore more than half of the parts should be recyclable or biodegradable.
- 7. The product must be durable
  - a. The product must maintain its quality throughout multiple uses
    - i. The product must withstand 5 years of normal use
- 8. The product be intuitive
  - a. The product must be utilized with minimal confusion
    - i. 100% of product features should have visible labels
- 9. The product must be efficient
  - i. The product must remove leaves from an area at least 1 m wide in 1 iteration of use
- 10. All product components and systems must be safe
  - a. Product systems must prevent injury
    - i. 100% of product systems must cause 0 injuries during usage

testing

11. The product must be suitable for multiple weather conditions
  - a. The product must pick up leaves in wet and windy conditions
    - i. In 44 km/h wind speed and 100 mm of rainfall, the product must pick up leaves and stay balanced
12. The product must be Functional
  - a. The product must remove leaves from properties
    1. 80% of leaves must be removed in 1 iteration of product use
      - a. In order for the product to make the task of clearing leaves fast and efficient, there should not be repetitive motions to successfully complete 1 task. A product that does not clear leaves is frustrating and useless.
  - b. The product must work in wet and windy conditions
    - i. See requirement 11 also.
  - c. The product must generate very little noise
    - i. Noises produced by the product should be less than 40 dB
      1. As discussed in the HF capability justifications, 40 dB is a non-invasive level of sound that is loud enough to be heard by users with mild hearing loss, but quiet to not disturb nearby neighbors or cause hearing damage
  - d. The product must reduce environmental damage
    - i. 60% of the product components must be recyclable

## discussion

# product architecture

# system identification matrix

*Table 37: System Identification Matrix*

Functional Requirement	Subsystem							
	Control	Power	Movement	Structural	Collection	Sorting	Storage	Disposal
Collect Leaves		X			X			
Dispose of Leaves Once Full								X
Store Leaves						X	X	
Drive Forward, Backward, and Turn	X	X	X	X				

### Collecting Leaves

- This functional requirement is fulfilled using the Power and Collection subsystem.
- The Power subsystem is what provides energy to the system in order for it to function,
- The Collection system works with the Power system to collect the leaves that must be gathered.

### Dispose of Leaves When Full

- This functional requirement is fulfilled using the Disposal subsystem.
- The Disposal subsystem disposes of the leaves once the action of Collection has taken place.

## Store Leaves

- This functional requirement is fulfilled using the Sorting and Storage subsystems.
- The Sorting subsystem works to sort out acceptable inputs from unacceptable inputs, and groups the acceptable inputs together to be placed in the Storage subsystem.
- The Storage subsystem holds the leaves in an appropriate location in order for them to be disposed of properly.

## Drive Forward, Backward, and Turn

- This functional requirement is fulfilled using the Control, Power, Movement and Structural subsystems.
- The Control subsystem allows the user to control the device while it is in operation.
- The Power subsystem provides energy to the Movement system, which allows the device to move as it is intended.
- The Structural subsystem provides stability and support to the structure, as well as the Power and Movement subsystems.

In the System Identification Matrix, there are a few asymmetries in regards to which functional requirement is satisfied by which particular subsystem. This is because while all subsystems are imperative to the overall system, there are some that have a higher importance or are used more frequently within the system. Some subsystems also have a very specific role inside the system, which means they can only be used for that particular function.

## Inputs and Outputs

In regards to the leaf management system, there are many inputs and outputs, both acceptable and unacceptable, that pass through the system during its usage.

Acceptable inputs are defined as the desired items to be collected by the device, the

items in which it was designed to collect. Unacceptable inputs include anything the sweeper is not equipped to process, that would not allow the brush function to work as it was designed. They have been listed in detail below.

## Inputs

- Mass
  - Leaves
  - Twigs (Unacceptable)
  - Grass
  - Rocks (Unacceptable)
  - Mud (Unacceptable)
  - Other plants
  - Air
  - Humans (Unacceptable)
  - Animals (Unacceptable)
  - Fecal matter (Unacceptable)
  - Plastic (Unacceptable)
  - Paper and paper products (Unacceptable)
  - Water and snow
  - Toys (Unacceptable)
  - Clothes and shoes (Unacceptable)
  - Sports equipment (Unacceptable)
  - Yard work tools (Unacceptable)
  - Compost
- Energy
  - Physical energy
  - Mechanical energy
  - Electrical energy
- Information
  - User commands

- User cognition
- User comprehension

## Outputs

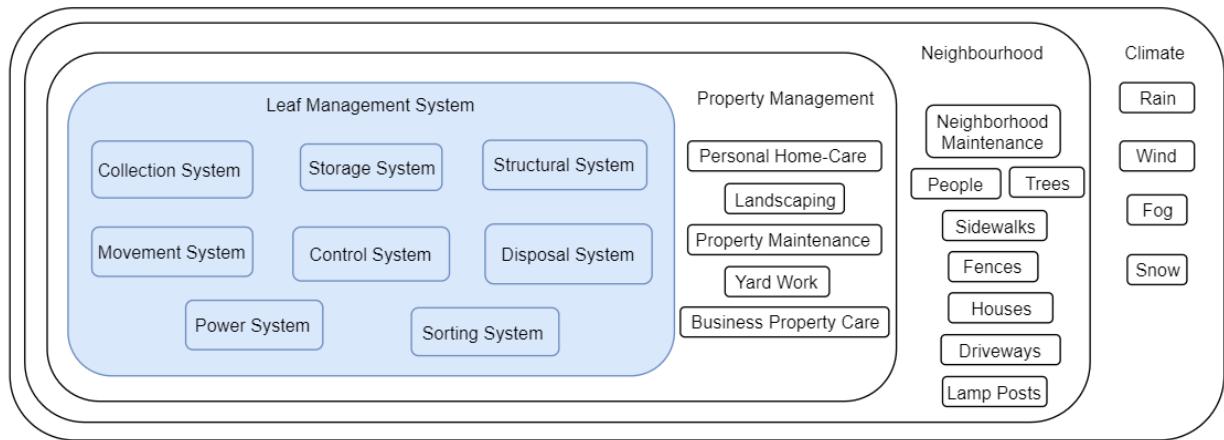
- Mass
  - Leaves
  - Twigs (Unacceptable)
  - Grass
  - Rocks (Unacceptable)
  - Mud (Unacceptable)
  - Other plants
  - Air
  - Humans (Unacceptable)
  - Animals (Unacceptable)
  - Fecal matter (Unacceptable)
  - Plastic (Unacceptable)
  - Paper and paper products (Unacceptable)
  - Water and snow
  - Toys (Unacceptable)
  - Clothes and shoes (Unacceptable)
  - Sports equipment (Unacceptable)
  - Yard work tools (Unacceptable)
  - Compost
- Energy
  - Kinetic energy
  - Friction (Unacceptable)
  - Heat (Unacceptable)
  - Noise (Unacceptable)
- Information
  - User Feedback

During the process of leaf management, the device may collect items other than what has been deemed acceptable. The system is not necessarily able to process these foreign objects properly, and they may get stuck in the device or rip the bag. An excess of these unwanted items can lead to product malfunction which would prevent the sweeper from collecting leaves, therefore making it a bad or unwanted input. The requirements for the leaf management system only discuss leaves, so anything other than leaves, grass or other plant matter is considered an unacceptable input.

## system diagram

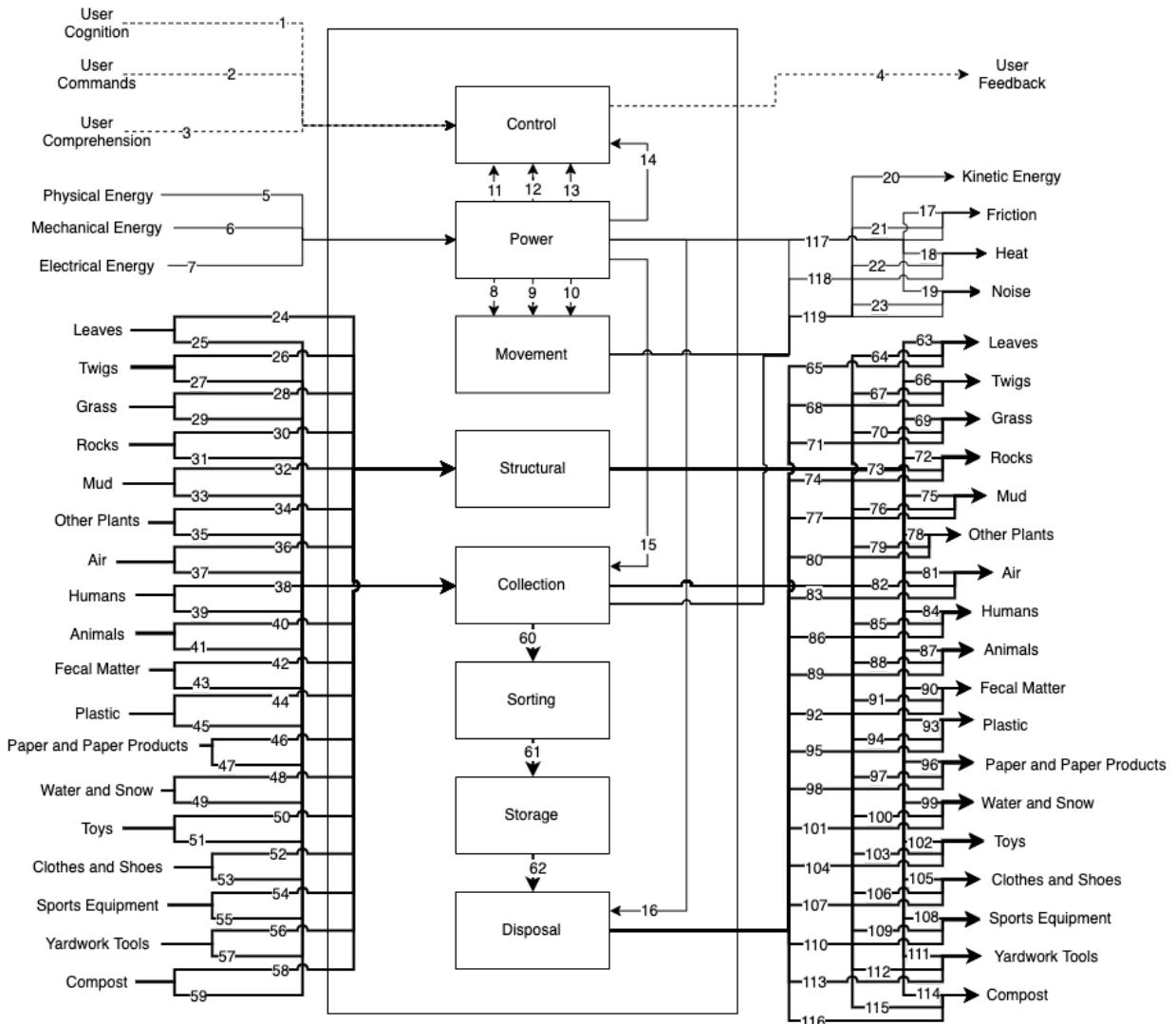
This is a nested system diagram that outlines the boundary of the leaf management system and highlights the larger system of which ours is contained.

Figure 18. Nested System Diagram For Leaf Management System



The System Diagram details the overarching system that encompasses the leaf management system. The diagram uses different subsystems to showcase the larger systems that play a part in the function of the device.

Figure 19. System Diagram for Leaf Management System



## Subsystems

- Control system
  - The Control system is what the user interacts with to get the machine moving. For a leaf sweeper, there is control needed, with handles being the focus of the interface.

- Power system
  - This system is required to power the device, providing energy to get the brush turning. For a leaf sweeper, the power required comes from the user.
- Movement system
  - Movement and range of mobility establish where the sweeper will be able to move. Smooth forwards and backwards motion is the main priority, with pivoting front axle to allow for turns.
- Structural system
  - Strength and durability define what conditions the sweeper will be able to work through. The sweeper needs the strength to hold the collection unit when the capacity is at full without putting stress on the system. The unit also needs to be durable in certain weather conditions such as rainy and cold days.
- Collection system
  - This system focuses on how the sweeper is able to collect leaves off the ground. For most sweepers, the rotation of wheels also spins brushes connected along the axle of the front wheel, which propels the leaves backwards into the hopper.
- Sorting system
  - A sorting system is incorporated into the system to sort the acceptable inputs from the unacceptable inputs.
- Storage system
  - The storage system is important as the leaves need a place to be temporarily stored while the sweeper is in use. The amount of storage defines how productive the product can be during long periods of usage.
- Disposal system

- The disposal system allows the user to empty the collection bag when it reached max capacity. A simple release switch is used for quick disposal to minimize wasted time.

## system interfaces

1. User Cognition is connected to the Control system.
2. User Commands is connected to the Control system.
3. User Comprehension is connected to the Control system.
4. The Control system is connected to User Feedback.
5. Physical Energy is connected to the Power system.
6. Mechanical Energy is connected to the Power system
7. Electrical Energy is connected to the Power system.
8. Physical Energy is connected to the Movement system.
9. Mechanical Energy is connected to the Movement system.
10. Electrical Energy is connected to the Movement system.
11. Physical Energy is connected to the Control system.
12. Mechanical Energy is connected to the Control system.
13. Electrical Energy is connected to the Control system.
14. The Power system is connected to the Control system.
15. The Power system is connected to the Collection system.
16. The Power system is connected to the Disposal system.
17. The Power system is connected to Kinetic Energy.
18. The Power system is connected to Friction.
19. The Power system is connected to Heat.
20. The Power system is connected to Noise.
21. The Movement system is connected to Friction.
22. The Movement system is connected to Heat.
23. The Movement system is connected to Noise.
24. Leaves are connected to the Structural system.

25. Leaves are connected to the Collection system.
26. Twigs are connected to the Structural system.
27. Twigs are connected to the Collection system.
28. Grass is connected to the Structural system.
29. Grass is connected to the Collection system.
30. Rocks are connected to the Structural system.
31. Rocks are connected to the Collection system.
32. Mud is connected to the Structural system.
33. Mud is connected to the Collection system.
34. Other Plants are connected to the Structural system.
35. Other Plants are connected to the Collection system.
36. Air is connected to the Structural system.
37. Air is connected to the Collection system.
38. Humans are connected to the Structural system.
39. Humans are connected to the Collection system.
40. Animals is connected to the Structural system.
41. Animals is connected to the Collection system.
42. Fecal Matter is connected to the Structural system.
43. Fecal Matter is connected to the Collection system.
44. Plastic is connected to the Structural system.
45. Plastic is connected to the Collection system.
46. Paper/paper products is connected to the Structural system.
47. Paper/paper products is connected to the Collection system.
48. Water/snow are connected to the Structural system.
49. Water/snow are connected to the Collection system.
50. Toys are connected to the Structural system.
51. Toys are connected to the Collection system.
52. Clothes/shoes are connected to the Structural system.
53. Clothes/shoes are connected to the Collection system.

54. Sports equipment are connected to the Structural system.
55. Sports equipment are connected to the Collection system.
56. Yardwork tools are connected to the Structural system.
57. Yardwork tools are connected to the Collection system.
58. Compost is connected to the Structural system.
59. Compost is connected to the Collection system.
60. The Collection system is connected to the Sorting system.
61. The Sorting system is connected to the Storage system.
62. The Storage system is connected to the Disposal system.
63. The Structural system is connected to Leaves.
64. The Collection system is connected to Leaves.
65. The Disposal system is connected to Leaves.
66. The Structural system is connected to Twigs.
67. The Collection system is connected to Twigs.
68. The Disposal system is connected to Twigs.
69. The Structural system is connected to Grass.
70. The Collection system is connected to Grass.
71. The Disposal system is connected to Grass.
72. The Structural system is connected to Rocks.
73. The Collection system is connected to Rocks.
74. The Disposal system is connected to Rocks.
75. The Structural system is connected to Mud.
76. The Collection system is connected to Mud.
77. The Disposal system is connected to Mud.

78. The Structural system is connected to Other Plants.
79. The Collection system is connected to Other Plants.
80. The Disposal system is connected to Other Plants.
81. The Structural system is connected to Air.
82. The Collection system is connected to Air.
83. The Disposal system is connected to Air.
84. The Structural system is connected to Humans.
85. The Collection system is connected to Humans.
86. The Disposal system is connected to Humans.
87. The Structural system is connected to Animals.
88. The Collection system is connected to Animals.
89. The Disposal system is connected to Animals.
90. The Structural system is connected to Fecal Matter.
91. The Collection system is connected to Fecal Matter.
92. The Disposal system is connected to Fecal Matter.
93. The Structural system is connected to Plastic.
94. The Collection system is connected to Plastic.
95. The Disposal system is connected to Plastic.
96. The Structural system is connected to Paper/paper products.
97. The Collection system is connected to Paper/paper products.
98. The Disposal system is connected to Paper/paper products.
99. The Structural system is connected to Water/snow.
100. The Collection system is connected to Water/snow.
101. The Disposal system is connected to Water/snow.
102. The Structural system is connected to Toys.
103. The Collection system is connected to Toys.
104. The Disposal system is connected to Toys.
105. The Structural system is connected to Clothes/shoes.
106. The Collection system is connected to Clothes/shoes.

107. The Disposal system is connected to Clothes/shoes.
108. The Structural system is connected to Sports Equipment.
109. The Collection system is connected to Sports Equipment.
110. The Disposal system is connected to Sports Equipment.
111. The Structural system is connected to Yardwork tools.
112. The Collection system is connected to Yardwork tools.
113. The Disposal system is connected to Yardwork tools.
114. The Structural system is connected to Compost.
115. The Collection system is connected to Compost.
116. The Disposal system is connected to Compost.
117. The Movement system is connected to Friction.
118. The Movement system is connected to Heat.
119. The Movement system is connected to Noise.

These inputs and outputs connect both to the requirements and usage scenarios by incorporating items that our personas might have on their lawn or in their backyard. Persona 4 may have children's toys on her lawn that may get swept up by the lawn sweeper, for example. We carefully examined our usage scenarios for instances where foreign objects may be where the user is also using the device. The unacceptable inputs still must go through the system, which is why they then become unacceptable outputs. Our requirements to collect, store, and dispose of leaves are used in every step of the system diagram.

## discussion

Changes were made to the System Diagram that incorporate more inputs and outputs into the system. Originally, our inputs and outputs were both too vague and too limited, For the final report, we have taken a look at our Usage Scenarios and Requirements and have added in ones that are relevant to these situations.

# concept design

## Ideation

Table 38. Morphological Chart

Subsystem	Embodiments							
Control								
Power								
Movement								
Structural								
Collection								
Sorting								

Storage								
Disposal								

Number of total concepts:

$$8 \times 4 \times 4 \times 8 \times 5 \times 2 \times 4 \times 4 = 163840$$

## inconsistent embodiments

- A1-A2
  - Storage container cannot be open-top while being closed-top as well
- B3-(A1-A4)
  - Inconsistent because a blower has no storage system
- F2-[A1-A2-A3-A4]
  - This is inconsistent because making a pile on the ground does not work if the leaves are in container
- E1-[B2-B3-D2-D7-D5--D8]
  - All of these need electricity in order to operate therefore it can not be human powered



# initial concepts

The hill-climbing method was used to create our design concepts. This method was chosen because our group ideated over 165000 concepts, and the brute force method would be inefficient for such a large number of concepts. Instead, our group went through the morphological chart and selected embodiments to create 11 unique concepts that suit our personas' needs. Continuing in the process, we updated some embodiments with others after detailing how they suit our requirements.

## Concept 1: Leaf Vacuum

Concept 1 functions similar to a household vacuum cleaner. It is powered by electricity and efficiently sucks up any leaves in its path. A single handle is used to control the direction of the vacuum cleaner, and wheels provide easy range of motion in 4 directions. The leaves are stored in a bag inside the machine, to be emptied into a compost bin. A key feature of this concept is the efficiency and minimal physical strain. Electricity provides the power to pick up leaves, meaning the user only has to steer the device. The user also does not need to worry about picking up the collected leaves, because the leaves are vacuumed into a bag.

This concept suits our requirements of collecting and storing leaves, as well as being able to move. However, this concept does not fulfill the requirement of disposing of the leaves afterwards, as the user is required to empty the bag into another yard-waste bag. This concept is also suitable for a number of our personas, including those with mobility issues, like Persona 1, and those with time constraints, Persona 4. It works for Persona 2 and 3 as well. For Persona 5, it may be too complicated of a concept for someone with a low IQ to use.

## Concept 2: Hand-held vacuum

Concept 2 is a hand-held vacuum without wheels. Similar to a leaf blower in shape, it has a shoulder-mounted bag and a connecting tube from the bag to the vacuum. There is a switch on handle to control it. Inspiration for concept 2 was taken from a compact car vacuum. The device is cordless, therefore the power must be supplied from a rechargeable battery. This device does not require physical exertion in the form of pushing, and is small enough to be carried easily. This device is unique because it is hand-held and small. There are switches on the handle to turn the device on and off. Some key features of this concept include precise control, easy storage, and portability. This concept suits our requirements as it is easily moveable, and collects and stores leaves. It does not meet our requirement for a disposal component.

This concept would be suitable for use for Persona 2, 3, and 5. These are all able-bodied men who would be able to carry the weight of the leaves on their back. For Persona 4, this concept would be difficult to use as she has recently given birth, and lifting heavy loads is not advised during this time. Persona 1 also has a physical disability, meaning she would not be able to complete this task using this concept because of its design.

### **Concept 3: Electric push-to-move rotating brush**

This concept uses a motorized brush to pull in leaves and debris, with the aid of an electric motor that plugs into an outlet. This way, there is no need to recharge the device, as it has no batteries. It utilizes a simple 4-wheel movement system, that is to be pushed by the user for movement. Steering is controlled with a handle that moves relative to the direction of the user's intention. A collection bag made of a mix of mesh and fabric will be used to store all the leaves and debris that is collected by the rotating brush. Construction consists of a mix of metal and composites, ensuring durability and reliability, while also maintaining minimal costs and weight.

This concept fulfills our requirements as it collects and stores leaves, and is able to be moved by the user. Once again, this concept fails to meet the disposal requirement. This concept can be used by all of our personas. Persona 1 would be able to use this concept as it has an electrical component which reduces the amount of force needed to be exerted by the user. All other personas, all able-bodied, would be able to use this with little hassle.

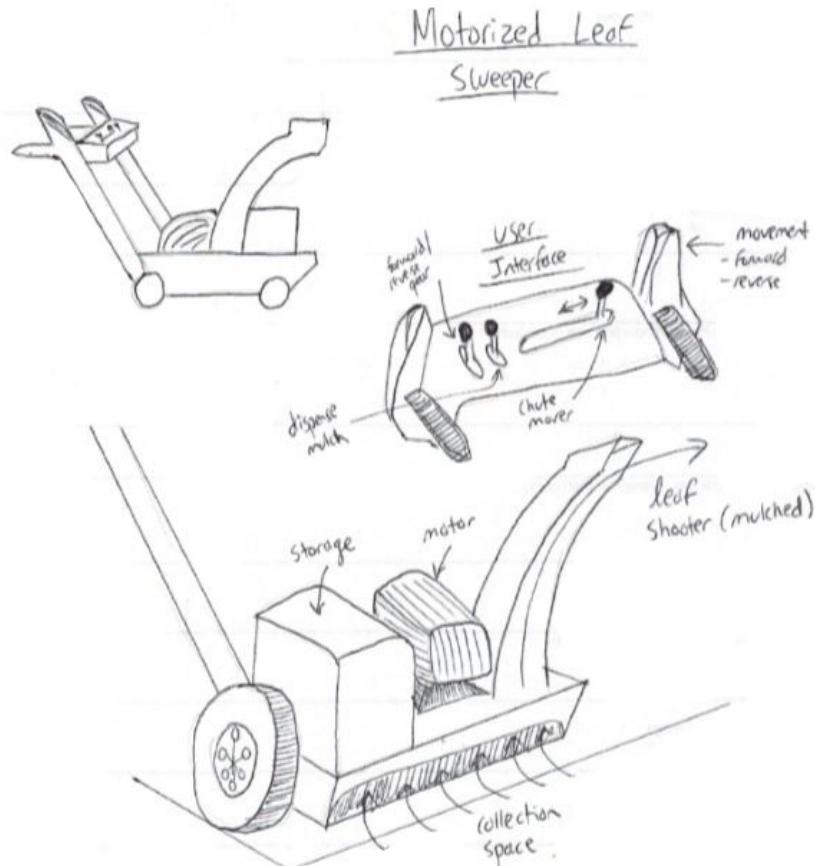
### **Concept 4: Motorized Leaf Sweeper with Mulcher**

Concept 4 is a motorized sweeper and mulcher, a heavy duty machine that produces efficient results at an expensive cost. With a motor to assist with straight line motion, this concept can be utilized for almost any user group due to low strength requirements. This concept comes with a built in mulcher, grinding leaves and other organic material down to mulch which can later be dispensed. With an escape chute similar to a snow blower, the user can aim and release the mulch in specific areas after collecting leaves, serving 2 main purposes. The user interface comes with multiple controls such as movement with reverse gear, escape chute positioning, and separate grind and dispense buttons. Strong metal construction that is welded will ensure that concept is durable and will last a long time.

This concept satisfies the requirements of being able to move and incorporating a disposal system, but does not have a collection or sorting system, which it does not necessarily need as it mulches the leaves, but may be required for added safety, ensuring that if something was caught underneath the device, there would be an opportunity to save it.

This concept would satisfy Personas 1, 2, 3, and 5. Because of its higher price-point, these personas would be able to purchase this without any hesitation. Persona 4, because of her young children, would not be satisfied with this concept as it would be quite dangerous to use with children present, in case they happened to get in the way of the device.

Figure 20. Motorized Leaf Sweeper with Mulcher



### Concept 5: Gas Powered Twin Leaf Blower

The gas powered twin leaf blower features 2 powerful blowers for each hand to move leaves at high speeds. Compared to the conventional leaf blower, this variation allows for more control as 2 separate blowers can better move objects that are stuck or around tight spaces. In addition, it can help organize the collected pile with more ease at the end. This concept features user controls on the handles, with 2 main triggers on each arm to start the machine. This concept will be gasoline based, requiring a pull crank

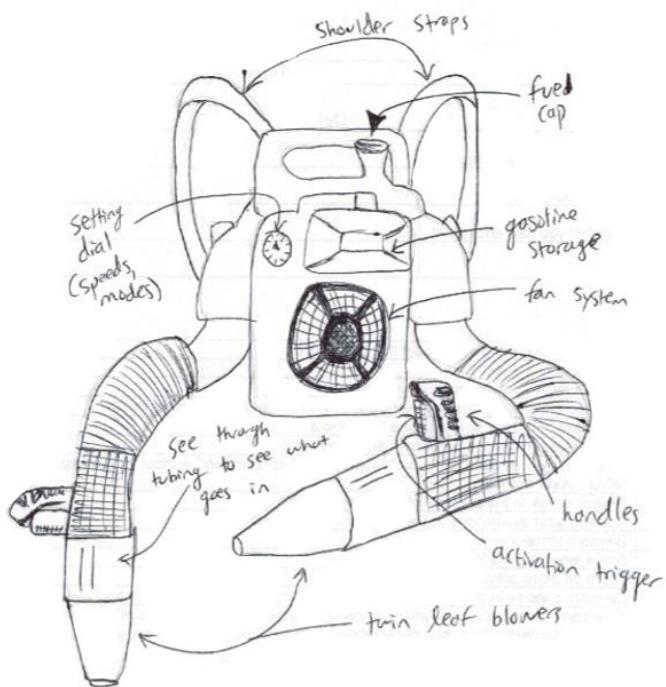
attached to the back to start the machine. With a lightweight softshell shoulder mounted bag, the machine will be mounted similar to a backpack to assist with mobility.

This concept satisfies the requirements to sort and collect leaves, and can be easily moved. However, it does not have a disposal system set in place.

This concept would not be suitable for Persona 1 and 4, as it would once again be too heavy for them to use. Personas 2, 3, and 5 would have no problem using this device.

Figure 21. Gas Powered Twin Leaf Blower

### Gas Powered Twin Leaf Blower



### **Concept 6: Rake with Tines**

Concept 6 is inspired by a rake. The handle is adjustable to allow different personas of different heights to use it. There is no power system so it is carbon neutral and environmentally friendly. The tines are used to pick up leaves similar to a fork. Leaves must be placed in an external storage system to be disposed of, as the device does not have an attachable storage system.

This satisfies the requirements of collection and sorting, by the user being able to use the concept to sort the leaves into piles and collect them into bags. The concept is also easily moveable and adjustable. The concept does not have a disposal system.

Because the rake can be easily adjusted, all personas would be able to use this device to the best of their abilities. For Persona 1, this is not the best solution as she will get tired very quickly because of the physical labour, but she can still use it if need be.

### **Concept 7: Driveable Leaf Collector**

Concept 7 is a device in which a person sits and drives around, collecting leaves. This is accomplished using tank treads with a shovel-like mechanism to pick up large amounts of leaves at a time. After it has picked up the leaves it goes through a strainer to sort out any foreign objects before it goes into a mulcher, where it then gets sorted out into a plastic container. The entire device is powered using a gas engine. It is made from metal and various welding techniques.

This concept satisfies all of our requirements. It is able to sort leaves, collect them and dispose of them without any extra help. It is also easily moveable.

Personas 1, 2, 3, and 5 would be able to use this concept, as it requires no extra physical labour. Persona 4 would also be able to use it as it collects the leaves rather than immediately mulching them, which provides added safety for her children.

### **Concept 8: Modified Rake**

This design is a hand held object which consists of tines and prongs to gather the leaves and pushes it into a detachable bucket, without sorting the items being inputted. This concept design would be made of plastic with mortise and tenon connections, and is controlled by the user via a handlebar without any external power sources.

This device satisfies our requirements for collection and movement, but fails to meet the requirements of sorting and disposal as neither of these elements are incorporated into the design.

Persona 1 would find this device difficult to use as there is not an external power source, meaning her physical disability will inhibit her to be able to use the concept properly. Persona 4 would also find this physical labour difficult. It would be suitable for Personas 2, 3, and 5.

### **Concept 9: Remote-controlled Leaf Sweeper**

The concept has a rotating brush, and uses tank treads instead of wheels. It is controlled by a touch screen remote, and its body is made of metal and plastic. It mulches leaves while it moves, and is battery powered. This concept is directly inspired by our reference design. Certain embodiments were swapped for others to improve usability and tailor the concept to our requirements. It is powered by electricity, which

reduces the strength demand it places on users, making it more usable for Persona 1 and other users with lower than average strength capability. The battery is rechargeable which makes it sustainable, however, it is not carbon neutral as it does still require a power source.

This satisfies our disposal, collection and movement requirement, but does not incorporate a sorting system into the design.

All personas would be able to use this device. Persona 4 would be able to control the movement of the device more precisely with a remote control, which solves the issue of safety for her children.

### **Concept 10: Electric Blower**

Concept 10 is similar to an electric leaf blower. It is made of metal so it is more durable, but this also makes it more expensive and heavy. The device moves by sliding on a structure similar to skis. The team decided to explore different movement systems, which is why skis were used. The electric leaf blower dispels air to collect leaves in piles, and the leaves are not stored inside the machine. The device is controlled using handlebars attached to the leaf blower. The skis provide more stability and balance than wheels, and the device will not roll away or fall over even on very windy days.

This concept satisfies our collection and movement system, but fails to meet the requirements for sorting and disposal. This concept has a bit more stability because the skis are flat on the ground, which eliminates the chance of it tipping over.

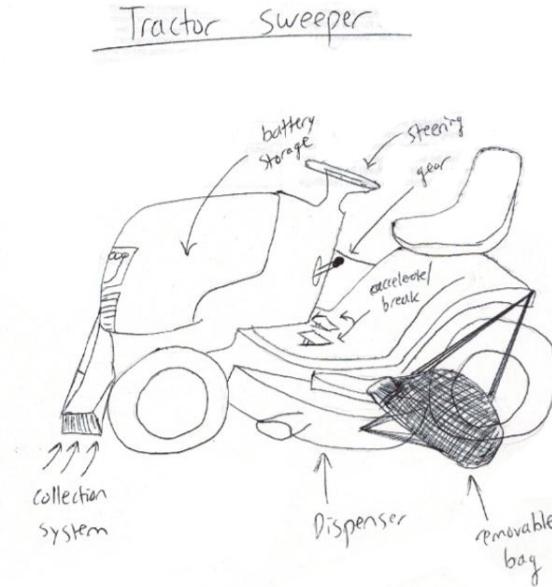
This device would be functional for Persona 2, 3, and 5 because it requires human force to move it around. Persona 1 and 4 would struggle with this, making it a poor concept for them.

### **Concept 11: Tractor Sweeper**

Concept 11 focuses on a heavily motorized sweeper. With a tractor-like body, the user will be able to sit down and drive the vehicle around while cleaning. Similar to previous concepts, it features a rotating brush for collection, where leaves and other inputs will be stored in a flexible closed removable storage bag. The system will feature 4 standard wheels for movement and turning. Improved grip will be added to tires for all terrain and weather conditions such as rain. Other features include battery power that can be recharged, simplified car like interface, and a strainer for the sorting system.

This device satisfies all requirements for our design. It has a collection and sorting system, can be easily controlled, and has a removable storage bag for disposal.

Every persona would be able to use this concept in the way it was designed. The seat makes it functional for Persona 1 and every other persona would be able to use it as well.

Figure 22. Motorized Leaf Sweeper

## concept evaluation #1

To evaluate our concepts, we used a pairwise comparison chart, shown below, to calculate the most important product characteristics, based on their priority as determined by us. These product characteristics listed in detail under Requirements.

Table 40. Pairwise Comparison Chart

	A	B	C	D	E	F	G	H	TOTALS	WGT
Safety	A		A	A	A	A	A	A	7	24.14%
Efficiency	B		B	D	B	B	B	H	5	17.24%
Comfort	C		C	C	C	C	C	H	4	13.79%
Affordability	D			E	F	F	D		2	6.90%
Portability	E				E	E	H		3	10.34%
Sustainability	F					G	H		2	6.90%
Manufacturability	G						H		1	3.45%
Durability	H								5	17.24%
									29	100.00%

Based on the Pairwise Comparison Chart shown above, our product characteristics shown are listed below, in order from highest priority to lowest priority:

- Safety

- Efficiency, Durability
- Comfort
- Portability
- Sustainability, Affordability
- Manufacturability

We made safety the most important priority, as we believe that no matter how good a product is, if it isn't safe, then we are not considering the user within the design.

Efficiency is the second most important priority, as we believe that a product should, most of all, be able to perform its intended functions efficiently, without any issues from the user. Durability was also the second most important priority, as we believe that users want a product that not only does its job, but it also lasts long, and can handle extreme conditions, with minimal failure. Comfort was the third most important priority, as the design must be user-friendly, with no ergonomic issues. It must be able to accomplish this without sacrificing its safety, durability, and efficiency. Sustainability and Affordability are less important to the design as other product characteristics. Manufacturability was our lowest priority, as we believe it's more important to have a product that is safe, functional, usable, and affordable, than for it to be easily manufacturable.

Once the weights of all the system requirements were established, we included all of the concepts, the product characteristics and their weights into a comparison chart called a Weight Distribution Matrix, which gave us a good comparison of all the different concepts, based on the characteristics. For our scoring system, we used a simple five-point scale as it provides adequate measurements without being overly precise. The scale is linear and ranges from -2 to +2, where the negative numbers indicate that the concept is worse than the reference design, the positive numbers indicate that the concept is better than the reference design, and a zero indicates that the concept comparably performs the same as the reference design.

Table 41. Weighted Decision Matrix

R: Rating, S: Score

ATTRIBUTUE	WGT	REF DESIG N																		
			1	2	3	4	5	6	7	8	9	10	11							
	%	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	R	S	
Safety	24.1	0.0	0	0	2	0	0	0	2	0	5	0	5	0	2	0	2	0	2	0
Efficie	17.2	0.0	0.	1.	0.	1.	0.	1.	0.	2.	0.	2.	0.	0.	0.	1.	0.	0.	0.	2.

ncy		0	0	2	0	2	0	2	0	3	0	3	0	0	0	2	0	0	0	3	0	2	3	
Comf ort	13.8	0.0	0	0	3	0	0	0	0	1	0.	-1.	-0.	-1.	-0.	2.	0.	-1.	-0.	2.	0.	1.	0.	
Afford ability	6.9	0.0	0	0	1	0	1	0	1	0	1	0	1	0	1	0	2	-0.	0.	0.	-2.	-0.	-1.	-0.
Porta bility	10.3	0.0	0	0	0	0	2	0	0	0	1	0	1	0	2	0	2	-0.	1.	0.	-1.	-0.	-1.	-0.
Sustai nabilit y	6.9	0.0	0	0	1	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1
Manuf actura bility	3.5	0.0	0	0	1	0	1	0	0	0	1	0	0	0	1	0	1	0	1	0	1	0	0	0
Durab ility	17.2	0.0	0	0	3	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	3
TOTA LS	100.	0	0	-0.	0.	-0.	-0.	-0.	-0.	0.	-0.	0.	-0.	0.	-0.	0.	0.	0.	0.	-0.	0.	-0.	0.	4

Each concept was rated against our Personas. This allowed us to justify the value we entered into the WDM. For Concept 1, the leaf vacuum, we compared its design against our personas' strengths and weaknesses. We considered that there is not a very high physical strain on the user, but there may be some cognitive stresses that Persona 5 would not be able to deal with. It also is not as easily moveable as some of our other concepts, but has the same physical strains as the reference design. Concept 2 places more stress on the user as they must hold it in order to use it. This excludes Persona 1 and 4 from being able to use it as they would be unable to carry such a heavy load for an extended period of time. It is also less functional than the reference design.

Concept 3 reduces the physical load on the personas, but it has some setbacks in other areas, including safety and portability. This device would be easy for Persona 1 and 4 to use during the process of leaf management, but becomes difficult once the user has to carry it to and from storage.

Concept 4 has about the same physical strain as the reference design, but is less safe because of the incorporated mulcher. This would be dangerous for Persona 4, who has young children to look after while she is using the device. For other personas, like Persona 2, 3, and 5, this concept would be easy to use.

Concept 5 once again places the weight of the device on the user rather than on the ground, which limits Persona 1 and 4 from using it properly. Persona 2, 3, and 5 would

be able to use this, but when compared to the rest of the product characteristics and the reference design, there are some things that could be improved.

Concept 6 is useful for all of our personas. It is the simplest design, but features have been incorporated to make it more functional for a greater number of users. Every Persona we have would be able to use this device.

Concept 7 has some comfort characteristics, but because of its many features it lacks in other areas. Although every persona would be able to use this concept, it does not have a high score because it is less portable and sustainable than the reference design.

Concept 8 is functional for most Personas, but Persona 1 would struggle with the detachable bucket feature and the human power source, as well as Persona 4. It is not as functional as the reference design.

Concept 9 may lack in affordability, but overall is a much-improved design compared to the reference design. It also works with all of our personas, and Persona 5 would have no problem using it because the touchscreen display is very simple.

Concept 10 uses skis instead of wheels, which may not be practical for our personas, as they would not have the space needed to store such a device. Compared to the reference design, a leaf blower would be much heavier, making it hard for Persona 1 and 4 to use.

Concept 11 would be beneficial for all of our personas because of its many safety features and comfort factor: it is rideable, meaning there is no human force required. When compared to the reference design, it functions much better.

As shown in the WDM, the top three scores chosen for concept refinement are highlighted in blue. Our top three concepts are: Concept 6, Concept 9 and Concept 11.

## concept refinement

Once we chose our 3 best performing concepts, we updated the design to create the best one possible.

For Concept 6, according to the WDM that we made in Concept Evaluation, it had 2 main weaknesses. Its comfort was compromised by its heavy metal construction, and its durability was affected by the flimsy and unreliable tines. As a result, the heavy metal frame structure was replaced with light, plastic construction. This would not only reduce weight, but would also make the product more affordable to the user, as plastic is cheaper to manufacture than metal. Secondly, the flimsy tines were replaced with a

thick rotating brush, which is less prone to failure, hence making the product more durable.

This improves the use for our personas as it makes the concept lighter, and the brush enables the user to keep the product on the ground, without having to do too much lifting.

For Concept 9, its first main flaw were the tank treads, which would not only increase weight and complexity, but also increase the cost in development, and in turn increase the cost to customers. This was replaced with a conventional 4-wheel movement system. This decreases weight and complexity, and improves manufacturability, which combined results in increased affordability. The second main flaw was the touch screen control system, which would add weight and development costs. This would decrease affordability, manufacturability, and durability. This was replaced with a more conventional control panel with buttons, a much simpler design, but it maintains the current usability and comfort. This will improve affordability, manufacturability, and durability of the design.

This leads to an improved persona experience with the concept, because eliminating a touch screen means Persona 5 would have no trouble directing the machine with simple buttons. It remains functional for all other personas as well.

Finally, for concept 11, the two main systems that were changed was the metal structure system, and the tank treads. Firstly the metal structure was changed to a lighter composite system, which reduces weight, improving portability, comfort, affordability, and manufacturability. Secondly, the heavy, complicated, and expensive tank tread system was replaced by a simple 4-wheel movement system. This reduces even more weight, complexity, and development costs, which would improve manufacturability, affordability, portability, and usability.

This device remains easy to use for our personas, especially Persona 1 and 4 because of the lighter frame.

## concept evaluation #2

Once the changes were made to Concept 11, Concept 6, and Concept 9, we used the WDM again, to see which one of the concepts fit our product characteristics the best.

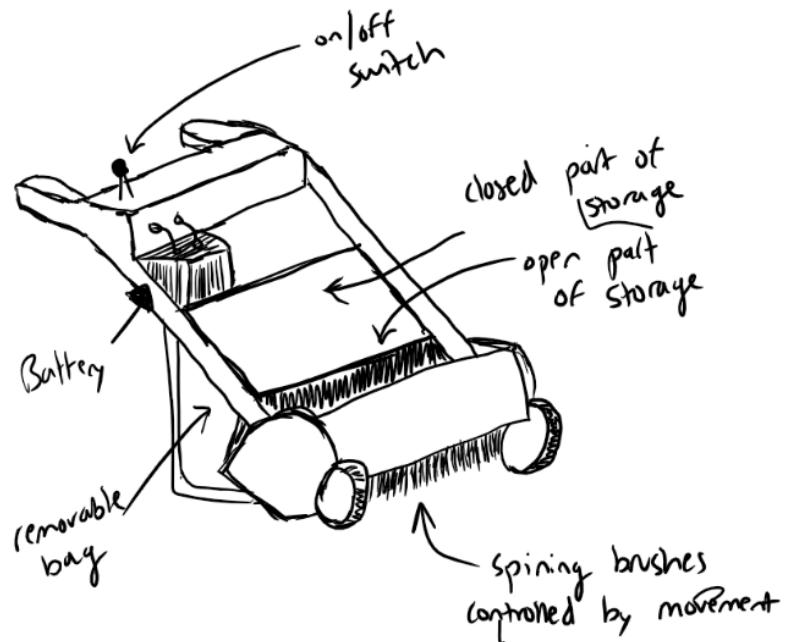
Table 43. Weighted Decision Matrix #2

ATTRIBUTE	WGT %	REF DESIGN		CONCEPT 11		CONCEPT 6		CONCEPT 9	
		RATING	SCORE	RATING	SCORE	RATING	SCORE	RATING	SCORE
Safety	24.1	0.0	0.0	2.0	0.5	1.0	0.2	-1.0	-0.2
Efficiency	17.2	0.0	0.0	2.0	0.3	0.0	0.0	2.0	0.3
Comfort	13.8	0.0	0.0	2.0	0.3	0.0	0.0	2.0	0.3
Affordability	6.9	0.0	0.0	-1.0	-0.1	2.0	0.1	-1.0	-0.1
Portability	10.3	0.0	0.0	0.0	0.0	2.0	0.2	0.0	0.0
Sustainability	6.9	0.0	0.0	-1.0	-0.1	0.0	0.0	-1.0	-0.1
Manufacturability	3.5	0.0	0.0	-2.0	-0.1	2.0	0.1	-1.0	0.0
Durability	17.2	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.2
TOTALS	100.0		0.0		0.9		0.7		0.4

The concept that best suited our WDM was Concept 11.

# final concept validation

Figure 23. Final Concept Plan



The winning concept addresses the needs of all the user groups and personas as every one of their needs was taken into consideration throughout the design roadmap. It also greatly improves upon the reference design by incorporating various upgraded features, including motorization and a removable bag.

The winning concept satisfies all the product characteristics and requirements that we laid out at the beginning of the report. It provides additional user comfort and efficiency compared to the original leaf sweeper in the reference design. It was also designed to be usable by a varied range of users and incorporates specific features to assist with this. The sweeper was made affordable for home owners looking for a long term leaf management solution, and is beneficial for anyone who would purchase it.

# detailed design

- ❖ The final design of the leaf management system was made to satisfy product characteristics, functional requirements and constraints, while providing an innovative solution to leaf management

## Part 1: Frame

- Material: 0.5" SCH 40 Aluminim 6061
  - Aluminium was chosen due to its balance of malleability and strength
  - Because of this versatility, manufacturers can easily configure aluminium into the desired shape while holding the durability of the metal
  - Aluminium is less vulnerable to extreme weather conditions and is rust-proof ("Wenzel Metal Spinning")
  - Weigh's one-third the mass of steel, making the overall design much lighter and easier to use by a larger HF envelope
- The frame is constructed with Ø0.63in. aluminum tubes
  - Entire frame is welded together
  - Round frames reduces stress concentration and prevents vulnerabilities corners would impose
- Features 6 inch handles extending from the top of the frame allowing users to maneuver the sweeper

## Part 2: Storage box

- Material: HDPE plastic
  - Lightweight and very strong, making it perfect for storing leaves
  - Impact resistant, allows for the storage box to hold its shape
  - Weather and mold resistant, a valuable quality due to the constant contact with leaves and other organic inputs

- 1.25 inch spacing from each side compared to frame for smooth placement and removal
- 24in. x 4in opening to allow the collection system to deposit leaves into the storage box

### Part 3: Brush case

- Material: 6061 Aluminum
  - Similar to the frame for consistency and manufacturing purposes
- Brush case will be the framework used to hold the sweeper brushes
- Frame encloses a Ø8in. brush; maximum tolerance for selected brush
  - Ø1in. opening for axle of the brush

### Part 4: Handle cover

- The handlebar is the main user interface between the device and the user. It has a polyurethane cover around it. This is done to improve grip between the user's hands and the handlebar.

### Part 5: Caster-to-frame mount

- Material: cast alloy steel
- Steel plate that allows for the front caster wheels to be mounted to the bottom of the frame

### Part 6, 7 & 8: Motor-to-frame mount #1, #2 & #3

- Material: cast alloy steel
- Steel plate that allows for the motor to be mounted to the frame of the sweeper
- 3 variations of the mount are used
  - Each variation is used to hold the motor and attach to specific parts of the frame for support

### Part 9: Collar Shaft

- Used to mount the motor to the rear wheels.
- Made from cast alloy steel

- Hollow shaft, 3.42" long, 0.63" diameter, with 0.25" hole through the length of the shaft

### **Part 10: Battery Mount**

- Material: Aluminum 6061
- Hollow aluminum frame with an opening to insert the battery
  - Mounted to the frame
- 0.20inch. thickness

### **Part 11: Off-the-shelf Parts**

- Off-the-shelf parts, such as the rear wheels, front caster wheels, and all other fasteners were taken from McMaster-Carr (“McMaster-Carr”). Parts were chosen based on their size and mounts that we thought would work best with our design.

# design discussion

- The designed motorized leaf sweeper is an updated version of the original leaf sweeper, built to better satisfy users
- It features assistance from the motor for both movement and collection
- Includes 4 wheels compared to the standard 2 wheel design
  - The front 2 wheels are caster wheels included for better movement
  - Caster wheels can rotate 360 degrees (same concept as shopping cart wheels)
  - The rear wheels are much bigger and have better grip, have power assisting them for movement when the user applies force
- 26.5 inch width for collection
- Sorting system was eliminated from the final design, due to added weight and complexity, which would affect many of our requirements, such as manufacturability, and affordability. So, it was decided that the sorting would be done manually, by the user.
- A lot of components were outsourced from third-part vendors, such as McMaster-Carr. This would save costs in development, improving manufacturability and affordability, while maintaining usability and functionality.

# Conclusion

Leaf management is a crucial area for innovation in current society. With areas such as the GTA having thousands of leaves fall onto people's area, it would be beneficial to find a more efficient way to manage and collect all the leaves compared to existing solutions. In addition, by considering human factors into design, a superior product can be designed which can be used by a larger audience due to inclusivity.

Before a final concept could be designed, a lot of research and idea generation had to be done beforehand. Firstly, understanding the situation, area, target population and other starting factors had to be considered. By looking at existing designs and choosing one for reference, our team was able to work and generate ideas from there. After this, human factor depends could be added into the mix to narrow down possible designs. By designing for users at the end of the HF envelope, our team can ensure that all the extreme cases would be accounted which would automatically consider users in the middle of the envelope.

After 3 stages of initial research, each focusing on different areas, ideation was implemented to help brainstorm our final design. By considering all features and using different methods to narrow down our search and remove inconsistent embodiments, our team finally reached the conclusion that our final design would be a motorized version of the leaf sweeper, providing additional benefits from the original such as caster wheels being used for guidance and movement and collection assistance from the motor.

The motorized leaf sweeper is a superior product to existing designs, due to the inclusivity of human factor capabilities being accounted for in the early stages of design. Our product features improvements and innovation compared to standard leaf management systems, making it a worthy competitor that can take over as the top leaf management system.

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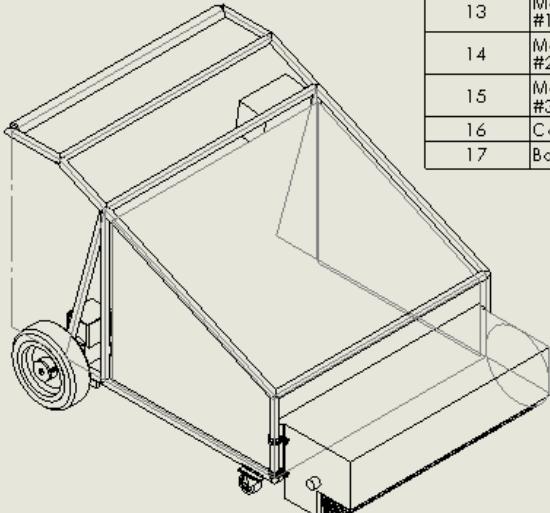
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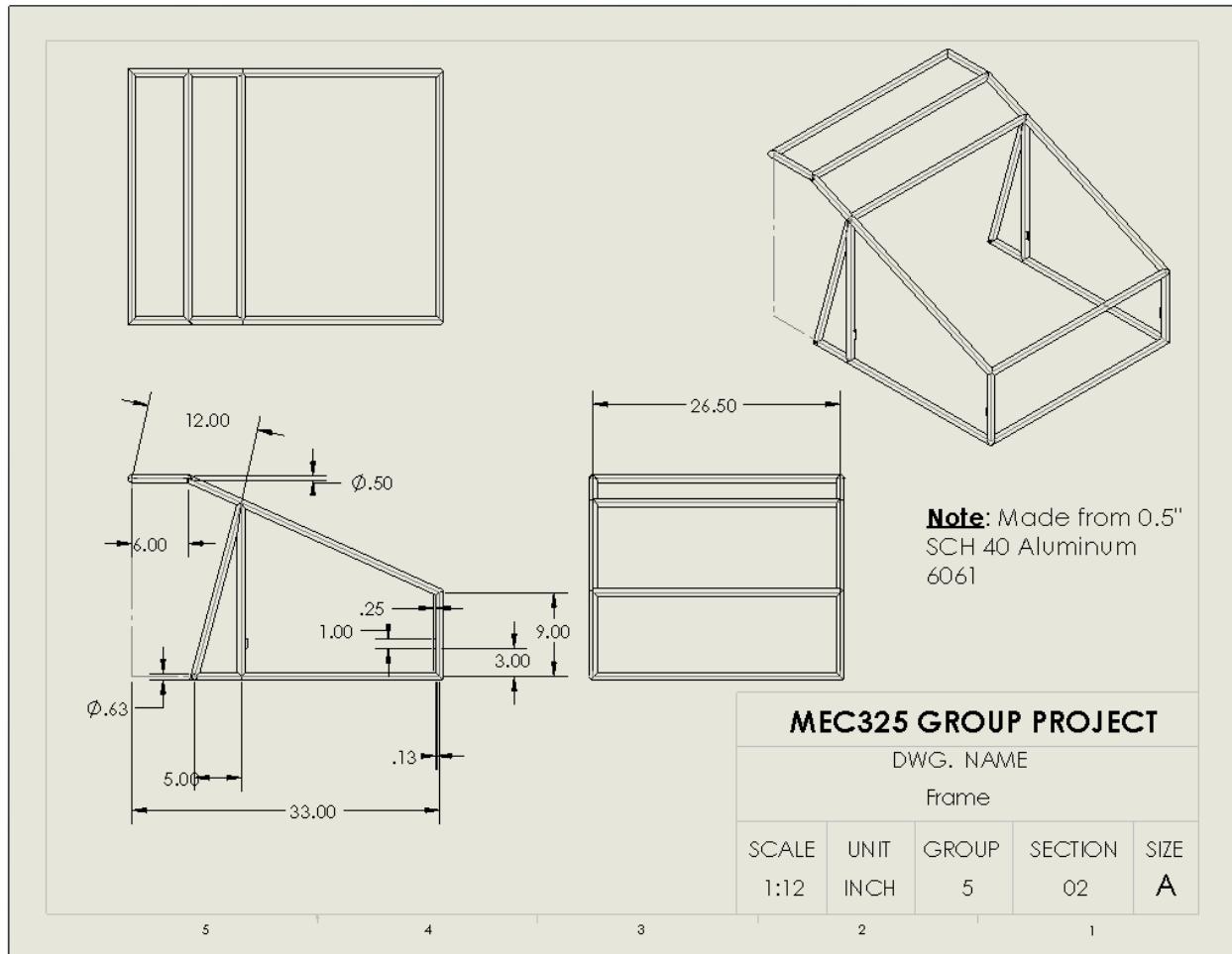
# appendix 1: part drawings

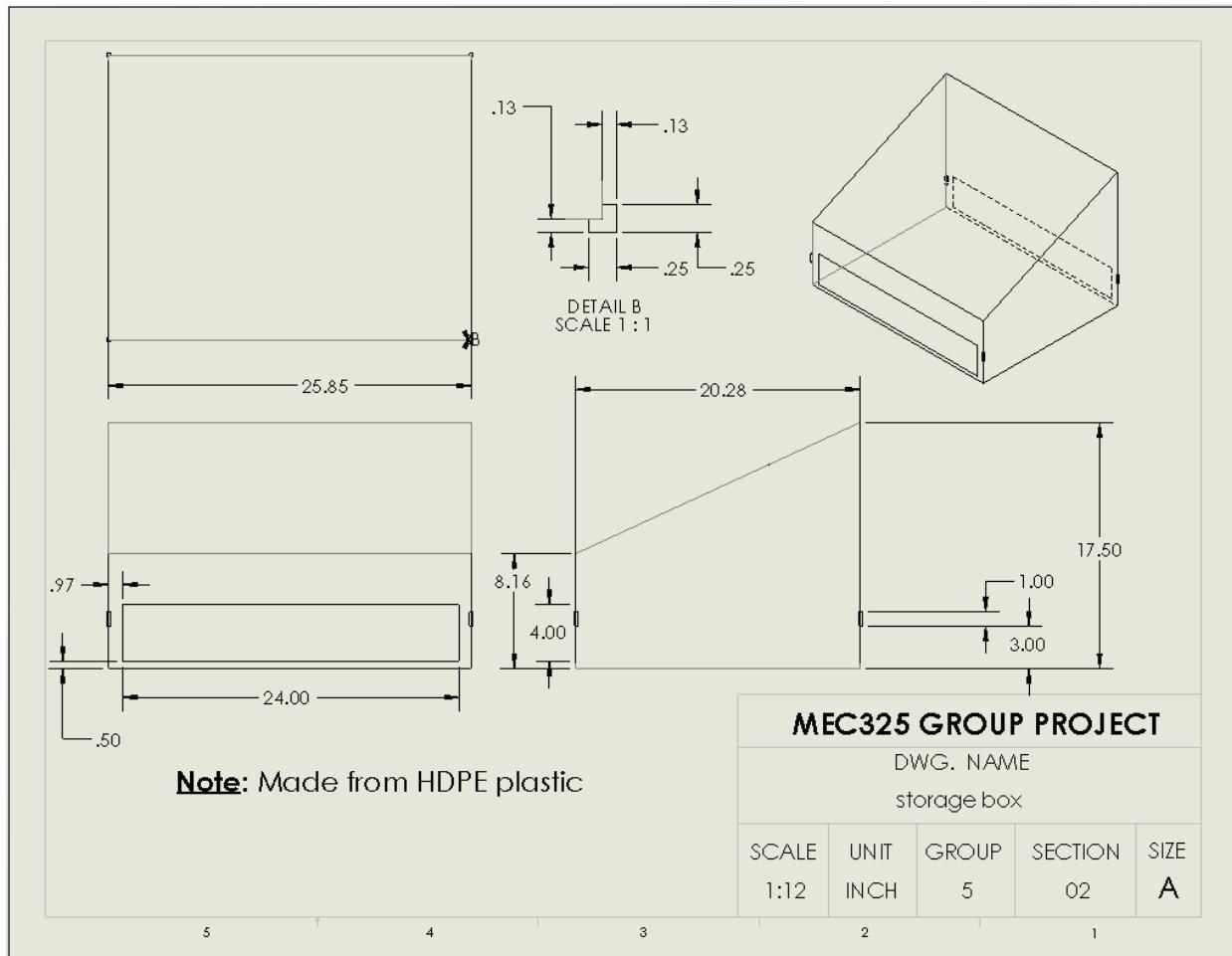
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame		1
2	Storage box		1
3	Brush		1
4	Brush Case		1
5	3177T15	7/8" P-clamp	4
6	91290A254	M5x0.8mm Screw	4
7	93625A200	M5x0.8mm Locknut	4
8	78155T11	2" diameter caster wheel	2
9	2336T13	8" wheels	2
10	Foam Handle cover		1
11	Default		2
12	Caster-to-frame mount		4
13	Motor-to-frame mount #1		2
14	Motor-to-frame mount #2		1
15	Motor-to-frame mount #3		1
16	Collar shaft		2
17	Battery mount		1

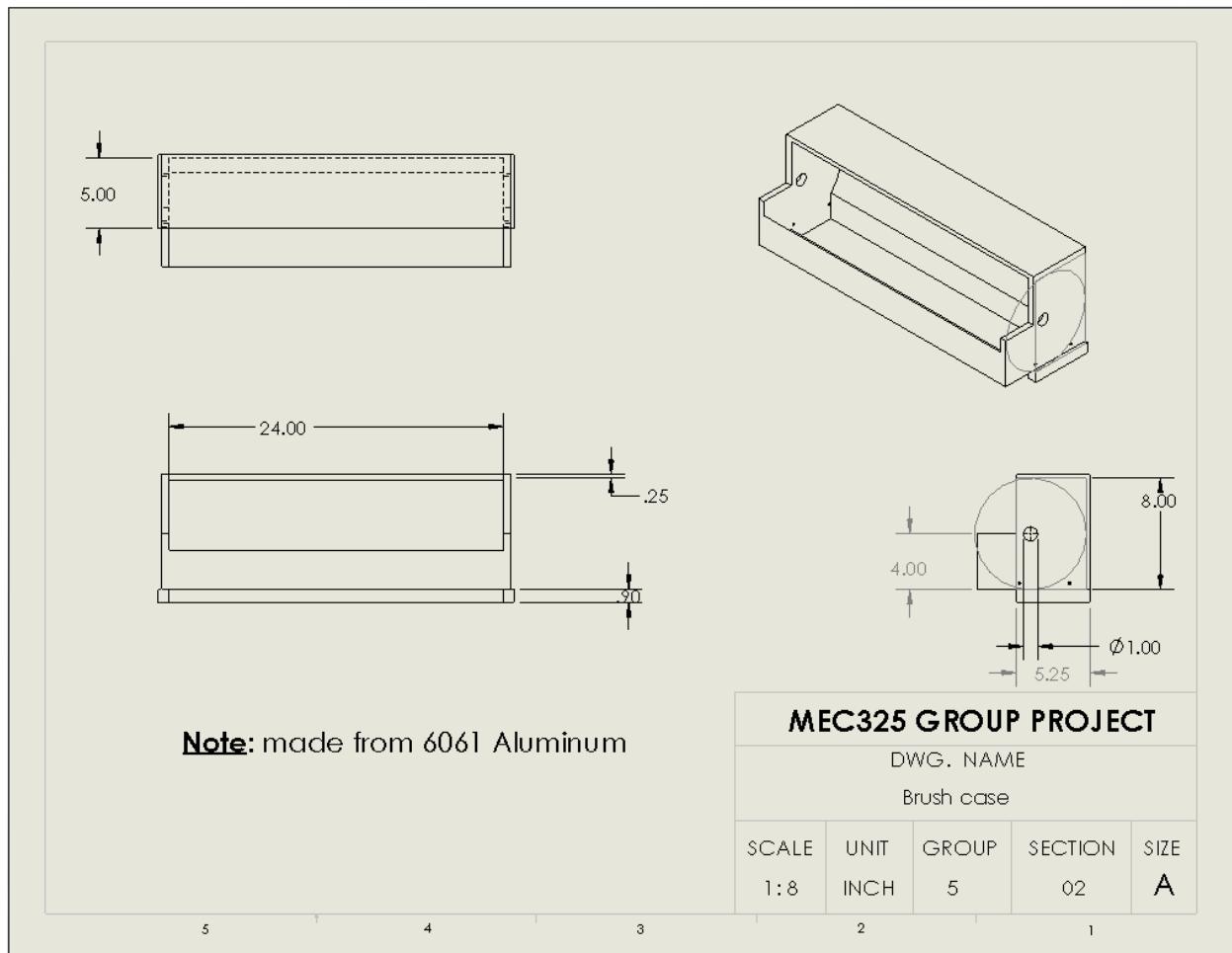
**Note:** Parts numbers for hardware, from McMaster-Carr

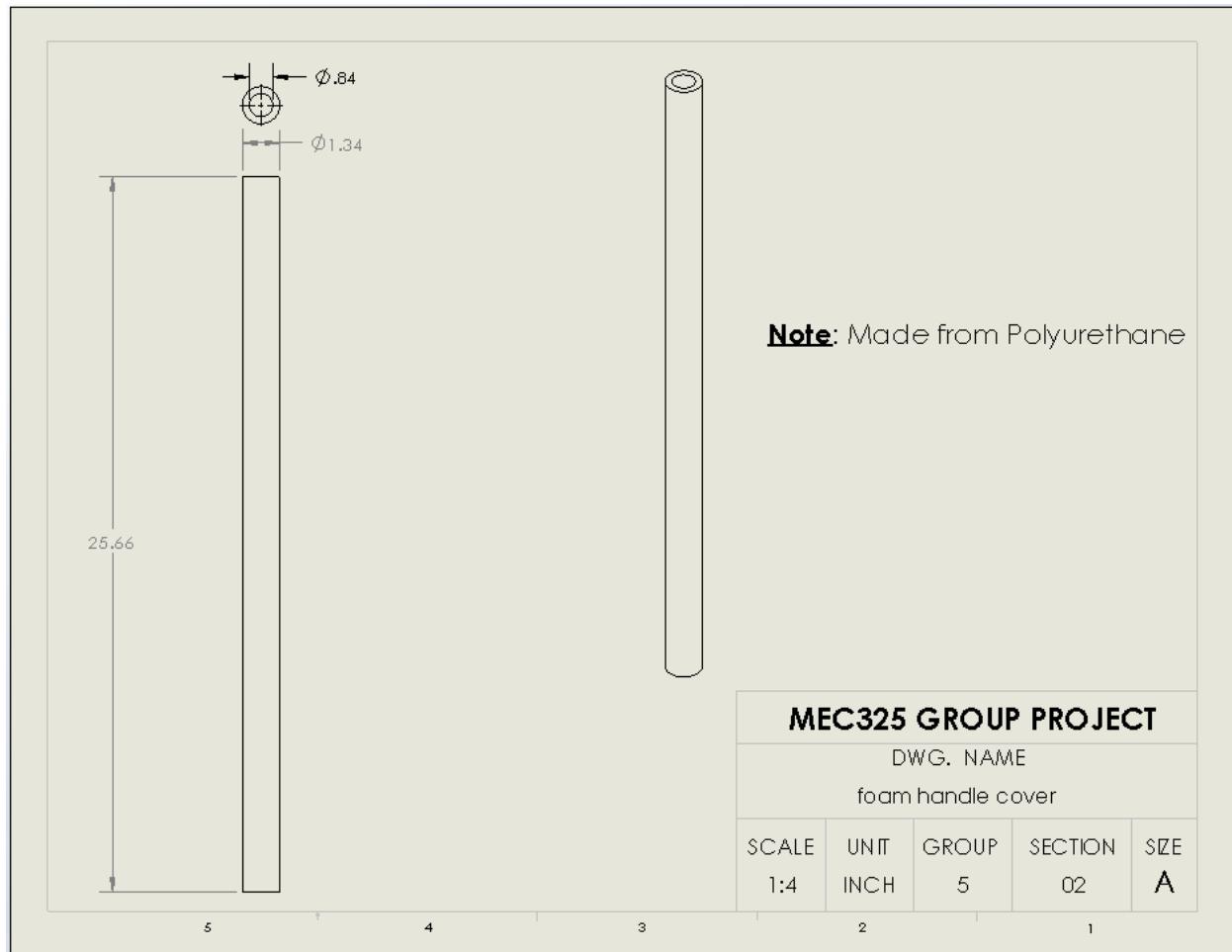


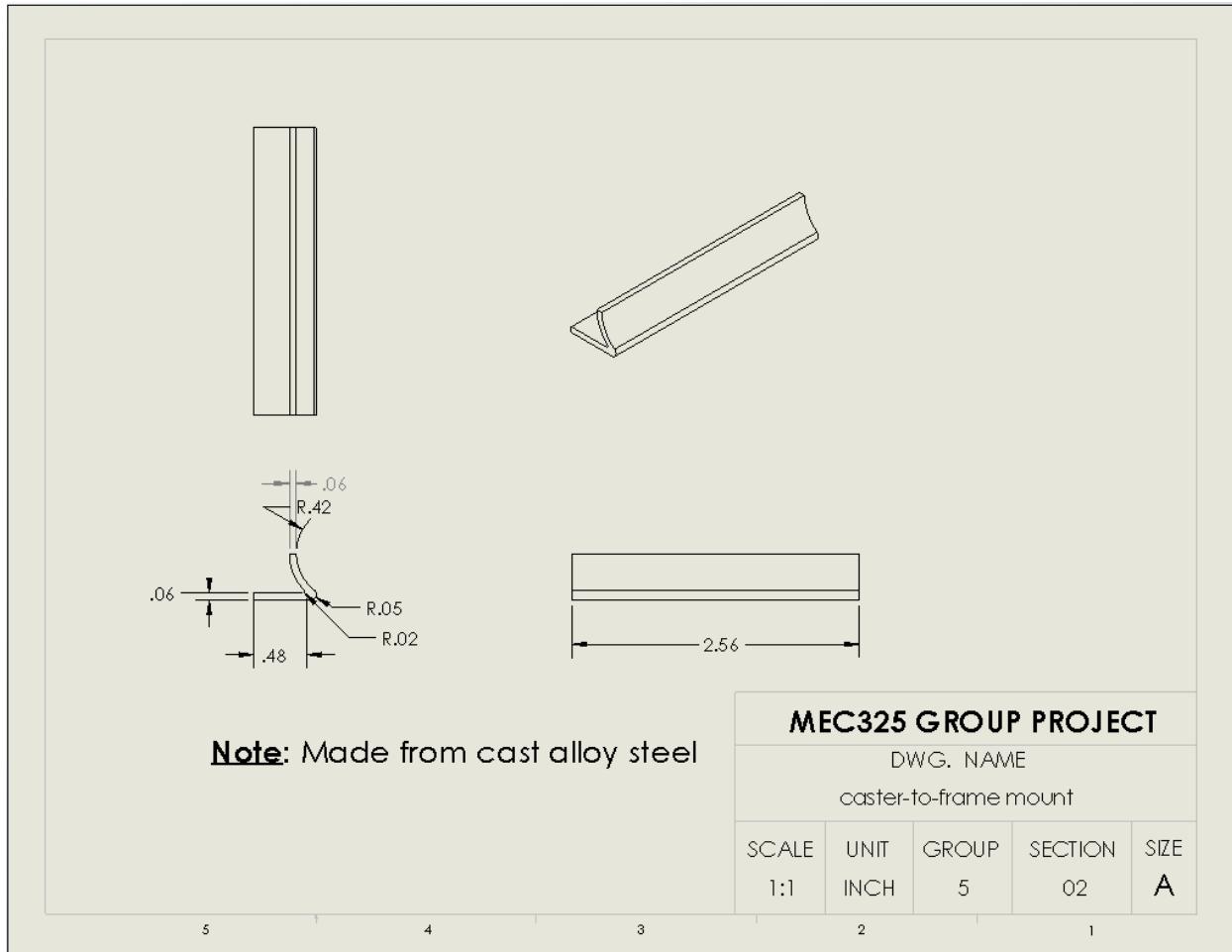
MEC325 GROUP PROJECT  
DWG. NAME  
Main Assembly  
SCALE 1:10 UNIT INCH GROUP 5 SECTION 02 SIZE A

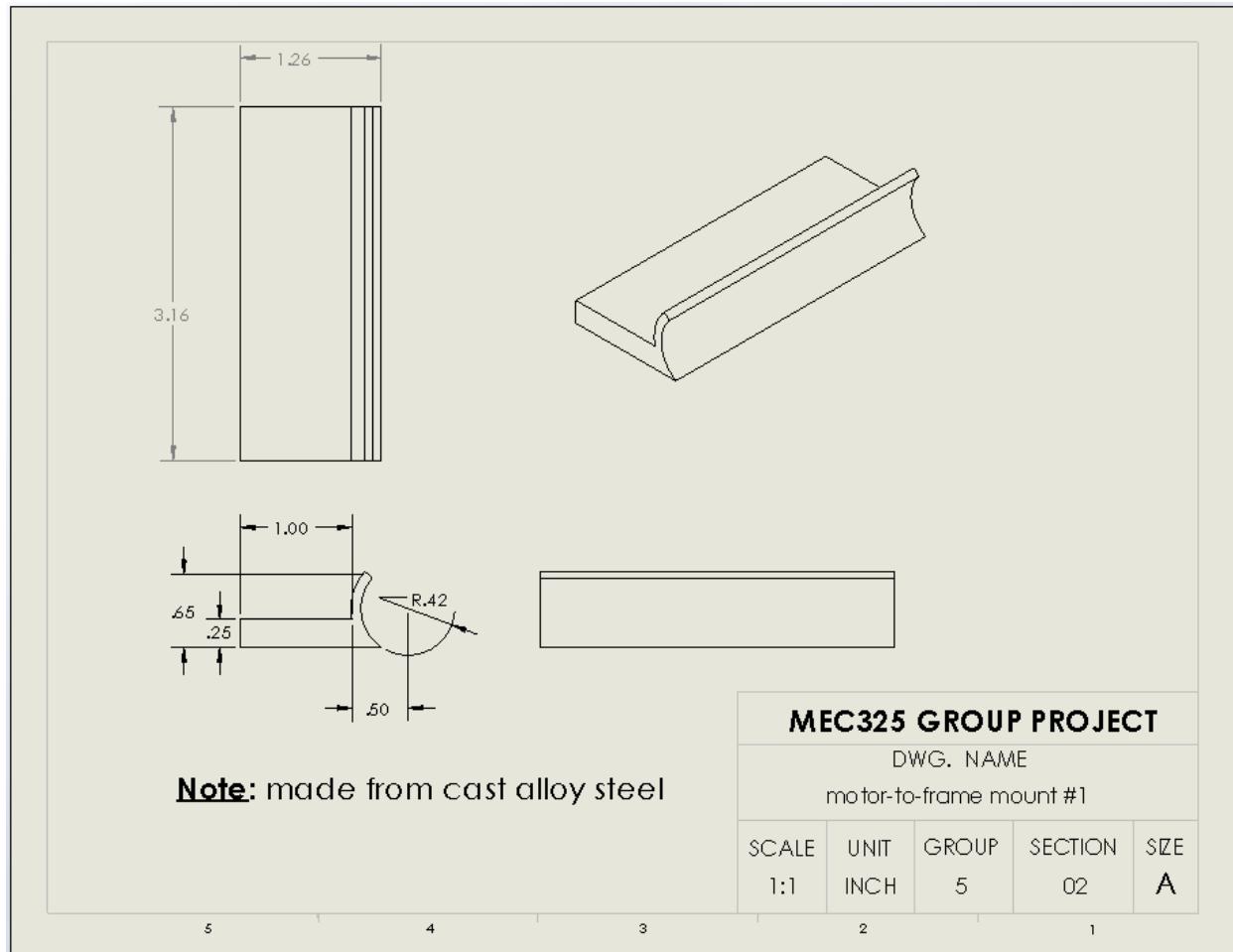


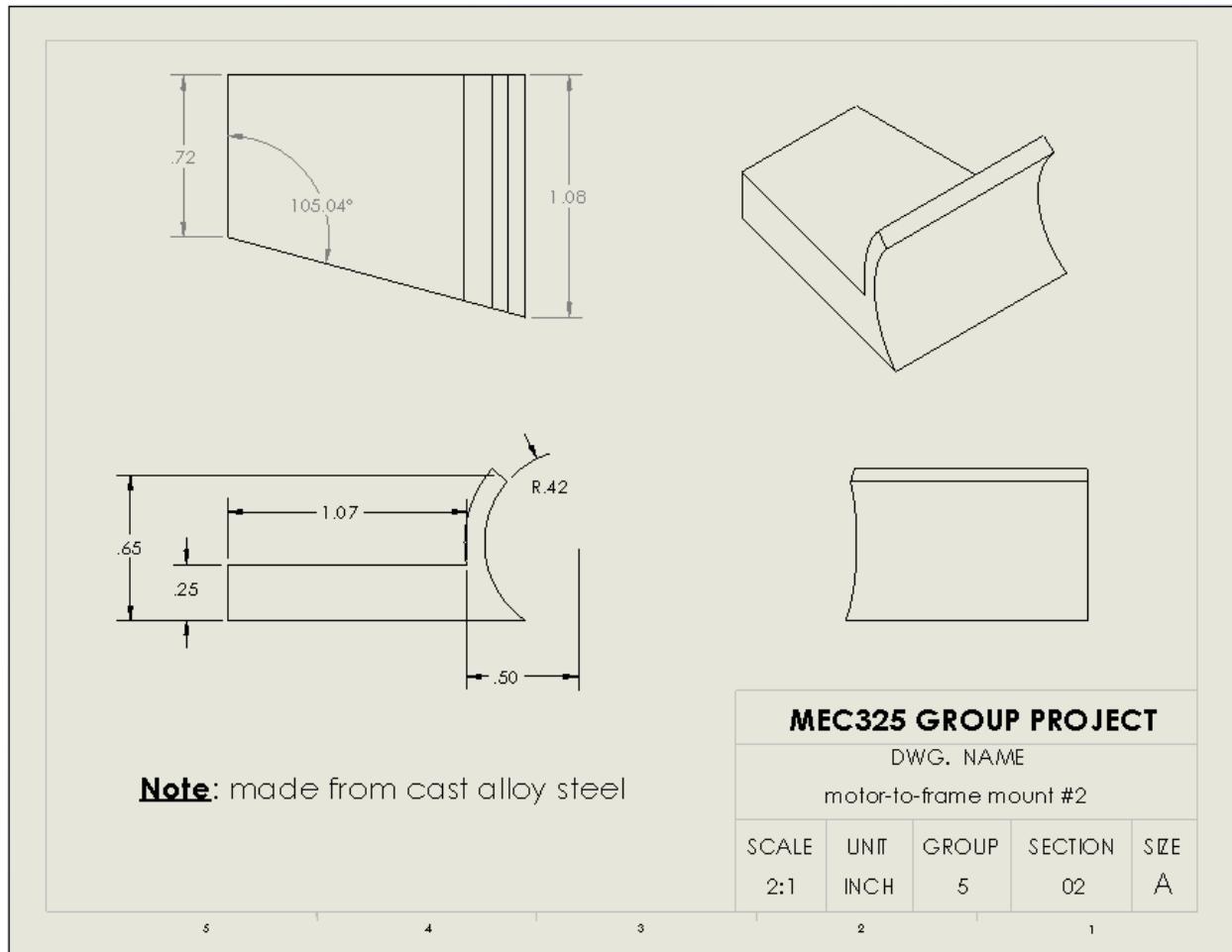


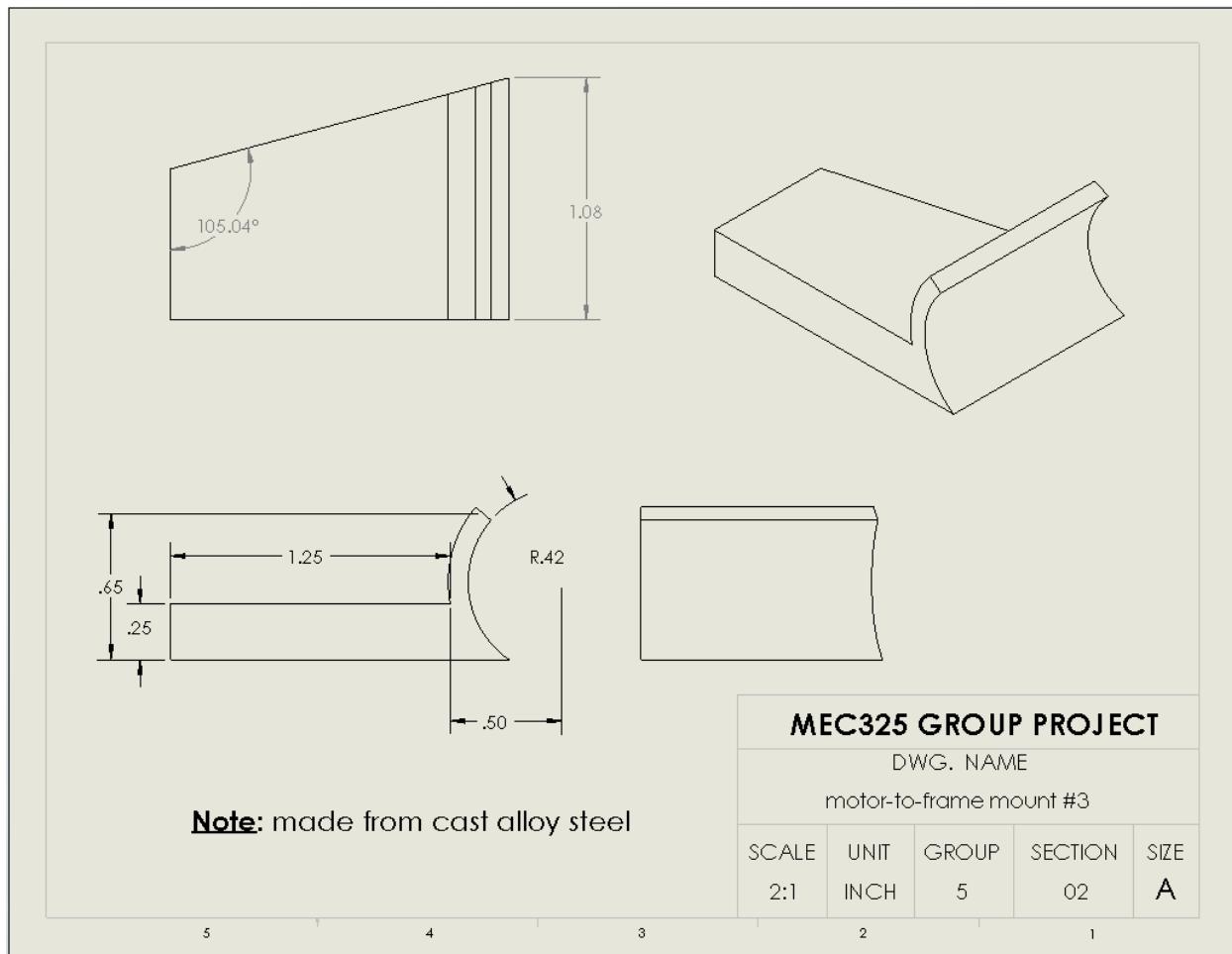


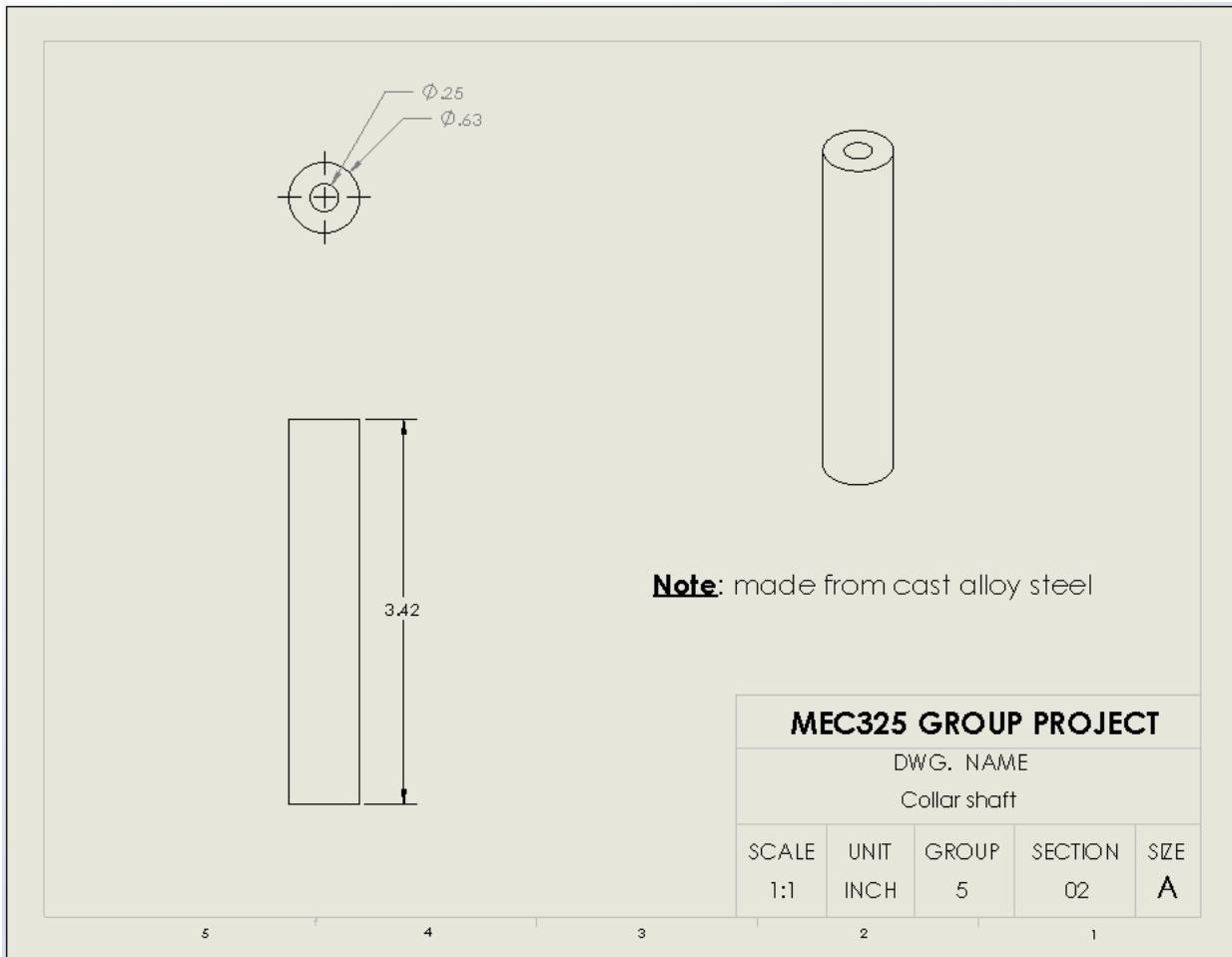


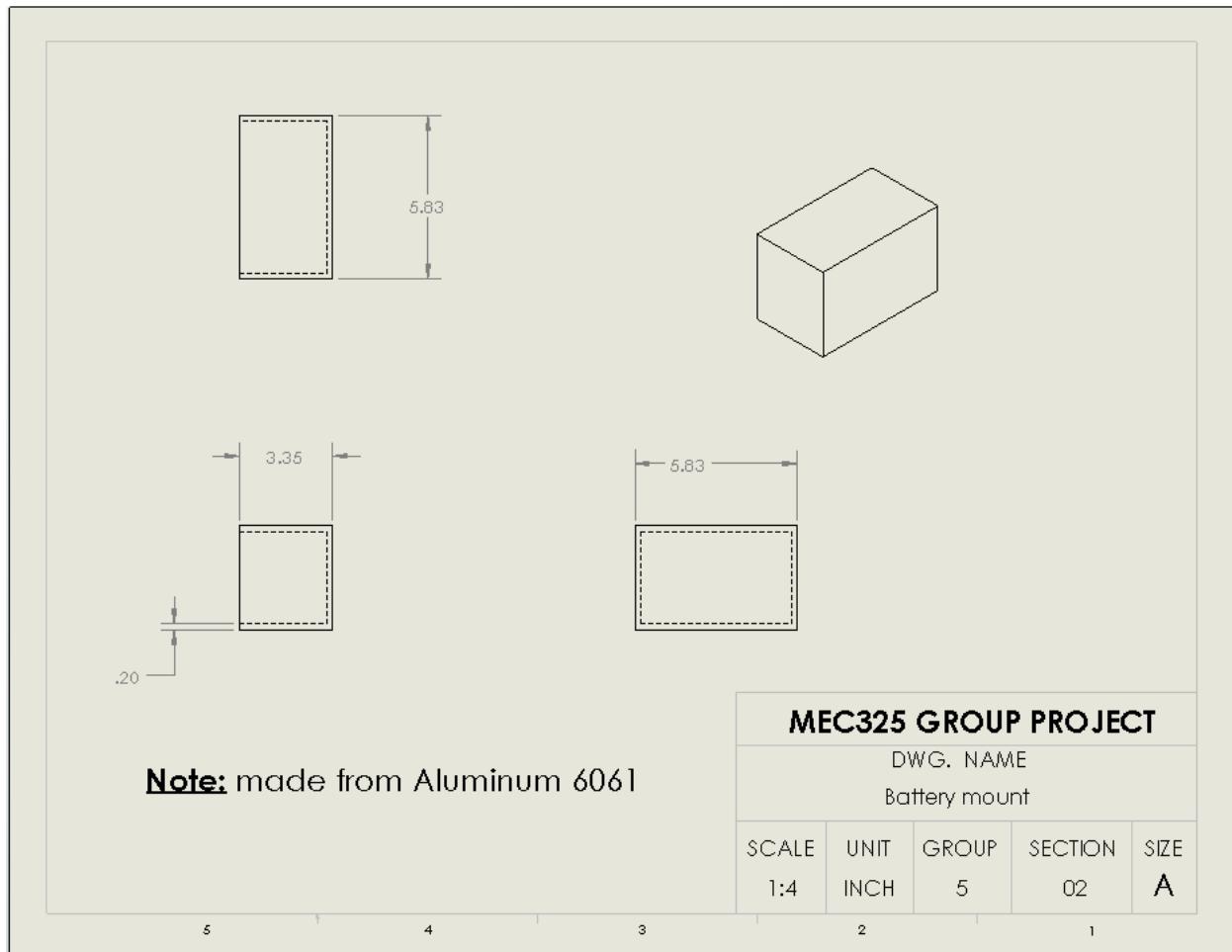












# appendix 2: human factors demands

**HUMAN FACTORS AND PERSONAS CHART**

		PRODUCT:						
HUMAN FACTORS		PERSONA NAME:	Leila	James	Auston	Erin	Billy	
		TEAM MEMBER	Zaira	Jesvin	Arpen	Maggie		
		RESPONSIBLE	Inayat	Joy	Patel	Malkin	Janakan	
		MINIMUM REQUIRED CAPABILITY FOR USE						
VISION		20/80	20/40	20/20	20/40	20/40	20/20	
HEARING		60 dB loss	10 dB loss	5 dB loss	10 dB loss	10 dB loss	60	
SMELL		-	-	-	-	-	-	
TOUCH		10%	15.8%	15.8%	15.8%	0.10%	1%	
BALANCE		0.1%	2.2%	0.10%	2.2%	2.20%	2.2%	
PERCEPTUAL	TEMPERATURE	-	-	-	-	-	-	
	MEMORY	1%	15.8%	0.1%	0.1%	15.80%	10%	
COGNITIVE	REASONING	1%	15.8%	0.1%	3.4%	2.20%	2.2%	

	STRENGTH	10% M, 15% F	7.6%	8% M	50%	30% F	5% M
	(BODY) MOBILITY	15.80%	5%	15.8%	25%	2.20%	10%
PHYSICAL	DEXTERITY & PRECISION	2.20%	5%	2.2%	11%	2.20%	2.2%

VISION

SUC	1	
Variable	Value	Justification
Task		
Font Size	N/A	No text required in this particular task of looking for leaves to sweep
Contrast	Some Contrast	Brown leaves are can stand out against the ground, but the grass in Autumn also turns duller, and mud/dirt is also brown so there may not be much contrast
Glare	Some Glare	Sunny days combined with dew on the ground can cause glare but these aren't typical conditions for Fall
White Space	No White Space	
Conclusion		
Population Included	20/20 to 20/60	

<b>% Population Excluded</b>	3.5%	
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**HEARING**

SUC	3	A father who works in construction using a leaf sweeper to clean his property
Variable	Value	Justification
Task	3.1.7	Task 3.1.7 requires hearing to ensure the sweeper is locked into place. After releasing the arm, an audible click should be heard at a very low decibel range. This task was chosen because the click is likely very faint, and a low level of hearing loss may affect a user's ability to hear it. This sound is a clear indicator that the sweeper has been assembled as intended, and that parts of the assembly will not move when the device is used. Failure to hear the sound may cause confusion as to whether the device has been assembled properly.
Volume (dB)	20 dB	The decibel range for a whisper is at 20dB, which was chosen by the team as a reference for the sound level of the click.
Conclusion		
Population Included	-10 to 15 dB loss	According to the Wyoming EHDI, this is normal hearing.
% Population Excluded	2.2%	
Notes		

**STRENGTH**

SUC	1				
US Task	Justification				
Pushing Sweeper	Pushing the sweeper requires moving the entire reference design, therefore this is the task where the most weight must be moved.				
Task (From Calculator)	Justification				
Pushing Task Sustained Forces	Best describes the act of pushing the sweeper over a lawn				
Input					
Male		Female			
Variable	Value	Justification	Variable	Value	Justification
Initial Pushing Force	14 lbs	The sweeper weighs 12 lbs + 2 lbs of leaves	Initial Pushing Force	14 lbs	The sweeper weighs 12 lbs + 2 lbs of leaves
Hand Height	57 in	Approximately chest height for someone 5ft 10 in. tall	Hand Height	53 in	Approximately chest height for someone 5.5 ft tall
Pushing Distance	50 in	Canadian lawns are 250 m^2 average	Pushing Distance	50 in	Canadian lawns are 250 m^2 average
Frequency	30 s	Continuous task	Frequency	30 s	Continuous task
Conclusion					
Population Included	Greater than 90%	Population Included	84%		

## Justifications

### Perceptual

- Vision: Our reference design contains no text on the product itself. The most difficult task from the usage scenarios related to vision was identifying leaves on the ground. This task is
- Hearing: About 3.2% of the Canadian population has disabilities relating to hearing. But only 0.5% of the population has a minimum of 60 dB loss. So therefore, it is valid to exclude no more than 2.2% of the population.
- Touch: Touch is a very important component of being able to use a product, in order to use a product effectively, as a good sense of touch ensures that the device in the proper orientation, each button on the device is being pushed in expectation, rather than hope, from the user. Touch is very important in order to develop fine motor skills and dexterity. As 3.5% of the population has dexterity related disabilities,, It makes more sense to exclude no more than 2.2% of the population. Therefore, it would be ideal if the range of excluded users was unchanged.
- Balance: About 7.6% of the Canadian population has flexibility-related disabilities, and 7.2% of the Canadian population has mobility-related disabilities. Both flexibility and mobility are needed to maintain good balance of the human body. Hence, it's a good idea to increase the excluded number of users from 0.1% to 2.2%.

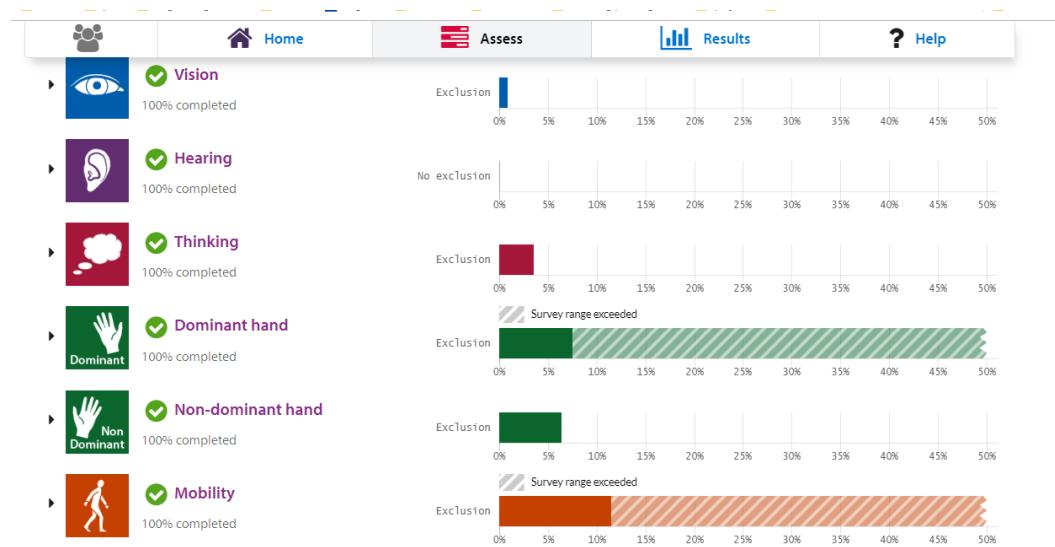
### Cognitive

- Memory: About 2.3% of the Canadian population has memory-related disabilities. Hence, it's a good idea to keep the number of excluded users at 2.2%.
- Reasoning: About 3.9% of the Canadian population has mental health related

disabilities, which affects their reasoning. Hence, it's a good idea to keep the number of excluded users at 2.2%.

## Physical

- Strength: About 7.2% of the Canadian population has mobility-related disabilities, which can affect their physical strength. Hence, it's a good idea to keep the number of excluded users at 2.2%.
- Mobility: As mentioned earlier, about 7.2% of the Canadian population has mobility-related disabilities. Hence, it's a good idea to keep the number of excluded users at 2.2%.
- Dexterity: As mentioned earlier, about 3.5% of the Canadian population has dexterity-related disabilities. Hence, it's a good idea to keep the number of excluded



# appendix 2: brainstorming

## Goals

- Design brief: design a way to manage leaves on one's property, determine where the boundary is
- Excluded: how we have to manufacture it, environment constraints in that sense, what happens once the leaves have been managed, property size, machine size, cost
- Goals: complete management system solution that reduces waste collected

## Users

- Landowners, maintenance, in varying degrees of health, mobile, full use of hands
- Historical backgrounds: varying degrees of socioeconomic status, impact on interaction may differ, maybe from a climate that does not have autumn
- Abilities: Full function of hands and arms, full range of motion in their back, use of legs, relative degree of strength
- Disabilities: could have various physical disabilities

## Circumstance

- Lawns, driveways, golf courses
- Sustainability: leaves can be composted

- First-world economy, stable society
- Different user groups: manufacturers, distributors, retailers, maintenance

## Competition

- Various number of interventions to compete against
- Rakes, lawnmowers, leafblower
- Can be physically challenging, bags needed

## Environment

- GTA has fall and spring, cold long winter
- Leaves need to be dealt with ASAP
- 7-8 hours of daylight
- Sometimes heavy rain

# appendix 3: interaction error list

SUC 1:

Initialization

1. Leila drops the sweeper while carrying it because it is too heavy. It falls on her foot and injures her

Ranked first because injury is unacceptable

2. Leila attempts to unfold the sweeper but the cold Autumn temperature is causing her muscle spasms. Straining to unfold the sweeper causes her pain and she is unable to unfold the sweeper.

Ranked second because she can't use the product

3. The mechanism to adjust the height of the steering control is stuck, and as Leila strains against it, she injures her muscles

Ranked third because she may or may not need to adjust the height

4. Leila contracts her muscles to grasp the sweeper, and is unable to relax them

Ranked 4th because it may not cause long-term injury

5. Leila attempts to lift the sweeper and is unable to because her muscles are weak. She strains her muscles and is in pain.

Ranked 5th because it may not cause long-term injury

6. Leila attempts to adjust the height of the steering control, and she attempts to hold the mechanism she is unable to get a grip because her fingers are spasming

Ranked 6th because it is frustrating but no apparent injury is caused

#### Usage

1. Leila lowers the brushes to sweep some leaves that are stuck, but this makes it harder to push and Leila can no longer continue

Ranked first because she can no longer use the product

2. Leila tries to see whether all the leaves have been cleaned from the lawn, but the sun is setting and she is unable to see clearly.

Ranked 2nd because it can affect even those with perfect vision

#### Finalization

3. Leila attempts to place leaves into the bin but has a muscle spasm and the leaves fall on as she is lifting them into the bin (Frustrating, but no injury)