Project Deliverable [D]: Conceptual Design

GNG1103[F]: Engineering Design

Professor: Rubina Lakhani

Team 5:

Amenah Waheed (300018138)

Thomas Baycroft (300157691)

Krishna Patel (300171101)

Jonathan Rivington (300164793)

Lucy McKenzie (300120299)

Due Date: February 21st, 2021

Table of Contents

Abstract

This stage of the design process required taking the knowledge gained to date and turning them into concepts. Each member of the group on their own made a general concept for the entire sidewalk and then was also given a subsystem to do. These included the wire coiling, control box, drainage system, assembly and finally the energy source. Through this process various ideas were introduced such as mats that roll up, panels that collect water, water that drains into the sewers, various methods to connect the electrical components and various more. These ideas were then sketched and the team re-convened to discuss and debate these independent ideas. Once the team agreed on a design that included the best of all of the ideas it was put into its own category to be further examined at a later date. There was a lot of overlap between the subsystems and eventually the team narrowed it down into three separate subsystems that were also going to be further analyzed. It was found that panels with a drain into the sewer system would be most effective. It will be run off of a 120V GFCI outlet typically found on the side of buildings. There will be a separate sensor to control the device and each panel will have heating wire coiled inside of it. The three subsystems found were assembly, drainage and the power input. This phase of the design process puts ideas onto paper and lets Team 5 converge on an idea that will begin to be perfected as the project goes on.

Introduction

In this report for project deliverable D, Team 5 was tasked with creating several conceptual designs for the entire system and any subsystems that may be necessary. Through discussion and debate, these various designs were explored, narrowed down and eventually one main design was converged upon. This report will start with a brief review of the information found in previous reports such as the problem statement, client needs, design criteria and more and then will transition into the brainstorming done this week. Each member will present their solution for the heated sidewalk and talk about how their solution meets and does not meet the design criteria and client needs found earlier. Next, each member of the group will present the subsystem they worked on and what their solution to it was. Similarly, they will talk about the advantages and disadvantages to this solution. Sketches will be provided for all the brainstorming in this stage. The next part of the report will dive into the solution that Team 5 came up with as a whole through mixing and matching the best parts of each individual solution. This is not a fully fledged solution but will lay the groundwork for further development as the project progresses. FInally, this report will end with recommendations and ideas for how this project will move forward in the future.

The problem given is to design a sidewalk that is capable of melting snow quickly while still being modular and scalable with the purpose of being used in multiple different areas throughout the University of Ottawa. This solution will be an alternative to the method currently being used which is salt. Although salt is effective and cost efficient, it has been proven to cause deterioration to buildings and is not safe for the surrounding nature.

Through the design process thus far, Team 5 has been able to determine the must haves or needs for the solution to the heated sidewalk. From the meeting with the client Team 5 was able to construct a list of needs for the sidewalk including a drainage system, easy assembly, ability to melt snow quickly and efficiently, and while still being environmentally safe. From this list of needs, benchmarking was conducted. Team 5 found that there are two leading designs for heated sidewalks, a glycol/water mixture or electric. After evaluating both designs, it was determined that the electrical heating systems would be the better model to base the design on. However, there are currently no solutions available right now that completely check off the needs of the client. Some of the more important specifications of the sidewalk include, having an on/off option, being durable, having the capability of operating in low temperatures, being slip resistant, having a melt rate of at least 2 inches an hour and having a drainage system that can keep up with the melting snow and ice.

Individual Brainstorming

Subsystems Brainstorming Designs

Electricity as a power source (Amenah)

In order for the brainstormed conceptual designs to function, a power source, and subsystem(s) to accommodate it is required. The easiest and most readily available power source at uOttawa is electricity; uOttawa hosts numerous standard 120 V sockets inside and around buildings. uOttawa also has a power plant which supports approximately 30,000 control points on campus. The plant is also used for a variety of purposes, such as electricity generation, heating/cooling of all facilities by using the 'hot water' or 'chilled water' method, respectively, and providing water quality tests and treatment as required. (Power Plant, 2020)

Electricity Subsystem Design (Amenah)

In the electric-powered heated mat solution, multiple components are required, such as wires, a power source, heating coils, and conductive/insulative materials. Refer to Appendix 1.5.1 A) for the design of the subsystem (fitted into the overall solution).The power source for this solution is a standard 120 V electric current, supplied throughout numerous outlets in uOttawa, courtesy of its power generation plant. The mat will demand consistent current throughout winter, therefore requiring a three-pronged plug(s) (with a ground wire) to accommodate the electric load of the mat. The material of the wire will need to be water-resistant to prevent damage to the electrical system; durable to withstand environmental conditions and potential occasional foot traffic; and insulative to prevent short circuiting. For the electric heated mat solution in panel-form, similar to the Team's final solution, additional plugs and/or wiring will need to be designed to attach each panel to another. Each panel should have three-pronged male plug(s) and female connector plug(s) to create as long of a heated mat chain as needed. Each panel will also have a long wire in case it is the first mat in the chain to be connected to an electrical socket. This design is similar to a series of connected extension cords. To prevent unused wire from creating a mess, a button to roll up and store the wire in or under the mat may be required. Wire storage under the mat would be a better alternative, thereby preventing overheating of the electrical components in use along with the unused wire, which may cause a fire risk. The heating mat panels' connectors will be 'foldable' such that they can be twisted out during use, or twisted back to fold into the panel for easier storage and neatness purposes. For example, this system is similar to the adapter of current multiple USB-accommodating iPhone chargers, which allow the user to twist out the two-pronged male plug when in use, and twist back into the charger afterwards. This creates a neater finish of the product, while avoiding damage to the plug component throughout its service life. Inside the mat, heating coils will be used to heat up the mat for snow/ice melting purposes. Various coil placements may be used, however a circular/spiral configuration would cover the most surface area of the mat. This system will be down-scaled in size to accommodate panel heated mats. Next, a heat-conductive, ductile metal will be used to uniformly heat up each mat and/or panel. The surface material will be fire-resistant, such as tough rubber or thermoplastic polymers, however it will accumulate/store heat to allow for a constant melt rate, without melting itself. Lastly, the mat and/or panels will have a space to accommodate a temperature and/or moisture sensor with a switch. The sensor will be programmed to turn the switch on/off inside each circuit, to prevent constant electricity demand if there is not enough snow/ice above the mat. There will also be a sensor to monitor the internal components' temperature, acting as a breaker switch if the mat/panel begins to uncontrollably overheat. More information on the components of the electrical subsystem will be provided in other sections of the report. Furthermore, this is a conceptual design for an electric subsystem. In the heated mat/panels, pipes can be incorporated in a somewhat similar manner, to determine a water-based subsystem for the heated sidewalk conceptual designs.

Water Heated Panels - Pipe Subsystem Design (Amenah)

In the water heated panel system solution, multiple components are required, such as pipes for drainage and water inflow/outflow, coil pipe for optimal heating of panel, and a sensor to relay information on external temperature and moisture conditions. Refer to Appendix 1.5.1 B) for the design of the subsystem (fitted into the overall solution). This subsystem will be placed beneath the sidewalks. As uOttawa uses the power plant generated hot water piping system to heat its buildings, it is very convenient as this exact system (with an additional pipe), can be implemented smoothly with the piping system of the water heated panels, to provide the hot water source for the sidewalks. The hot water will enter from the boiler to pump(s) and will enter the top pipe (closer to the sidewalk for additional melting), and will enter the pipe coil (with an initial larger cross sectional area). The larger surface area will allow more hot water to enter the coil. Once the hot water passes through the coil, it will have cooled after transferring its heat to the sidewalk to melt the snow/ice. The now cold water will be pushed through the end of the coil with a smaller cross section, to increase the velocity of the flow, and increase the pressure in the pipe such that the chilled water does not freeze and block the system. Also, by increasing the velocity of the water, less pumps will be required to keep the water flowing in the system, thereby reducing the potential for pump malfunction and costs related to repair/maintenance of the system. The coils will also be surrounded by valves, which will typically be open to allow the continuous flow of water. However, when the panels need repair/replacement, the valves will close so that the entire system may keep running and heating the rest of the sidewalk. The top of the heating pipe coil will be made of a metal with high conductivity, thus allowing a uniform heating of the metal and the sidewalk. A sensor will also be added in the pipe to monitor the temperature of the external climate, as well as the moisture content of the sidewalk so that the system can be turned on or off as needed (by valves); an improvement to the system would be if the valves were controlled by the sensor as well. Lastly, the shape of the coil pipe will be curvy to maximize the surface area of the heated water on the sidewalk. Moreover, the cold water will escape from the coil in a pipe below the heated water, so that it can also retain some heat and not freeze when being looped through the system. This exact system can be used to pump other fluids such as glycol (that may retain heat longer than water), however the drawback of replacing water with the other fluids is that the uOttawa power plant water supply will not be used despite being readily available. The other fluid will need to be pumped throughout the system, while keeping in mind the quantity of fluid, its cost, etc. Therefore, water is the best alternative for cycling through the aforementioned subsystem.

Wire coiling (Johnathan)

The heated wire needs to be placed to be secure and displace heat to the surface above. The layer sandwiched between the bottom and upper layers of the heating mat is where the heat wire will be coiled. The wiring needs to be positioned to displace the heat and needs to be secured to make sure there is no movement when walked on. The wiring creates loops around the separators to evenly displace the heat. The separators are used to keep the wires a distance from each other. To ensure that the wires are secure, staples are used.

Using heating wires will allow for easy connections versus a hot water system. Electrical heating wires will also not be a problem in very low temperatures. The flexibility of the wires will make the coiling process simple, as the wires will be capable of spreading out across the surface to make sure all the snow and ice on the surface is melted. The problem with coiling the heating wire in loops is that depending on the top layer material, the heat may not be capable of being transferred throughout the entire top surface. Another problem with the coiling pattern is that putting the heating wire directly beside itself when coiling it will cause heat between wires and could start fire, because of this problem it is important to have a material that is capable of conducting heat efficiently.

Control Subsystem Design (Thomas)

When deciding how to approach the control subsystem there were three main ways it can be done. The first method which is widely used in heated driveways is a control box hardwired into the house. This is both expensive to install and hard to modify once installed. It requires a predetermined location for each box and cannot be changed without an electrician. The next way to approach this is to have all of the electronics inside the device itself. This makes it incredibly portable and easy to move around but also becomes costly since every single section of the sidewalk must have all the required electronics to run. This also becomes an issue when storing and transporting because the fragile electronics will be exposed to a lot of rough conditions. They also will be exposed to rough conditions when in place due to the water that will collect and people that will walk over the sidewalk. This leaves the best option for this situation which is a separate box with all of the electronics inside of it, but one that is not hardwired and can be moved around with the system if required. This way it can be stored with the sidewalk in the summer and deployed in the winter with the rest of the sidewalk. Being separate, the box can be kept out of the elements unlike the design with the electronics directly in the sidewalk. It will ideally be able to be plugged in anywhere on the campus where there is electricity and have any section of the mat be able to connect to it. This will make it replaceable, the cheapest of the options, portable, modular and easy to use.

Drainage Subsystem (Lucy)

The design process was executed to generate brainstorming ideas for design of the drainage subsystem. The drainage system is considered a subsystem because the overall system is dependent on the subsystem to function, however the subsystem is functional independent of the other subsystems in the overall system. The drainage system is an important system, as it allows for excess liquid to be removed from the surface platform, preventing slipping hazards and the excess liquid from freezing. Following this design process, the customers needs were translated into design criteria (See Appendix 1.2.1.A.; Table 6). There were four points that were highlighted as a requirement for this subsystem: a method for the excess surface liquid to be collected, to be removed, to prevent the liquid from freezing, and for the subsystem to be compact and lightweight. Based on the design criteria, three different products were benchmarked. All three products are solutions for sidewalk/driveway drainage solutions. The designs were similar in application, although offered a range of diversity in the physical design of the solution. The most effective design found was the third product "Compact Series, Trench and Channel Drain Kit with Black Grate (3-Pack : 9.8 ft)." This product was the most cost effective and provided a solution for all 4 design criteria. This product scored the highest ranking of 96 points (See Appendices 1.2.1.A,B,C.; Tables 7,8,9). From the information provided from the benchmarking scheme, the design specifications were defined into three groups: functional, constraints, and non-functional requirements (See Appendix 1.2.1.E.; Table 10). Before starting the brainstorming process, the functional requirements were compared against the benchmarked products to generate more ideas about how the design can meet these requirements. Aligning with the design criteria, there were four specifications that allowed for a design component to be generated.

For the first specification, collecting the excess surface liquid, three designs were illustrated. The first design consisted of a grated surface layer with a box section below. The surface layer has grated slots that are perpendicular to the length of the drainage system and lies flat with a barrier attached to the base layer (perpendicular to the surface and base layer). To provide more insulation, of the heat generated from the system and preventing the outside air conditions from freezing the excess liquid, the bottom section of the box section curves down (paraboloid shape). This design allows for the surface liquid to drip through the grated slots and be collected in the box section (See Appendix 1.2.1 F; Table 11). The second design consisted of the same functional properties as the first design, however there is no barrier between the surface and base layer. The surface layer does not lie flat across the box section. There is a slight decline angle on both sides to maximize the drainage of the excess liquid. There are small holes that line both edges and the middle section of the surface layer (as well as the grated slots). The box section is the same design as the first (without the barrier) (See Appendix 1.2.1 F; Table 11). The third design is more similar to the first design as the surface layer lies flat across the box section. There is no grated section in this design, small squares (5 or 6 columns across the width of the surface layer). There are two barriers with holes at the bottom sections (to allow for draining) that are perpendicular to the surface and base layer. The box section has a thin layer to insulate the liquid, however it is a rectangular shape, as this is the main difference from the other designs (See Appendix 1.2.1 F; Table 11). All three models are designed to be installed in individual panel sections and the sketches for each design are not drawn to scale.

For the second specification, the removal of the liquid, three designs were illustrated. The first design requires a sewer street drain to be accessible. The surface layer consists of a grated section lining the center of the panel, similar to the previous designs. The surface layer of the panel extends out, over the sidewalk forming a hook shape. This design feature is to reduce the contact of the liquid with the outside air conditions to reduce the risk of freezing and backing up the system. Underneath the surface layer, there is a T-shape system, to allow the excess liquid from either end to drain into the T-shape and be directed down the sewer drain. The end that opens to the sewer drain is on a slight angle to maximize the drainage of liquid (See Appendix 1.2.1 F; Table 11). The second design is similar to the first, however the main difference is that the T-shape decreases in width as it reaches the sewer drain. This design is to reduce the amount of the product that extends off the sidewalk. Large chunks of ice and snow, or snowplows would cause more damage to the system, if too much material is extended out. This design allows for the panel to be installed directly onto the sewer drain, hooking the end spout onto the drain. The surface layer of this design has the grated section down the centre and does not hang over the edge of the sidewalk (See Appendix 1.2.1 F; Table 11). The third design differs from the first two designs, as it does not require access to a sewer grate. The third design consists of the same T-shape end that is placed facing the opposite side of the sidewalk (draining onto the grass section). This design is not as effective as the other two mainly because it creates a safety hazard. The intended use of this product is in high traffic areas, creating a slippery surface beside the product would require another form of an ice removal system (such as salt), on top of the expenses for this product. The first two designs are highly preferred and allow for a more effective drainage solution.

For the third specification, preventing the liquid from freezing, one design was illustrated. Each panel will be lined with multiple strands of the electric wire coiling to maintain the system temperature. The wire can line the grated section, as well as the T-shape sections (below the surface) and supply heat to prevent ice formation (See Appendix 1.2.1 F; Table 11). The temperature of the system is required to be above the freezing point of a water mixture (above 0°C). In the panel sections that attach to the sewer drain, the most exposed area to the outside conditions, can be lined with more wire and will be exposed to the heat given off from the sewer drain. This should reduce the risk of the liquid freezing and safely remove the liquid. To maintain the overall system temperature, a sensor or switch can also be included in the design.

For the fourth specification, the product is designed to be compact and expandable. To meet this requirement, each panel will be able to connect to another by means of sections that fit similar building blocks. The section that sticks out off the panel will be along the one side of the panel, and the matching holes will line the other side of the panel. Each panel will also have a contact piece at eithers ends to allow for the flow of electricity throughout the wires to generate and transfer heat (See Appendix 1.2.1 F; Table 11). The system will also include end caps, closing off the draining tubes and provide insulation for the end section panel (See Appendix 1.2.1 F; Table 11). This property allows for the panels to be used at any desired lengths and prevent heat from escaping the system.

Assembly (surface materials) (Krishna)

The main goal of an assembly system for this project proposal is flexibility in terms of functionality. The assembly system is the main component that separates the internal environment from the external winter environment. As the client stated, the superficial surface of the system should have an anti-slip surface preventing injuries from falling that were previously fulfilled by salts. To effectively create a good assembly system, the shape for the component and the material by which the component is made must be decided upon by criteria (See Appendices 1.1.1.A,B.; Tables 1,2). After researching the shape and material which was optimal for our assembly system; benchmarking was initiated to determine which material and shape would serve our solution. It was decided, by highest score on equal weighted design criteria, that a horizontal component system and a copper aluminum alloy will be the best structure and material as it combines all advantageous properties and cancels out most disadvantages (See Appendices 1.1.1.C,D.; Tables 3,4).

For optimal functionality, storage and maintenance had to be taken into account. Rollability is an efficient way to store large devices that have seasonal uses such as this modular, heated sidewalk. It minimizes the space needed to store the device. This is one of the reasons why the horizontal component system was selected. Having horizontal components that assemble together allow for easy and cost efficient maintenance as a defect in one horizontal plate will not damage the whole system. Replacement costs will finish as only specific plates would need replacement rather than the whole device. The grooves cause the small gaps between horizontal plates to have the ability to drain water from the system and also add grip providing a slip-free surface.

To maximum thermal output and minimize electrical input, a highly conductive and heat damage resistant material must be used. Both aluminium and copper had their respective advantages and disadvantages. They weighed the same when benchmarked against each other (See Appendix 1.1.1.D.; Table 4). After further research and analysis, it was determined that a copper aluminium alloy would serve as the optimal material as it combined low cost with high functionality.

Overall System Design

In this section, each individual team member was given one week to come up with an overall system solution proposal that would act as a basis on which our group discussion could evolve from. This allowed for a more productive and qualitative discussion which led to the formation of our overall solution.

Krishna:

(See Appendix 1.1.2.A.; Table 5)

Safe to walk on and ensurable slip-free surface to prevent any injuries	Horizontal component system aids in creating pre-designed grooves between connectors of individual components. Additional grooves are placed on top to increase anti-slip surface [①]. A rubber will aid with this specification as well [②].
Melt any precipitation as it is falling	Electric heating system that will be energy efficient by utilising the heat generated to heat high conductive, thermal insulators that are fabricated with an alloy of aluminum and copper [③]. Three cylindrical rods will be warped

	in a figure-eight formation to create a thermally conductive system which will maintain a constant temperature between 2-3 degrees Celsius [④]. Electric current will be connected in parallel allowing for easy maintenance and replacement as necessary [⑤]. Input will be via a grounded plugin system.
Storable	Devices will have the ability to be rolled up and stored. It has the ability to be separated into segments that are best suited for the user. Very flexible in terms of modularity [⑥].
Modularity	Has the ability to be assembled and disassembled as the user pleases. A flexible design ensures high personalization in many aspects of the sidewalk.
Environmentally safe	All materials are non-toxic and non-polluting, thus will be safe for wildlife and humans [⑦]. Most materials will be recyclable.
Easy maintenance	Due to the horizontal component system, maintenance will be straightforward and easy. There will never be a need to remove and replace the whole system, simply sections that need maintenance [⑧].
Low cost	All materials and components used will be minimal cost, maximum functionality.
Energy Efficient	Conductors fabricated by a copper-aluminum alloy will be imputed with three vertically placed cylindrical rods wrapped in a figure-eight formation to use the electrical energy inputted to the maximum efficiency [④].

Numbers reference visual representations of specified functionality in Figure Set 1 of Appendix 1

Lucy:

This overall system design is a draft based on the initial design process steps completed in previous Project Deliverables B and C, to help the team generate ideas about possible product designs. The system that is the most efficient energy, is the electric wire coiling system. This system would use an external power source, powered off standard household electricity. The system consists of a temperature sensor and an on and off switch. The temperature sensor would turn on the heating element (complete the circuit) when the surface temperature drops below 0°C (freezing point of water). The temperature sensor is an important element to the design, as it is implemented to reduce the amount of heat wasted. There is a drainage system that is connected throughout the different panels, similar to the designs mentioned previous for the Drainage Subsystem (See Appendix 1.2.1 F.; Table 11). There are two types of panels, standard connecting panels and the drainage panels. The panels can be connected in any order and have end caps to insulate and end the section. The wire coiling is run parallel to the draining system in each panel. The drainage system is placed down the centre of the panel and the wire runs on either side (length wise) (See Appendix 1.2.2.A.; Table 12). This solution meets the clients expectations, as it is an eco-friendly solution in reducing the risk of exposing toxins such as antifreeze or ice-salt into the environment. This solution also reduces the amount of energy required to maintain the solution, as it only requires an electrical current to run the wire coiling, heating up the wire. As opposed to other options, such as running an external liquid heater, a pump to maintain pressure and flow of liquid and the electricity to fuel this equipment. The drawbacks to this design are that it requires some sort of drainage dispenser, whether it be a sewer drain or other liquid removal system. This system can not function without this requirement, as there would be no place for this system to drain the liquid safely.

Amenah:

Electric Heated Mat Solution

Description, Sketch, and Properties

One possible solution to solve the heated-sidewalk problem is to use an electrically-powered heated mat, which can be rolled onto the sidewalks. The conceptual sketch of the heated mat, with its electric subsystem, is located in Appendix 1.5.1, Figure 5.

The mat will be plugged into standard 120 V socket(s), which are readily available throughout campus, and require the minimum possible amount of voltage. The mat will have electric coils, placed under a ductile, conductive metal sheet, which will help heat the mat uniformly, and ideally provide a snow melt rate of at least 2 inches per hour. The ductile metal will help mould to the slight slopes of the sidewalk, which will help in drainage of the melted snow. The top of the mat may be created using anti-slip materials, such as fire-resistant rubber or rough thermoplastics, which will help both standard pedestrians and those with disabilities, use the sidewalk safely. To further prevent slipping, or displacement of the mat due to continual use, the heated mat will also have the option to be bolted down into the sidewalk. These bolts will be removable with the mat, and to keep the holes clean in the sidewalk, 'lids' will be used until the mat is required again in the next winter season. The mat will ideally be black to help retain more heat, while being starkly visible against the snow for those with visual impairments. The size of one mat will be that of a typical sidewalk (i.e. 2 m in width, and varying length). The mat will also include a sensor with temperature and moisture gauges to prevent continual, 24/7 use, unless needed. The mat will also be easily removable, transportable, and storable due to its structure.

Feasibility of solution with respect to Client Needs, Design Criteria, and Target Specifications

Ranked highest to lowest importance, the client, Jonathan Rausseo's needs are that the solution should have a drainage system, clear snow/ice off of the sidewalk quickly, be safe to walk on, be durable, environmentally friendly, and easy to maintain, assemble, and remove. Other, less important, needs include the energy efficiency, cost, and storability of the solution. With the proposed electric mat solution, the mat will have a drainage system made from its ductile metal sheet (which moulds to the sidewalk slopes) and use these slopes to guide melted snow into nearby stormwater/sewage drains. The mat will drain snow/ice off quickly, as it will be similar to the *Heat-Trak HR20-60* electric heated mat, which was benchmarked for user perceptions and technical specifications in Project Deliverables B and C, respectively. Its durability and level of safety for pedestrian traffic will be ensured by the use of rubber or rough thermoplastic polymer materials. To be environmentally friendly and energy efficient, the electric mat will use low 120 V electricity; it will be turned on/off with a sensor to prevent 24/7 use unless needed; its surface material will be made from a (potentially reused) rubber/thermoplastics, with water-resistant properties, preventing any leeching of dissolved chemicals from the mat surface to the environment. The heated mat is easy to maintain, assemble, remove, and store due to its mouldable structure (mat form), and because each mat is a separate unit placed on top of the sidewalk, therefore being easily accessible for troubleshooting, assembly, etc.

From the design criteria established in Project Deliverable B, and target specifications developed in Project Deliverable C, the following tables show various electric heated mat products currently in the market, their properties, and their specifications: "PD-C - Table 3: Technical Benchmarking Electric Heated Sidewalks", "PD-B - Table 5. User Benchmarking Electric Heated Sidewalks". Please refer to previous submissions of PD-B and PD-C for more information. Of these products, the *Heat-Trak HR20-60,* best meets all design criteria, and the electric heated mat solution will mimic its best properties, while improving upon its less desirable traits, such as providing variability in sizes to suit uOttawa sidewalks.

In terms of target specifications, described in Project Deliverable C, the electric heated mat will meet all of the functional requirements, such as having a melt rate of at least 2 inches per hour, a heating system, drainage, portability, slip-resistance, and multiple sizes, as described in the “Description, Sketch and Properties” section.The constraints will also be be met if/when the cost analysis is complete and the prototype is created in future deliverables. Lastly, some of the non-functional requirements of the electric heated mat will be met with this solution, as the mat will include a temperature/moisture sensor which will allow for an on/off option; however, product life and durability requirements will be met when the product withstands the test of time and use.

Advantages of the electric heated mat solution

A summary of some of the advantages of the electric heated mat solution include:

- Environmental sustainability and energy efficiency due to its use of lower voltage electricity (120 V), while using a temperature sensor to control the on/off functionality of the heated mat
- This solution meets all of the client needs, and majority of the design criteria and target specifications
- The mat is easily accessible, repairable, and replaceable as it is a temporary, above-sidewalk solution

Additional advantages are previously discussed before the list, and will be discussed in the final solution’s advantage-analysis.

Disadvantages of the electric heated mat solution

Some disadvantages of the electric heated mat solution include:

- May be costly in the long term as it requires a constant source of energy (electricity)
- Current products in the market are sold in standard sizes, which may not accommodate different sidewalks; the electric heated mat solution will need to modify existing products or create a new product from scratch
- The wiring in the solution may be a trip hazard
- The solution will not work if there is a power outage, unless it uses backup generator electricity

Amenah:

Water heated panel solution

Description, Sketch, and Properties

Another solution to the design problem is to use panels that will be fitted under the sidewalk, which will heat the sidewalk by using hot water in its pipes. Refer to Appendix 1.5.1 A) Figure 6 for the conceptual sketch of the solution This solution will be convenient as the uOttawa plant uses the hot water/chilled water method to heat/cool all facilities in the University. As this method uses hot water in the pipes to heat buildings, additional hot water pipes can be fitted to the water heated sidewalk system, thereby continuously supplying hot water to the panels and melting snow on the sidewalk. Each panel will have a pipe coil which allows the entry of hot water, which will travel through the coil and cool as it provides heat to the sidewalk above. The hot water will enter through a fatter pipe cross-section to allow more hot water to enter the system, however, the cold water will exit the pipe coil through a smaller cross-section, thereby allowing it to flow out of the system without a pump at a high velocity (as per Bernoulli and Continuity equation analysis). The hot water will be supplied with a pump from the power plant, and the cold water pipe will loop and run under the hot water pipe, thereby putting less load on the boiler of the power plant, as the cold water will already have begun heating on its way back to the plant. Drainage will be provided parallel to the panels, by a trough above the panels (by the sidewalk), which will collect the melted snow/ice and will transport the water to a sewage drain. The water will not freeze as it will be near the heat source of the pipes. A sensor may also be added to the design to monitor the external temperature to detect the presence of snow. The sensor will also contain a moisture detector, which may help flag a potential accumulation of water on the surface of the sidewalk (i.e. this will help regulate drainage).

Feasibility of solution with respect to Client Needs, Design Criteria, and Target Specifications

Ranked highest to lowest importance, the client, Jonathan Rausseo's needs are that the solution should have a drainage system, clear snow/ice off of the sidewalk quickly, be safe to walk on, be durable, environmentally friendly, and easy to maintain, assemble, and remove. Other, less important, needs include the energy efficiency, cost, and storability of the solution.

With the proposed water heated panel sidewalk solution, the panels will have a drainage system (pipe) made from insulating metal, to allow for heat retention and quicker and easier flow of the water down the sidewalk, to the stormwater drain; this is similar to the drainage of a typical sidewalk, except the flow will be directed through the thin pipe, thus meeting the client's need. In terms of durability, this solution will be durable as it is below ground and does not experience direct exposure to the elements, and does not directly experience heavy foot/vehicle pedestrian traffic. However, in terms of safety, the solution will be average as it will melt the snow/ice off of the sidewalk, but it will not provide any more grip than the existing sidewalk concrete. This solution will be environmentally friendly as it uses and reuses water, which is not leaked to the surrounding environment, and can be treated directly on site if needed. The water provides heat to both the panels, and the looping cold water, thus allowing for less boiler usage. The pump(s) will also be required less due to the application of fluid mechanics principles on the pipe shapes. The water heated panels will be easy to assemble and store, however they will not be as accessible as the electric heated mats.

From the design criteria established in Project Deliverable B, and target specifications developed in Project Deliverable C, the following tables show various electric heated mat products currently in the market, their properties, and their specifications: "PD-B - Table 3: User Benchmarking Water/Glycol Heated Sidewalks", "PD-C - Table 5. Technical Benchmarking Glycol/Water Heated Sidewalks". Please refer to previous submissions of PD-B and PD-C for more information. Of these products, the *ThermaHexx,* best meets all design criteria, and the electric heated mat solution will mimic its best properties, while improving upon its less desirable traits, such as providing variability in sizes to suit uOttawa sidewalks.

In terms of target specifications, described in Project Deliverable C, the water heated panel mat will meet all of the functional requirements, such as having a melt rate of at least 2 inches per hour, a heating system, drainage, portability, slip-resistance, however, it will not meet the multiple sizes requirement as this is not possible with this system. .The constraints will also be be met if/when the cost analysis is complete and the prototype is created in future deliverables. Lastly, some of the non-functional requirements of the electric heated mat will be met with this solution, as the mat will include a temperature/moisture sensor which will allow for an on/off option; however, product life and durability requirements will be met when the product withstands the test of time and use.

Advantages of the water heated panel solution

A summary of some of the advantages of the electric heated mat solution include:

- The panels have valves which allow for the system to keep operating while a single panel is being repaired/removed
- The solution is environmentally friendly as it uses water, already heated and supplied from the power plant; the water is reused in the plant, and will be relatively free of contaminants. The power plant will also treat the water if needed, resulting in a zero waste system.
- This solution may be more cost-effective than the electric heated mat solution as it will use less electricity
- This solution is durable as it is placed beneath the sidewalk, and is therefore safe from the wear and tear of constant foot traffic and direct exposure to the elements

Disadvantages of the water heated panel solution

Some disadvantages of the electric heated mat solution include:

- The panel will be beneath the sidewalk, so it will not be as easy as the electric mat solution to remove/replace/fix.
- The water faces freeze/thaw cycles throughout the year, which is a typical concern for concrete sidewalks/roads; therefore, if there are freeze thaw cycles occurring in the system, pipes may eventually burst over time.
- This solution does not provide additional grip to prevent slips on the sidewalk
- If the solution malfunctions, or if the water is not hot enough to counter extremely heavy snowfall rate, the snow/ice may not fully melt, and ice patches may form from refrozen water, thus creating slippery patches
- The solution will not work if there is a power outage, as the pump and boiler both require electricity. However, if the pump and boiler use natural gas, then the problem is fixable in a power outage.

Thomas:

The solution for this problem is based on electricity. It is a rubber mat similar to those put at the entrances of buildings in the winter and has a heating element run through it. It will be the width of a standard sidewalk (48”) and will be 8 ft long to allow for compact storage by either rolling or stacking on top of one another. It will be interlocked similar to how children’s foam play mats are (See Appendix 1.3.1.A.; Figure 1). Each mat will have one male and one female electrical connection that are in series similar to the ones made by Anderson Power Products to allow for easy connections between mats and allow only the required amounts to be used. This will also let one section break without affecting the others. These connectors will need to be rated to 50 A to make sure it can withstand the current from the outlet and more to be safe. The rubber mats will have holes on the top and bottom to allow for water drainage and keep the surface of the mats free from ice buildup and allow them to be non-slip. This will go against the needs and design criteria though because it will be protected from salt and sand and this will lead to a shorter life span. This is modular, but the width is a set size so for this to fit into the many different sized walkways on campus there will need to be alternate sizes made for the smaller walkways.

Johnathan:

The design solution I came up with was based on an electrical mat used for removing snow and ice using heat. The mat is to be connected via power source to cover a larger surface area. The design allows for drainage of melted snow and ice and because of mat style assembly will be simple. The mat is designed to roll up for storage and can then roll flat for use. A material that is flexible will be needed. The ends of the mat are made to interlock with other electrical mats alike. The design would have both ends angled to perfectly connect with each other. This design will not only supply power in series, but it will also interlock the mats making them safer to walk on without the fear of tripping. The use of a USB like connection between a female and male inlet will prevent the use of outside power cords which may be a tripping hazard. Perpendicular slits placed across the mat would drain melted snow or ice. The slits would need to be placed on an angle towards the street drainage system. This design should remove excess water before it becomes a slipping hazard.

Final Solution Subsystem Design

In this section, a group brainstorming session was initiated. After assigning tasks of time keeper, chairman and notetaker, ideas, porprosols feedback, suggestions were all voiced and discussed respectively. As a team, we came together to create three subsystems that would be the basis of our proptype.

Assembly System Design

One of the component concepts that was decided by consensus after a group discussion was the assembly system. This system has a purpose to be modular and easy to maintain. This includes flexibility in terms of assembly and disassembly as well as cost of replacement. The goal was achieved by a component system that would be connected via electrical connection devices such as the Saf-D-Grid® Connector Series or Powerpole® Connector Series. This ensures that the power supply is safe and remains functional after a situation of flooding inside the device. Safety is held paramount and this set up allows for optimal safely via ability to control the situation. The internal environment of each individual component will be protected with heat resistive materials that will act as insulators creating an energy efficient solution. The external surface will include anti-slip grooves and treads as well as a thin layer of material which will be able to remain functioning as an anti-slip surface in the presence of water and precipitation. Overall, the assembly component of the device will ensure modularity and flexibility for efficient use, maintenance and storage as well as an anti-slip surface and external power surface to ensure maximum safety during operation.

Drainage System Design

The functional requirements of the subsystem were broken down into four sections within the overall system: a method to collect liquid, to remove liquid, to prevent the liquid from freezing, and to allow the system to be compact and expandable/collapsible. As multiple design components for each requirement were illustrated in the previous section (See Appendix 1.2.1.F.; Table 11), the team reviewed each design and selected one of each design for each of the four sections to generate a final solution for this subsystem.

For the method to collect liquid, the first design was chosen. The barrier in the centre of the trough was removed from to prevent flooding and reduce complications when constructing the prototype. The grated surface layer was defined to be circular holes, instead of slots.

For the method to remove liquid from the system, the second design was selected. This design was chosen as it provides a safe method of disposing the liquid, without requiring another form of ice removal. This design was preferred over the first design, as the overhang of the surface layer of the panel is smaller. This will reduce the amount of ice, snow or slush that would get stuck between the panel and the sidewalk. This design allows for a spout to be hooked onto the sewer drain. The heat released from the drain also will help to insulate and reduce the heat loss from the drainage panel as it is exposed to the outside atmosphere.

For the third method to prevent the liquid from freezing, the wire coil lining the sections of the drain was implemented. A temperature sensor that is automated to turn on when the temperature drops below the freezing point, will also be included in the design. This will help to reduce blockage within the system and prevent ice from forming on the surface layer of the panel.

For the fourth method the design was modified to include prongs that can be added or removed from the two types of panels, connecting and drainage. The prongs will not only attach the panels together (to hold them in place), the prongs can also transfer an electrical current. This current will be used to heat the wire coiling.

The main limitation to this system is that the system requires a sewer drain to safely dispose of the melted snow and ice. This was the safest method the team was able to find. Ideally, the system would be able to have a drain installed underground below the panels, however this would cause the system to be a permanent solution. One of the client's main requirements is for the system to be modular and removable in the warmer seasons. This results in finding methods of safely removing liquid from the system to become more challenging. Another option that was considered was to have a hose remove the liquid from the system. The main limitation to this option was that the liquid would freeze within the hose, and to supply heat to the hose would be an extra expense on top of heating the overall system.

Power Input System and Sensor Design

The first step in designing this control system was to (in addition to the steps already taken for the system in its entirety) determine the needs of this subsystem and turn it into design criteria. It needed to be modular, cost effective, easy to use, maintain and durable. These were then ranked respectively based on importance. Once this was done it was compared and benchmarked against solutions already available on the market such as the Warmup WSM-252W and the ASE DS-5C. These solutions were neither cost effective nor modular since they cost more than $300 each and needed to be hardwired into the building. This made it clear that no existing solutions would work and a new one would need to be designed. The new concept meets all required design criteria and can now be improved into in future stages of development.

For the power input subsystem design, please refer to the section, “Electricity Subsystem Design” in the brainstorming section of this report, for additional details, as it is discussed at length in that section.. The sensor subsystem design will be elaborated on in this section. The subsystem developed is the sensor and control box for this device. It will consist of a box mounted near the 120V power supply. Inside the box there will be an arduino with a TMP36 temperature sensor and a rain and snow sensor on the top of the box (appendix 1.3.2 A figure 2). The arduino will be programmed so that if the temperature is below 0℃ and the rain and snow sensor is sensing snow the device will be on for a set amount of time. This time will still need to be determined through product testing. There will be a switch on the front of the control box to manually override the sensors if required and to turn it off all together. The arduino will act only as a control signal to turn on a relay inside the box to pass the entire 120V required to the mats since 5 volts will not be enough and will burn out the arduino. The 120V coming from the control box will have the same connectors as the mats therefore allowing any mat to be placed first. Drawbacks to this design are that the box will need to be controlled at the box instead of remotely and there will need to be several of these as more mats are added and the power is diminished. There is also a risk that the snow sensor will be covered as snow accumulates making the system think it is alway on. This will require monitoring and possibly someone to go around cleaning the sensors off from time to time. The control box MUST be connected to a GFCI outlet because the box itself is not grounded.

Team Solution

Our solution encompasses all design criteria determined by the client. After completing individual brainstorming of possible subsystems and overall solutions, a group brainstorming session took place in which all ideas were discussed. Solid and effective feedback and suggestions were introduced. It was concluded that our solution would encompass three main subsystems that could function individually form each other. They are dependent on each other for functionally of the whole device; but also have the ability to function independently as individual component systems. This was the main goal to ensure a flexible design for future upgrades and revelation of technological components. With a component system, maintenance is facilitated ensuring a cost effective solution. Instead of having to destroy large segments of the device, component assembly ensures that a select area can be targeted for maintenance and fixing while undamaged areas can continue to function optimally.

The final solution device has a power input of electrical energy. Refer to the section, "Electricity Subsystem Design" in the brainstorming section of this report for additional details. Essentially, the electricity will be accessed via 120V plugin systems that will be grounded to ensure optimal safety. A power box type device will be the first system to access the source energy. This ensures control over any and all electricity related situations. Controls on this device will occur via this control device. As the electricity is controlled in one area, control upon the full device is ensured in an effective and efficient way. Having all control systems in one allows for easy maintenance, safe assemble and disassembly as well as safe storage. Attached assembly component systems, one disconnected from the power supply, will have no ability to cause dangerous situations; furthermore, it allows individual components to be lightweight and easily transportable. Since this assembly and control systems harmony allows optimal safety, easy transportation and maximum control over temperature, electrical input and future upgrades; this solution was chosen for our client.

The electrical input, after passing through the control device, will run throughout each individual assembly component. The wire will be insulated and protected from water damage. This ensures safety during application of the device in winter conditions. The drainage system will run above the current to further ensure that water and moisture will not reach the electrical current running through the device. The drainage system will maintain heat from the electrical of the systems as well as the heat produced within the sewer system as well. This ensures that the transportation of liquefied precipitation will not freeze as it is being transported. Our solution encompasses water drainage into the sewers of the university and surrounding city streets. This was put into place to avoid the creation of other additional safety concerns. As the meatled precipitated and existing snow and ice is melted by the heated sidewalk system, the excess water will flow out to the sides and freeze. This has the potential to create icey areas which arise safety concerns as well as the freezing of liquid near the heating device may cause additional functional problems if not controlled. Thus, our drainage subsystem will be applied to the assembly-component system and will transport the melted products straight to the sewer system. By avoiding any additional safety concerns as well as utilising a free heat source, our solution device ensures many possible circumstances to be controlled.

Assembly, power/electrical control and drainage subsystems function together in a winter setting to allow effective snow-clearing and removing solutions which hold safety paramonent. The simplicity of our proposal allows modularity of all components and systems as well as easy transportation and storage. All technologies and parts can easily be upgraded, changed and maintained as seen fit by the client. It allows for future growth and increases the potential life of the device. The device also ensures a cost effective and energy efficient solution which will ensure the change from salt snow-melting solution to a heated sidewalk solution to be smooth. These are the consideration and reasons as to why we have decided on this solution proposal.

A summary of the **advantages** of the final team solution (electric heated mat) is listed below. The electric heated mat is:

- Easy to transport
- Easy to install
- Easy to repair or replace as it is an above-ground, temporary solution
- Easy to stack and store with minimal space required
- Environmentally sustainable/friendly - uses electricity, and possibly recycled rubber (tire) or thermoplastics as surface material
- Slip resistant, allowing pedestrians and those with disabilities, alike to travel safely on the mat
- Durable as it can withstand constant foot traffic and exposure to the elements (and typical Ottawa climate)
- The plugs of each panel are able to be hooked in or under the panel, to avoid any tripping/accidents, while reducing the amount of damage to the plugs, and making the panel easier to stack with less storage area required
- Circuit breaker switch is included in each panel to prevent damage to the internal components in case of overheating
- External moisture and temperature sensor is included in each panel to monitor the surrounding environment and prevent 24/7 use of the mat as much as possible
- The panels are placed above the sidewalk, and can be easily accessed and replaced without turning off the entire system
- Each panel has plugs which allow extension cords to attach them to multiple buildings (sockets), if the chain of heating panels provides too heavy of a load on a singular socket
- Meets all client needs and most design criteria and target specifications (as explained earlier in the report)
- Black coloured panels, to retain more heat while being starkly visible against the snow/ice/slush for the visually impaired
- May eventually be created in multiple sizes
- Can be turned on/off as needed by unplugging the system
- The electric heated mat solution is superior to the heated water panel solution as:
    - it provides grip for pedestrians on the sidewalk
    - it is an above-ground solution, and thus easier to remove/fix/replace, etc)
    - it uses electricity over water which may freeze/thaw and cause pipe failures

    - if the heated water panel solution malfunctions, or if the water is not hot enough to counter extremely heavy snowfall rate, the snow/ice may not fully melt, and ice patches may form from refrozen water, thus creating slippery patches, however the electric heated mat will provide a constant flow of heat (as electricity generates more heat than water), thus avoiding the slippery patches
    - It uses less materials (lack of pumps and pipes) versus the water heated panel solution, and therefore may be a lower initial capital investment
- As the electric heated mat final solution is almost identical to the electric heated mat solution in the brainstorming phase, the advantage of the final solution is that it is the sum of the best parts of the existing products and the brainstormed solutions, while avoiding the drawbacks of the other designs. For example, the addition of a sensor greatly helps reduce the risk of overusing the mat and melting its internal components by monitoring the internal environment of the mat, thereby increasing its service life and capital investment in repairs/replacements.

Disadvantages of the final solution include:

- It may be costly in the long term as it requires a constant source of energy (electricity) - however, the client does not prioritize cost as much as other needs
- The prototype will currently only be available in one size
- Unlike the heated water panel solution:
    - the electric powered heated mat solution will need to withstand constant wear and tear due to constant direct exposure to the elements and pedestrian/light vehicle traffic; therefore, the electric powered heated mat may have a shorter service life than the other solution
    - if there is a power outage, the system will not work unless it uses backup generator electricity. Unlike the heated water panel solution, the electric heated mat solution does not have the option of using natural gas to continue running the system.
- If a small piece of the wire melts or short circuits, there may be electric backlash on the other components of the the panel, or even on surrounding panels
- There are no disadvantages to the final solution in comparison to the brainstormed electric heated mat designs, as the final solution was created while keeping in mind the individual designs' drawbacks and by combining the individual designs' best parts.

By having a solution with three subsystems that can function individually, the clients' needs of having a sidewalk that can be deconstructed easily and being easy to maintain are met, as it would only need to be deconstructed in the damaged areas to be fixed. The source of electricity being controlled creates an efficient heating system that will also be safe for the assembly, deconstruction, and maintenance. Melting ice and snow will be taken off the surface using a drainage system that will be capable of not only removing the water, but also making sure no ice accumulates doing the runoff. The heated sidewalk will be safer for the environment as salt is no longer needed, and over time the switch from salt will be more cost efficient. One of few needs that are not fully met in this solution are having a system in place to remove the salt and sand brought onto the sidewalk from foot traffic, however, this will partly be fixed when the melting snow runs off the sidewalk taking sand and salt with it.

As said at the start, this design solution meets all design criteria put forth by our customer. The solution meets the specification of being portable, having multiple sizes, and lightweight for storage. The electrical system capable of being controlled remotely will check off the criteria of maintaining a constant temperature, quick melt rate, and minimal voltage input while having controllable heat output. A drainage system with the purpose of removing the melted ice or snow from the surface has been implemented which will help the surface to be safe for people to walk on without slipping.

Conclusion and Recommendations

In closing, this report documents Team 5's work towards begging the Prototype stage of the design process. To summarize, the team individually brainstormed different design ideas based on the previous steps completed in the Project Deliverables B and C. During the weekly meetings, the team was able to categorize and define three subsystems and develop a basic design from each, as well as a basic design for the overall system. Using the onshape program, a basic visual draft of the overall system design was created. The design is not final and was used to help visualize the system better (See Appendices 2.1,2.2,2.3,2.4,2.5; Figures 8,9,10,11,12). The workload was evenly distributed amongst all team members and the use of Wrike allowed for the team to complete all components of this Deliverable on time (See Appendices 3.1,3.2,3.3,3.4; Figures 13,14,15,16).

Recommendations for the next steps in completing the design process are to further develop the design, including the different types of material that will be used, dimensioning, and a breakdown of the cost and expenses of each component of the design. For the design component, the team will be focusing on the design of the use of prongs to connect the panels and supply a source of power, as well as updating the onshape design to allow for a better visual representation of the system.

-

Reference List

Accessories for snow melting heated mats. (n.d.). Retrieved February 21, 2021, from https://canadamats.ca/products/accessories-for-snow-melting-heated-mats?variant=19838244257921&utm_source=google&utm_medium=cpc&adpos=&scid=scplpHTAS-120V&sc_intid=HTAS-120V

Compact Series 5.4 in. W x 3.2 in. D x 39.4 in. L Trench and Channel Drain Kit with Black Grate (3-Pack : 9.8 ft). (n.d.). Retrieved from Home Depot: https://www.homedepot.com/p/U-S-TRENCH-DRAIN-Compact-Series-5-4-in-W-x-3-2-in-D-x-39-4-in-L-Trench-and-Channel-Drain-Kit-with-Black-Grate-3-Pack-9-8-ft-83500-3/302782641#product-overview

Hust. (1984). *THERMAL CONDUCTIVITY OF ALUMINUM, COPPER, IRON, AND TUNGSTEN FOR TEMPERATURES FROM 1 K TO THE MELTING POINT National Bureau of Standards*.

NDS. (n.d.). *5" Pro Series Channel Drain Kit*. Retrieved from NDS We put water in its place: https://www.ndspro.com/5-pro-series-channel-drain-kit.html

"Power Plant." *Facilities*, www.uottawa.ca/facilities/sectors/operations-maintenance/power-plant.

TDS. (n.d.). *ULMA 497 / PE100KCBM Class B ADA Compliant Mesh HDPE 122mm x 500mm Grate*. Retrieved from Trench Drain Systems: https://drainagekits.com/product/ulma-mearin-4-8-ada-mesh-polypropylene-grate-500mm/

Top 10 Thermally Conductive Materials - Thermtest Inc. (n.d.). Retrieved February 21, 2021, from

https://thermtest.com/thermal-resources/top-10-thermally-conductive-materials

Warmup WSM-252W. (n.d.). Retrieved February 21, 2021, from https://canadamats.ca/products/warmup-wsm-252w?variant=32910502363265&utm_source=google&utm_medium=cpc&adpos=&scid=scplpWSM-252W&sc_intid=WSM-252W

Appendices

Appendix 1: Initial Brainstorming

Appendix 1.1.1: Krishna's Subsystem Brainstorming Designs

Appendix 1.1.1. A): Shape Selection Analysis

Table 1: *Shape selection analysis*

Possible solution	Advantages	Disadvantages	Image
Rollable mat - Horizontal components	1. Component system a. Easy maintenance (in the case of damage) b. Easy assembly/disassembly c. Flexible storage 2. Rollable a. Efficient storage placement b. Flexible, thus durable 3. Anti-slip a. Gaps create grooves that act as grips	1. Will be heavy, thus additional support/assistance required 2. Must handle with care as both sides of the system will be unprotected 3. May be a tripping hazard	
Rollable mat - Brick-like components	1. Component system a. Easy maintenance (in the case of damage) b. Easy assembly/disassembly c. Flexible storage d. Small parts thus more precise solutions 2. Rollable a. Efficient storage placement b. Flexible, thus durable 3. Anti-slip a. Many groves already implemented into the design	1. Will be heavy, thus additional support/assistance required 2. Must handle with care as both sides of the system will be unprotected 3. May be the source of a tripping hazard 4. Smaller components thus invidival heating system within is more detailed a. May prodec maintenance challenge 5. Rollability takes up extra space	
Sidewalk square component mats	1. Easily assembly a. Large components 2. Easy maintained as components are larger (less detail) 3. Stalkable a. space/storage efficient 4. Provides leveled walkway	1. Anti-slip surface required 2. Heavy 3. Subject to environmental damage (from under, sidewalk lifted/cracked)	

Appendix 1.1.1. B): Material Selection Analysis

Table 2: *Material selection analysis (Top 10 Thermally Conductive Materials - Thermtest Inc., n.d.), (Hust, 1984)*

Possible solution	Advantages	Disadvantages

Copper	• 398 W/m•K
	• Most commonly used metal for manufacturing conductive appliances (United States)
	• High melting point and moderate corrosion rate
	  ○ Important as for an application in wet environment of winter
	• Effective metal for minimizing energy loss during heat transfer
		• Costly due to the care needed for storage (quick to oxidize if not protected)
		• Heavy metal
		  ○ Assembly and disassembly may be slightly more different/requires more effort
		• susceptibility to corrosion through oxidation
		  ○ Not ideal for wet, winter applications
		• Shock hazard (compared to a fiber optic cable)
		• Semiconductor, unreliable bonding agent

Aluminium Nitride	• 310 W/m•K
	• Does not impose a health hazard to manufacture
	• Aluminum nitride is one of the few known materials to offer electrical insulation (heat sink)
	• High thermal conductivity
	  ○ It has extraordinary thermal shock resistance and acts as an electrical insulator
		• Very expensive
		• After moisture absorption of aluminum nitride, it reacts with water and perform hydrolysis (breakdown of metals)
		  ○ Not effective for wet, winter applications
		• Many limitations must be considered
		  ○ Toxicity (dijection, inhalation)

Tungsten	• 173 W/m•K • High melting point and a low vapor pressure making it an ○ Ideal material for appliances that are exposed to high levels of electricity • Inertive	• Brittleness • May cause eye/respiration irritation is smoked/high degree of exposure • Fire and explosion hazard • Slightly more pricey
Aluminium	• 247 W/m•K • Cost-effective replacement for copper • abundant and easy to manipulate due to its low melting point. • Copper aluminum mixes harness the properties of both copper and aluminum and can be manufactured at a lower cost ○ Cost effective and efficient	• Not as conductive as copper • Not a very strong metal • If nor in an metal alloy (pure state), heat sensitive • Manufactation and fabrication process is messy • Poor strength to weight ratio

Appendix 1.1.1. C): Benchmarking Colour Legend

Table 3: *Benchmarking Colour Legend*

Good = 3
Average = 2
Bad = 1

Appendix 1.1.1. D): Cumulative requirements of all assembly systems

Table 4: *Cumulative requirements of all assembly systems*

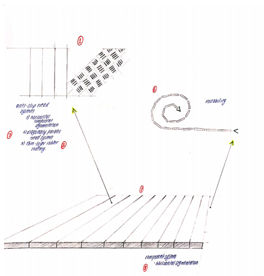
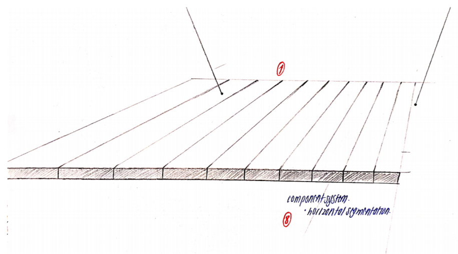
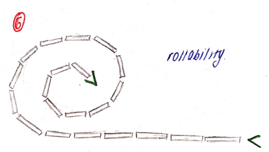
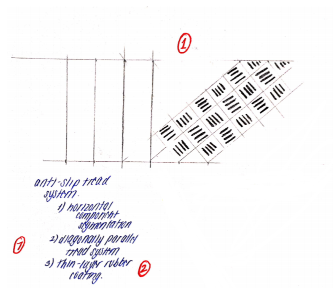
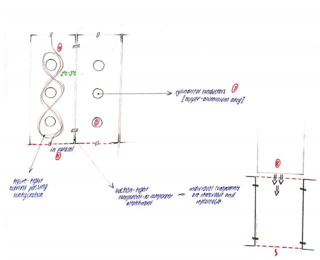
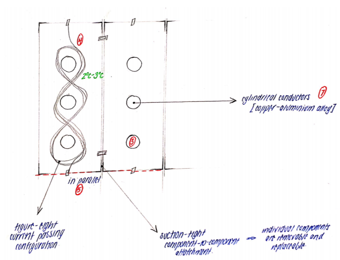
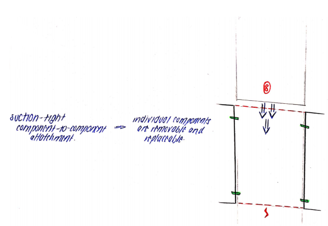
		Horizontal components	**Brick-shaped components**	**Tile components**	---
STRUCTURE	Safe to walk on and ensurable slip-free surface to prevent any injuries	2	2	2	---
	Modularity	3	2	2	---
	Environmentally safe	3	3	3	---
	Easy maintenance	3	2	3	---
	Modularity	3	2	3	---
	Storable	3	3	2	---
TOTAL		**17**	**14**	**15**	
		Copper	**Aluminium Nitride**	**Tungsten**	**Aluminium**
MATERIAL	Modularity	3	2	3	2
	Environmentally safe	2	1	1	3
	Easy maintenance	1	1	1	1
	Low cost	2	1	1	3
	Energy Efficient	3	3	3	2
TOTAL		**11**	**8**	**9**	**11**

****from design criteria****
****all criteria are of the same importance (high importance)****

Appendix 1.1.2: Krishna’s Overall System Brainstorming Designs

Appendix 1.1.2. A): Overall System Brainstorming Sketches

Table 5: *Overall System Brainstorming Sketches*

Overall System Brainstorming Sketches	
	
	
	
	

Appendix 1.2.1: Lucy's Subsystem Brainstorming Designs

Appendix 1.2.1. A): Translating Customer Needs to Design Criteria

Table 6: Translating Customer Needs to Design Criteria

#	Customer Needs for Drainage System	Design Criteria of Drainage System
1	There needs to be a place for the excess liquid to drain.	Method of collecting the excess liquid.
2	Needs to be capable of melting snow right away	Method of removing the excess liquid.
3	Product will be used in high traffic areas – where customers will be on and off product	Method of preventing the excess liquid from freezing.
4	Needs to be scalable to deploy across all of campus	Compact and Lightweight.

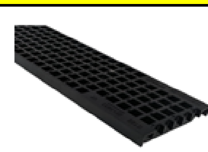
Appendix 1.2.1. B): User/Technical Benchmarking Drainage Solutions

Table 7: User/Technical Benchmarking Colour Legend

Good
Average
Bad

Appendix 1.2.1. C): User/Technical Benchmarking Drainage Solutions

Table 8: User/Technical Benchmarking Drainage Solutions

Specifications of Drainage System	**5" Pro Series Channel Drain Kit** (NDS, n.d.)	**ULMA 497 / PE100KCBM Class B ADA Compliant Mesh HDPE 122mm x 500mm Grate** (TDS, n.d.)	**Compact Series, Trench and Channel Drain Kit with Black Grate (3-Pack : 9.8 ft)** (Compact Series 5.4 in. W x 3.2 in. D x 39.4 in. L Trench and Channel Drain Kit with Black Grate (3-Pack : 9.8 ft), n.d.)
Width	5- ½" outside lining 5-¼" inside lining 4-½" outside lining of base	122 mm (4.8")	5.40"
Depth	Both 4-¾" Grate section ¾"	20 mm (0.78")	3.2"
Length	39.5"	500 mm (19.6")	39.4"
Weight	5.6 lb	Not Listed	Not Listed
Shallow/Deep	Deep	Shallow	Deep
Pre-assembled	Yes	Yes	Yes
Durable	Yes - Extended ribs and lies flat	Yes – square pattern and lines flat	Yes – extended ribs and lies flat
Extendable	Yes - Clip-in feature (channel to channel)	Yes - Two-point locking bar system per piece	Yes – extension pieces sold separately
Material	HDPE	Non-slip mesh composite grating (water absorbing mesh)	Heavy duty – recycled UV stabilized polypropylene polymer
Colour	Metallic	Black	Black or metallic
Grate surface and box attachment	Grated surface with box attachment	Grated surface	Grated surface with box with rounded bottom
Cost	$57.99	$25.85	$53.99 (3 pack)
Image			

Appendix 1.2.1. D): User/Technical Benchmarking Drainage Solutions by Importance

Table 9: User/Technical Benchmarking Drainage Solutions by Importance

Specifications of Drainage System	**Importance**	**5" Pro Series Channel Drain Kit** (NDS, n.d.)	**ULMA 497 / PE100KCBM Class B ADA Compliant Mesh HDPE 122mm x 500mm Grate** (TDS, n.d.)	**Compact Series, Trench and Channel Drain Kit with Black Grate (3-Pack : 9.8 ft)** (Compact Series 5.4 in. W x 3.2 in. D x 39.4 in. L Trench and Channel Drain Kit with Black Grate (3-Pack : 9.8 ft), n.d.)
Width	**4**	**2**	**3**	**2**
Depth	**4**	**2**	**1**	**3**
Length	**4**	**2**	**3**	**2**
Weight	**3**	**3**	**1**	**1**
Shallow/Deep	**4**	**3**	**2**	**3**
Pre-assembled	**2**	**3**	**3**	**3**
Durable	**4**	**3**	**3**	**3**
Extendable	**4**	**3**	**3**	**2**
Material	**3**	**3**	**3**	**3**
Colour	**1**	**3**	**3**	**3**
Grate surface and box attachment	3	2	1	**3**
Cost	2	1	2	3
Total		95	88	**96**

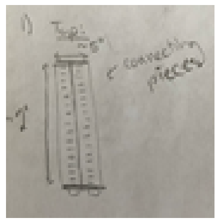
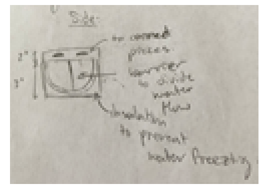
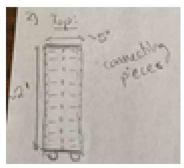
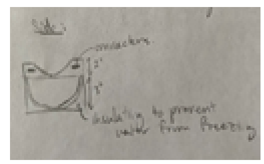
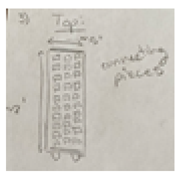
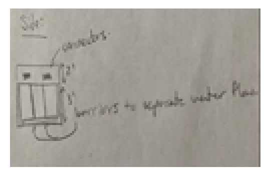
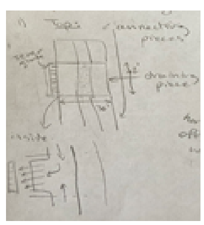
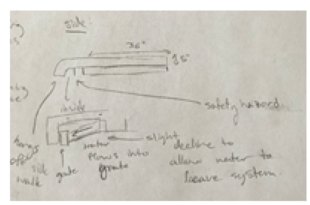
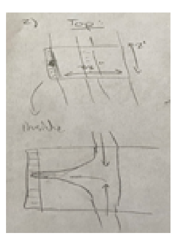
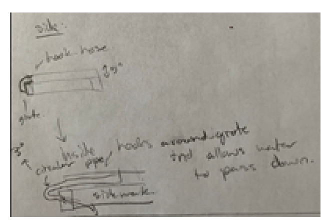
Appendix 1.2.1. E): Design Specifications for Drainage Solutions

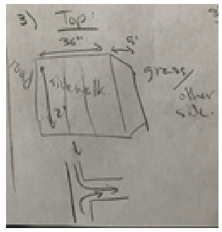
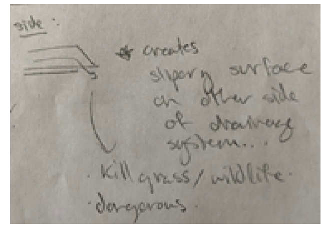
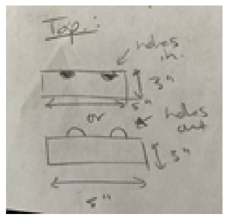
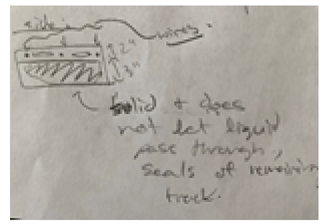
Table 10: Design Specifications for Drainage Solutions

Design Specifications of Drainage System	Relation (=, < or >)	Value	Units	Verification Method
Functional Requirements				
Collecting excess surface liquid	=	Yes	N/A	Test
Removing excess surface liquid	=	Yes	N/A	Test
Preventing the excess surface liquid from freezing	=	Yes	N/A	Test
Constraints				
Cost	<	100	$	Estimate, final check
Non-functional requirements				
Weight	>	90	kg	Analysis
Extendable	=	Yes	N/A	Test
Durable	=	Yes	N/A	Test
Colour	=	Yes	N/A	N/A

Appendix 1.2.1. F): Brainstorming Sketches for Drainage Solutions

Table 11: Brainstorming Sketches for Drainage Solutions

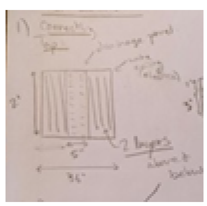
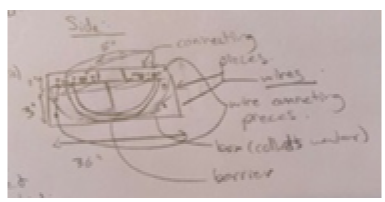
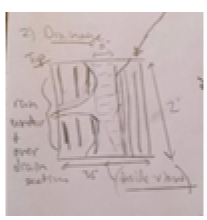
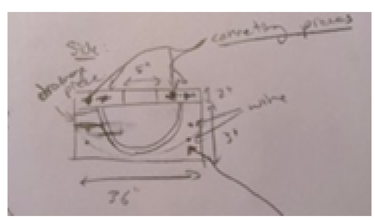
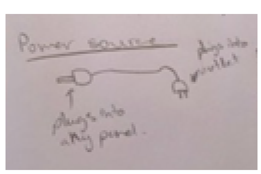
Brainstorming Sketches based on each Design Specifications:	**Sketch Illustration:**	
	Top view:	Side View:
Method of collecting excess surface liquid:		
First Design		
Second Design		
Third Design		
Method of removing excess surface liquid:		
First Design		
Second Design		

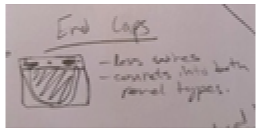
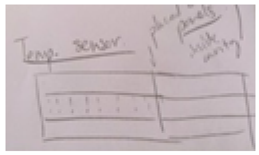
Third Design		
Method of preventing the excess surface liquid from freezing:		
First Design		

Appendix 1.2.2: Lucy's Overall System Brainstorming Designs

Appendix 1.2.2. A): Overall System Brainstorming Design Sketches

Table 12: Overall System Brainstorming Design Sketches

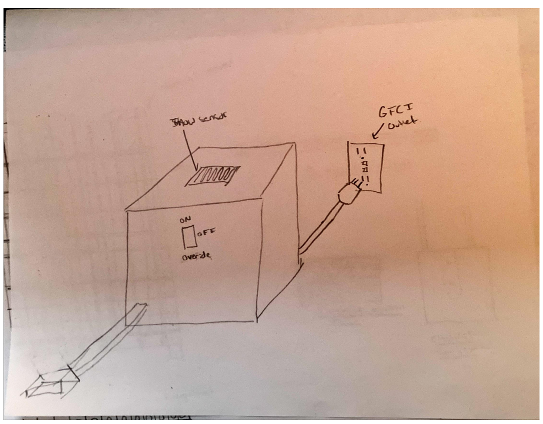
Design Drawings:	**Section Illustration:**	
	Top View:	Side View:
Panel Section: Connecting Pieces		
Panel Section: Drainage		
Power Source:		

End Caps:	
Temperature Sensor:	

Appendix 1.3.1: Thomas's Subsystem Brainstorming Designs

Appendix 1.3.1. A): Overall Subsystem Brainstorming Design Sketch

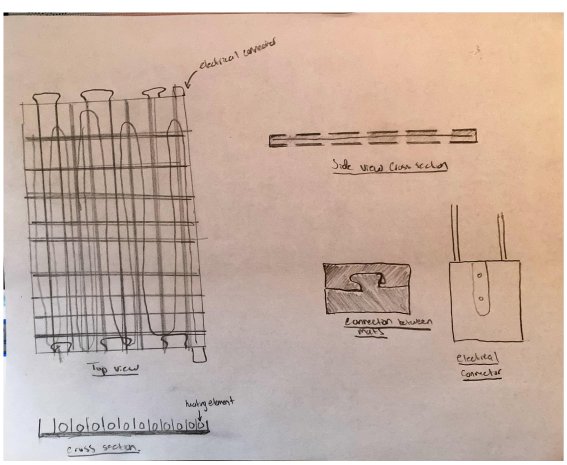
<u>Figure 1: Overall Subsystem Brainstorming Design Sketch</u>



Appendix 1.3.2: Thomas's Overall System Brainstorming Designs

Appendix 1.3.2. A): Overall System Brainstorming Design Sketches

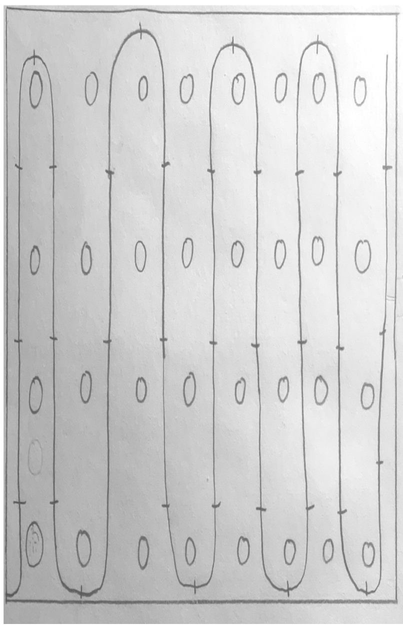
<u>Figure 2: Overall System Brainstorming Design Sketch</u>



Appendix 1.4.1: Johnathan's Subsystem Brainstorming Designs

Appendix 1.4.1. A): Wire Coiling Subsystem Brainstorming Design Sketches

Figure 3: Wire Coiling Subsystem Brainstorming Design Sketch



Appendix 1.4.1. B): Wire Coiling Subsystem Benchmarking

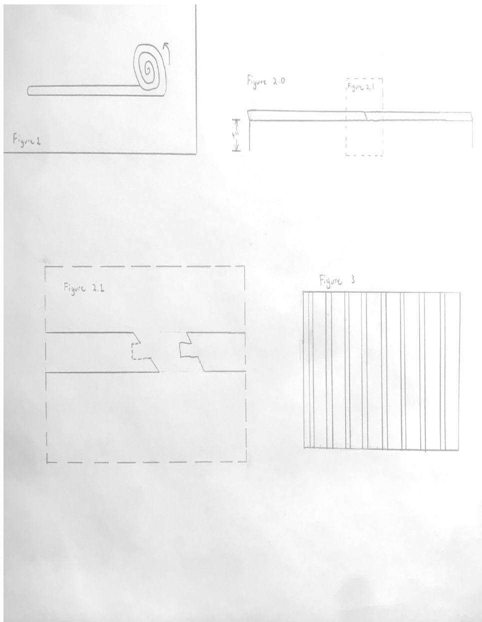
Table 13: Wire Coiling Subsystem Benchmarking

Specifications:	Eclectic Coiling System:		
Type of System	*Radiant Floor Heating*	*Roof de-icing system*	*Sidewalk Heating system*
Coil	Zigzagging loops	'U' Shape	'S' Shape loops
Membrane	Yes	No	No
Wire	120-V heating cable	120-V heating cable	120-V to 277-V Snow melting cable
Electricity source	Wired	Plug in outlet	Plug in outlet
Lowest Capable Operating Temperature	N/A	-40C	-40C+

Appendix 1.4.2: Johnathan's Overall System Brainstorming Designs

Appendix 1.4.2. A): Overall System Brainstorming Design Sketches

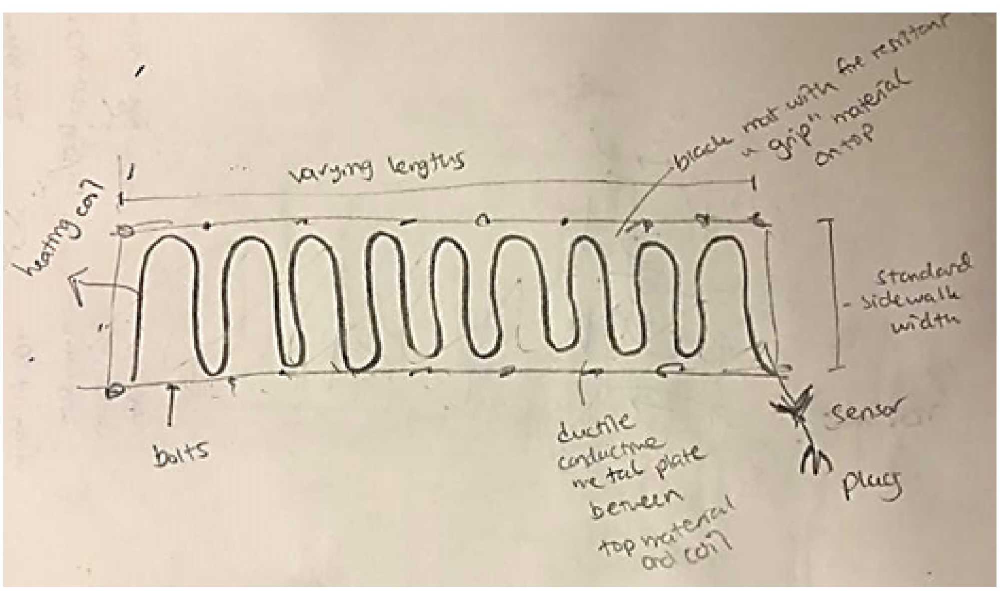
Figure 4: Overall System Brainstorming Design Sketch



Appendix 1.5.1: Amenah's Overall System and Subsystem Conceptual Design Sketches

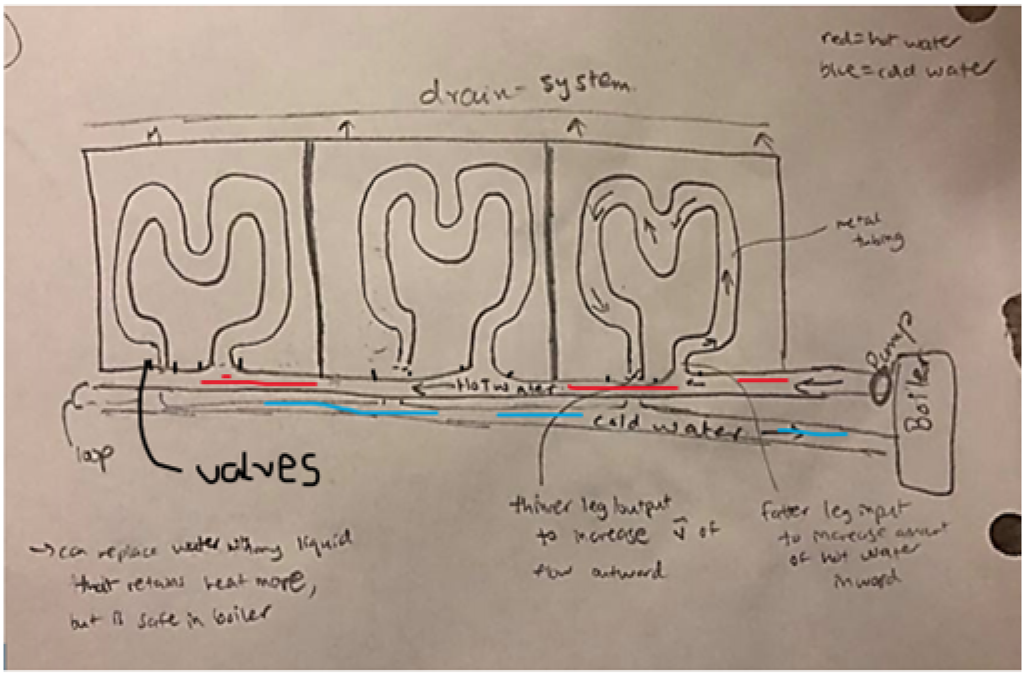
Appendix 1.5.1. A): Overall System Conceptual Design Sketches A

Figure 5: Overall System Brainstorming Design Sketch of electric heated mat with electric subsystem design



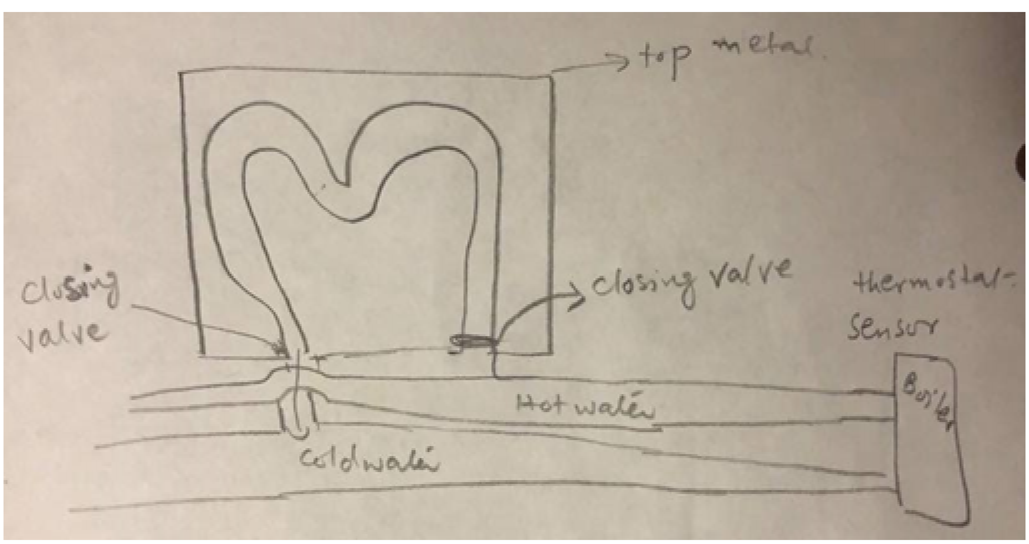
Appendix 1.5.1. B): Overall System Conceptual Design Sketches B

<u>Figure 6: Overall System Brainstorming Design Sketch of water heated panels with pipe subsystem design</u>



Appendix 1.5.1. C): Overall Subsystem Conceptual Design Sketches C

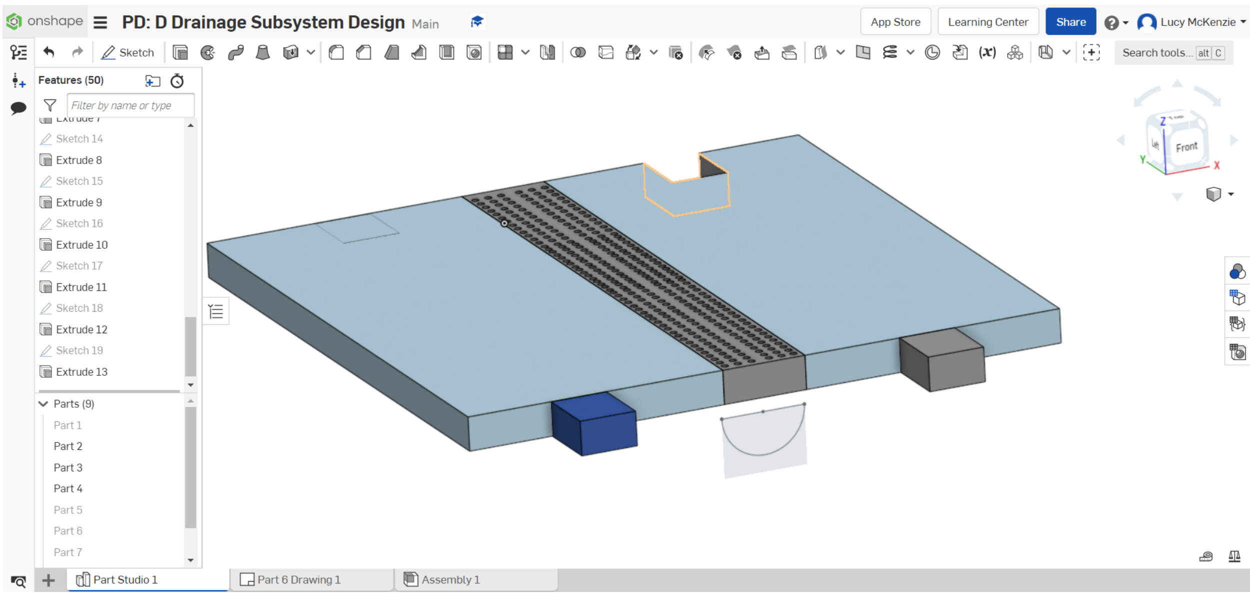
<u>Figure 7: Overall Subsystem Brainstorming Design Sketch of water heated panels' pipe subsystem design</u>



Appendix 2: Screenshot of onShape Design for the Team’s Solution

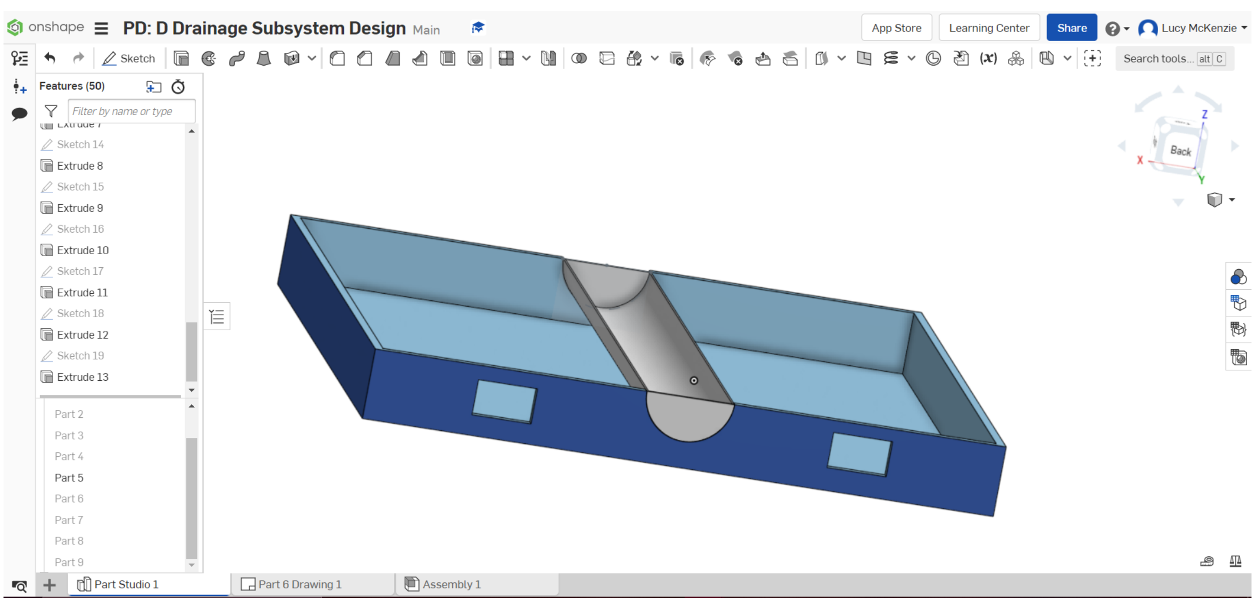
Appendix 2.1: Screenshot of onShape Surface Layer Design

Figure 8: Screenshot of onShape Design Surface Layer



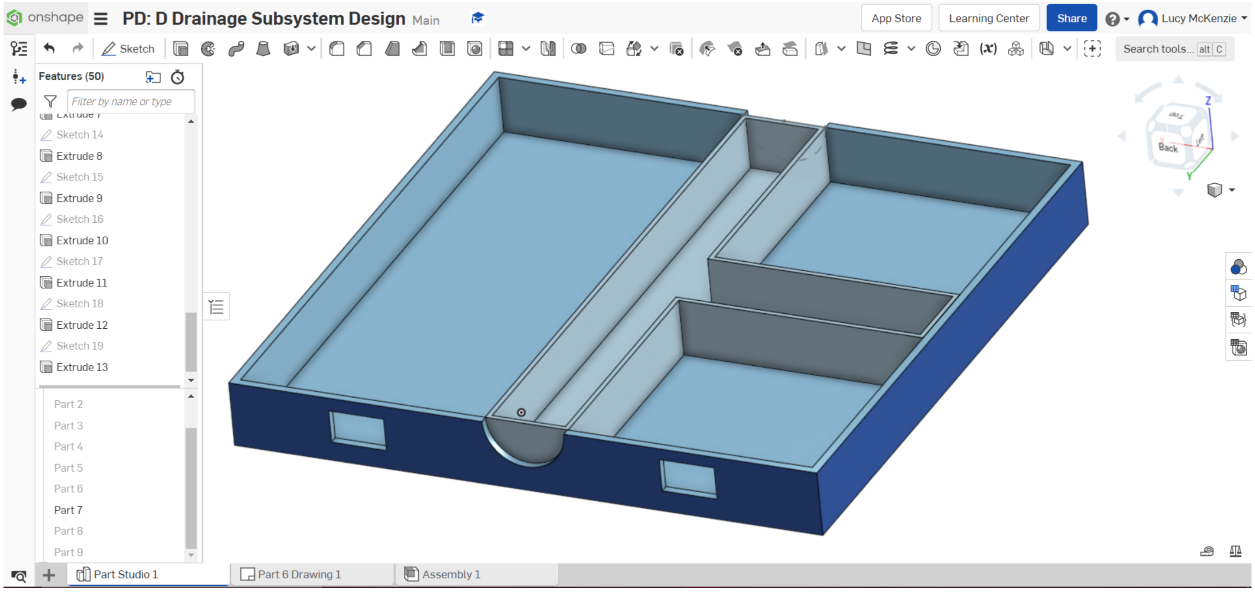
Appendix 2.2: Screenshot of onShape Connecting Panel Base Design

Figure 9: Screenshot of onShape Design Connecting Panel Base Design



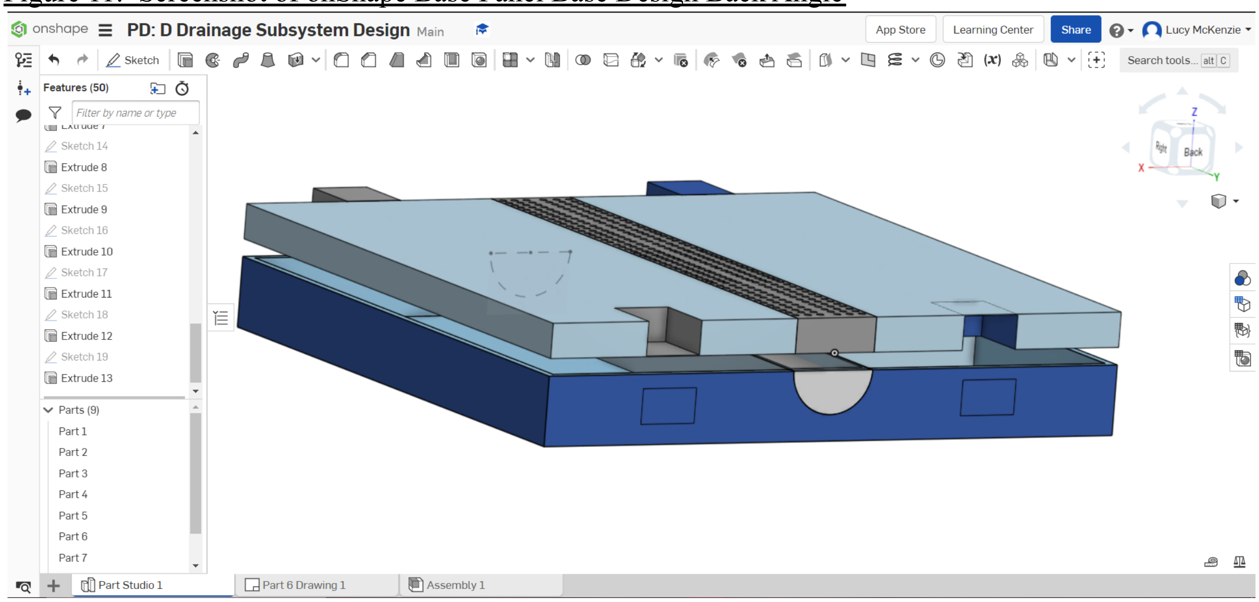
Appendix 2.3: Screenshot of onShape Drainage Panel Base Design

Figure 10: Screenshot of onShape Design Drainage Panel Base Design



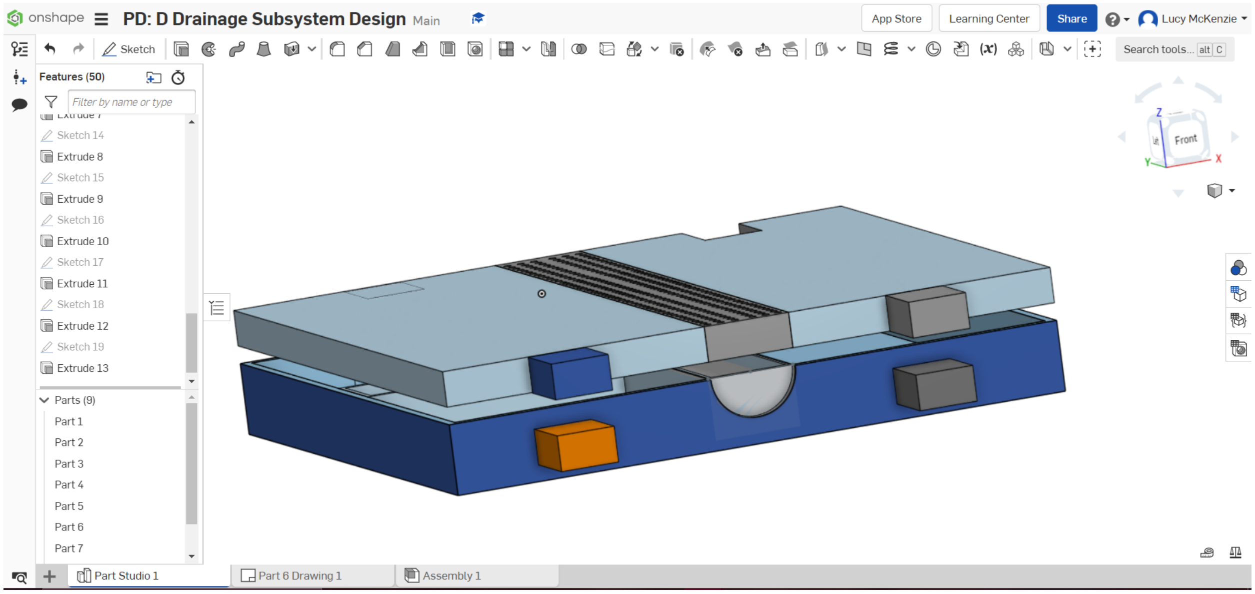
Appendix 2.4: Screenshot of onShape Base Panel Base Design Back Angle

Figure 11: Screenshot of onShape Base Panel Base Design Back Angle



Appendix 2.5: Screenshot of onShape Base Panel Base Design Front Angle

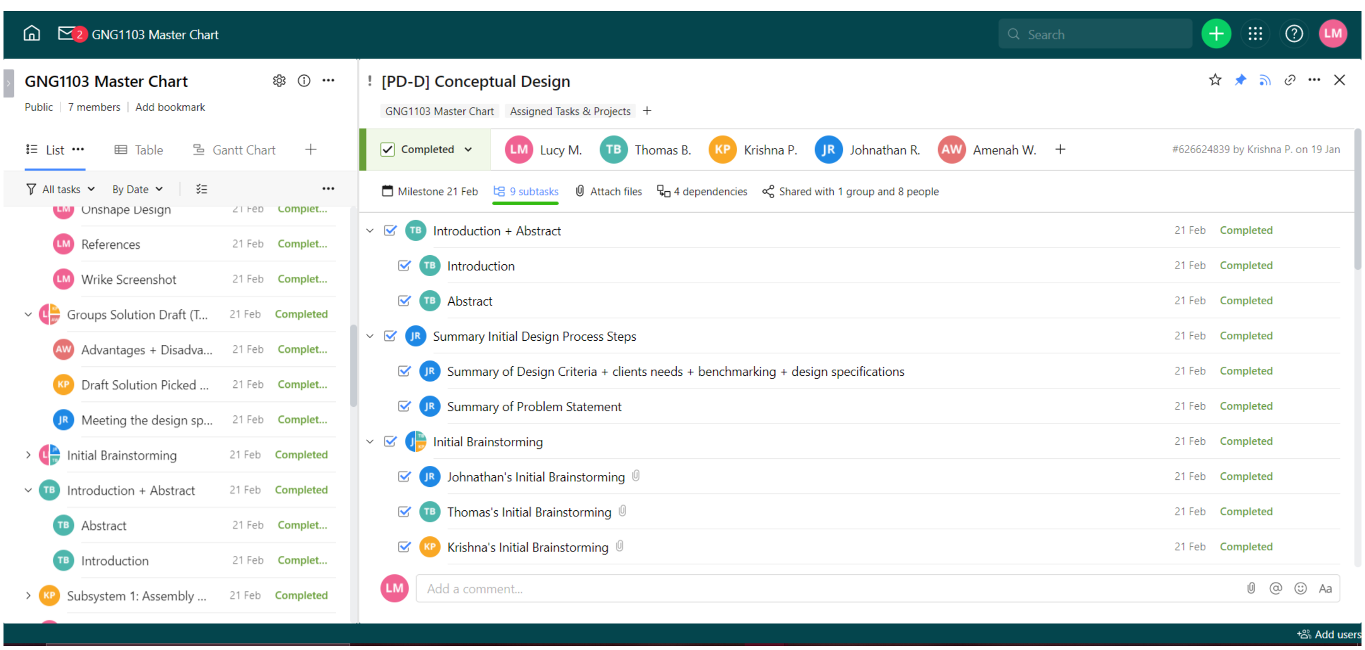
Figure 12: Screenshot of onShape Base Panel Base Design Front Angle



Appendix 3: Wrike Screenshots

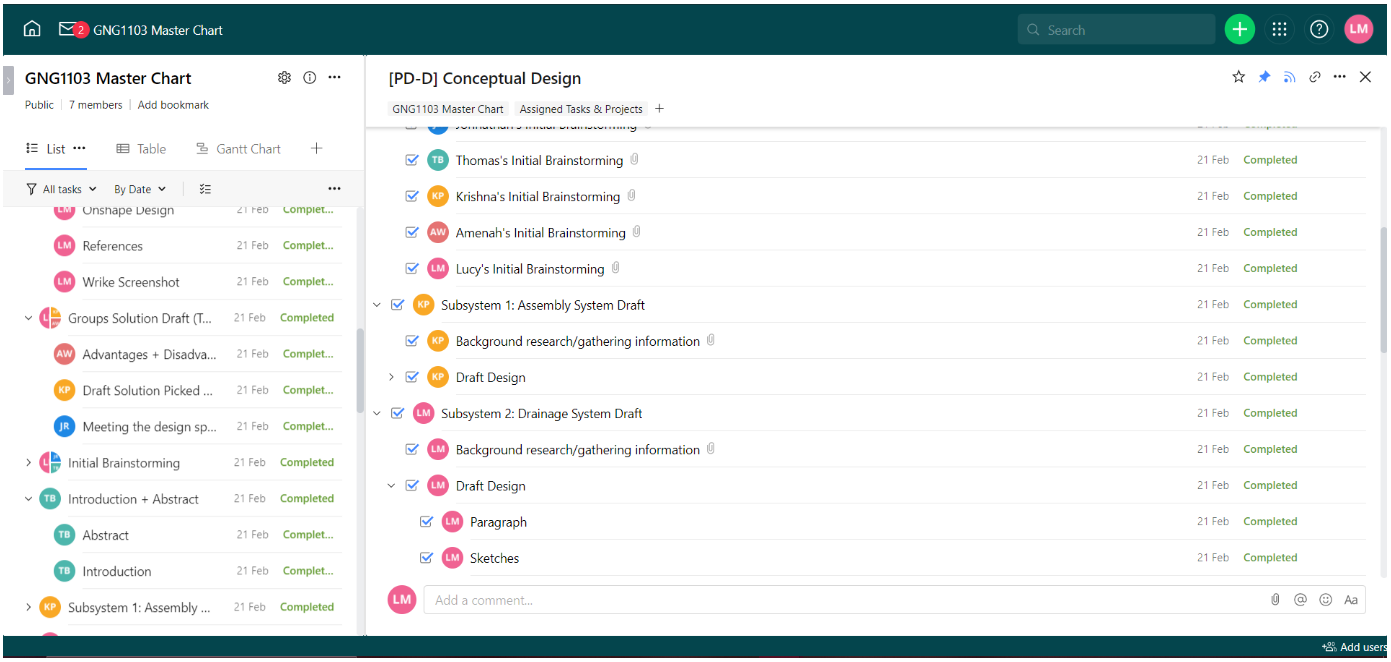
Appendix 3.1: Wrike Screenshot List A

Figure 13: Wrike Screenshot List A



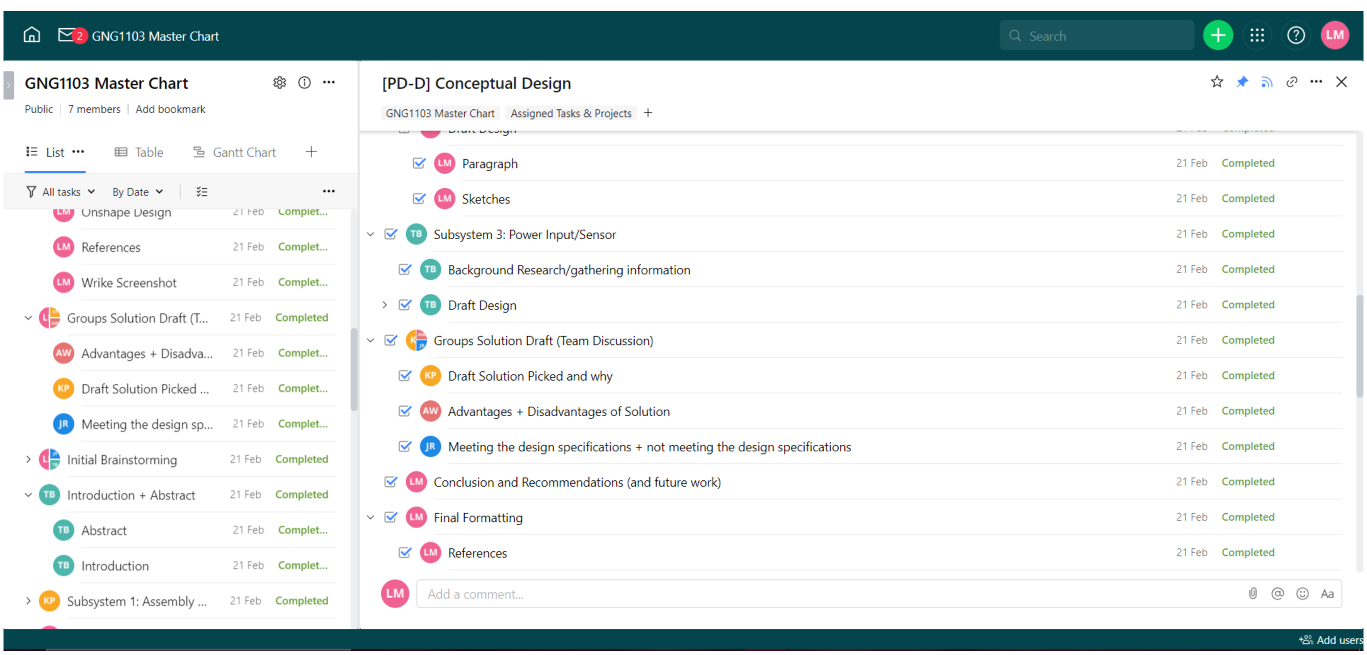
Appendix 3.2: Wrike Screenshot List B

Figure 14: Wrike Screenshot List B



Appendix 3.3: Wrike Screenshot List C

Figure 15: Wrike Screenshot List C



Appendix 3.4: Wrike Screenshot List D

Figure 16: Wrike Screenshot List D