Engineering Strategies & Practice

University of Toronto
Faculty of Applied Science and Engineering
APS112 & APS113
Conceptual Design Specifications (CDS)

Project #	170	Date	April 05, 2021

Project Title	Automatic Indoor Plant Watering System
Client	Ian Fejtek
Client Contact Person	Charlie Sun
Tutorial Section	29
Teaching Assistant	Alex Gordon
Prepared By (Names and Student #s of Team Members)	1007067086 Melissa Ma 1007033185 Ciel Li 1006669179 Cenyichao (Charlie) Sun 1007041817 Zayneb Hussain 1007121703 Shuolin (Bonney) Wu 1006878185 Haodong (Ethan) Ma

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

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

Executive Summary

Indoor plants provide a wide range of benefits, but potential plant owners are shown to be discouraged by the responsibilities of plant care. Our client, Ian Fejtek, commissioned the design of an automatic indoor plant watering system to reduce hesitation for plant ownership and increase accessibility to its benefits. The Conceptual Design Specifications (CDS) document includes revised project requirements, potential design solutions, and the ways in which our proposed solutions meet or do not meet the project requirements.

The primary function of the design is to automatically transport water from a reservoir to the plant. Thus, all solutions must be able to detect when the water should be extracted and how much, extract some amount of water, transport it to the plant, and release it towards soil. Furthermore, they must be commercially viable, adhere to safety regulations, and be operable within its service environment. Designs that meet these requirements should then attempt to meet our team's objective goals for ease of use, durability, affordability, aesthetic value, and ease of installation. While it is not necessary to meet all objective goals, those that better fit the objectives are determined to be better fit for the project.

Our team employed various methods for idea generation such as free and structured brainstorming, morph charts, and analogy research. A total of 70+ ideas were generated during this process over two iterations, which were narrowed to three alternative designs through feasibility checks, multi-voting, Pugh charts, etc. The first design is an integrated plant watering system that uses gravity to extract and transport water through a tube, and a latch which responds to the moisture meter. The second is a similar tap system, also using gravity to transport water and receiving a Bluetooth signal from a buried moisture meter to determine when to release water. The third is a sleeve which contains the moisture meter and holds the transport tubes, using a pneumatic pump to transport water. Using a weighted decision matrix, our final proposed design solution was determined to be the Snap-On sleeve watering system.

The Snap-On sleeve watering system was judged to be well-rounded in all objectives, and particularly affordability and durability. It consists of a plant "sleeve" with a built-in soil moisture sensor and motor pump system. Water is pumped from a reservoir through a tube and into the soil. The prototyping phase of this design will involve trial and error to ensure the successful function of its individual components, then use various measurement tools to check that it meets objectives and constraints.

The team has proposed a design solution to the problem brought forth by the client. Next, we will further the design process through further prototyping, modelling, and research of the proposed design and present the final product to the client. The presentation will seek the client's approval of the design by outlining the ways in which our proposed solution meets our project requirements using our measures of success.

Table of Contents

1.0 Introduction

As requested by the client, Dr. Fejtek, the team has been working on designing an Automatic Indoor Plant Watering System. Following the completion of the project requirements, the team generated a wide range of ideas and applied idea selection techniques to determine 3 alternative designs. This document will detail the problem statement and the project requirements, as well as the idea generation and selection process for the design. In addition, it will outline the alternative designs, proposed conceptual design, and its measures of success.

2.0 Problem Statement

Indoor plants significantly decrease the concentration of volatile organic compounds in the air and produce oxygen through photosynthesis [1], [2], while lifting one's mood and attention span [3], [4]. However, inadequacies, specifically underwatering and overwatering, present barriers in indoor plant care for inexperienced plant owners [5]. This project seeks to address the problem of maintaining indoor plants health, and thus reduce the hesitation to grow plants in home and office spaces in North America due to concerns regarding the time and effort associated with plants care [6].

The client need is a commercially viable means of maintaining plant health. Prospective plant owners are concerned with the responsibilities of plant care. A survey reports that 20% of the 2000 millennials surveyed would rather have a root canal than keep a plant, with 22% explaining that it was due to past failures in plant care [6]. Existing systems such as Figure 1. address this concern to an extent through timed watering but fail to satisfy client expectations in terms of combinations of affordability, means of watering that result in negative effects, lack of feedback and visual appearance. Thus, the gap is an aesthetically pleasing means to address the watering needs of plants without the need of their intervention. To satisfy client needs, our system will care for indoor plants through automating the watering process via a system. Indoor plants in the context of this project will refer to individual potted plants that can be grown indoors and in soil.

Figure 1. Commercial timer-based wick-watering systems fail to meet the client's need of optimal watering based on the state of the plant [7].

3.0 Service Environment

The physical, living and virtual aspects of the design will operate in is homes and office spaces in North America. The design will be mobile / installed in various locations around the specified environment (e.g. living room, bedroom) with have similar conditions such as humidity levels and temperature for optimal plant growth.

3.1 Physical Environment

Elements of the physical environment can be found in Table 1.

Table 3.1: Physical Environment of a home and office.

Physical Environment suitable for household plants	**Specifications**	
Temperature/Humidity (depending on outdoor temperatures) [8]	Temperature (°C)	Humidity Levels
	>10	<50%
	>-6.67	<40%
	-6.67>-12.22	<35%
	-17.78>-6.67	<30%
	-23.33>-17.78	<25%
	-23.33>-28.89	<20%
	<-28.89	<15%
Dirt/Dust	45 toxic compounds in dust are found in homes [9]	
Room dimensions (see figure 2. for illustration)	Home: 37.08 – 367.55m^2 [10] Office: 1260m^2 [11]	
Items found in environment	Home: Couch, coffee table, television, chairs, side tables Office: PC, Telephone, desk [11]	
Sunlight	Office: Window blinds closed [11]	
Main parts of plant pots	Pot (avg ~20cm radius) [12] Dirt (manure) Pot water collector Plant supports	
Energy Supply	Domestic electrical outlet supply: 120V [13]	
Artificial illuminance	500–700 lx [11]	
Natural Light illuminance	154–18706 lx [14]	

3.2 Living Things

Living organisms that can be found in the service environment are identified in Table 2.

Table 3.2: Living organisms that interact with the service environment.

Living Organisms	**Specifications**
Humans	Average household size: 2.9 people [15]
Pets	1.6 – 2.1 companion animals are in households

	[16]
Bacteria	E.coli, salmonella, MRSA [17]
Insects and Bugs	Millipedes, ants, cockroaches [18]
Plants	Jade plant, Chinese Money plant, Spider plant, Peace Lily, Aloe [19]

3.3 Virtual Environment

Virtual elements found in the service environment can be identified in Table 3.

Table 3.3: Virtual environment of homes and offices.

Virtual Environment	**Specifications**
Wi-fi and cellular networks	99.0% of households have access to broadband internet access [20]

4.0 Stakeholders

Table 4 presents potential stakeholders that may find interest in the design as a commercial product (in addition to the major influencers like consumers/prospective plant-owners), in descending order of relevance as determined using stakeholder interest/influence analysis.

Table 4.1: Stakeholders and possible interests in the project.

Stakeholder	**Possible Interest / Concerns with…**
Plant hobbyist associations • National Gardening Association [21] • Ontario Herbalists Association [22]	• Performance of the design in comparison to manual plant-care methods. • Reduced sense of participation to plant-keeping that the design may induce.
Plant distributors • The Home Depot [23] • The Sill [24] • InteriorPlants.ca [25]	• The design seeks to promote raising indoor plants and thus may impact the sale of plants. • Plant distributors may be interested in the economic value of the product and its association with their main products.
Competing companies • OYSIR [26] • KiKiHeim [27] • Firlar [28]	• Companies will have legal interest in the design's similarity to their own inventions [29], [30]. • May be impacted economically and may take interest in comparison between the performance/principle of the design and their existing commercial systems.

5.0 Detailed Requirements

The detailed requirements present precise specifications that our design will follow, including functions, objectives and constraints.

5.1 Functions

Our team used the Black Box Method to identify the main function of our design, then applied the Functional Decomposition Method to derive specific secondary functions (Appendix B).

Primary Functions:

- Automatically transport water from the water reservoir to the plants

Secondary Functions:

- Detect when to water plant and amount of water
- Extract water from the water reservoir
- Transport water when required
- Release water towards soil
- Indicate the moisture level of the soil and water level in the water reservoir

5.2 Objectives

Table 5.1 ranks objectives in terms of descending order. See Appendix C for the How-Why Tree used during the ranking process, as well as additional objectives considered. Appendix C.

Table 5.1: Objectives and corresponding metrics and goals in descending order of priority.

Design should be….	**Objective Goal**	**Metric**
1. Easy to use (C)	• Require 3 steps or less to use. (The average number of steps to use existing products is 3 steps.) [7] [31]	• Number of steps estimated from design.
2. Durable (E)	• Minimal number of moving parts in comparison to existing systems.	• Number of moving parts from sketch of design.
3. Affordable (B)	• Less than $170. Existing products range from $50 to $170 upon research. [7] [31] [32] [33]	• Amount of Canadian dollars estimated based on production costs and profit analysis.
4. Aesthetically pleasing (A)	• Material is matte and non-lustrous, so the color is customizable as it is very subjective to the user. • Geometry has curved edges instead of sharp ones [34].	• CAD modeling with potential market survey.
5. Easy to	• No special tools required.	• Detailed breakdown of

install/remove (D)		how to use design to ensure that no special tools are required.

5.3 Constraints

Constraints on this design incorporate client feedback as well as stakeholder interest. Legal obligations and industry standards for the designated service environment were also contributing factors.

Table 5.2: Constraints and corresponding metrics.

Category	**The design must/shall…**
Operational	• Be <20kg in weight.
	• Dimensions must be less than 2x8 m. [35]
	• Not produce more than 40dB of noise [36].
	• No permanent alterations to the design space during installation/operation.
	• Be able to operate automatically for one month without battery recharge/replacement.
Commercial Viability	• Not infringe upon designs recognized by the Canadian Intellectual Property Office or the United States Patent and Trademark Office.
	• Not exceed a retail price of $300.
Safety and Regulations	• Adhere to the international safety standards for household appliances, IEC 60335-1 [37].
	• Materials of product must meet requirements with the US Consumer Product Safety Act, 76 FR 68580 [38].
	• Meet requirements of certification and testing from organizations such as the Underwriter Labs [39] and the Canadian Standards Association. [40]

6.0 Alternative Design Generation, Selection, and Description

Sections 6.1 and 6.2 outlines the idea generation and selection process.

6.1 Idea Generation Process

Various methods of idea generation were used to enhance the overall breadth and creativity of our ideas, documented in Appendix D. The team began the process with a meeting that used a mixture of free and structured brainstorming to generate a list of over fifty ideas (Appendix D). The purpose of the list was to have a comprehensive collection of “points” that our design could potentially incorporate, focused specifically on creativity. The team then created a morph chart and took part in a few rounds of multi-voting in order to think more critically about design solutions, before using a worksheet to generate a list of 20 full design ideas (Appendix D).

6.2 Alternative Design Selection Process

The team engaged in two iterations of idea selection, the first of which consisted of three rounds of multi-voting with the brainstormed ideas and resulted in 10 partial ideas that do not meet all functional needs. For the latter, we conducted multi-voting and feasibility check as a Microsoft Forms poll with five votes per member for the 20 full design ideas (Appendix D), ideas with zero votes were eliminated or at least 2 member indicating failure in any constraint are removed. The resulting 8 ideas were assessed in terms of material requirement for secondary functions, then compared against timer-based wick watering systems in a Pugh Chart with our top five objectives (section 5.2). The remaining four ideas were rated using a weighted decision matrix to recommend a final design.

The team encountered the problem of an inconsistency of ideas during the first iteration of idea selection, resulting in the need of a second one, which significantly improved in efficiency due to time invested in organizing ideas and effective use of polls.

6.3 Alternative Designs

Through selection processes describes in section 6.2, three alternative designs were chosen that best meets the detailed requirements. All three systems use internal batteries that have capacities large enough so that they do not need to be charged regularly.

6.3.1 Design 1 – Automatic Integrated Self Supply Watering System

This system uses gravity to extract and transport water from a reservoir and a latch system to dispense the water to the plants. A built-in moisture meter sends signals to control the latch system, while Bluetooth signals from the reservoir are sent to an app to notify of water level.

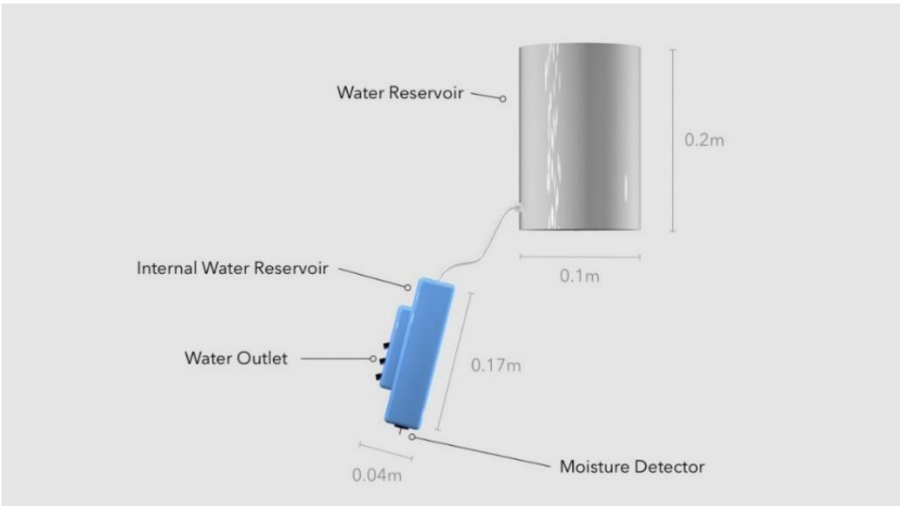

Figure 2. 3D view of the Automatic Integrated Self Supply Watering System.

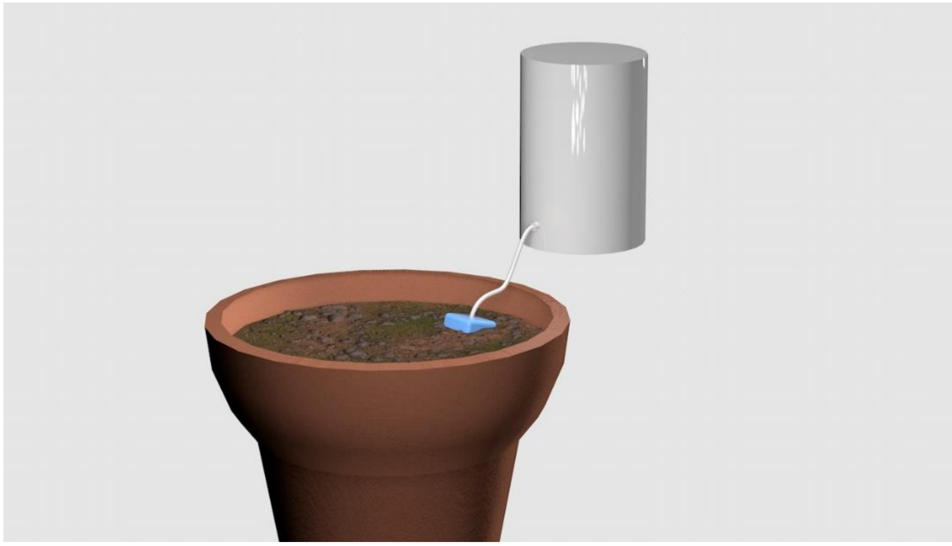

Figure 3. How to use the Automatic Integrated Self Supply Watering System

Table 6.3.1: Comparison of Design 1 to the Objectives

Objective	**How it meets the Metrics**
Easy to use	It requires no more than two steps to use this product. 1. Fill the reservoir (white) with water. 2. Bury the system (blue) into the pot and turn it on.
Durable	This design has three moving components including an internal water reservoir with water outlet, a tube, and a water reservoir.
Affordable	This design employs a moisture sensor meter ($3 [41]), a tube ($1 [42]), two plastic water reservoirs ($34 each [43]). These materials and parts total to $75.
Aesthetically pleasing	The color of the design is customizable by the user.
Easy to install/remove	No special tool needed to connect the tube to the external water reservoir and the internal water reservoir.

Please see Appendix E to see how this alternative design meets all the constraints.

6.3.2 Design 2 – Automatic Tap Watering System

The system water reservoir is connected to a tap-like electric solenoid valve by a tube. The water reservoir is placed on a higher place than the valve so that the water can be transferred to the valve due to gravity. The external moisture sensor is buried into the pot to detect the moisture level of the soil. The electric valve is snapped on the edge of the pot by a clip and controlled by the moisture sensor. Its main function is to adjust the watering frequency according to the information sent by the moisture sensor. Moreover, this system also includes a user-app to reflect the status of the product.

Table 6.3.3: Comparison of Design 2 to the Objectives

Objectives should be…	**How it meets the Metrics**
1. Easy to use	Requires only three steps. Filling water reservoir, bury the moisture sensor into the soil and snap the valve onto the pot and turn it on.
2. Durable	There are four moving components including a moisture sensor, a tube, a water reservoir, and an electric valve.
3. Affordable	This design employs a moisture sensor meter ($3 [41]), a tube ($1 [42]), a plastic water reservoir ($34 [43]), and an electric valve ($30 [44]). These materials and parts total to $70.
4. Aesthetically pleasing	The color of the design is customizable by the user.
5. Easy to install/remove	The only tool needed is a screwdriver to connect the tube to the reservoir and valve.

Please see Appendix E to see how this alternative design meets all the constraints.

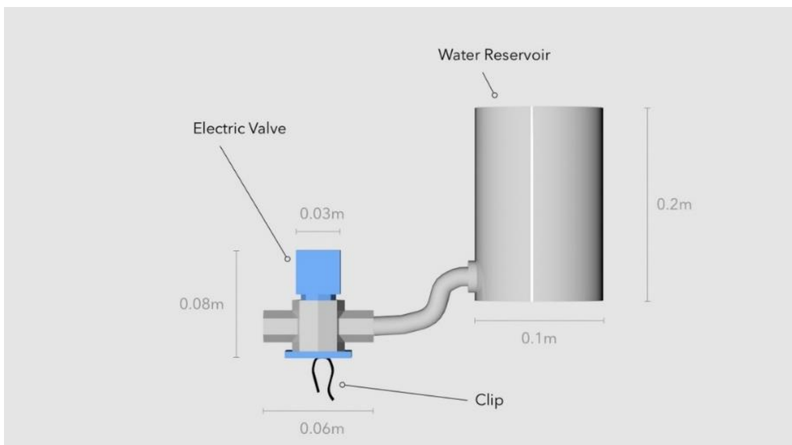

Figure 4. 2D View of the Automatic Tap Watering System

Figure 5. 3D View of the Automatic Tap Watering System

6.3.3 Design 3 – Snap-on Sleeve Watering System

This Snap-On sleeve automatic watering system will provide water to the plant via tubes that are attached to the interior of the adjustable rubber sleeve. The customizable sleeve can be strapped to the plant stem using a magnet that ties the two ends of the sleeve. An internal electrical moisture meter (built-in to the sleeve) sticks into the plant soil and sends electric signals to the electromechanical pump in the water reservoir. Once activated, water will be pumped and transferred to the soil via the tubes. The system information will be reflected in a user-app.

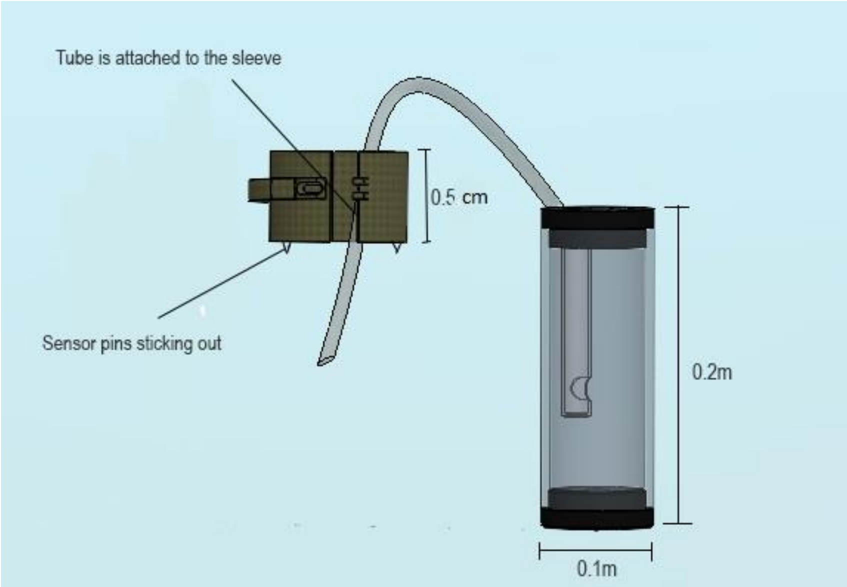

Figure 6. 2D view of the Snap-On Sleeve Automatic Watering System. The sleeve diameter and tube length are adjustable

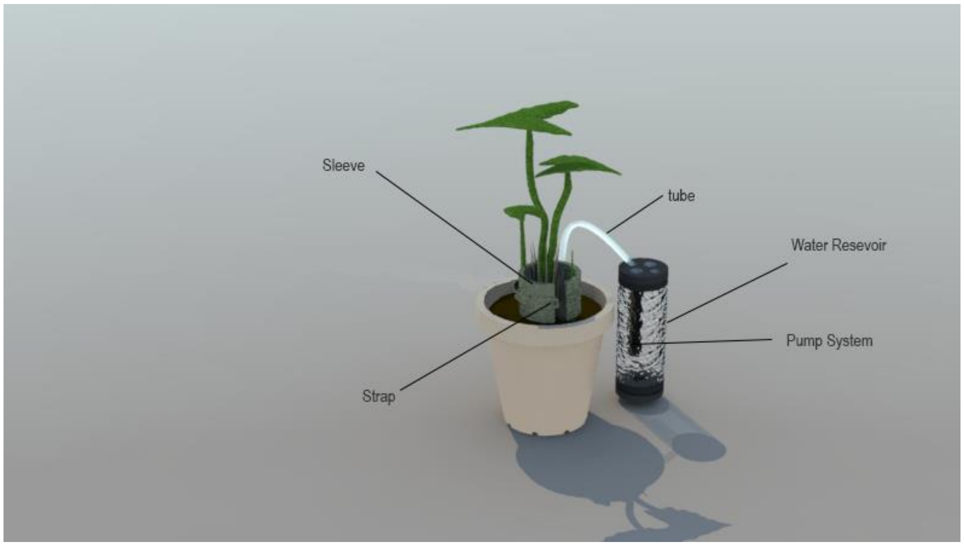

Figure 7. 3D view of the Snap-On Sleeve Automatic Watering System

Table 6.3.5: Comparison of Design 3 to the Objectives

Objectives should be…	**How it meets the Metrics**
Easy to use	Using this design requires approximately 3 steps; secure the strap to the plant stem, stick the sensor into the soil and turn it on, and fill the water reservoir with water.
Durable	This design has 3 moving parts; the moisture meter, the sleeve plus tube, and the water reservoir.
Affordable	This design employs an electric sensor meter ($3 [41]), a rubber and magnet-based sleeve ($14 [45]), some tubes ($1 [42]), a water pump ($2 [46]), and a plastic water reservoir ($50 [47]). These materials and parts total to $70.
Aesthetically pleasing	The sleeve is matte, customizable by the user and will both organize and hide the tubes.
Easy to install/remove	The sleeve is easily attachable and detachable by using its magnetic strap.

Please see Appendix E to see how this alternative design meets all the constraints.

7.0 Proposed Conceptual Design

The Snap-On sleeve Automatic Watering System demonstrates an ability to solve the client's problem in an efficient manner. This design allows the user to water the plant without human interference which fulfills the clients need.

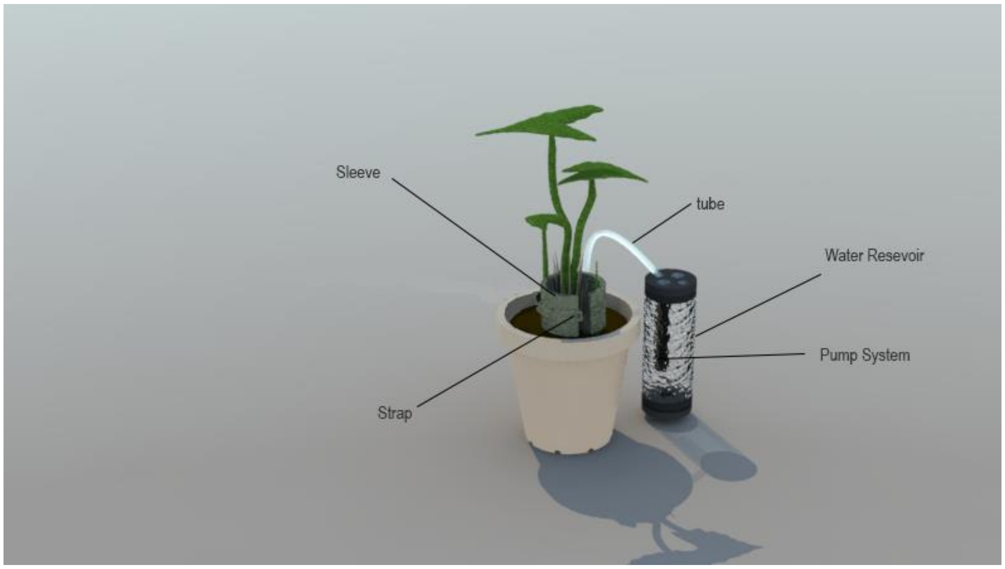

Figure 8. 3D view of the Snap-On Sleeve Automatic Watering System

It can be seen in the Pugh Chart (Appendix D) that the sleeve is the most compliant with the objectives when compared against a simple solution (timer based wicking watering system). It obtained an overall score of 1 as opposed to the scores 0 and 0 obtained by the other two designs. It can also be seen in the weighted decision matrix (Appendix D) that the sleeve received the highest score of 61.5, as opposed to the scores of 60.75 and 58 obtained by the other two designs.

The gap and need are filled with the Snap-On sleeve because water will be extracted from the water reservoir via the motor-pump system, and water will be transported using tubes and released towards the plant in a controlled manner. The system will be able to detect soil moisture level using an electric moisture meter and this meter controls the pump. All information regarding the system will be reflected in an app. This design is customizable by the user and the tubes will be hidden inside the sleeve, and thus improves the aesthetically pleasing aspect. Thus, will also increase the portability and thus minimalize the number of moving parts. The strap on component will allow the system to be easily installed/removed.

8.0 Measures of Success

To test the feasibility of the proposed design, one member of the team will execute a plan to create a prototype of the proposed design in the coming four weeks.

In the first week, one member will gather materials listed in table 6.3.5 plus a moisture sensor, ammeter, water reservoir volume measurements, and decibel meter (through phone app) and build the design with the help of team members through a video. The member shall weigh all manufactured parts of the system to make sure < 20kg and < 2m tall and 0.8 meters wide. They shall then send a copy of the design to the patent office for confirmation about it, for copyright purposes.

Once assembled, they will test the different components of the design separately before putting it together and observing its activity. Installation will be done on flat surface so no alterations to service environment occurs.

8.1 Week 2: Moisture level detection

The second week, they will first create the system (code) of the product using Arduino which will start/stop transferring water, read the moisture meter etc. After, they will test soil the moisture sensor by placing the product in different soil moistures that reads the moisture level within 3% accuracy from a real moisture meter.

8.2 Week 3: Latch and pump operation

The third week, they will test the release process (latch) of the design by reading initial moisture content then release latch until it meets a required/final moisture content within in 3% accuracy.

After they will test the water extraction process from water reservoir by observing the water transportation through the system and ensuring no leakage.

8.3 Week 4: Consumption of power/water

The final week, they will test the accuracy of the moisture and battery on the cell-phone app by checking with external devices. Then, they will test the entire system while using a decibel meter to check if the noise created is <40dB. After they will calculate the amount of work it takes for the system to function and calculate the amount of battery it needs for the product to last for at least 1 month. Please read Appendix F for information on how the team will test objectives.

9.0 Conclusion

The team generated and narrowed down ideas with various methods including multi-voting and Pugh chart to determine three alternative designs and the Snap-On Sleeve Automatic Watering System best satisfies the objectives. Our proposed measures of success will be implemented/estimated to ensure functionality and evaluate performance with respect to the objectives. For the next steps, the team will record a final presentation of the project, which will be submitted by April 25th.

References

[1] H.-H. KIm, J.-Y. Yang, J.-Y. Lee, J.-W. Park, K.-J. Kim, B.-S. Lim, G.-W. Lee, S.-E. Lee, D.-C. Shin and Y.-W. Lim, "House-plant placement for indoor air purification and health benefits on asthmatics," The Korean Society of Environmental Health and Toxicology/Korea Society for Environmental Analysis, 8 October 2014. [Online]. Available: https://www.eaht.org/journal/view.php?doi=10.5620/eht.e2014014. [Accessed 17 February 2021].

[2] K.-T. Han and L.-W. Ruan, "Effects of indoor plants on air quality: a systematic review," *Environmental Science and Pollution Research*, no. 27, p. 16019–16051, 2020.

[3] T. Bringslimark, T. Hartig and G. . G. Patil, "The psychological benefits of indoor plants: A critical review of the experimental literature," 18 May 2009. [Online]. Available: https://www-sciencedirect-com.myaccess.library.utoronto.ca/science/article/pii/S0272494409000413?via%3Dihub. [Accessed 17 February 2021].

[4] R. K. Raanaas, K. H. Evensen, D. Rich, G. Sjøstrøm and G. Patil, "Benefits of indoor plants on attention capacity in an office setting," 10 December 2010. [Online]. Available: https://www-sciencedirect-com.myaccess.library.utoronto.ca/science/article/pii/S0272494410001027?via%3Dihub. [Accessed 17 February 2021].

[5] P. Sheppard, Houseplants 101: How to choose, style, grow and nurture your indoor plants, Wryting Ltd, 2020.

[6] C. Ritschel, "Millenials Find Caring for Plants Daunting, Survey finds One in five millennials say they'd rather have a root canal than look after a plant," Independent, 27 January 2020. [Online]. Available: https://www.independent.co.uk./life-style/millennials-plants-water-alive-indoor-anxiety-survey-a9304596.html. [Accessed 17 February 2021].

[7] OYSIR, "Automatic Drip Irrigation Kit, Self Watering System with Timer and USB Charging for Deck, Patio, Garden, Vegetable Gardens or Potted Plants, DIY 30-Day," 2021. [Online]. Available: https://www.amazon.ca/OYOY-Automatic-Irrigation-Vegetable-Simultaneously/dp/B079Q1HR9V/ref=asc_df_B079Q1HR9V/?tag=googleshopc0c-20&linkCode=df0&hvadid=292964373580&hvpos=&hvnetw=g&hvrand=6404890014118341337&hvpone=&hvptwo=&hvqmt=&hvdev=t&hvdvcmdl=&hvlocin. [Accessed 17 February 2021].

[8] W. Housh, "WHAT IS THE IDEAL HUMIDITY LEVEL FOR YOUR HOUSE?," 08 August 2017. [Online]. Available: https://www.hvac.com/faq/recommended-humidity-level-home/. [Accessed 04 April 2021].

[9] J. Pelley, "Tracing the chemistry of household dust," c&en, February 7 2017. [Online]. Available: https://cen.acs.org/articles/95/i7/Tracing-chemistry-household-dust.html.

[Accessed 18 February 2021].

[10] B. V. Iman Khajehzadeh, "How house size impacts type, combination and size of rooms: a floor plan study of New Zealand houses," *Architectural Engineering and Design Management,* vol. 13, no. 4, pp. 291 - 307, 2017.

[11] M. Toyoda, Y. Yokota, M. Barnes and M. Kaneko, "Potential of a Small Indoor Plant on the Desk for Reducing Office Workers' Stress," *HortTechnology,* vol. 30, no. 1, p. February, 2020.

[12] "How to Pick the Best Kind of Pot for Your Plant," MiracleGro, [Online]. Available: https://www.miraclegro.com/en-us/library/container-gardening/how-pick-right-pot-your-plant. [Accessed 18 February 2021].

[13] G. D. J. H. J. D. Allison Campbell, "Electrical Outlet," Energy Education, 28 April 2020. [Online]. Available: https://energyeducation.ca/encyclopedia/Electrical_outlet. [Accessed 18 February 2021].

[14] N. Jamala, "Analysis of Natural Light Distribution in the Building," in *IOP Conference Series*, 2019.

[15] "Census Profile, 2016 Census," Statistics Canada, 2016. [Online]. Available: https://www12.statcan.gc.ca/census-recensement/2016/dp-pd/prof/details/page.cfm?Lang=E&Geo1=PR&Code1=01&Geo2=PR&Code2=01&SearchText=Canada&SearchType=Begins&SearchPR=01&B1=Families,%20households%20and%20marital%20status&TABID=1&type=0. [Accessed 18 February 2021].

[16] "U.S. pet ownership statistics," American Veterinary Medical Association, 2017. [Online]. Available: https://www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics. [Accessed 18 February 2021].

[17] C. Ramnarace, "Where Germs Are Hiding in Your Home," AARP, [Online]. Available: https://www.aarp.org/home-garden/home-improvement/info-03-2011/germs-in-your-house.html. [Accessed 18 February 2021].

[18] W. Cranshaw, "A Review of Nuisance Invader Household Pests of the United States," *American Entomologist,* vol. 57, no. 3, pp. 165 - 169, 2011.

[19] E. E. Rexford, Indoor Gardening, Philadelphia, London: J. B. Lippincott Company, 1910.

[20] "Communications Monitoring Report 2019," 2020. [Online]. Available: https://crtc.gc.ca/pubs/cmr2019-en.pdf. [Accessed 18 February 2021].

[21] "National Gardening Association," Garden.org, [Online]. Available: https://garden.org/forums/view/houseplants/. [Accessed 26 02 2021].

[22] Ontario Herbalists Association, "WELCOME TO THE ONTARIO HERBALISTS ASSOCIATION," [Online]. Available: https://ontarioherbalists.ca/. [Accessed 25 February 2021].

[23] The Home Depot, "Indoor Plants," [Online]. Available:

https://www.homedepot.com/b/Outdoors-Garden-Center-Plants-Garden-Flowers-Indoor-Plants/N-5yc1vZc8rn. [Accessed 25 February 2021].

[24] The Sill, "The Sill: Indoor Plants Delivered to Your Door," [Online]. Available: https://www.thesill.com/. [Accessed 25 February 2021].

[25] InteriorPlants.ca, "InteriorPlants.ca," [Online]. Available: https://interiorplants.ca/. [Accessed 25 February 2021].

[26] OYSIR, "Automatic Drip Irrigation Kit, Self Watering System with Timer and USB Charging for Deck, Patio, Garden, Vegetable Gardens or Potted Plants, DIY 30-Day Programmable Water Timer for 8 pots flowers," [Online]. Available: • https://www.amazon.ca/OYOY-Automatic-Irrigation-Vegetable-Simultaneously/dp/B079Q1HR9V/ref=asc_df_B079Q1HR9V/?tag=googleshopc0c-20&linkCode=df0&hvadid=292964373580&hvpos=&hvnetw=g&hvrand=6404890014118341337&hvpone=&hvptwo=&hvqmt=&hvdev=t&hvdvcmdl=&hvloc. [Accessed 19 February 2021].

[27] KiKiHeim, "KiKiHeim Automatic Watering System with Timer, Indoor Plant Drip Irrigation System Kit with Programming Memory, USB and Battery Operated Self Watering System," [Online]. Available: https://www.amazon.ca/KiKiHeim-Automatic-Watering-Irrigation-Programming/dp/B08JQC23W5/ref=pd_di_sccai_3?pd_rd_w=Cj4pB&pf_rd_p=e92f388e-b766-4f7f-aac1-ee1d0056e8fb&pf_rd_r=ERSQZWN1G2SHSD0KYMHZ&pd_rd_r=829a7203-e9f4-495b-b666-3d813e017fc3&pd_rd_wg=XqDWU&pd. [Accessed 19 February 2021].

[28] Firlar, "Firlar Self Plant Watering Devices,12 Pack Plant Watering Spikes Automatic Watering Drip Irrigation System Gardening Tools for Indoor Outdoor Use," [Online]. Available: https://www.amazon.ca/Firlar-Watering-Automatic-Irrigation-Gardening/dp/B07N5Q99M5/ref=pd_di_sccai_5?pd_rd_w=Cj4pB&pf_rd_p=e92f388e-b766-4f7f-aac1-ee1d0056e8fb&pf_rd_r=ERSQZWN1G2SHSD0KYMHZ&pd_rd_r=829a7203-e9f4-495b-b666-3d813e017fc3&pd_rd_wg=XqDWU&pd_rd_. [Accessed 19 February 2021].

[29] M. A. Muxlow, "Automatic plant watering system". United States of America Patent US6845588B2, 25 January 2005.

[30] J. Marsh, "Automated plant watering system". United States of America Patent US8584397B1, 19 November 2013.

[31] sPlant, "Amazon," 2021. [Online]. Available: https://www.amazon.ca/Upgraded-Automatic-Irrigation-Watering-Programmable/dp/B07Z4T67V5/ref=pd_lpo_86_img_1/135-2130192-6525225?_encoding=UTF8&pd_rd_i=B07Z4T67V5&pd_rd_r=2d2eada0-8424-4e4e-b45f-5ee2150b9bcc&pd_rd_w=F9d1l&pd_rd_wg=Cu8vE&pf_rd_p=76d05b53-3c. [Accessed 17 February 2021].

[32] lechuza, "Self-watering System," 14 February 2021. [Online]. Available: https://www.lechuza.ca/en/trend/cube-color-14-white/13380.html?src=AdProductCA&gclid=Cj0KCQiA0-6ABhDMARIsAFVdQv8Rxguvy_4YrdS-B9a4voaV-Xrzalpr5pDThxaQ4Lzc87YwoF_XqvsaAgiwEALw_wcB. [Accessed 17 February 2021].

[33] P. H. &. G. Supply, "AutoPot 4-Pot System," 2021. [Online]. Available: https://www.google.com/shopping/product/4344778191286540942?lsf=seller:136611985,store:10329026224358027891&prds=oid:13834783640251911891&hl=en-US&ei=WGwcYLa5LO-3ggfc0YXACA#sgro=od. [Accessed 17 February 2021].

[34] A. C. Little, "NCBI," 12 June 2011. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3130383/. [Accessed 25 February 2021].

[35] R. o. Movev, "RemodelMove," 2 December 2020. [Online]. Available: https://www.remodelormove.com/what-is-the-standard-bedroom-door-size/. [Accessed 19 February 2021].

[36] E. McPhillips, "Noise levels of everyday sounds," Audicus, 20 September 2020. [Online]. Available: https://www.audicus.com/noise-levels-of-everyday-sounds/#:~:text=20%20dB%3A%20Whispering%20from%20five,50%20dB%3A%20Refrigerator. [Accessed 19 February 2021].

[37] W. I. E. Commission, 12 May 2021. [Online]. Available: https://webstore.iec.ch/publication/1499. [Accessed 26 February 2021].

[38] U. C. P. S. Commission, "The Consumer Product Safety Improvement Act (CPSIA)," 2008. [Online]. Available: https://www.cpsc.gov/Regulations-Laws--Standards/Statutes/The-Consumer-Product-Safety-Improvement-Act. [Accessed 26 February 2021].

[39] UL, UL, 2021. [Online]. Available: https://www.ul.com/industries/products-and-components/appliances. [Accessed 25 March 2021].

[40] CSA, 2021. [Online]. Available: https://www.csagroup.org/. [Accessed 25 March 2021].

[41] AliExpress, TZT, 2021. [Online]. Available: https://www.aliexpress.com/item/1005001968295880.html?spm=a2g0o.search0302.0.0.5e9c494bvOO6up&algo_pvid=f205810b-ce94-419c-8a7a-03490a3d6170&algo_expid=f205810b-ce94-419c-8a7a-03490a3d6170-7&btsid=0bb0623d16172003243775839edcd2&ws_ab_test=searchweb0_0,sea. [Accessed 31 March 2021].

[42] ULine, "Clear Plastic Tubes," ULine, 2021. [Online]. Available: https://www.uline.ca/Product/Detail/S-14119/Clear-Tubes/Clear-Plastic-Tubes-1-2-x-8?pricode=YJ591&gadtype=pla&id=S-14119&gclid=CjwKCAjwu5CDBhB9EiwA0w6sLbT37NaSf7p8EPaeNgn-mPVx-_BCqekK615YLUUeZHbz0fePIWW51RoCVywQAvD_BwE&gclsrc=aw.ds. [Accessed

31 March 2021].

[43] "Amazon," 2021. [Online]. Available: https://www.amazon.ca/s?k=water+reservoir&crid=1ZJS6XSY82J43&sprefix=water+reser%2Caps%2C164&ref=nb_sb_ss_ts-doa-p_1_11. [Accessed 3 April 2021].

[44] "Amazon," 2021. [Online]. Available: https://www.amazon.ca/Best-Sellers-Industrial-Scientific-Solenoid-Valves/zgbs/industrial/12572427011. [Accessed 1 April 2021].

[45] Amazon, "Amazon," BQS, 2021. [Online]. Available: https://www.amazon.ca/Width-Adhesive-Sticky-Fastener-Black/dp/B077LMZ47W/ref=sr_1_6?dchild=1&keywords=VELCRO+Tape&qid=1617200624&sr=8-6. [Accessed March 31 2021].

[46] AliExpress, "AliExpress," Yikeshu, 2021. [Online]. Available: https://www.aliexpress.com/item/32814651788.html?src=google&albch=shopping&acnt=708-803-3821&isdl=y&slnk=&plac=&mtctp=&albbt=Google_7_shopping&aff_platform=google&aff_short_key=UneMJZVf&&albagn=888888&isSmbAutoCall=false&needSmbHouyi=false&albcp=114749415. [Accessed 31 March 2021].

[47] Amazon, "Plastic Water Tank," Nestle, 2021. [Online]. Available: https://www.amazon.ca/Reservoir-Replacement-Suitable-Nespresso-DeLonghi/dp/B07FLHLGKQ. [Accessed 31 March 2021].

[48] R. University, "Motors," [Online]. Available: https://www.clear.rice.edu/elec201/Book/motors.html#:~:text=A%20low%20voltage%20(e.g.%2C%2012,stall%2C%20depending%20on%20its%20design.. [Accessed 25 March 2021].

[49] C. Chapman, "Cause and Effect - Exploring Color Psychology," 2018. [Online]. Available: https://www.toptal.com/designers/ux/color-psychology. [Accessed 17 2 2021].

[50] "Thermal Comfort for Office Work," Government of Canada, 17 February 2021. [Online]. Available: https://www.ccohs.ca/oshanswers/phys_agents/thermal_comfort.html. [Accessed 17 February 2021].

[51] D. QUALMAN, 8 May 2018. [Online]. Available: http://www.darrinqualman.com/house-size/. [Accessed 17 February 2021].

[52] RobinPowered, "Moving to a New Office? Determine the Right Office Space Size," 2021. [Online]. Available: https://robinpowered.com/blog/new-office-determine-right-office-space-size. [Accessed 17 February 2021].

[53] WM, "RECYCLING 101," 2021. [Online]. Available: https://www.wm.com/ca/en/recycle-right/recycling-101. [Accessed 17 February 2021].

[54] C. L. P. Anton TenWolde, "The Effect of Indoor HUmidity on Water Vapour Release in Homes," 2007. [Online]. Available: https://www.fpl.fs.fed.us/documnts/pdf2007/fpl_2007_tenwolde001.pdf. [Accessed 18

February 2021].

[55] Kleenway, "Kleenway Comprehensive Facility Care," 20 September 2020. [Online]. Available: https://kleenwayservices.com/services/facility-maintenance-program/. [Accessed 19 February 2021].

[56] Durabond, "Durabond Janitorial Services," [Online]. Available: https://durabond.ca/covid-19-cleaning-and-disinfecting/. [Accessed 19 February 2021].

[57] Matt, "Ambius," 18 02 2021. [Online]. Available: https://www.ambius.com/blog/the-ultimate-guide-to-indoor-plants/#:~:text=On%20average%2C%20indoor%20house%20plants,to%20invest%20in%20another%20plant.. [Accessed 30 May 2018].

[58] H. T. C. Weihua Zhuang, "Bluetooth-enabled in-home patient monitoring system: Early detection of Alzheimer's disease," *IEEE Wireless Communications,* vol. 17, no. 1, pp. 74 - 79, 2010.

[59] Hobby Greenhouse Association, "Welcome to the Hobby Greenhouse Association," [Online]. Available: https://www.hobbygreenhouse.org/. [Accessed 25 February 2021].

[60] BOMA Canada, "Making Commercial Real Estate Greener, Smarter, Stronger," 28 August 2020. [Online]. Available: http://bomacanada.ca/. [Accessed 19 February 2021].

[61] M. A. F. B. R. K. I. I. Ridwan Siskandar, "Internet of Things: Automatic plant watering system using android," *The Directory of Open Access Journals,* vol. 9, no. 4, pp. 297-310, 2020.

[62] J. S. Ashlinn Quinn, "Indoor temperature and humidity in New York City apartments during winter," *Science of The Total Environment,* vol. 583, pp. 29-35, 2017.

[63] "Amazon," 2021. [Online]. Available: https://www.amazon.ca/Best-Sellers-Industrial-Scientific-Solenoid-Valves/zgbs/industrial/12572427011. [Accessed 1 April 2021].

Appendices

Appendix A – Stakeholders Analysis Methods:

Table A-1: Stakeholder Analysis (Stakeholders)

High Influence	Plant distributors Competing companies Landlords	(Users: existing and potential plant owners)
Low Influence	Maintenance personnel	Plant hobbyist associations
	Low Interest	**High Interest**

Appendix B – Functions:

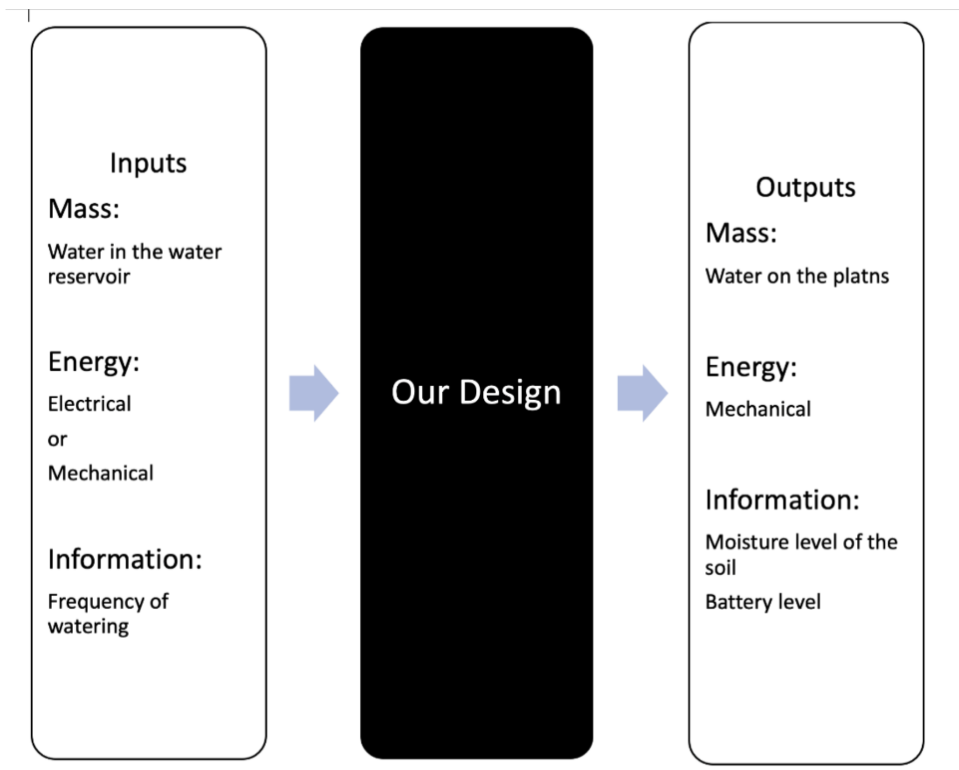

Figure B-1. Black Box Method (Functions)

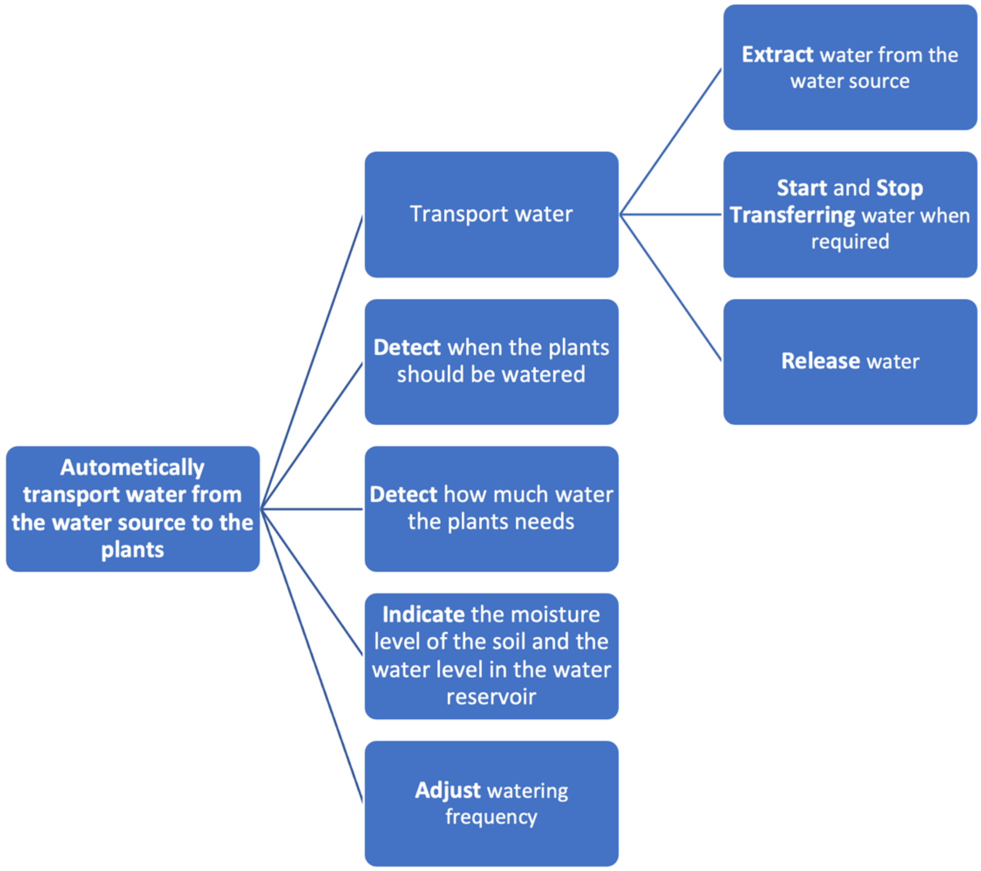

Figure B-2. Functional Decomposition (Functions)

Appendix C – Objectives:

Figure C-1. How-Why Tree (Objectives)

Table C-1: Pairwise Comparison (Objectives)

	A	B	C	D	E	F	G	H	I	Score
A	-	1	0	0	1	1	1	1	1	6+1 (additional one point from revote to break the tie)
B	1	-	0	1	1	1	1	1	1	7
C	1	1	-	1	1	1	1	1	1	8
D	1	1	0	-	0	1	1	1	1	6
E	1	1	0	1	-	1	1	1	1	7+1 (additional one point from revote to break the tie)
F	0	0	0	0	0	-	1	1	0	2
G	0	0	0	0	0	0	-	0	0	0
H	0	0	0	0	0	0	1	-	0	1
I	0	0	0	1	0	1	1	1	-	4

Table C-2: Additional Objectives, Means analysis

6.Used for multiple plants at the same time (F)	Can be used for more than one plant at the same time.	Prototype testing.
7.Minimal environmental impact (G)	Should take least amount of electricity if system is electricity based. Be able to be recycled as per North American recycling standards. [44]	Prototype testing number of watts needed to operate. Control prototype material based on its ability to be recycled.
8.Portable (H)	Takes minimal force to move around	Estimate weight based on CAD modeling.

9.Provide remote user feedback (I)	Allow user access to system status and plant condition internationally.	Prototype testing.

Appendix D – Idea generation process:

Ideas generated by Brainstorming:

- Tube system that distributes water
- Sprinkler that distributes water to plants
- A robot with a spray bottle
- A system that shovels soil into itself and tests the soil condition
- A system that generates water on its own using some chemical
- A system that recycles rain/snow water to be used for the plants
- A system that dunks the pot of plant into a bowl of water when moisture levels are low
- A water wheel system that can control the watering speed and frequency
- A device that you plant into the pot like a plant, and it waters the plants as it grows with the plant
- A system that genetically modifies the plant so that the plant waters itself
- A robot housekeeper that waters the plants
- A system that is integrates into a pot where we can fill water in and test soil moisture
- A tube that’s connected to the sink and can put water in all plants w/o people moving
- Mouse tube, where mouses deliver water to plants (the office)
- A water drip system
- Supervising the color of the leaves of the plant instead of measuring the soil moisture
- Supervising the color of the leaves of the plant instead of measuring the soil moisture
- Measuring plant dehydration instead of soil moisture
- A solar powered system that provides energy supply to the plant watering system
- A system that is connected to one’s sink and transports water to the plants
- A system that uses the oxygen produced by the plant to react it with hydrogen gas to make H2O
- A system that creates bubbles of water and releases them at set intervals
- A drip system to keep soil constantly wet + a system to oxygenate plant roots
- A system that measures air humidity and calculates when to water plant
- Water catapult
- A clamp on the plant to monitor the transportation of water in its roots
- A pot as the system
- X-ray for the plant to figure out how it’s doing
- Using a thermometer to measure stuff

- Measuring soil moisture level through compression/expansion of soil due to being wet/dry
- A system that can capture the vapour in the air
- A system that uses liquid hydrogen and liquid oxygen to produce water
- A donut-shaped container with water that you put on the pot and the plant pokes through the hole and releases water at times
- A water container that has many small holes on the surface, and it can heat up, then it waters the plant by steam
- A snap on pot that waters the plants
- A pot that contains water and monitoring stuff itself
- A mug of water that the plants can drink from on its own just like a human
- An aesthetically pleasing bucket in which plants stay and are sprinkled upon when necessary like the ugly but nice example from the internet
- A water reservoir shaped like a bowl that one can place the potted plant into to save some space laterally
- A layer of "clothes" for the plants that diffuses water into the plant
- Something like a facial steamer but for plants
- A stick-in meter that measures soil moisture
- A device that pokes into the plant stem or leaves to determine the moisture level
- An AI that automatically determines the moisture level according to the water in and the water out with factors of temperature, humidity etc.
- A device that takes a picture of the soil and uses machine learning to identify the soil moisture
- An equipment that has a needle that goes into the plant to determine if the plant is health or not
- A device shaped like a warm so that it can dig into the soil and measure the soil moisture
- A sensor (eletrode/cement based etc) that's integrated into the plant and analyzes if the plant needs water
- A device that can send messages to people's phone to notify the status of the plant
- An app that allows people to adjust the watering pattern
- A device that supervises the length of the roots of the plant instead of measuring the moisture level
- The device that sends the data using WiFi to the central server and send SMS/Email to the user about the plant whenever needed according to user preference
- A device that let user inputs the water amount needed for the plant as a moisture level
- A device that let user inputs the plant type and the system will automatically know how much water is needed for the plant
- An App that does input and output at the same time

Ideas after several rounds of Multi-Voting:

- A water wheel system that can control the watering speed and frequency

- Measuring soil moisture level through compression/expansion of soil due to being wet/dry
- Something like a facial steamer but for plants
- A stick-in meter that measures soil moisture
- A device that takes a picture of the soil and uses machine learning to identify the soil moisture
- Suction/pump using a pneumatic system with a tube system, pressure differentiation between water and plant to release water to plants. An app that communicates with the watering system's electrical signal, use an electric moisture meter to detect the moisture level of the soil. Receive signals from the soil moisture level detector and the battery. Reflect this information in an app.
    - Tube that uses pressure to transport and release water. Moisture will be measured using stick.
- Uses electric moisture meter to detect soil moisture level, sets sponge expansion to certain size, allows sponge to absorb water through tube system using adhesion, then closing off the suction and squeezing the water in the sponge onto a sort of plate that will slide the water into the plant. Weight of water is measured by plate as it drops in order to detect how much water has been used and notify user when reservoir is almost dry.
- A mini fridge serves as the water reservoir and an ice cube(s) is dispensed when necessary, via a slide to the plant. Ice cubes melt in room temperature to water the plant. Identifies watering needs through a water meter stuck into the soil. Electrical visual display and controls on the mini fridge which also processes information.
- Put the water reservoir in a higher place and then gravity pulls the water down. A latch releases the water. An app that that an electrical system to input the amount of water. Use electric moisture meter. Receive soil moisture and battery levels through electric signals.
- Using air pressure. Make the pressure in the water reservoir lower than the air pressure so that the water in the reservoir can be squeezed out, then make the release end of the system has higher pressure than the air pressure to release the water. By changing the air pressure in the water reservoir and transport tube we can adjust the watering frequency. Use electric moisture meter to detect soil moisture level. Use WI-FI to reflect the information.

Table D-1: Morph Chart

Idea #	Name	Frequency detection	Extraction	Transportation	Release	Extra
1	Drip + oxygenation	N/A	Pump	Tube	Tube	Something holding it above plate
2	Suction tube	Moisture meter	Pressure	Tube	Tube	LED

3	Buried-latch-tube	Integrated moisture meter	Gravity	Tube	Mechanical latch	
4	Sleeve	Moisture meter	Gravity + pressure	Tube	tube	Something like a rubber material that acts as the sleeve and holds all the components together
5	Water tap	Moisture meter	gravity	Gravity + tube	Mechanical latch	
6	Gravity tube	Moisture meter Moisture meter	gravity	Tube	Mechanical latch	
7	Blender	Air humidity/temperature meter	N/A	Splash it everywhere	N/A	Lots of noise and power, low accuracy, probably lots of metal components
8	Continuous dip	N/A	Directly absorb water through contact	N/A	N/A	Must remain positioned inside water thing

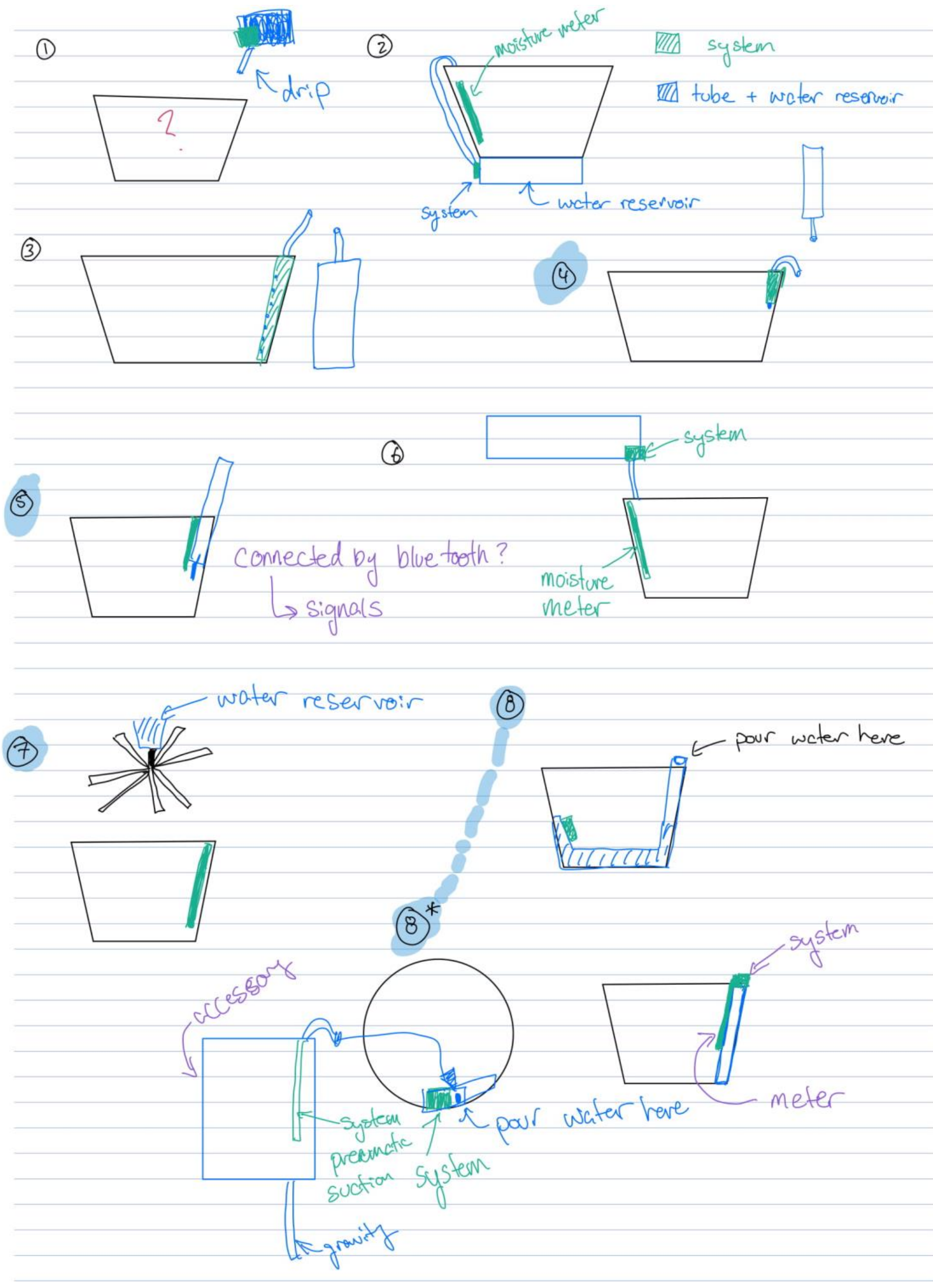

Figure D-2. Draft Designs

Objectives:

A. Aesthetic – size, customizability
B. Affordable – minimize cost
C. Easy to use – minimize # of steps

D. Easy to install – no special tools required.
E. Durable – minimize # of moving parts

Table D-3: Pugh Chart
Standard – Timer based wicking

	Stand.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
A	S	-1	0	0	1	0	0	0	1
B	S	1	-1	-1	-1	0	0	-1	-1
C	S	0	0	1	1	0	0	1	1
D	S	-1	0	0	0	1	0	1	0
E	S	-1	0	-1	0	-1	-1	-1	-1
SUM	0	-2	-1	-1	1	0	-1	0	0

Table D-4: Weighted decision matrix

Objective	Idea 8	Idea 4	Idea 7	Idea 5
C = 0.35	60	60	50	60
E = 0.3	65	60	20	60
B = 0.15	55	70	40	60
A = 0.1	60	50	50	20
D = 0.1	60	70	70	80
Total	60.75	61.5	41.5	58

Appendix E - Constraints:

Design 1:
C1 – The products materials are mostly plastic; therefore, it will be light and weigh < 20 kg. The product is 20cm tall and 16cm wide; therefore, it will be smaller than the average door space. The product can be removed and installed without making holes or alteration in the environment. All systems have an internal battery.
C2 – The product does not have any patents on it through searching the web. With all the materials and parts calculated, cost is about $75.
C3 – Product adheres to all safety regulations.

Design 2:
C1 – The products materials are mostly plastic; therefore, it will be light and weigh < 20 kg. The product is 20cm tall and 10cm wide; therefore, it will be smaller than the average door space. The product can be removed and installed without making holes or alteration in the environment. All systems have an internal battery.
C2 – The product does not have any patents on it through searching the web. With all the materials and parts calculated, cost is about $70.

C3 – Product adheres to all safety regulations.

Design 3:
C1 – The products materials are mostly plastic; therefore, it will be light and weigh < 20 kg. The product is 20 cm tall and 10 cm wide plus the adjustable sleeve. Therefore, it will be smaller than the average door space. The product can be removed and installed without making holes or alteration in the environment. All systems have an internal battery.
C2 – The product does not have any patents on it through searching the web. With all the materials and parts calculated, cost is about $70.
C3 – Product adheres to all safety regulations.

Appendix F – Measures of Success:

Table F-1: Objectives and How they will be Measured for the Snap-on Sleeve

Objective	**Test Plan –** The team will…
Easy to use	Press the operating button, and when needed fill the water reservoir by communication from the user-app, which ensures >3 step plan.
Durable	Use system 25 times (dispense water) to check if the moving parts of the design receive minimal damage from use.
Affordable	Examine the amount and type of materials used to build the prototype. It will give the team a good idea of how much the entire system will cost.
Aesthetically pleasing	Take a survey from the public showing the prototype and its functions through images/video to deem if the product has an aesthetic look, since aesthetics is subjective.
Easy to install/remove	Check if the product doesn't require additional tools